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Chemical changes during composting of plant residues reduce their mineralisation in soil and cancel the priming effect

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Summary

Applying composts is useful for increasing soil carbon (C) stocks and improving agricultural productivity. In order to understand the effects of composts on soil organic matter (SOM) formation and mineralisation, ¹³C-labelled plant residues, previously composted or not, were incubated in an arable soil. The amount of ¹³C was quantified in the CO₂ evolved, the dissolved organic carbon (DOC) and in the microbial biomass (MB). Composting decreased (from 29 to 9%) the proportion of the plant residue labile pool and increased the residence time of both labile and more stable pools from 21 to 34 days and 1.5 to 5.5 years, respectively. At the beginning of the incubation, the amounts of ¹³C in the DOC and MB were significantly higher when adding fresh residues than composted ones to the soil. A priming effect on SOM mineralisation (+21% over 3 years) was only observed for non-composted residues. These differences were attributed to changes in the chemical composition of plant materials during composting (less sugars and lipids, more lignins). In terms of C budget, the total loss of CO₂ (including the composting process and the SOM priming by fresh residues) was comparable for both treatments after 600 days of incubation.

Keywords: ¹³C-labelling, CO₂, lignin, sugars, lipid, DOC, microbial biomass, C budget

Composting is a cost-effective means of recycling waste organic matter in agriculture and can improve soil C storage, as has been shown in long term field experiments (Peltre et al., 2012). Composts are produced through the stabilization of organic wastes progressively processed by microorganisms under controlled aerobic conditions (de Bertoldi et al., 1987). The degree of maturation of the compost, depending on the initial feedstock and process parameters, directly influences its subsequent decomposition, once applied to soils (Bernal et al. 1998; Cambardella et al., 2003). The influence of compost addition on soil properties and plant productivity is well documented. However, the effects of compost on SOM mineralisation are still poorly studied. It is known that fresh OM inputs can stimulate native SOM degradation, a phenomenon called priming effect (PE) (Löhnis 1926; Fontaine et al. 2003). In a recent study, it has been shown that SOC stocks dynamics between agricultural soils receiving fresh or composted straw over 52 years were similar, suggesting no long-term impact of priming effect (Cardinael et al., 2015). The reason for the lack of difference are not well understood however. The objective of this work was to evaluate the impact of composting on the chemical composition of plant residues, their mineralisation in soil and any related SOM priming effect. We hypothesized that composting would reduce the labile fraction of plant material and consequently would reduce both their decomposition by soil microorganisms any potential priming effects. We incubated composted and non-composted ¹³C-labelled plant residues in an arable soil for 3 years and determined the ¹³C-labelling in the CO₂ evolved, the dissolved organic carbon (DOC) and the soil microbial biomass.

The mixture of plant residues was composed of 23 g DW of ¹³C-labelled wheat straw ($\delta^{13}\text{C}=1749\text{‰}$), 31 g DW rapeseed leaves ($\delta^{13}\text{C}=1459\text{‰}$), 40 g DW corn stalks and leaves ($\delta^{13}\text{C}=1639\text{‰}$), mixed with 403 g DW of non-labelled (-26‰) grass clippings. All residues were almost dried (5% humidity) except for grass clippings (69% humidity). Ten boxes (2L) containing a subsample (40g) of the mixture were placed in 170 L-composting pilot devices

during 90 days with forced aeration (Doublet et al., 2011). Before analyses and incubation in the soil, all residues were ground to 0.2mm. The C content and ^{13}C signature were measured by EA-IRMS (NA-1500, Carlo-Erba). The chemical composition and the uniformity of the labelling at the molecular level was checked by analysing the lignin units by the CuO oxydation method (Dignac et al., 2005), the non-cellulosic sugars by the acetate alditol method (Rumpel and Dignac, 2006) and the lipid extract using BF_3 -methanol method (Lerch et al., 2007) by means of GC-c-IRMS. The agricultural soil (0-28 cm plough horizon) used for the incubation is located at Feucherolles, France (latitude 48.8°, longitude 1.96°). It is a silt loam soil (Soil Taxonomy: Typic Hapludalf; FAO system: Albic Luvisol) with 7% sand, 76% silt, 17% clay, 8.9 g kg⁻¹ of organic C, 1.1 g kg⁻¹ of N and a pH of 6.9. The soil bulk ^{13}C signature was -24.8‰. After being collected and sieved moist to < 5 mm, soil samples (125 g dry weight equivalent) were preincubated for 3 weeks at 20 °C and 60% of the water holding capacity (WHC=0.24 mL g⁻¹ soil) in serum bottles (565 mL). Soil samples were then amended either with composted or non-composted plant residues, corresponding to a C addition of 11.5% of the soil organic C. Control samples did not receive any amendment. Three experimental replicates were used. All samples were adjusted to 80% of the WHC, flushed with CO₂ free air (19% O₂, 81% N₂) and incubated at 20 °C in the dark for 36 months.

Soil respiration, dissolved organic carbon (DOC) and microbial-C (MB) were monitored throughout the incubation as described by Lerch et al. (2009). Briefly, the concentration and isotopic signature ($\delta^{13}\text{C}$, ‰) of the CO₂ were measured at each sampling date. Then, samples that were not used for destructive DOC and MB analyses, were flushed with CO₂ free air, sealed again and placed back in the incubation chamber until the subsequent gas measurement. The amounts of C and ^{13}C in the MB were measured on 20 g subsamples by fumigation-extraction (FE) using 0.03 M K₂SO₄ as an extractant (Gaillard et al., 1999). A correction factor (K_{EC}) of 0.45 was used to estimate microbial C (Vance et al., 1987). The

non-fumigated soil was also used to assess the DOC content. All extracts were freeze-dried and their elemental and isotopic contents measured with an EA-IRMS. The relative amount of ^{13}C in each fraction was obtained using a mass balance equation (see supplementary information). Three analytical replicates were performed for all experimental replicates. All statistical analyses (ANOVA and non-linear regression) were performed using R software (version 2.12.0 R Development Core Team, 2008) and graphical representations with SigmaPlot 14.0 (Systat Software, Inc.).

Mass loss during composting was 60% dry weight, 64% for C, and 43% for nitrogen (N). The C content was $35\pm 1\%$ and $39\pm 1\%$, the C/N ratio 15.0 ± 0.4 and 9.3 ± 0.2 and the ^{13}C signature $271\pm 10\text{‰}$ and $263\pm 13\text{‰}$ for the mixture of composted and non-composted plant residues, respectively. The mean of the molecular ^{13}C signature (Figure S1) was similar to that of the bulk ($253\pm 47\text{‰}$ and $274\pm 53\text{‰}$ for composted and non-composted plant residues, respectively). Composting increased by 69% the lignin contribution to total remaining C (Fig. 1A) and decreased by 58% the ratio of cinnamic to syringic units. Conversely, the relative amount of non-cellulosic sugars decreased by 53% after composting (Fig. 1B) with an increase of C6 to C5 ratio. The lipid concentration decreased by 55% with a preferential degradation of n-alcohols and n-alkanes. Comparatively, steroids and terpenes were preserved and n-acids increased significantly. As expected, total CO_2 evolved was much higher in soil amended with non-composted than composted plant material and control samples (Fig. 2A). After 3 years of incubation, the mineralisation reached $36\pm 4\%$ and $79\pm 8\%$ of the initial C of the composted and non-composted residues, respectively (Fig. 2B). The mineralisation curves were fitted ($r^2 = 0.99$, $P < 0.001$) with a first order kinetic equation with 2 compartments: $y = a(1-e^{-\alpha t}) + b(1-e^{-\beta t})$, where a and b are the mineralisation potentials and α and β the first order rate constants, respectively for the labile and non-labile C pools (Lerch et al., 2011). The parameters values were $a = 9\%$ and 29% , $b = 91\%$ and 71% , $\alpha = 0.03$ and 0.05 day^{-1} and $\beta =$

0.5x10⁻³ and 1.8x10⁻³ day⁻¹, respectively for composted and non-composted materials. These values indicate a clear relationship among the chemical composition, the dynamics of DOC and MB as well as the mineralisation kinetics. Composting reduced in particular the relative concentration of energetic compounds (e.g. sugars), the DOC and the amount of C incorporated into the microbial biomass. Kinetics parameters also suggest that composting increased significantly the residence time of added organic matter. Up until 21 days, the amounts of DOC were significantly higher for samples amended with both fresh and composted plant residues compared to control samples and beyond 21 days remained around 45 µgC g⁻¹ soil (Fig. 3A). Composting affected the amount of DOC and ¹³C-DOC only on the first day of incubation, with a maximum of 4±1% and 8±1% of the initial ¹³C amount of composted and non-composted plant materials, respectively (Fig. 3B). The microbial C was significantly higher for amended than non-amended samples at day 3 (Fig. 3C) but no difference were observed between non-composted and composted samples. Initially, a similar amount of ¹³C-biomass was found in both fresh and composted plant residues (1 to 2% of the initial ¹³C amount). Subsequently, during the first 30 days of incubation, the amount of ¹³C incorporated into the microbial biomass was significantly higher for non-composted residues (Fig. 3D). The maximum values were observed after 3 days of incubation with 3±1% and 6±1% of the initial amount of ¹³C, respectively for composted and non-composted plant residues. We did not observed a PE with composted residues while non-composted ones increased SOM mineralisation by 21±7% after 3 years of incubation, compared to the control (Fig. 2C).

It is known that composting affects the chemical composition of fresh organic material (e.g. Almendros et al., 1991; González-Vila et al., 1999; Dignac et al., 2005). Here we observed a preferential decrease of carbohydrates and lipids compared to the lignin monomers, which is in line with previous studies made on plant composting (Almendros et

al., 2000). The increase of the C6 to C5 ratio upon composting (from 0.63 to 1.44) indicates that some plant-derived sugars were degraded while new sugars were synthesized by microbes (Goyal et al., 2005; Kato and Miura, 2008). This is consistent with the relative increase of fatty acids originated from the microbial biomass in the lipid extract such as mono-unsaturated, cyclopropyl, iso- and anteiso fatty acids (data not shown). The preferential degradation of n-alcohols and n-alkanes and the relative preservation of steroids and terpenes during composting have been reported by Spaccini and Piccolo (2007). The decreased in the ratio of cinnamic to syringic units is in agreement with the results from González-Vila et al. (2009) which indicates that the lignocellulosic material was partly transformed during the thermophilic stage. As expected, the chemical changes of plant residues during composting affected significantly their mineralisation in soil. We estimated that the size of the labile C pool was decreased by 70%, which is consistent with the decrease of lipids and sugars proportion after composting. The turnover of labile and non-labile C pools increased, probably due to the preservation of more recalcitrant compounds in both pools, as observed in the chemical analyses. The absence of PE when adding compost to the soil could be explained by the fact that the more labile organic compounds that served as potential C and energy source for microbial growth had previously been used during composting (Said-Pullicino et al., 2007). Sikora and Yakovchenko (1996) also observed that compost addition did not stimulate the mineralisation of two-year old SOM previously labelled with ^{14}C -straw. In terms of C budget, the total loss of CO_2 (including the composting process and the SOM priming) was comparable for both treatments after 600 days of incubation (Fig. 2D). It would have taken about 300 more days to reach this equivalence if SOM priming effect was not included, which shows the importance of taking this mechanism into account when comparing soil amendments C budget. These results could be useful to better incorporate PE mechanisms into global carbon models (Guenet et al., 2018). From a practical point of view, this study

demonstrates that composting plant residues increases soil C inputs but does not increase SOM decomposition rate as commonly observed when adding fresh residues.

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References list

- Almendros, G., Fründ, R., González-Vila, F.J., Haider, K.M., Knicker, H., Lüdemann, H.D., 1991. Analysis of ^{13}C and ^{15}N CPMAS NMR-spectra of soil organic matter and composts. *FEBS Letters* 282, 119–121.
- Almendros, G., Dorado, J., González-Vila, F.J., Blanco, M.J., Lankes, U., 2000. ^{13}C -NMR assessment of decomposition patterns during composting of forest and shrub biomass. *Soil Biology Biochemistry* 32, 793–804.
- Bernal, M.P., Sánchez-Monedero, M.A., Paredes, C., Roig, A. 1998. Carbon mineralization from organic wastes at different composting stages during their incubation with soil. *Agriculture, Ecosystems and Environment* 69, 175-189.
- Cambardella, C.A., Richard, T.L., Russell, A., 2003. Compost mineralization in soil as a function of composting process conditions. *European Journal of Soil Biology* 39, 117–127.
- Cardinael R, Eglin T, Guenet B, Neill C, Houot S, Chenu C. 2015. Is priming effect a significant process for long-term SOC dynamics? Analysis of a 52-years old experiment *Biogeochemistry*. 123(1-2):203-219.

179 Dignac, M.F., Bahri, H., Rumpel, C., Rasse, D.P., Bardoux, G., Balesdent, J., Girardin, C.,
180 Chenu, C., Mariotti, A., 2005. Carbon-13 natural abundance as a tool to study the dynamics
181 of lignin monomers in soil: an appraisal at the Closeaux experimental field (France).
182 *Geoderma* 128, 3-17.

183 Dignac, M.-F., Houot, S., Derenne, S., Francou, C., Derenne, S., 2005. Pyrolytic study of
184 compost and waste organic matter. *Organic Geochemistry*. 36, 1054–1071.

185 Doublet J., Francou C., Poitrenaud M., Houot S., 2011. Influence of bulking agents on
186 organic matter evolution during sewage sludge composting; consequences on compost
187 organic matter stability and N availability. *Bioresource Technology*, 102, 2, 1298-1307.

188 Fontaine, S., Mariotti, A., Abbadie, L., 2003. The priming effect of organic matter: a
189 question of microbial competition? *Soil Biology and Biochemistry* 35, 837-843.

190 Gaillard, V., Chenu, C., Recous, S., Richard, G., 1999. Carbon, nitrogen and microbial
191 gradients induced by plant residues decomposing in soil. *European Journal of Soil Science*
192 50, 567–578.

193 Guenet, B., Camino-Serrano, M., Ciais, P., Tifafi, M., Maignan, F., Soong, J. L., Janssens, I.
194 A., 2018. Impact of priming on global soil carbon stocks. *Global Change Biology* 24, 1873–
195 1883.

196 González-Vila, F.J., Almendros, G., Madrid, F., 1999. Molecular alterations of organic
197 fractions from urban waste in the course of composting and their further transformation in
198 amended soil. *Sciences of the Total Environment* 236, 215–229.

199 González-Vila, F. J., González-Pérez, J. A., Akdi, K., Gómis, M. D., Pérez-Barrera, F.,
200 Verdejo, T., 2009. Assessing the efficiency of urban waste biocomposting by analytical
201 pyrolysis (Py-GC/MS). *Bioresource Technology* 100, 1304–1309.

202 Goyal, S., Dhull, S.K., Kapoor, K.K., 2005. Chemical and biological changes during
203 composting of different organic wastes and assessment of compost maturity. *Bioresource*
204 *Technology* 14, 1584- 1591.

205 Kato, K., Miura, N., 2008. Effect of matured compost as a bulking and inoculating agent on
206 the microbial community and maturity of cattle manure compost. *Bioresource Technology*
207 99, 372–3380.

208 Lal, R., 2005. Soil erosion and carbon dynamics. *Soil and Tillage Research* 81, 137–142.

209 Lerch, T.Z., Dignac, M.F., Barriuso, E., Bardoux, G., Mariotti, A. 2007. Tracing 2,4-D
210 metabolism in *Cupriavidus necator* JMP134 with ¹³C-labelling technique and fatty acid
211 profiling. *Journal of Microbiological Methods* 71, 162–174.

212 Lerch, T.Z., Dignac, M.F., Nunan N., Bardoux, G., Barriuso, E., Mariotti, A., 2009.
213 Dynamics of soil microbial populations involved in 2,4-D biodegradation in soil revealed by
214 FAME-based Stable Isotope Probing. *Soil Biology and Biochemistry*, 41, 77-85.

215 Lerch T.Z., Nunan N., Dignac M.F., Chenu C., Mariotti A., 2011. Variations in microbial
216 isotopic fractionation during soil organic matter decomposition. *Biogeochemistry* 106, 5-21.

217 Peltre, C., Christensen, B.T., Dragon, S., Icard, C., Kätterer, T., Houot, S., 2012. RothC
218 simulation of carbon accumulation in soil after repeated application of widely different
219 organic amendments. *Soil Biology and Biochemistry* 52:49–60.

220 Rumpel, C., Dignac, M.F., 2006. Gas chromatographic analysis of monosaccharides in a
221 forest soil profile: Analysis by gas chromatography after trifluoroacetic acid hydrolysis and
222 reduction–acetylation. *Soil Biology and Biochemistry* 38, 1478-1481.

223 Said-Pullicino, D., Kaiser, K., Guggenberger, G., Gigliotti, G., 2007. Changes in the
224 chemical composition of water-extractable organic matter during composting: Distribution
225 between stable and labile organic matter pools. *Chemosphere* 66, 2166–2176.

226 Sikora, L.J., Yakovchenko, V., 1996. Soil organic matter mineralization after compost
227 amendment. *Soil Science Society of America Journal* 60, 1401-1404.

228 Spaccini, R., Piccolo, A., 2007. Molecular characterization of compost at increasing stages
229 of maturity 1. Chemical fractionation and infrared spectroscopy. *Journal of Agriculture and*
230 *Food Chemistry* 55, 2293–302.

231 Vance, E.D., Brookes, P.C., Jenkinson, D.S., 1987. An extraction method for measuring soil
232 microbial biomass C. *Soil Biology and Biochemistry* 19, 703–707.

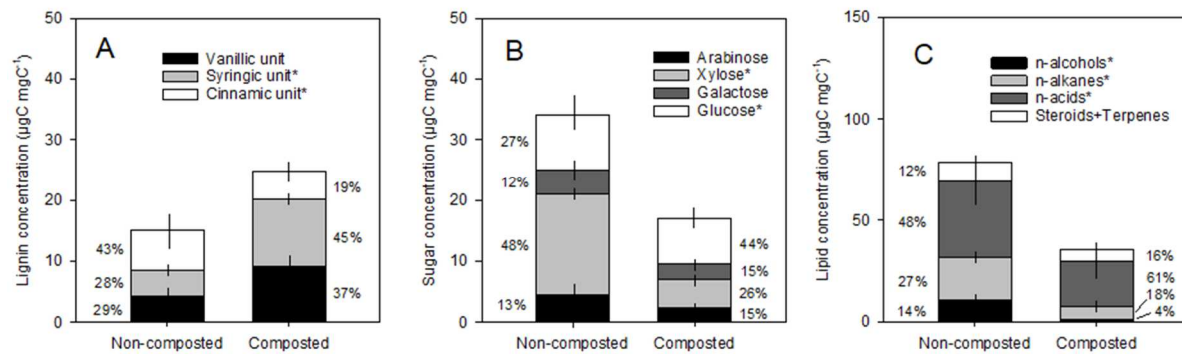


Figure 1: Lignin (A), non-cellulosic sugar (B) and lipid concentration (C) in the non-composted and composted plant residues. Lignin content is the sum of vanillic, syringic and cinnamic units. Non-cellulosic sugar content is the sum of arabinose, xylose, galactose, glucose (other minor molecules represented less than 10%). Lipid content is the sum of n-alcohols, n-alkanes, n-acids, steroids and terpenes. Data are the mean of three replicates. The proportion of each molecules (%) in a given fraction is represented beside the bars. Significant differences ($P < 0.005$) in the mass proportion of a molecule upon composting are indicated by a star (*) in the legend.

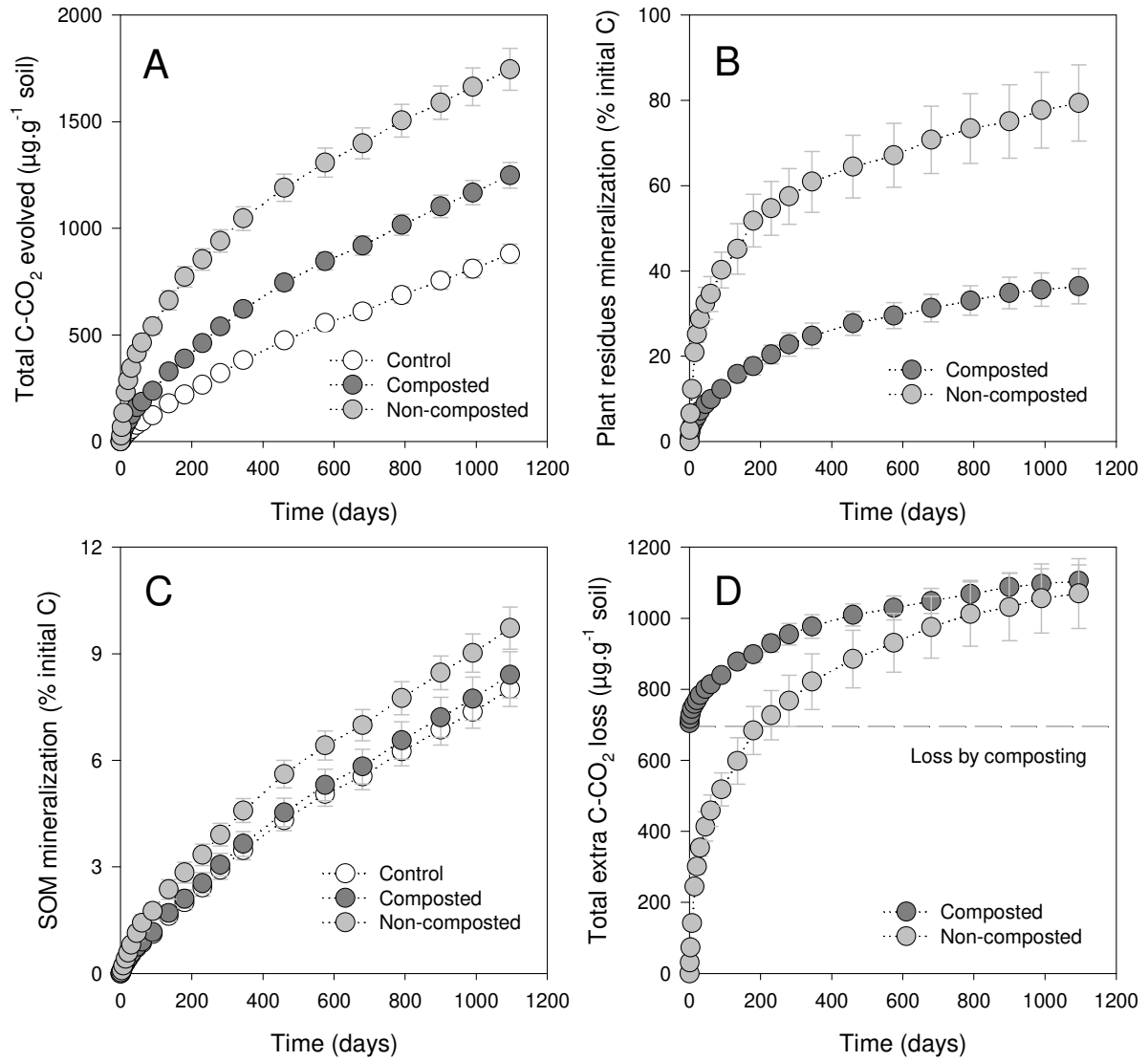
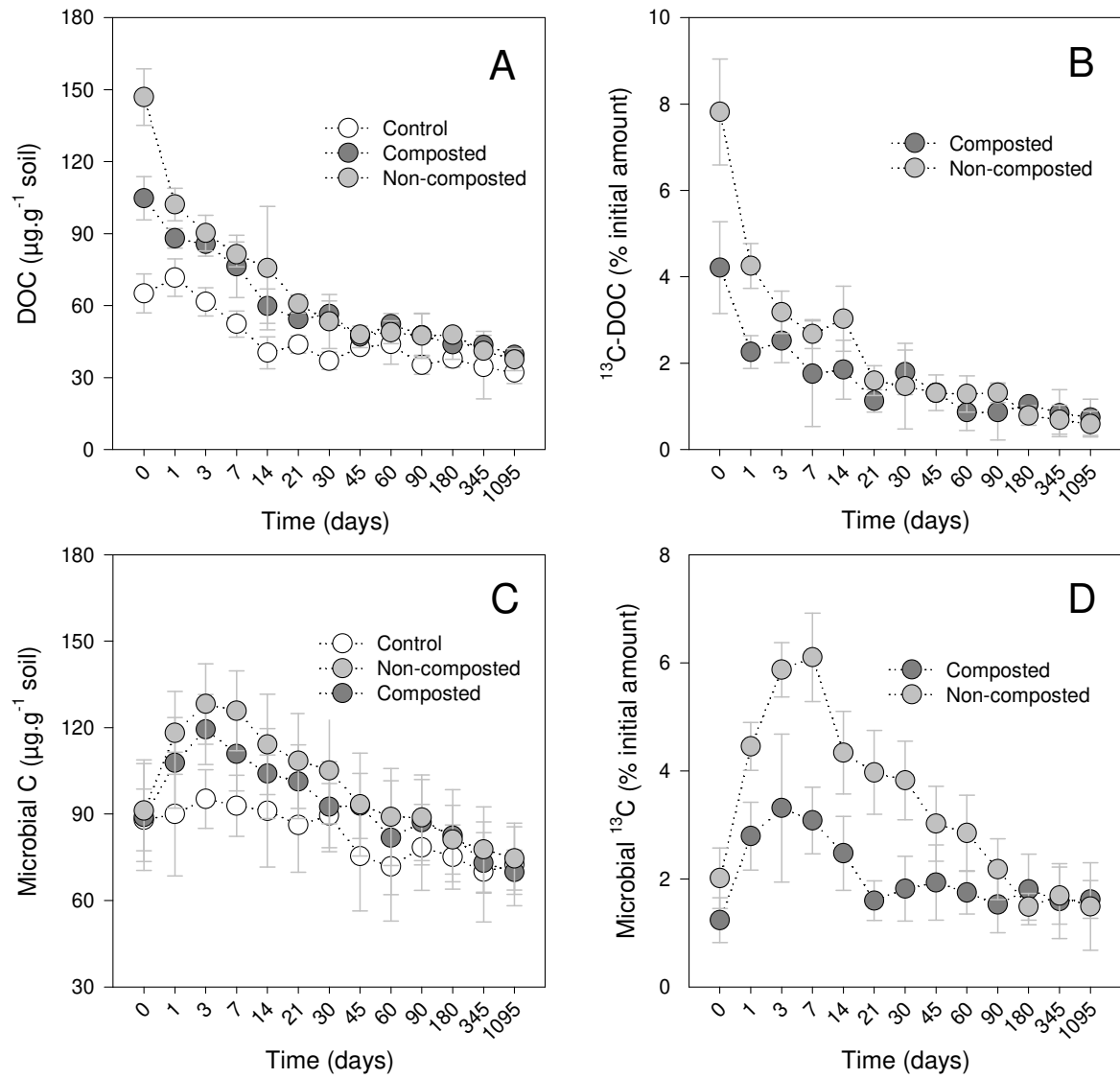


Figure 2: Total CO₂ emitted in μC g⁻¹ soil (A), plant residues mineralization (relative to the initial amount of C from composted or non-composted material) (B), SOM mineralization in μC g⁻¹ soil (C) and CO₂ evolved relative to the initial amount of carbon prior composting with CO₂ lost during composting and taken into account priming effect (D). Standard deviations correspond to three replicates.



15

16 **Figure 3:** Dissolved organic carbon (DOC) in $\mu\text{C g}^{-1}$ soil (A), ^{13}C -labelled DOC relative to the initial ^{13}C amount
 17 of composted or non-composted plant residues (B), microbial C in $\mu\text{C g}^{-1}$ soil (C) and microbial- ^{13}C relative to the
 18 initial ^{13}C amount of composted or non-composted plant residues (D). Standard deviations correspond to three
 19 replicates. The scale of time is nonlinear.