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INTRODUCTION

Organic matter stabilization and ecosystem functions: proceedings of the fourth conference on the mechanisms of organic matter stabilization and destabilization (SOM-2010, Presqu'île de Giens, France)

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Introduction

A better knowledge of soil organic matter (SOM) stabilisation and destabilisation processes may help improving soil management strategies and practices to optimize ecosystem services such as organic carbon (C) storage and mitigation of greenhouse gases, improvement of soil structure and protection against erosion, sustainability of soil fertility (Lal 2004).

A series of international conferences on the mechanisms of organic matter stabilization and destabilization was launched in 2003 in Hohenkammer in Germany (Kögel-Knabner et al. 2005). The next editions took place in Asilomar in 2005 (Sollins et al. 2007) and in Glenelg, near Adelaide, Australia in 2007 (Smernik and Skjemstad 2009). This special issue of Biogeochemistry, presents in 10 articles some of the results from the fourth edition of these conferences (SOM-2010), which took place on 19–23 September 2010 in the Presqu'île de Giens, France. This edition was organized by the soil organic matter group of the Bioemco laboratory (Biogeochemistry and Ecology of Continental Ecosystems) based in Thiverval-Grignon, France, and was entitled "Organic matter stabilization and ecosystem functions". It was also part of the series of conferences of the group Molter (Molecular structures as drivers and tracers of terrestrial C fluxes), an ESF-funded research networking programme for the 2008–2013 period. The conference was attended by 177 delegates (including 65 students) from 21 countries, with most from France, Germany and USA. This fourth conference was specifically dedicated to ecological aspects of OM stabilization and destabilization mechanisms in sediments and soils.

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Conference highlights

While the traditional physico-chemical approach of SOM stabilization was the focus of most of the previous conferences of this series we concentrated on an ecological approach on the role of biological processes on SOM stabilization and implications for ecosystem functions. The conference was organized in six sessions, focusing on different ecological factors (below and aboveground parts of plants, microorganisms, trophic networks) and environmental factors (molecular composition, global changes and soil heterogeneity) possibly influencing SOM stabilization/destabilization processes. In the following some of these themes of the conference and of this special issue will be addressed in detail.

Molecular drivers of decomposition/stabilisation of SOM: plant molecular proxies

Most models of the behavior of C in soils are considering several conceptual compartments with

different decomposition rates (e.g., Parton et al. 1987; Liski et al. 2005; Jenkinson and Coleman 2008). The actual chemical forms associated with these conceptual compartments remain unknown. New attempts have to be made to reconcile the observations that recalcitrant plant-derived molecules are not necessarily subject to stabilisation in soil, such as assumed in many model approaches for lignin (Thevenot et al. 2010). The origin of stabilised SOM is still poorly known, even if there is general agreement that microbial-derived N-containing compounds may be important (Kleber et al. 2007). Next to stabilisation processes decomposition is operating. Future research should quantitatively address these two processes under different pedoclimatic conditions and identify their effect on OM molecular composition. Such identification may be obtained by solid-state ^{13}C cross-polarization and magic-angle spinning nuclear magnetic resonance (CPMAS NMR) spectroscopy, which provides information on OM bulk chemical composition (Kögel-Knabner 1997; Preston 2001). Using litterbag experiments in forest stands throughout Japan, and ^{13}C-NMR, Ono et al. (2012) found that the decomposition of aromatic and aliphatic constituents of the litter varied significantly between litter types. Their behaviour in decomposing litter was related to the initial physicochemical quality of the litter and to local microbial communities.

Further insight into the study of SOM formation may be provided by molecular biomarkers for example through the study of plant-derived alkanes, which can be used to assess postsedimentary modification of OM related to rooting of plants (Gocke et al. 2010). To improve understanding of OM in loess profile and to determine whether the loess OM reflects original or postsedimentary OM, Gocke et al. (2012) assessed the sources of loess and rhizolith OM via molecular proxies.

Cutin and suberin are effective biomarkers for above and belowground plant tissues in soils (Mendez-Millan et al. 2010, 2012) and may be used to assess the contribution of root-derived C to SOM (Crow et al. 2009; Mendez-Millan et al. 2011). In this issue, Andreetta et al. (2012) showed that in a dry environment the strategies adopted by plants to cope with water and nutrients scarcity, lead to a preferential preservation of these compounds. Root-derived SOM plays a major role for C cycling and C storage in soils, as a considerable proportion becomes incorporated into the soil as below-ground input (Rasse et al. 2005). Several processes may be implicated in preferential preservation of root carbon. The importance of hydrophobic protection of SOM through the accumulation of aliphatic root-derived compounds needs to be addressed in future studies as well as the importance of microbial transformations before stabilisation.

Soil microbial activity: influence of global change, pH, salt content

Soil microorganisms play a pivotal role in C mineralisation and nutrient cycling and their activities can be affected by various environmental factors, such as temperature, soil pH, or salt accumulation.

The accumulation of organic matter in hostile environments with reduced microbial decomposition has prompted concern about the state and vulnerability of SOM when exposed to environmental change. This concern stimulated research in particular with regards to temperature, whereas the influence of pH on SOM stabilisation and destabilisation processes was often neglected. In this issue, Leifeld et al. (2012) studied the role of soil pH as a modifier for soil and root carbon turnover in subalpine permanent grassland, confirming and quantifying the strong dependency of turnover rates on pH under long-term steady-state field conditions. They conclude that soil pH should be an integrative part of global C and N turnover modelling. Their results point to another important issue concerning SOM turnover: the influence of plant activity. In the rhizosphere, plants are able to alter pH values as well as nutrient concentrations, which may affect microbial activity and hence SOM turnover. As plant activity is influenced by climate change this should be taken into account in conceptual models of SOM turnover.

In arid regions, salt accumulation is observed in soils (Lambers 2003). Salts reduce soil microbial activity since they cause osmotic stress and can kill soil microorganisms (Wichern et al. 2006). In this issue, (Baumann and Marschner 2012) assessed the interactive effect of salt and drought stress on soil microbial activity and community structure. Their results showed that increasing soil salinity can reduce microbial activity but may not affect the resistance of microbes to drying/rewetting cycles as water stress was found to override any previous effects of salinity.

Environmental parameters affect microbial activity and this was mainly evidenced by studying decomposition processes. Up to now it is not known, how these parameters interact with SOM stabilisation, for example association of SOM compounds to the mineral phase, which can be pH dependent.

Mineral-associated SOM: influence of mineralogy

Several studies have shown that protection of mineral-associated C, an important component in the global C cycle, is affected by soil mineral types (Kaiser and Guggenberger 2003; Mikutta et al. 2006; Schulten and Leinweber 2000; Six et al. 2002), composition of organic C inputs (Oades 1988) and soil specific surface area, which is closely associated with mineralogy (Kahle et al. 2002; Wiseman and Puettmann 2006). This led to questions about the maximum SOM stabilisation capacity of soil, which may be related to saturation of mineral surfaces. Using a least-square linear regression model on soils with a wide range of mass proportions of fine soil particles, Hassink (1997) and Six et al. (2002) predicted a maximal organic C content of fine soil particles, which represent the theoretical protective capacity. These estimates are relatively low compared to observed C concentrations of fine soil particles. In this issue, Feng et al. (2012) propose an alternative organic C loading method based on organic C stabilization on soil mineral specific surface area. Their study emphasizes the importance of soil mineralogical properties for assessing C saturation.

In addition to aluminosilicate clays, iron (Fe) and aluminum (Al) phases greatly contribute to SOM stabilization (Sollins et al. 1996; Baldock and Skjemstad 2000). Recently, Kleber et al. (2007) emphazised the importance of proteins as building blocks for OM stabilised by mineral interactions. Despite the importance of nitrogen for SOM stabilisation, most studies are concerned with carbon compounds. Wagai et al. (2012, this issue) assessed the dynamics of mineral associated N. Fe and Al phases are mainly studied after selective dissolution of these metal phases (e.g. Parfitt and Childs 1988). Most of the dissolution methods use carbon-based compounds as complexing agents to dissolve Fe and Al, making it difficult to assess released SOC. Since many of these extractants are nitrogen-free, Wagai et al. (2012) propose to use N dissolved in nitrogen-free extractants as a reasonable proxy for OM to assess the contribution of metal phases on OM stabilization. They suggest that accumulation/remobilization of soil OC and N may be more dependent on the dynamics of organo-metal complexes than those of FeOx, AlOx, and poorly-crystalline aluminosilicates.

Separating operationally defined pools: isotopic studies

Physical fractionation separates POM from mineral-associated SOM in finer size fractions, which is thought to be more recalcitrant and older (Christensen 2001). However, the resulting pools are too heterogeneous to represent the conceptual model pools (Smith et al. 2002; von Lützow et al. 2007). Chemical fractionation uses hydrolysis or oxidation methods to isolate a fraction supposed to be more resistant to enzymatic degradation. Although residues of chemical fractionation are generally much older than the bulk soil C (e.g. Eusterhues et al. 2005; Leavitt et al. 1996; Paul et al. 2001), they do not always represent the slow turnover pools conceptualized in SOM models (Bruun et al. 2008; Plante et al. 2004; Poirier et al. 2006). Thus, O'Brien et al. (2012, this issue) propose to test a more promising approach for isolating functionally meaningful SOM pools combining physical and chemical fractionation schemes (Kögel-Knabner 2000; Olk and Gregorich 2006; von Lützow et al. 2007). O'Brien et al. (2012) isolate discrete pools with moderate to long turnover times, taking advantage of both ^{14}C measurements and the natural C_4/C_3 ^{13}C isotopic labelling of soil samples. Their results suggest that every fraction is composite, even the ones that appear to be largely unreactive, based on their ^{14}C ages. The work of O'Brien et al. (2012) provides further evidence that SOM chemistry may not reflect its age, and demonstrates that pools appearing to be extremely stable on the basis of their long ^{14}C-derived turnover times can have a substantial fraction that is dynamic over decadal timescales.

Baisden et al. (2012) uses a physical separation of only two soil density fractions to quantify soil C turnover with approximately the same degree of certainty as a more complex separation into five density fractions (Baisden et al. 2002). Due to the relatively small size of the active pool and large size of the stabilized pool in the New Zealand soils they studied and to the decadal and millennial scale of the

radiocarbon tracer, they could assume that the active pool is negligible, and calculate residence times and pool sizes for the large stabilized and passive C pools. Baisden et al. (2012) demonstrates that Andisols have greater soil C residence times, and larger passive soil C pools than non-Andisol counterparts. The contrasting soil C dynamics in these different soils might have major implications for the response of the 'stabilized' pool over decadal timescales upon land-use change (Baisden et al. 2012).

The ^{14}C tracer can be used for estimating C ages, but ^{14}C-enriched organic substrates are also useful for tracing biochemical and geochemical C pathways (e.g. Rovira et al. 1998; Kuzyakov and Jones 2006; Bruun et al. 2008; Philip and Simard 2008; Gocke et al. 2011). In this issue, Lopez-Sangil and Rovira (2012) propose a simple new experimental design which eliminates the risk of cross-contamination during sample preparation for ^{14}C measurement. The main advantages of the Lopez-Sangil and Rovira (2012) method are that it can be implemented for organic as well inorganic form of C with standard and cheap laboratory glassware pieces without cross-contaminations.

Conclusions

The conference held in Presqu'île of Giens brought together scientists of various backgrounds. It emphasised the necessity to look at SOM stabilisation in an integrated ecological approach, considering soil physics and chemistry as well as biology and environmental parameters. The importance of microbial diversity and community dynamics as well as spatial separation and location of SOM for its protection needs to be further evaluated in future studies. In particular the SOM compounds affected by spatial separation need to be identified. The relationship between microbial diversity and functioning needs to be elucidated. Molecular methods for the characterization of OM quality, reactivity and dynamics need to be applied more widely in order to detangle stabilisation processes and to identify the implication of specific compounds in particular stabilisation processes. Isotopic methods, which are very useful to quantify SOM turnover or follow single compounds are still underexploited and under development.

The fifth conference in this series will be hosted by Michael W. I. Schmidt, Samuel Abiven, Timothy Eglinton, Jens Leifeld and Frank Hagedorn in Switzerland in October 2012 (http://www.som5.ethz.ch/).

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References

Andreetta A, Dignac MF, Carnicelli S (2012) Biological and physico-chemical processes influence cutin and suberin biomarker distribution in two Mediterranean forest soil profiles. Biogeochemistry. doi:10.1007/s10533-011-9693-9

Baisden WT, Amundson R, Brenner DL, Cook AC, Kendall C, Harden J (2002) A multi-isotope C and N modeling analysis of soil organic matter turnover and transport as a function of soil depth in a California annual grassland soil chronosequence. Glob Biogeochem Cycles 16:1117–1122

Baisden WT, Parfitt RL, Ross C, Schipper LA, Canessa S (2012) Evaluating 50 years of time-series soil radiocarbon data: towards routine calculation of robust C residence times. Biogeochemistry. doi:10.1007/s10533-011-9675-y

Baldock JA, Skjemstad JO (2000) Role of the mineral matrix and minerals in protecting natural organic materials against decomposition. Org Geochem 31:697–710

Baumann K, Marschner P (2012) Effects of salinity on microbial tolerance to drying and rewetting. Biogeochemistry. doi:10.1007/s10533-011-9672-1

Bruun S, Thomsen IK, Christensen BT, Jensen LS (2008) In search of stable soil organic carbon fractions: a comparison of methods applied to soils labelled with C-14 for 40 days or 40 years. Eur J Soil Sci 59:247–256

Christensen BT (2001) Physical fractionation of soil and structural and functional complexity in organic matter turnover. Eur J Soil Sci 52:345–353

Crow SE, Lajtha K, Filley TR, Swanston CW, Bowden RD, Caldwell BA (2009) Sources of plant-derived carbon and stability of organic matter in soil: implications for global change. Glob Change Biol 15:2003–2019

Eusterhues K, Rumpel C, Kögel-Knabner I (2005) Stabilization of soil organic matter isolated by oxidative degradation. Org Geochem 36:1567–1575

Feng W, Plante AF, Six J (2012) Improving estimates of maximal organic carbon stabilization by fine soil particles. Biogeochemistry. doi:10.1007/s10533-011-9679-7

Gocke M, Kuzyakov Y, Wiesenberg GLB (2010) Rhizoliths in loess—evidence for post-sedimentary incorporation of root-derived organic matter in terrestrial sediments as assessed from molecular proxies. Org Geochem 41:1198–1206

Gocke M, Pustovoytov K, Kuzyakov Y (2011) Carbonate recrystallization in root-free soil and rhizosphere of *Triticum aestivum* and *Lolium perenne* estimated by ^{14}C labelling. Biogeochemistry. doi:10.1007/s10533-010-9456-z

Gocke M, Kuzyakov Y, Wiesenberg GLB (2012) Differentiation of plant derived organic matter in soil, loess and

rhizoliths based on *n*-alkane molecular proxies. Biogeochemistry. doi:10.1007/s10533-011-9659-y

Hassink J (1997) The capacity of soils to preserve organic C and N by their association with clay and silt particles. Plant Soil 191:77–87

Jenkinson DS, Coleman K (2008) The turnover of organic carbon in subsoils. Part 2. Modelling carbon turnover. Eur J Soil Sci 59:400–413

Kahle M, Kleber M, Jahn R (2002) Carbon storage in loess derived surface soils from Central Germany: influence of mineral phase variables. J Plant Nutr Soil Sci 165:141–149

Kaiser K, Guggenberger G (2003) Mineral surfaces and soil organic matter. Eur J Soil Sci 54:219–236

Kleber M, Sollins P, Sutton R (2007) A conceptual model of organo-mineral interactions in soils: self-assembly of organic molecular fragments into zonal structures on mineral surfaces. Biogeochemistry 85:9–24

Kögel-Knabner I (1997) ^{13}C and ^{15}N NMR spectroscopy as a tool in soil organic matter studies. Geoderma 80:243–270

Kögel-Knabner I (2000) Analytical approaches for characterizing soil organic matter. Org Geochem 31:609–625

Kögel-Knabner I, von Lützow M, Guggenberger G, Flessa H, Marschner B, Matzner E, Ekschmitt K (2005) Mechanisms and regulation of organic matter stabilisation in soils. Geoderma 128:1–2

Kuzyakov Y, Jones DL (2006) Glucose uptake by maize roots and its transformation in the rhizosphere. Soil Biol Biochem 38:851–860

Lal R (2004) Soil carbon sequestration impacts on global climate change and food security. Science 304:1623–1627

Lambers H (2003) Dryland salinity: a key environmental issue in southern Australia introduction. Plant Soil 257:V–VII

Leavitt SW, Follett RF, Paul EA (1996) Estimation of slow- and fast-cycling soil organic carbon pools from 6 N HCl hydrolysis. Radiocarbon 38:231–239

Leifeld L, Bassin S, Conen F, Hajdas I, Egli M, Fuhrer J (2012) Control of soil pH on turnover of belowground organic matter in subalpine grassland. Biogeochemistry. doi:10.1007/s10533-011-9689-5

Liski J, Palosuo T, Peltoniemi M, Sievanen R (2005) Carbon and decomposition model Yasso for forest soils. Ecol Model 189:168–182

Lopez-Sangil L, Rovira P (2012) Individual closed chamber: an alternative method for quantifying ^{14}C in both labeled organic and inorganic carbon substrates. Biogeochemistry. doi:10.1007/s10533-011-9643-6

Mendez-Millan M, Dignac MF, Rumpel C, Rasse DP, Derenne S (2010) Molecular dynamics of shoot versus root biomarkers in an agricultural soil estimated by natural abundance ^{13}C labelling. Soil Biol Biochem 42:169–177

Mendez-Millan M, Dignac MF, Rumpel C, Derenne S (2011) Can cutin and suberin biomarkers be used to trace shoot and root-derived organic matter? A molecular and isotopic approach. Biogeochemistry 106:23–38

Mendez-Millan M, Dignac MF, Rumpel C, Rasse DP, Bardoux G, Derenne S (2012) Contribution of maize root derived-C to soil organic carbon throughout an agricultural soil profile assessed by compound-specific ^{13}C analysis. Org Geochem 42:1502–1511

Mikutta R, Kleber M, Torn MS, Jahn R (2006) Stabilization of soil organic matter: association with minerals or chemical recalcitrance? Biogeochemistry 77:25–56

O'Brien SL, Jastrow JD, McFarlane KJ, Guilderson TP, Gonzalez-Meler MA (2012) Decadal cycling within long-lived carbon pools revealed by dual isotopic analysis of mineral-associated soil organic matter. Biogeochemistry. doi:10.1007/s10533-011-9673-0

Oades JM (1988) The retention of organic matter in soils. Biogeochemistry 5:35–70

Olk DC, Gregorich EG (2006) Overview of the symposium proceedings, "Meaningful pools in determining soil carbon and nitrogen dynamics". Soil Sci Soc Am J 70:967–974

Ono K, Hiradate S, Morita S, Hirai K (2012) Fate of organic carbon during decomposition of different litter types in Japan. Biogeochemistry. doi:10.1007/s10533-011-9682-z

Parfitt RL, Childs CW (1988) Estimation of forms of Fe and Al: a review, and analysis of contrasting soils by dissolution and Moessbauer methods. Aust J Soil Res 26:121–144

Parton WJ, Schimel DS, Cole CV, Ojima DS (1987) Analysis of factors controlling soil organic matter levels in Great Plains Grasslands. Soil Sci Soc Am J 51:1173–1179

Paul EA, Collins HP, Leavitt SW (2001) Dynamics of resistant soil carbon of Midwestern agricultural soils measured by naturally occurring C-14 abundance. Geoderma 104:239–256

Philip LJ, Simard SW (2008) Minimum pulses of stable and radioactive carbon isotopes to detect belowground carbon transfer between plants. Plant Soil 308:23–35

Plante AF, Chenu C, Balabane M, Mariotti A, Righi D (2004) Peroxide oxidation of clay-associated organic matter in a cultivation chronosequence. Eur J Soil Sci 55:471–478

Poirier N, Derenne S, Balesdent J, Chenu C, Bardoux G, Mariotti A, Largeau C (2006) Dynamics and origin of the non-hydrolysable organic fraction in a forest and a cultivated temperate soil, as determined by isotopic and microscopic studies. Eur J Soil Sci 57:719–730

Preston CM (2001) Carbon-13 solid-state NMR of soil organic matter—using the technique effectively. Can J Soil Sci 81:255–270

Rasse DP, Rumpel C, Dignac M-F (2005) Is soil carbon mostly root carbon? Mechanisms for a specific stabilisation. Plant Soil 269:341–356

Rovira P, Casals P, Romanya J, Bottner P, Couteaux MM, Vallejo VR (1998) Recovery of fresh debris of different sizes in density fractions of two contrasting soils. Eur J Soil Biol 54:31–37

Schulten HR, Leinweber P (2000) New insights into organic-mineral particles: composition, properties and models of molecular structure. Biol Fertil Soils 30:399–432

Six J, Conant RT, Paul EA, Paustian K (2002) Stabilization mechanisms of soil organic matter: implications for C-saturation of soils. Plant Soil 241:155–176

Smernik R, Skjemstad JO (2009) Mechanisms of organic matter stabilization and destabilization in soils and sediments: conference introduction. Biogeochemistry 92:3–8

Smith JU, Smith P, Monaghan R, MacDonald J (2002) When is a measured soil organic matter fraction equivalent to a model pool? Eur J Soil Sci 53:405–416

Sollins P, Homann P, Caldwell BA (1996) Stabilization and destabilization of soil organic matter: mechanisms and controls. Geoderma 74:65–105

Sollins P, Swanston C, Kramer M (2007) Stabilization and destabilization of soil organic matter—a new focus. Biogeochemistry 85:1–7

Thevenot M, Dignac M-F, Rumpel C (2010) Fate of lignins in soil. Soil Biol Biochem 42:1200–1211

von Lützow M, Kögel-Knabner I, Ekschmitt K, Flessa H, Guggenberger G, Matzner E, Marschner B (2007) SOM fractionation methods: relevance to functional pools and to stabilization mechanisms. Soil Biol Biochem 39:2183–2207

Wagai R, Mayer LM, Kitayama K, Shirato Y (2012) Association of organic matter with iron and aluminium across a range of soils determined via selective dissolution techniques coupled with dissolved nitrogen analysis. Biogeochemistry. doi:10.1007/s10533-011-9652-5

Wichern J, Wichern F, Joergensen RG (2006) Impact of salinity on soil microbial communities and the decomposition of maize in acidic soils. Geoderma 137:100–108

Wiseman CLS, Puettmann W (2006) Interactions between mineral phases in the preservation of soil organic matter. Geoderma 134:109–118