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Preface: Environmental benefits of biochar

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Biochar is defined as a carbon-rich solid obtained from the thermal decomposition of organic matter under a limited supply of oxygen and at relatively low temperatures. Biochar can be prepared not only from the thermal treatment of different organic feedstocks such as wood, biomass crops, and agricultural by-products, including cereal straw, but also from sewage sludge or urban waste. The application of biochar in soil poses several benefits to soil quality and therefore to crop yields. For example, biochar can increase soil water holding capacity and improve soil structure and biological properties as well as increase cation exchange capacity and pH, leading to an amelioration of agricultural yield and at the same time contributing to carbon sequestration due to the intrinsic carbon stability of biochar materials. Recently, biochar has been used for multiple applications in soil remediation due to its adsorption of pesticides or metals, both in laboratory and field studies. Since 2012 the European Geosciences Union meeting has provided a forum to discuss biochar research. Articles submitted to the 2013 and 2014 editions were considered for publication in this special issue "Environmental benefits of biochar" published in *Solid Earth*. The issue constitutes an adequate state of the art for all the potential biochar applications, comprising from soil carbon sequestration or biochar for soil improvement to new trends including the combination of biochar and phytoremediation, biochar use as growing media, or coal production from waste materials. The objective of this preface is to collect the major findings of the different contributions to this special issue.

Due to its molecular structure, the carbon in the resulting biochar is chemically and biologically in a much more stable form than that in the original raw material, and therefore can be stored in soils for much longer periods of time. However, our knowledge about the residing times of biochar in soil and its priming effect are incomplete. Cely et al. (2014) modelled the biochar effect on CO_2 soil emissions and concluded that the presence of a positive or negative priming effect depends on the feedstock of biochar and preparation conditions, providing a comprehensive view as how different biochar properties can affect the priming effect on soil CO_2 emissions and completing the guidelines of International Biochar Initiative (2012) and Delinat Institute (Schmidt et al., 2012) for the use of biochar in soil.

In this research field, Mukherjee et al. (2014) studied how different biochar amendments affect soil chemistry and, thus, fertility and C sequestration over the longer term. Also, Mukherjee et al. (2014) observed that biochar particles picked from aged soil–biochar mixtures had abundant microbial colonies on internal and external surface organic matter (OM) or microbial exudates.

Also, this special issue has very interesting contributions to the study of the effect of biochar on soil biological properties, which is a scope that has increasingly been the subject for study in the past few years. One of the first studies on this topic was made by Paz-Ferreiro et al. (2012) who observed that individual biochemical properties showed a different response to the application of sewage sludge biochar proposing the geometric mean of enzyme activities as a suitable index to condense the whole set of soil enzyme values in a single numerical value. Jindo et al. (2014) concluded that *p*-nitrophenol, a product obtained in several colorimetric assays of soil enzymes, is strongly retained in biochar-blended composts, which makes if difficult to estimate soil enzymatic activity in these kinds of samples. The paper of Weyers and Spokas (2014) found that no significant alteration in the microbial dynamics of the soil decomposer communities occurred as a consequence of the application of several plant-based biochars.

In the past few years, the multiple benefits of organic amendments to recover degraded land have been well understood (Hueso-González et al., 2014), but there was a lack of information concerning the use of biochar for soil remediation. Recently, biochar has been used to remediate heavy metal polluted soil. Paz-Ferreiro et al. (2014) have collected information in an in-depth review of the combination of phytoremediation and biochar to mitigate soil pollution, providing an overview of the state of the art. The novelty of this review lies in the discussion of the potential advantages of combining these two techniques and in the identification of the specific research needs to ensure a sustainable use of phytoremediation and biochar as remediation tools. Also, this special issue includes a very interesting short incubation experiment conducted by Wu et al. (2014) who observed how biochar can play a more important role in saline soil remediation reducing exchangeable sodium percentage of saline soil and that biochar can improve soil fertility due to the increment of soil organic carbon, cation exchange capacity and enhanced available phosphorus. Biochar not only improves chemical and biological soil properties but also can play an important role in the enhancement of different soil physical properties, although this fact is not usually studied.

With respect to the effect of biochar on soil physical properties, de Melo Carvalho et al. (2014) have contributed to the special issue with an interesting study of the impact of eucalyptus wood biochar rate (0, 8, 16 and 32 $Mg\,ha^{-1}$) on the water retention capacity of a sandy loam Dystric Plinthosol. They concluded that biochar increments soil water retention and that this effect was proportional to the amount of biochar added to the soil. Thus, biochar can be used as a mulch (Lee et al., 2013) to protect the soil from the rainfall erosivity (Lee et al., 2013) or to improve soil quality (Paz-Ferreiro and Fu, 2014). All these improvements could result in an increase in the vegetation cover (Giménez-Morera et al., 2010) and positive feedbacks to carbon sequestration.

Other interesting results on the influence of biochar in physical, chemical, and biological soil properties or on the use of biochar in soil remediation can be consulted, respectively, in the studies of Méndez et al. (2012), on the application of biochar in Mediterranean areas, and Lu et al. (2014), on the use of biochar and phytoextractors for cadmium remediation.

Biochar was also used in the context of this special issue (Ghezzehei et al., 2014) as a way to capture nutrients from dairy wastewater. This could not only prevent water pollution and eutrophication but also lead to biochars that are more suitable for agronomic purposes, acting as slow-release fertilisers.

Another use of biochar is as a growing media for crop production in greenhouses, reducing the environmental impact of peat excavation. Indeed, there is an important trend in Europe for peat replacement with biochar as evidenced by the creation of a working group on peat replacement in the cost action *Biochar as option for sustainable resource management* funded by the European Union. Recently, Sohi et al. (2013) have written a very interesting report on the technical and economic feasibility of using peat in the formulation of growing media. They concluded that biochar has a diverse range of properties relevant to the formulation of growing media, each related in some way to the production process and selected feedstock, but the competitive price of peat is one barrier to the development and use of replacement ingredients and for this reason more research is needed.

According to this trend, Steiner and Harttung (2014) mixed peat with biochar in different ratios 1 : 4, 1 : 1, and 4 : 1 and they observed a similar growth of miniature sunflower in all peat-biochar mixtures, perlite and clay granules. This fact is very interesting as it can lead to reducing the use of peat in growing media.

Finally, Kalderis et al. (2014) described the production of hydrochar from rice husks using a simple, safe and environmentally friendly experimental set-up. They obtained hydrochars with a higher heating value of 17.8 $MJ\,kg^{-1}$ indicating a promising use as a fuel.

We believe that the variety of research topic addressed in this special issue will help to identify current research needs and will provide the reader with an updated information about current research needs and opportunities in biochar research.

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