

Expert Commentary B

THE GLOBAL EXTENT OF BLACK C IN SOILS: IS IT EVERYWHERE?

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THE ROLE OF BLACK CARBON IN GLOBAL CLIMATE MODELS

The latest projections of the Intergovernmental Panel on Climate Change (IPCC) estimate a 3°C increase in global temperatures within the next 100 years (IPCC 4th Assessment Report, 2007), and global warming is seen as a major driver in accelerating decomposition of soil organic matter, resulting in increased production of CO₂ (e.g. Davidson and Janssens, 2006). The 2007 IPCC report recommended coupling models of terrestrial biogeochemical and atmospheric and oceanic processes in order to improve general circulation models and to recognize the quantitative value of soil organic carbon (SOC) in the global carbon cycle.

Estimates of CO₂ emissions from soil rely on predictions of the response of different SOC pools to global warming and correct estimation of the size of these pools. In comparison to the pool representing the most stable and biologically unreactive fraction, commonly referred to as passive or inert organic carbon (IOC), the decomposition of labile C is expected to be faster as a response to temperature increase. IOC is a fraction of the SOC pool that is not readily available for microbial decomposition and has turnover times exceeding 100 years (e.g. Krull et al., 2003).

Black C (BC) is usually considered the most abundant form of IOC and is defined as the 'carbonaceous residue of incomplete combustion of biomass and fossil fuels' (Schmidt and Noack, 2000). BC is important to several biogeochemical processes; for example, BC potentially modifies climate by acting as a potential carbon sink for greenhouse gases (Kuhlbusch, 1998) and leads to increasing solar reflectance of the Earth's atmosphere, but

also to a heating of the atmosphere (Crutzen and Andreae, 1990). BC production from fossil fuel combustion contributes to aerosol C, decreasing surface albedo and solar radiation (IPCC 4th Assessment Report). Due to its condensed aromatic structure, BC has a low biochemical reactivity. ¹⁴C ages of BC in soils vary between 1160 and 5040 years (e.g. Schmidt et al. 2002).

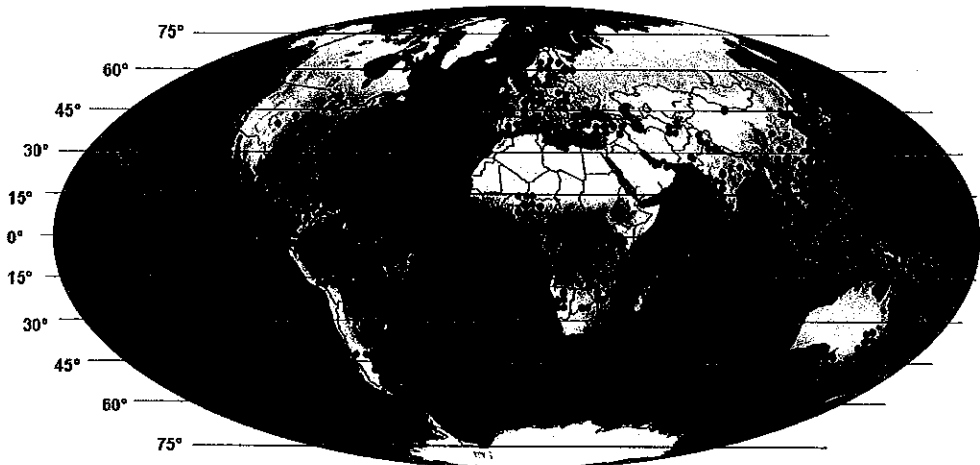


Figure 1. Distribution of soils used for the prediction of BC in surface soils and global NPP.

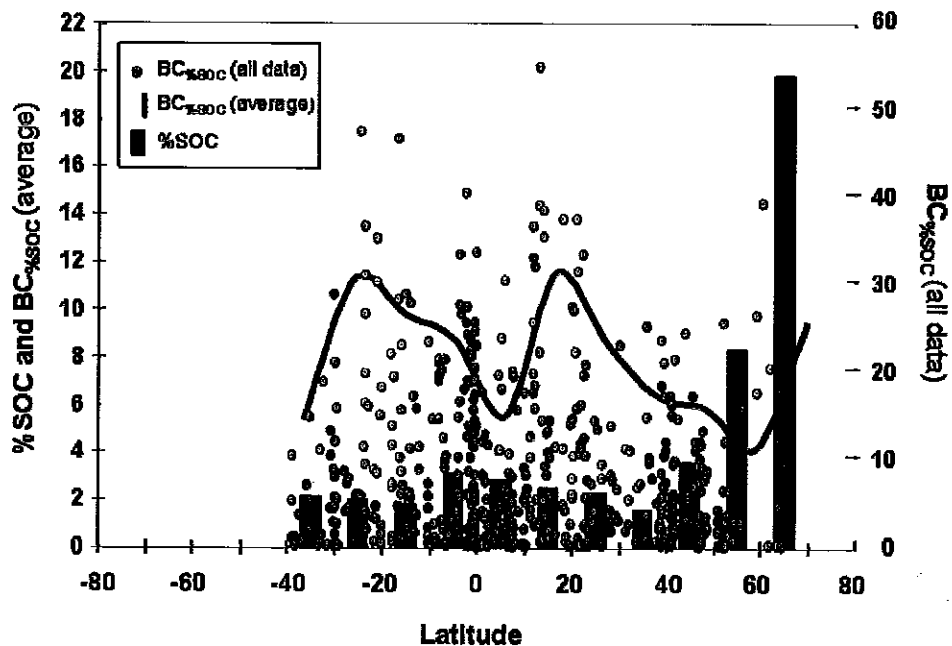


Figure 2. Distribution of BC_{%SOC} and %SOC in surface soils across latitudes.

Baldock (2007) reported that BC constitutes up to 60% of SOC, indicating that BC can make up a significant part of SOC affecting the response of SOC to temperature changes and the overall turnover time of SOC. Thus, the effect of such a large and unreactive C pool must

be effectively integrated into global C cycle and climate models. However, the latest IPCC report regards BC only as an aerosol and not as part of SOC, despite an earlier recommendation to the IPCC to "... better gauge the influence of BC on the global carbon cycle" as the result would ensure a "more accurate global black C budget and a better understanding of the role of BC as a potential sink in the global C cycle." (2006 IPCC guidelines for national greenhouse gas inventories; appendix 1). The lack of incorporating soil BC in global climate change assessments may be largely due to the lack of global databases on BC in soils and sediments and the understanding of factors and processes that may influence BC contents in soils (climate, soil texture, primary productivity and fire abundance).

In order to provide reliable projections of future CO₂ emissions from soils, due to global warming, it is important to consider the global distribution of soil BC. Through an initial assessment of the World Soil Archive (<http://library.wur.nl/isric/>) we demonstrate the variability and trends of global soil BC distribution between different climates and soil types and discuss the implications of this chemically recalcitrant form of C on the global C cycle. By doing this, we also demonstrate that current methods exist to routinely analyse BC and in the future to develop a global BC map.

ARE THERE ROUTINE METHODS TO GENERATE A GLOBAL BC MAP?

We have developed a rapid fourier-transform infrared-based technique that provides predictive capability for major soil properties, including BC content. BC was quantified by a novel mid-infrared (MIR) method coupled with partial least squares (PLS) (Janik et al., 2007) that allowed rapid analysis of a large number of samples, not feasible by other published methods (Hammes et al., 2007). This method was originally developed and calibrated on Australian soils (Janik et al., 2007); however, subsequently, we were able to verify that the predictive capacity of the MIR technique for soils from other parts of the world was robust in most cases.

BC IN WORLD SOILS: WHAT DRIVES BC PRODUCTION AND DECOMPOSITION?

Our initial assessment took advantage of the large collection of soils that constitute part of the ISRIC – world soil information database (<http://library.wur.nl/isric/>). We obtained over 400 samples that span all major climate zones and soil types across most parts of the world (Fig. 1). Utilising the MIR/PLS technique, we developed a database that illustrates for the first time the predicted proportion of BC in this large soils dataset. We hope that this initial dataset may become an incentive for the rigorous establishment of a global BC map, data from which may then be incorporated into future IPCC reports and C cycle models.

Figure 2 shows the proportion of BC (as % of total SOC: BC_{%SOC}) as well as total SOC contents across northern and southern hemispheres. These data show that BC in surface soils (A and A/B horizons) is ubiquitous in large parts of the world and occurs in the majority of the sampled locations. The variability was large, resulting in BC_{%SOC} varying from over 50%

to almost 0%. The soils richest in BC occur in latitudes of 20-30° in both hemispheres, situated mostly in central and South America and southern parts of Africa. These areas correspond to tropical climates with a pronounced dry season in winter ('Aw' in the Koeppen classification). In higher latitudes in the northern hemisphere (60-70°), BC contents were also high and were associated with an increase in total SOC (Fig. 2). These areas are classified as humid-temperate, constantly moist climates (Cf in Koeppen classification). Higher SOC content at high latitudes results from cool climates and low decomposition rates, which promotes accumulation of organic matter.

Despite the high spatial variability of $BC_{\%SOC}$, soils with a high proportion of BC fell largely in the soil group of Vertisols. Vertisols occur worldwide in seasonal climate zones and in lower relief positions (Richardson and Vepraskas, 2000). Such areas of deposition would favour accumulation of BC through erosion and deposition. Another factor contributing to the high amounts of $BC_{\%SOC}$ in Vertisols could be the comparably high proportion of clay (known to stabilize soil organic matter) and the type of clay (smectitic). The MIR-predicted data showed that Vertisols were amongst the soil types with the highest clay contents (average 44%). High clay content may promote retention of fine BC. However, clay alone is not a determining factor for high $BC_{\%SOC}$. Oxisols and Ultisols, having the highest clay content (from MIR prediction) of all analysed soil types (45%), had the lowest $BC_{\%SOC}$ values. Oxisols, and to a lesser degree Ultisols, are mostly found in high-rainfall tropical climates, lacking seasonal rainfall (Af in Koeppen classification) and having a lower fire activity. While fire activity and BC content are both high in the southern hemisphere this relationship is not consistent and does not concur with findings in parts of the northern hemisphere where fire activity is lower, yet $BC_{\%SOC}$ is still high (Carmona-Moreno et al., 2005).

Thus, a combination of factors, such as climate (the necessity of a pronounced dry season to ensure fire occurrence), position in the landscape (areas of accumulation) and mineralogy (high amount of expansive clays) may be instrumental in promoting the formation and/or retention of $BC_{\%SOC}$ in soils. As illustrated in Figure 1, net primary productivity alone did not appear to be a significant factor globally as it is highest in equatorial regions where $BC_{\%SOC}$ was lowest.

While we show here that BC contents in surface soils are often significant, BC can also accumulate deeper in the soil. In addition, soil erosion and transport of BC may result in significant accumulation of BC in rivers, estuaries and off-shore sediments (Krull et al., 2006). Thus, the inclusion of BC in global climate models will require a thorough assessment of BC contents not only in surface but in deeper soil horizons as well as aquatic sediments. The analyses conducted in this study indicate that methods exist to accomplish BC measurements for large areas. However, the high variability of the data indicates that broad empirical measurements and extrapolation over large areas are not sufficient for the aim of producing a global BC map. Thus, the next steps in a comprehensive assessment of global BC stocks and distribution have to include a detailed and consistent sampling format as well as a thorough assessment of the processes that control sources and sinks of BC.

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