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BLACK CARBON IN SOILS: RELEVANCE, ANALYSIS, DISTRIBUTION

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Black carbon (BC), a graphitic, particulate form of carbon that results from the incomplete combustion of organic material, is a significant part of the soil organic carbon (SOC) in soils worldwide. Burning biomass and fossil fuels releases black carbon in the form of soot, char, and charcoal in soils and the atmosphere. It is pervasive compared to other SOC components, BC is less reactive and more persistent in soils. Important implications for nutrient storage result from its stability as well as chemical and physical characteristics including high surface area and porosity. Black carbon poses a particular threat to human health due to its minute size. In addition to having an effect on human health, black carbon also reduces visibility, damages ecosystems, lowers agricultural production and hastens global warming. The BC particles that give soot its black appearance intensely absorb sunlight. As a result of the incomplete combustion of fossil fuels, biofuels and biomass, BC is created both naturally and through human activity. The main contributors include wood burning, cook stove emissions, diesel engine pollution and forest fires. Black carbon is 460–1,500 times more effective than CO₂ at absorbing heat or warming the atmosphere. Black carbon, which is floating in the atmosphere, causes warming by converting solar radiation into heat. Additionally, it affects regional circulation and rainfall patterns, as well as cloud formation. Production of biochar BC and its storage in soils are considered to be particularly effective methods for sequestering carbon. Due to the continuum of materials found in BC, numerous analytical techniques, such as optical, chemical, and thermal ones, have been developed for its examination. This makes it challenging to evaluate research side by side and to construct a comprehensive picture of BC distribution. An assessment of black carbon in soils would be helpful to pinpoint the variables and processes impacting BC in soils and perhaps offer a critical tip for comprehending the global carbon cycle.

Formation of Black Carbon

The chemical structure of BC is highly aromatic, and carbon can form manifold forms of solid structures because of its ability to occur in different hybridization state. The BC created by vegetation fires frequently comprises of stacks of a few randomly oriented graphitic layers. The short-, medium-, and long-term orders of BC are influenced by factors such fuel moisture content and temperature during combustion. Combined with ozonation experiments, Fourier transform infrared (FTIR) spectroscopy was used to examine the structure and reactivity of BC (Akhter et al., 1985). Due to drastically expanded deforestation, changed agricultural practises and the burning of coal and oil for industrial energy supplies, BC production has surged over the past several centuries. These sources have different regional and temporal distributions based on the eco-system, climate, living conditions, and population density. The seasonal fire season influences the annual cycles of vegetation and fossil fuel combustion, with winter being the peak season for household heating. Fossil fuel combustion is a significant source of BC.

BC And Soil Organic Matter Composition

It has been suggested that the presence of BC is a source of highly fragrant components of soil humic acids that may be extracted from soils (Haumaier and Zech, 1995). In his 1983 study, Klmda contrasted humic acids made from burnt materials with those found in soil. The highest concentrations of humic acids were found in charcoal samples taken from soil horizons, followed by samples taken from bonfires. According to Klmda's (1983) theory, the carbonaceous byproducts of plant combustion weather naturally to produce some of the humic and fulvic acid component. According to Takahashi et al. (1994), burning plants was a significant contributor to the development of deep black soils. Several researchers have discovered that blackish, coal-like particles with sizes between 2 and 10 gm frequently exist and have a cellular structure. Many typical Chernozems and other soil types with dark A horizons include these particles. (Beck *et al.*, 1982). Additionally, there is indirect proof that BC in soils like volcanic ash soils and Chernozems produces extremely fragrant humic acids (Kononova, 1966). Humic acid contents increased in the following order in a systematic investigation of soils: grey forest soils, dark grey forest soils, and Chernozems (Kononova, 1966). Overall, these findings lend more credence to the idea that soil organic matter's chemically stable aromatic components are derived from burnt organic molecules. It

appears that soils that have been continuously burned contain a significant quantity of BC and frequently have a black tint.

BC as a Potential Sink in the Global Carbon Cycle

BC is one of the most resistant forms of reduced carbon toward chemical oxidation and is often found in sediments and soils. Due to its high anticipated production rates and excellent resilience to degradation, BC may make up a sizable fraction of the organic carbon buried in sediments (Kuhlbusch and Crutzen, 1995). BC must either be rapidly building up in soils and terrestrial sediments or must be mineralized in these environments by severe oxidative mechanisms if it is not being transported off the continents at this fast pace. Oxidation of BC in soils is known to be caused by microbes. Vegetation fires are hypothesized to act as a sink for atmospheric CO₂ as a part of the global carbon cycle (Kuhlbusch and Crutzen, 1995). Not all of the CO₂ released by the combustion of fossil fuels and biomass is accounted for by the increase in atmospheric CO₂ concentration since the start of the industrial revolution. Some of this CO₂ is absorbed by the ocean in the form of carbonates and bicarbonates but this does not fully offset the estimated CO₂ emissions. One key sink for the missing carbon has been proposed as an increase in plant CO₂ absorption. BC's contribution as a sink in the global carbon budget was evaluated by Seiler and Crutzen in 1980.

Persistence in Soils

Black carbon is very stable in soils, but it is not inert. That conforms to our understanding of microbial decomposers and their ability to decompose, as long as temperature, humidity and aeration are acceptable and it has frequently been observed in the extremely old fractions of SOM. It is well acknowledged that BC must be somewhat deteriorated (Schmidt, 2004), if not, our soils would have massive layers dating back to the comparable ancient BC. However, compared to non-BC SOM, the decomposition rate of BC is much lower. Chemical recalcitrance resulting from BC's aromatic structure, high molecular weight that prevents microbial ingestion and hydrophobic nature are the key factors for the substance's stability in soils (Bachmann et al., 2008).

Adsorber for Nutrients and Contaminants

Charcoal, or so-called "biochar," has a high surface area due to its high porosity, which makes it a good adsorber for pollutants and nutrients. The solutes are physically and

temporally trapped in the charcoal particle's micropores, causing them to precipitate if the water phase evaporates and adhering to polar and nonpolar adsorption sites respectively. In field tests, adding charcoal to soils could increase their fertility (Nehls, 2002). In sandy soils, charcoal can also function as a preferred adsorber for heavy metals. Not only biochar BC, soot BC is a good adsorber for hydrophobic contaminants such as polyaromatic hydrocarbons (PAHs) in soils and sediments (Gustafsson and Gschwend, 1997). Reaction with BC results in a reduction in desorption and bioaccumulation rates, limited biodegradation, potential transport of adsorbed contaminants through the soil.

Black Carbon Analysis in the Lab Methods

BC is studied in atmospheric, oceanic and soil sciences. Hammes et al. (2007) introduces the quantitative and qualitative BC analysis methods used in soil science and compared them based on ring trial results. Three of the methods are described in the following sections-out of three, two uses the chemical resistance

- The Benzene Polycarboxylic Acids (BPCA) Method
- Acid Dichromate Oxidation (Cr₂O₇) Method
- Chemical Thermal Oxidation (CTO 375) Method

Identifying Black Carbon in the Soil Profile

Forest, shrub and grassland fires can all serve as natural supplies of char and charcoal. Burning fossil fuels and biomass are recent and ancient human sources. Strong evidence for anthropogenic effects at the site can also be seen in distinct accumulations of coarse charcoal residues in the soil strata. They could serve as markers for char-burning locations or offer hints for old or historic towns. With particle diameters ranging from 2 to 10 μm, BC may also be scattered quite evenly in the profile, as seen in Chernozems, in addition to conspicuous accumulations of coarse charcoal particles. To find burnt plant remnants in the field, a straightforward light microscope is helpful. The char contains preserved plant cellular structures that can be seen. A larger perspective clearly shows that BC darkens the colour of soil horizons. Schmidt et al. (1999) studied a 10 km colour sequence of chernozemic soils and discovered that, aside from BC concentrations, the soils were chemically and physically comparable and that the colour is mostly produced by varying BC contents. The earth may also be stained by soot accumulations from the past or present. These colored topsoil layers are primarily found around roadways and in populated areas, but they can also be found near

current or former train tracks because locomotive soot emissions then were much higher than they are now.

Distribution of Black Carbon in Soils

Black carbon is present in all soils and the atmosphere. It builds up more heavily in areas with frequent vegetation fires and close to areas where a lot of fossil fuel is used. Every climatic zone, from boreal woods to tropical rain forests, from prairies to high mountain regions, has recorded the accumulation of BC in soils (Deluca and Aplet, 2008). Black carbon has been found in both the arctic and metropolitan atmospheres.

Conclusions

Since the Devonian, black carbon has come from burning vegetation, and more recently, it has come from burning fossil fuels. BC has been widely dispersed via fluvial and atmospheric transport to become a practically universal component in soils, lacustrine and marine sediments. Combining short-term lab tests with field tests where BC has already been exposed to weathering and biological activity for decades, centuries, or millennia would be a promising strategy. Analysis has mostly focused on determining bulk features, such as micromorphology, elemental composition, isotopy and chemical structure, to determine BC origins. BC is relatively resistant to environmental degradation processes. Dark-colored soils, especially those impacted by regular vegetation or fossil fuel burning, appear to be abundant in BC. Understanding the processes involved in BC degradation is essential for calculating the BC stocks in soils and sediments. Analytical methods that clarify degradation processes at the molecular level are necessary for practical advancement in calculating BC degradation rates on a global basis.

References

- Akhter, M. S., Chughtai, A. R., & Smith, D. M. (1985). The structure of hexane soot I: spectroscopic studies. *Applied spectroscopy*, 39(1), 143-153.
- Bachmann, J., Guggenberger, G., Baumgartl, T., Ellerbrock, R. H., Urbanek, E., Goebel, M. O., ...& Fischer, W. R. (2008). Physical carbon-sequestration mechanisms under special consideration of soil wettability. *Journal of Plant Nutrition and Soil Science*, 171(1), 14-26.

- Beck, C. B., Coy, K., & Schmid, R. (1982). Observations on the fine structure of Callixylon wood. *American Journal of Botany*, 69(1), 54-76.
- DeLuca, T. H., & Aplet, G. H. (2008). Charcoal and carbon storage in forest soils of the Rocky Mountain West. *Frontiers in Ecology and the Environment*, 6(1), 18-24.
- Gustafsson, Ö., & Gschwend, P. M. (1997). Soot as a strong partition medium for polycyclic aromatic hydrocarbons in aquatic systems.
- Hammes, K., M.w.I. Schmidt, R.J. Smernik, L.A. Currie, w.P. Ball, T.H. Nguyen, P. Louchouart, S. Houel, O. Gustafsson, M. Elmquist, G. Cornelissen, J.O. Skjemstad, C.A. Masiello, J. Song, P. Peng, S. Mitra, J.C. Dunn, P.G. Hatcher, W.C. Hockaday, D.M. Smith, C. Hartkopf-Froeder, A. Boehmer, B. Luer, B.J. Huebert, W. Amelung, S. Brodowski, L. Huang, W. Zhang, P.M. Gschwend, D.X. Flores-Cervantes, C. Largeau, J.N. Rouzaud, C. Rumpel, G. Guggenberger, K. Kaiser, A. Rodionov, F.J. Gonzalez-Vila, JA Gonzalez-Perez, J.M. de la Rosa, DAC. Manning, E. Lopez-Capel, and L. Ding. (2007) Comparison of quantification methods to measure fire-derived (black/elemental) carbon in soils and sediments using reference materials from soil, water, sediment and the atmosphere. *Global Biogeochem. Cycles* 21:GB3016, doi:10.1029/2006GB002914.
- Haumaier, L., & Zech, W. (1995). Black carbon—possible source of highly aromatic components of soil humic acids. *Organic Geochemistry*, 23(3), 191-196.
- Schmidt, M. W., & Noack, A. G. (2000). Black carbon in soils and sediments: analysis, distribution, implications, and current challenges. *Global biogeochemical cycles*, 14(3), 777-793.
- Klmada, K. (1983). Carbonaceous materials as a possible source of soil humus. *Soil Science and Plant Nutrition*, 29(3), 383-386.
- Kuhlbusch, T. A. J., & Crutzen, P. J. (1995). Toward a global estimate of black carbon in residues of vegetation fires representing a sink of atmospheric CO₂ and a source of O₂. *Global Biogeochemical Cycles*, 9(4), 491-501.
- Nehls, T. (2002). Fertility improvement of a Terra Firme Oxisol in Central Amazonia by charcoal applications. *Final thesis in Geoecology, University of Bayreuth, Institute of Soil Science and Soil Geography*, 81.

- Schmidt, M. W. I., Skjemstad, J. O., Gehrt, E., &Kögel-Knabner, I. (1999). Charred organic carbon in German chernozemic soils. *European Journal of Soil Science*, 50(2), 351-365.
- Schmidt, M. W. (2004). Carbon budget in the black. *Nature*, 427(6972), 305-307.
- Seiler, W., &Crutzen, P. J. (1980). Estimates of gross and net fluxes of carbon between the biosphere and the atmosphere from biomass burning. *Climatic change*, 2(3), 207-247.
- Takahashi, T., Dahlgren, R. A., &Sase, T. (1994). Formation of melanicepipedons under forest vegetation in the xeric moisture regime of northern California. *Soil Science and Plant Nutrition*, 40(4), 617-628.