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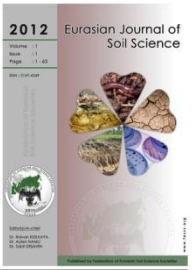

Dynamic of the active fraction of organic matter in some meadow soils

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Abstract

The microbial biomass (MB) and light fraction (LF) of organic matter are often considered as active fraction of organic matter (AFOM) and as indices of soil fertility and microbial activity. This study was performed in order to assess the turnover of AFOM using long-term incubation (56 weeks) at 25 °C in 34 meadow soils with different physical and chemical properties such as soil texture, organic C and total N. The MB and LF were determined at 8 and 5 times during the incubation period using fumigation-extraction technique for MB and densimetric method for LF. The amount of MB-C and MB-N mineralized increased with time of incubation. At the beginning of incubation, the C and N content of soil MB represented respectively 0.76 to 3.7% of total organic C and 1.94 to 10.7% of total N. The C and N content of LF represented respectively 2.9 to 25.6% of total organic C and 1.7 to 17.5% of total N. At the end of incubation, the losses of MB-C and MB-N from soils reached respectively 71 and 82% of the initial amounts. The MB and LF dynamic were well described by a two-component first-order rate model. The amount of N in the labile MB and LF pools represented respectively 54% of total MB-N and 61% of total LF-N. The more stable MB and LF pools had higher half-life than labile pools. The results obtained indicated that the stable LF would be the precursor of soil humic compounds.

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Introduction

It is generally accepted that soil organic matter (SOM) is composed of a number of pools ranging from very active (labile) to stable (non-labile) (Whitbread, 1994). The active pool of OM plays an important role in the short-term of nutrients turnover in soil (Alvarez et al., 1998). The SOM can be differentiated into two fractions based on their sedimentation under gravity in an inorganic or organic liquid (density = d): (i) a light fraction (LF) with a density, and (ii) a dense fraction with a density (Wander and Traina, 1996; Rovira et al., 1998). The LF is considered to be fresh undecomposed plant debris; partially decomposed fragments of roots and aboveground litter; decomposing plant and animal residues with a relatively high C:N ratio and a rapid turnover (Boone, 1994; Golchin et al., 1994; Whitbread, 1994; Gregorich et al., 1996; Tan et al., 2007). Although LF is usually associated to the labile pool of SOM because of its rapid turnover (Gregorich et al., 1994; Six et al., 2002), it is an intermediate or transitory pool between undecomposed residues and humified stable OM (Saviozzi et al., 1999; Wang and Wang, 2011). The LF fractions play a dominant role in soil nutrient dynamics (Paré and Bedard-Haughn, 2010). The dense fraction is assumed to be composed of more

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humified organic matter, generally linked to the mineral matrix, with a lower C concentration, a narrower C:N ratio and a very slow turnover time. The dense fraction also is part of OM adsorbed on mineral surfaces or contained within microaggregates (Sollins et al., 1984; Elliott and Cambardella, 1991; Christensen, 1992; Boone, 1994; Whitbread, 1994; Golchin et al., 1995; Kalinina et al., 2010). Numerous authors have suggested that the active fraction of OM (AFOM) is composed of LF (Janzen et al., 1992; Wander and Traina, 1996). The AFOM has been associated to particulate OM, water-soluble OM, LF, microbial biomass (MB), and potentially mineralizable OM or mineralizable C and N (Woods and Schuman, 1988; Woods, 1989; Biederbeck et al., 1994; Haynes, 2000; Yan et al., 2007). Several studies demonstrated that AFOM is more sensitive to land use and crop management practices, and more related to biologically mediated soil properties, such as MB and soil respiration and aggregation (Biederbeck et al., 1994; Weil et al., 2003; O'hara et al., 2006; Wallenstein et al., 2006; Cusack et al., 2011). In addition, AFOM can be influenced by crop rotations (Biederbeck et al., 1994), tillage (Angers et al., 1993), mineral or manure fertilization (N'Dayegamiye et al., 1997; Wallenstein et al., 2006; Cusack et al., 2011), and soil warming (Belay-Tedla et al., 2009). The aim of this study was to assess the dynamic and kinetics of the active fraction of OM in 34 meadow soils from eastern Quebec, Canada.

Materials and Method

Soil and sampling

The thirty-four surface (0-15 cm) soil samples (Gleyed Humo-Ferric Podzol) used in this study were collected from dairy farms that changed from conventional management to low-input biological cropping systems 4 or 5 yr before sampling. The farms were situated at Sainte-Croix de Lotbinière, in eastern Quebec, Canada. The forage crop was red clover (*Trifolium pretense* L.), bromegrass (*Bromus inermis* Leyss) mix. Low-input systems entail no mineral fertilizer input, which is replaced by solid dairy cattle manure applied each spring at a rate of 20 t/ha. Soil sub-samples were field-moist sieved through a 6 mm screen and kept at 4°C until the beginning of the incubation study. Properties of the soils investigated and details of the incubation method have been described elsewhere (Sbih et al., 2003).

Incubation method

One hundred-gram of soil (oven-dry basis) was incubated, in duplicate, in 1-L polyethylene flasks at 25°C for 56 wk. The water content of the samples was adjusted to 85% of their water holding capacity. Moisture losses during incubation were replenished weekly with demineralized water.

Microbial biomass C and N

At t = 0, 4, 8, 16, 25, 32, 40 and 56 wk, soil microbial biomass was determined by the chloroform fumigation-extraction method (modified after Vance et al., 1987). Fumigated and non-fumigated soil samples were extracted with 0.5 *M* K_2SO_4. The amounts of total C and N in the extracts of the fumigated and non-fumigated soils were determined respectively by wet oxidization technique and standard Kjeldahl digestion method (Carter and Gregorich, 2007). Microbial biomass C was calculated as MB-C = E_C/k_C, where E_C = [(organic C extracted from fumigated soils) − (organic C extracted from non-fumigated soils)] and k_C (extraction efficiency) = 0.38 (Joergensen, 1996). Microbial biomass N was calculated as: MB-N = $E_N,/k_N$ where E_N = [(total N extracted from fumigated soils) − (total N extracted from non-fumigated soils)] and k_N = 0.54 (Brookes et al., 1985; Olfs et al., 2004). Data were expressed in mg kg^{-1} dry soil and represented the average of two replicates.

Light fraction organic C and N

At t= 0, 4, 16, 32 and 56 wk, light fraction (LF) organic material was isolated by a modified density separation technique (Janzen et al., 1992), and then washed, dried, ground (Larney et al., 1997), and analyzed for total C and N. Data were expressed in mg kg^{-1} dry soil or mg g^{-1} dry LF and represented the average of two replicates.

Kinetic model

In terms of microbial biomass turnover time or rate of decomposition, soil microbial biomass may be simply subdivided into two components (Benbi and Nieder, 2003; Nieder and Benbi, 2008): (i) a labile component (L), or nonprotected biomass, that is readily decayed (labile MB), and (ii) a resistant component (R) that is physically protected, relatively slowly decomposed or resistant to decay (resistant or stable MB). To obtain no-linear kinetic coefficients, the C and N content of MB and LF as a function of incubation time were fitted to

a two-component exponential decay model, following the mathematical equation suggested by Bonde et al. (1988):

$$MB_t = MB_L\, e^{-kt} + MB_R\, e^{-ht} \quad [1]$$

where MB_t is the amount of C or N found in the MB at time t; MB_L is the amount of C ($MB\text{-}C_L$) or N ($MB\text{-}N_L$) in the labile MB pool, MB_R is the amount of C ($MB\text{-}C_R$) or N ($MB\text{-}N_R$) in the resistant MB pool, k and h are first-order rate constants belonging to MB_L and MB_R, and t is the period of incubation.

The same conceptual model was used to describe the decomposition of soil organic LF :

$$LF_t = LF_L\, e^{-kt} + LF_R\, e^{-ht} \quad [2]$$

where LF_t is the amount of C or N found in the LF of OM extracted from soil at time t; LF_L and LF_R are the amount of C or N in the labile and resistant LF pool, respectively, k and h are first-order rate constants belonging to LF_L and LF_R, and t is the period of incubation. The optimal variable parameters were estimated using nonlinear regression (SYSTAT, 1992).

Results and Discussion

Turnover of microbial biomass C and N

The C content of MB (MB-C) at the beginning of incubation (t=0) ranged from 185 to 687 mg kg^{-1}, depending of soil texture. This represented 0.76-3.7% of total organic C. The N content of MB (MB-N) ranged from 41 to 148 mg kg^{-1}, which represented between 1.94 and 10.7% of the total-N. The patterns of MB-C (Fig. 1A) were similar to those observed for MB-N (Fig. 1B). However, MB-N declined by more than 45% in the first 4 wk of incubation while MB-C declined by 14- 50% (mean 28%) of initial size (Fig. 1B). Thereafter, both MB-N and MB-C decreased slowly.

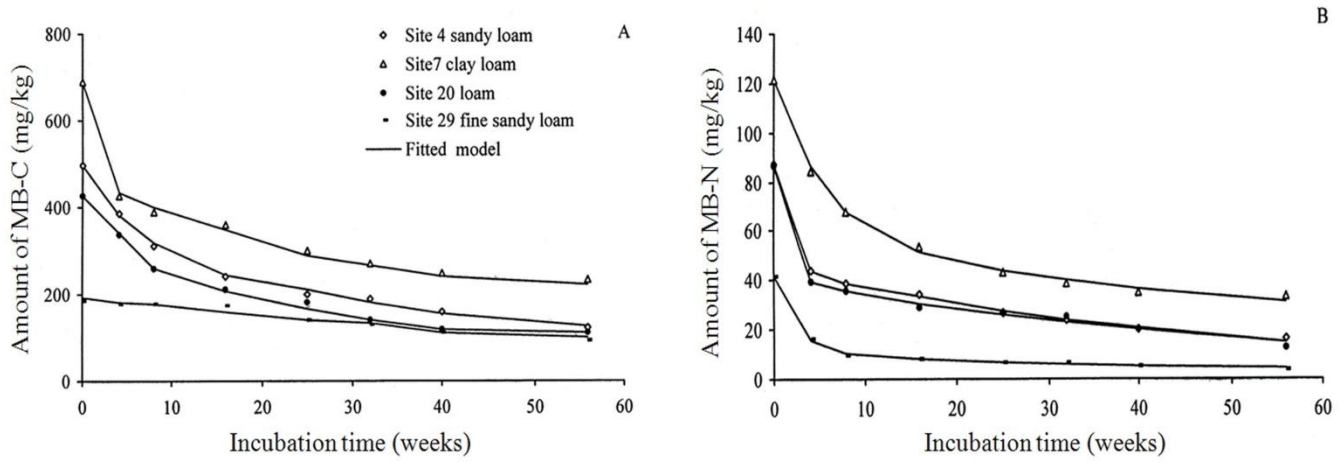

Fig. 1. Carbon content (A) and nitrogen content (B) of the microbial biomass in soils as a function of incubation time. Symbols represent experimental data, and line represent fitted model.

At the end of the incubation period, MB-N and MB-C were reduced, on average, to 6% and 10% of initial size, respectively. The losses of MB-C and MB-N from soils reached respectively 71 and 82% of the initial amounts. Anderson and Domsch, (1987) and Bonde et al. (1988) found a comparable high loss of microbial-C (25-40%) after 4 wk at a temperature of 28°C. Nicolardot (1988) observed that the mineralization of the microbial ^{13}C reached 80% during the first week of incubation. Paul et al. (2011) found that loss of microbial biomass N during long-term incubation of two former grassland soils, where wheat or corn are currently growing, accounted for a significant portion of the N mineralized. Comparable results were also obtained by Bonde et al. (1988) for MB-N where MB-N was reduced to 7-14% (mean 9%) of initial size at week 47.

Microbial biomass kinetics

In general, the model [1] fit well the MB experimental data, with R^2 values ranged between 0.991 and 0.999 except for two soils where R^2 = 0.88. This is in agreement with the findings of Paul et al. (2011) who demonstrated that two-pool first-order kinetics effectively described losses of microbial biomass C and N. The amount of MB-C_L ranged between 35 and 287 mg kg^{-1} with rate constant varying between 0.012 and 9.27 wk^{-1}. This result suggested that labile compartment of MB-C is mineralized between 0.1 to 8 weeks. The amount of MB-N_L ranged between 26 and 108 mg kg^{-1} with short half-life time, varying between 1.4 to 29.2 days. The mineralization of MB-N contributed approximately to 20-70% (mean 42%) of the N mineralized during 56 weeks of incubation. This result appear to be similar to that observed by Paul et al. (2011) who found that the loss of microbial biomass N during incubation accounted for a significant portion of the N mineralized. Bonde et al. (1988) found that N-MB could contribute between 55 to 89% of the N mineralized. The resistant compartment of MB (MB_R) had higher half-life time, ranging from 0.6 to 5.5 years for MB-C_R and 1.3 to 1.9 years for MB-N_R.

Turnover of the light fraction of soil organic matter

At the beginning of incubation, the amount of LF varied between 4.0 and 17.9 g kg^{-1} soil. The amounts of LF-C and LF-N ranged respectively from 1.4 to 3.6 g kg^{-1} (mean 9.5% of the total soil C) and 0.033 to 0.185 g kg^{-1}. The concentrations of C in LF varied from 106 to 566 mg C g^{-1} LF and those of N from 4 and 28 mg N g^{-1} LF. During the first 4 wk of incubation, the amount of LF passed from 10.3 to 5.3 g LF kg^{-1} soil, which represented 46% of the initial FL. At 16 wk, the amount of LF decreased to 3.8 g kg^{-1}. At the end of incubation, LF mass decreased by more than 78% of initial size. Decline of LF during laboratory incubations has been explained by the conversion of LF to dense fraction or turnover LF (Boone, 1994). At the beginning of incubation, the amounts of LF-C and LF-N represented respectively 2.9 to 25.6% of total organic C and 1.7 to 17.5% of total N. During the first 4 wk, the amount of LF-C decreased by 27% of initial LF-C (Fig.2A). At 16, 32 and 56 wk, LF-C decreased by 40, 67 and 73% of initial FL-C. In contrast to LF-C mineralization, the amount of FL-N increased in 15 soils during the first 4 wk and then decreased until the end of incubation time (Fig.2B). Finally, we observed a relative proportionality between weight loss of LF and reduction of LF-C over the 57 wk. This would suggest that two concomitant phenomena are taking place, mineralization and molecular condensation.

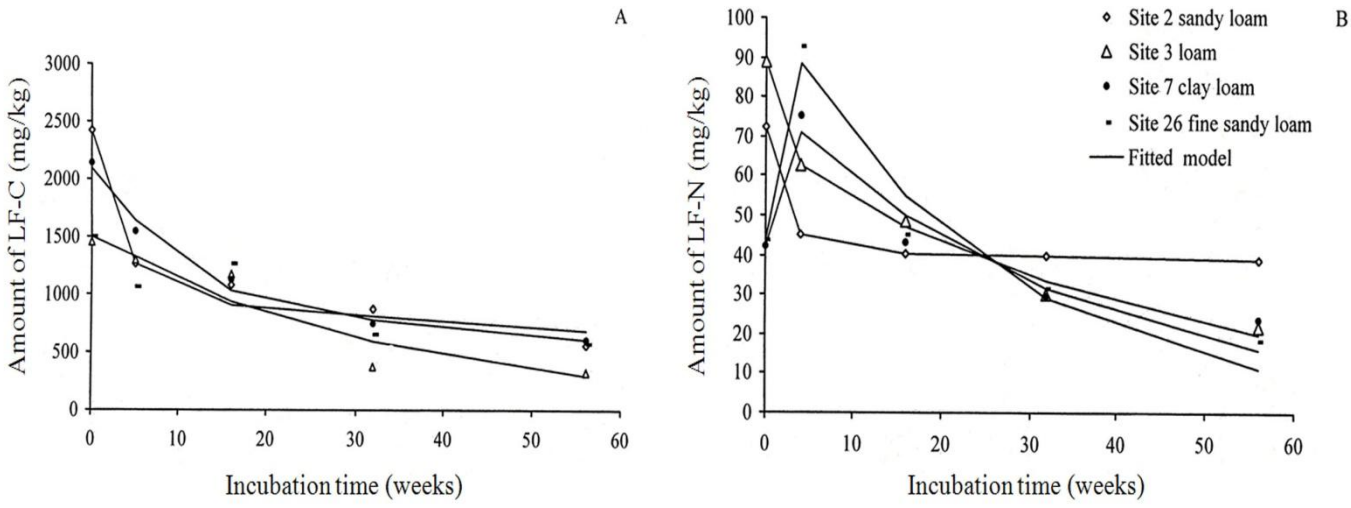

Fig. 2. Carbon content (A) and nitrogen content (B) of the light fraction of soil organic matter as a function of incubation time. Symbols represent experimental data, and line represent fitted model.

Light fraction kinetics

The amount of LF-C_L ranged from 8 to 50 % of total C-FL (mean 37%) with rate constant varying between 0.078 and 6.64 wk^{-1}, which are equivalent to half-life varying between 0.1 and 8.8 weeks. This result

indicated that 37% of the light fraction of soil organic matter (FOM) would be degraded rapidly over the first 6 wk of incubation. The half-life of the resistant fraction (LF-C_R) was higher and varied between 0.3 and 4.28 yr. Gregorich et al. (1997), in a study on the turnover of light fraction organic matter in arable systems, found that the mean decay constant of the C_3-derived C in the free LFOM material of tilled soils was 0.110 yr^{-1} for a half-life of 6 yr. The estimated mean decay constant of C_3-derived C in physically protected LFOM was 0.045 yr^{-1} for a half-life of 15 yr. The data indicate that LF fraction would be act as humic precursor (Amalfitano et al., 1995). The two pools (labile and resistant) of FL correspond to compartments that McGill et al. (1981) and Parton et al. (1987) referred as metabolic and structural compartments; the first is metabolized by soil microorganisms, while the other is precursor of humic substances.

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