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LETTER TO EDITOR

Black carbon aerosol from biochar threats its negative emission potential

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Smith (2016) defines the use of biochar to sequester atmospheric carbon as a sustainable negative emission technology (NET). The author stresses that comprehensive studies are still needed to assess the full climate impact including the feedback due to albedo changes and to the release of black carbon aerosol (BC_a) to the atmosphere. The first issue is addressed by several papers (see Bozzi *et al.*, 2015), while BC_a emission potentials from biochar and their impact has not been properly assessed yet.

When produced, transported, manipulated and weathered, biochar is unavoidably fragmented into a spectrum of particle size (Spokas *et al.*, 2014). The smallest particles (≤2.5 μm) fall in the category of BC_a, defined as a refractory, water-insoluble carbonaceous material strongly absorbing visible light at wavelength of 550 nm (Bond *et al.*, 2013). Recent investigations showed that when grinded for 4 min, up to 2% of the biochar mass deriving from *Eucalyptus* sp. is made by ultrafine particles (≤2.5 μm), having very low settling velocities (Gao & Wu, 2014), thus being potentially transported over long ranges at high altitudes in the atmosphere (Wang *et al.*, 2014). Atmospheric BC_a is known to cause a positive direct radiative forcing (DRF) by absorbing shortwave solar irradiance and re-emitting energy as long-wave radiation (Bond *et al.*, 2013). In addition, BC_a causes indirect radiative forcing when deposited over ice and snow modifying surface albedo. Current average DRF of BC_a (excluding indirect effects) is estimated in 0.19 W m^{-2} with 90% uncertainty bounds from 0.17 to 0.31 W m^{-2} (Wang *et al.*, 2014).

Production, distribution and management of biochar can potentially release BC_a in the atmosphere. The global biochar application scenario discussed by Woolf *et al.* (2010) considers that up to 101.5 Pg C from biochar could be applied to 4.03 Gha of cropland and pastures in the next 100 years. The maximum potential DRF of emitted BC_a ($BC_{a\text{-}DRF}$) can be calculated as:

$$BC_{a-DRF}(t) = \frac{A}{c} f \times l \times MAC \times AFE \quad (1)$$

where A is the biochar application (g C m^{-2} s^{-1}), c is the mean C content of biochar (0.7), f is the estimated fraction of BC_a contained in the grinded biochar (0.02 ± 0.007), l is the mean lifetime of BC_a in the atmosphere expressed in seconds, MAC is the mass absorption coefficient of BC_a (m^2 g^{-1}) and AFE is its global mean absorption forcing efficiency per unit of absorbing aerosol optical depth (W m^{-2}/AAOD) (Wang *et al.*, 2014). In the unlikely case that all BC_a contained in biochar is released to the atmosphere, $BC_{a\text{-}DRF}$ is estimated to add 0.82 ± 0.51 W m^{-2}, to the background, globally. Given the large uncertainty on the global distribution of BC_a, which affects the magnitude of both MAC and AAOD, $BC_{a\text{-}DRF}$ boundaries may range from 0.77 to 1.44 W m^{-2}. Those values would reverse the negative radiative forcing (RF) of biochar due to C-sequestration that is estimated in −0.65 W m^{-2}, including avoided emissions, according to:

$$RF_{biochar}(t) = \frac{\Delta C_{atm}}{k} \frac{\beta}{CO_2(t)} \quad (2)$$

where ΔC_{atm} (in PgC) is the amount of CO_2-C removed from the atmosphere, k = 2.14 PgC ppm^{-1} is a conversion factor, $CO_2(t)$ (in μmol mol^{-1}) is the reference atmospheric CO_2 concentration in the absence of C-sequestration (500 μmol mol^{-1}) and β = 5.35 W m^{-2} is the pre-industrial RF.

However, the actual $BC_{a\text{-}DRF}$ is likely to be much lower as a number of factors may limit BC_a release as, for instance:

- the actual fragmentation of biochar in real production/applications is likely to be much lower than it was estimated herein, thus limiting BC_a content;
- a fraction of BC_a will remain in the path-length of the biochar layer deposited over the soil, and those particles will not be transported into the air (Olshevski *et al.*, 2015);
- potential BC_a emission will be reduced by deeper biochar incorporation to the soil;

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- the use of biochar in pellets, as recommended by Woolf *et al.* (2010), will limit BC_a emissions by decreasing fragmentation;
- the use of wet instead of dry biochar during application will decrease wind erosion (Silva *et al.*, 2015);
- field application of biochar under low turbulence conditions (low wind speed) will limit BC_a release.

Our conclusion is that RF effects due the particulate emission that unavoidably follow biochar applications may not be at all negligible, even if this is unlikely to attain the $BC_{a\text{-}DRF}$ shown above. This aspect is of importance if biochar applications aimed at *C*-sequestration and soil amendment will reach the intensity discussed by Woolf *et al.* (2010) in their maximum sustainable technical potential scenario. We agree with Smith (2016) that more research is urgently needed to quantify such potential offset and to address in a quantitative way and under realistic field conditions actual BC_a emission scenarios. This information will improve the existing biochar application guidelines (Major, 2010) enabling to identify the best agronomic practices to ensure a quantifiable NET effect in the balance between negative (*C*-sequestration) and positive (lower soil albedo + BC_a emission) radiative forcing components.

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