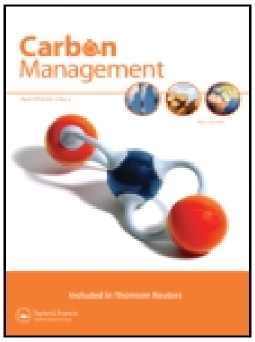

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Biochar soil amendment for sustainable agriculture with carbon and contaminant sequestration

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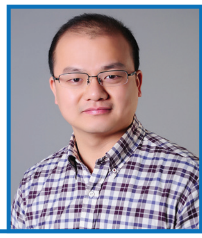
“Biochar offers a chance for sustainable agriculture with co-benefits of carbon sequestration and contaminant immobilization in soil”

Ming Zhang [1*] **& Yong Sik Ok** [1,2]




Keywords: black carbon ■ charcoal ■ carbon stabilization ■ bioavailability ■ chemical stabilization ■ food security

The rising concentration of atmospheric greenhouse gas (GHG) in the 20th century is one of the most important factors leading to global warming. Human intervention in the carbon cycle is considered to be the main reason, including fossil fuel utilization. Preventing CO_2 emission into the atmosphere and storing carbon in the geological environment are two main strategies for mitigating global warming. Rapid industrial development, especially in developing countries, makes the former ineffective due to the huge demand for energy. Accordingly, more attention is being paid to the latter.

Biochar, a charred carbon-rich solid created by thermo-chemical biomass conversion [1], has recently received worldwide interest because it encompasses high-priority research areas including climate change mitigation. Converting biomass to biochar can stabilize the carbon captured by plants as a form of charcoal, which is highly resistant to biological decomposition [2]. Biochar fractions (water-soluble organics, aliphatics and aromatics) are known to have different mineralization rates in soil [3]. The proportion of aromatic structure in biochar is relatively high, and the condensed aromatics are more recalcitrant against decomposition [4]. One of the most common examples of the long-term existence of char in soil is the dark earth in the Amazon region, a char-rich soil known as *Terra Preta*, which was created using slash-and-char techniques hundreds of years ago [5]. Singh *et al.* estimated the mean residence time (MRT) of 11 biochars as ranging from 90 to 1600 years in clay soil, indicating a persistent carbon sequestration [3]. Thus, converting biomass to biochar has great potential to mitigate GHG emission and to store carbon in soil. In a case study, it was reported that 885 kg CO_2 equivalent per ton dry biomass was saved when switching from yard waste composting to the production and application of biochar [6]. Moreover, it has been estimated that a sustainable biochar system could mitigate the emission of GHG (CO_2, methane and nitrous oxide) up to 1.8 Pg CO_2-C equivalent annually, which is about 12% of the current anthropogenic CO_2-C equivalent [7]. Meanwhile, utilization of bio-fuel produced during biochar pyrolysis can offset about 10% of the anthropogenic CO_2-C equivalent emission [7].

On the other hand, with a continuous decline in the land area available for crop cultivation, soil contamination poses a threat to food safety. Heavy metals, pesticides and persistent organic contaminants (POPs) have been frequently detected in agroecosystems. For

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example, about 3.3 million ha of cropland are reported to be intermediately or heavily polluted in China [101], and high concentrations of heavy metals, such as Cd, were found in rice harvested from the polluted soil [8]. For consideration of inadequate cropland availability, especially in some developing countries with large populations, the retention of contaminants in soil and preventing their translocation from soil to crops became one of the complementary options for food security.

Recently, biochar has been studied as a sorbent due to its porous carbonaceous nature and its cost-effectiveness compared to commercial activated carbon. Application of biochar in soil is expected to significantly immobilize contaminants in soil, and subsequently decrease their availability to crops. For instance, sewage sludge biochar lowered leaching and plant availability of heavy metals in soil [9]. Similarly, Yang *et al.* reported a remarkable decrease in dissipation of two pesticides in agricultural soil, and consequently pronounced decreases in pesticide uptake by plants [10]. The retention capability of biochar for contaminants was related to the sorption capability, which varied significantly depending on the biomass feedstock and pyrolysis conditions [11]. Ahmad *et al.* summarized important parameters that related to sorption capabilities of biochar from recent published data, and found that the surface area of biochar can range from several to hundreds of m^2/g, while the pore volume can be up to 1.3 cm^3/g [12]. The large surface area and pore volume of biochar can provide sufficient sorption sites available for contaminants.

Generally, the biochar produced at high temperatures is effective in the sorption of organic contaminants because of its high surface area, pore volume and hydrophobicity, while that at low temperatures is more effective to remove polar organics or heavy metals since it has more polar functional groups, which can interact with contaminants via electrostatic attraction or precipitation. Chen *et al.* [13] and Ahmad *et al.* [14] suggested that for the organic contaminants, partitioning to the non-carbonized fraction of biochar derived at low temperatures and adsorption on the carbonized fraction of biochar derived at high temperatures dominated the sorption process.

Furthermore, biochar was also reported as a soil conditioner, which can increase water holding capacity (WHC) [15], improve the nutrient level of soil [16] and consequently increase seed germination, plant growth and crop production yield [17], which also contribute to the feasibility of biochar application to soil for the purpose of carbon sequestration and food safety.

However, there are some challenges to applying biochar in soil. For instance, biochar only acts as a reservoir of contaminants in soil, rather than removing or eliminating them. Thus, contaminants still exist in the soil, although they are hardly available. In addition, biochar properties are varied, and each biochar is not universal to every single contaminant. Even a very few applications of biochar in soil were reported to increase the availability of some specific heavy metals [18, 19]. Thus, careful selection and comprehensive evaluation should be made before field-scale application of biochar in agricultural soil.

To conclude, climate change mitigation and contaminant retention can simultaneously be achieved, theoretically, via soil biochar application, which offers a good chance for sustainable agriculture. The approach is promising for its long-term carbon negativity and persistent capture of contaminants. However, before application, the properties of biochars should be optimized for a certain soil and crop, and the viability of large-scale application, for example regional, national or even global application, needs to be evaluated based on financial and environmental benefits.

Disclaimer

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