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Dynamics of carbon in deep soils inferred from carbon stable isotopes signatures : a worldwide meta-analysis

Jérôme Balesdent (1), Isabelle Basile-Doelsch (2), Joël Chadoeuf (3), Sophie Cornu (1), Delphine Derrien (4), Zuzana Fekiacova (1), and Christine Hatté (5)

(1) INRA, UR1119 Géochimie des Sols et des Eaux, F-13100 Aix-en-Provence, France (jerome.balesdent@aix.inra.fr), (2) Aix-Marseille Université, CNRS, IRD, CEREGE UM34, F-13545 Aix en Provence, France, (3) INRA, UR546 Biostatistique et Processus Spatiaux, F-84000 Avignon, France, (4) INRA, UR1138 Biogéochimie des Ecosystemes Forestiers, Centre de Nancy, F-54280 Champenoux, France, (5) CEA, CNRS, UVSQ, Laboratoire des Sciences du Climat et de l'Environnement UMR8212, F-91198 Gif-sur-Yvette, France

The contribution of soil carbon deeper than 30 cm to the atmospheric carbon balance is still poorly understood. A very straightforward quantification of the gross exchange of carbon between the atmosphere and soil organic matter can be obtained at places where the $^{13}C/^{12}C$ signature of vegetation has been changed for known durations, due to switch of the photosynthetic metabolism (C3 or C4) or to Free Air Carbon Enrichment experiments.

We compiled C and ^{13}C profile data of 113 sites of this type, either gahered from the literature or from our own measurements. Each site comprised two profiles : one where the $^{13}C/^{12}C$ of the vegetation had been changed, and a reference profile with unchanged vegetation $^{13}C/^{12}C$. An isotope mixing equation was used, which takes into account the natural isotope enrichments with depth and decay. Three main variables were calculated at any depth from 0 to 100 cm and in a few sites down to 200 cm : the carbon content, the proportion of new carbon (aged less than the duration of change t) and the amount of new carbon. The database concerned 23 countries, various climates (58% intertropical and 42% between 23° to 56° latitude) and various soil types and textures. Landuses and vegetation consisted in 26% of forests and woodlands, 35% of grasslands and 38% of cropped systems. The duration of the natural labelling t ranged from 2 years to ca. 4000 years. Peatlands, boreal, and desert environments were absent from the database.

Non-linear regressions with time across the dataset yielded kinetic parameters of the age distribution on one hand and of the flux of new carbon incorporation (kg C m^{-2} yr^{-1}) on the other, each calculated by 10 cm depth increments. On the average, the median ages of carbon increase from *ca*. 15 years at 0 cm to more than 1000 years at 100 cm. Turnover is on the average 2 to 3 times slower for the subsoil (30-100 cm) than for the topsoil (0-30 cm). Based on the incorporation of new C in the first decades, the carbon input to the 30-100 cm layer was estimated to 0.3 times (with 1 S.D. = 0.2 times) that to the topsoil 0-30 cm, whereas the corresponding ratio for total carbon stocks is close to 1.

A multivariate analysis confirmed that the turnover rate in the topsoil is dependent on land use and mean annual temperature, and related to a lesser extent to aridity index and clay content. The relative proportion of carbon input to the subsoil is higher in croplands than in forests or grasslands, in probable accordance with the exportation of plant aerial parts as crops.

We derive from this study quantitative constraints on depth-dependent mechanisms that drive carbon dynamics, such as decreasing decay rates down the depth and the magnitude of priming effects, the rate and intensity of carbon transport downwards, or the occurrence of stable C throughout the profiles. We also propose simplified expressions for the parameterization of models of carbon exchanges between deep soil organic carbon and the atmosphere.