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Review

Impact of biochar amendment in agricultural soils on the sorption, desorption, and degradation of pesticides: A review

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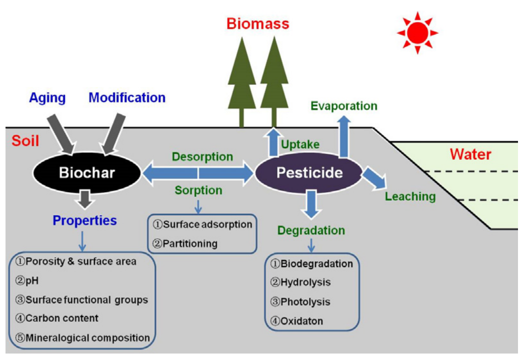
HIGHLIGHTS

- Dominant biochar properties affecting pesticide sorption-desorption were reviewed.
- Biochar effect on pesticide sorption-desorption in the soil was evaluated.
- Aging process usually causes lower sorption capacity of biochar.
- Modified biochar provides higher sorption efficiency for pesticides.
- How biochar affects the biodegradation of pesticides in soils is inconclusive.

GRAPHICAL ABSTRACT



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ABSTRACT

Extensive and inefficient use of pesticides over the last several decades resulted in serious soil and water contamination by imposing severe toxic effects on living organisms. Soil remediation using environment-friendly amendments to counteract the presence of pesticides in soil seems to be one suitable approach to solve this problem. Biochar has emerged as a promising material for adsorbing and thus decreasing the bioavailability of pesticides in polluted soils, due to its high porosity, surface area, pH, abundant functional groups, and highly aromatic structure, mainly depending on the feedstock and pyrolysis temperature. However, biochar effects and mechanisms on the sorption and desorption of pesticides in the soil are poorly understood. Either high or low pyrolysis temperature has both positive and negative effects on sorption of pesticides in soil, one by larger surface area and the other by a large number of functional groups. Therefore, a clear understanding of these effects and mechanisms are necessary to engineer biochar production with desirable properties. This review critically evaluates the role of biochar in sorption, desorption, and degradation of pesticides in the soil, along with dominant properties of biochar including porosity and surface area, pH, surface functional groups, carbon content and aromatic structure, and mineralogical composition. Moreover, an insight into future research directions has been provided by evaluating the bioavailability of pesticide residues in the soil, effect of other contaminants on pesticide removal by biochar in soils, effect of pesticide properties on its behavior in biochar-amended soils, combined effect of biochar and soil microorganisms on pesticide degradation, and large-scale application of biochar in agricultural soils for multifunction.

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1. Introduction

With the rapid industrialization and modern agricultural practices, soil quality is gradually declining. Extensive and inefficient use of pesticides over the last several decades led to the accumulation of pesticide residues exceeding the self-purification capacity of the soil, which resulted in serious soil pollution and deteriorated soil quality (Vangronsveld et al., 2009). The potential impacts of pesticides on the environment and public health have now been getting extensive attention. Hence, soil remediation using sustainable and environment-friendly alternatives to counteract soil contamination appears to be one suitable approach (Cheng et al., 2016; Mench et al., 2010; Powlson et al., 2011).

Previous studies reported a wide range of soil remediation techniques, such as washing with extractants, chemical oxidation/reduction, and bioremediation (Morillo and Villaverde, 2017). However, although some of these techniques are effective, such methods are usually not applicable in large agricultural fields due to some drawbacks and potential problems emerging after their application, such as high costs, soil erosion, nutrient leaching, fertility loss, and high environmental risks (Kumpiene et al., 2008; Powlson et al., 2011; Kong et al., 2014). Therefore, the in-situ application of amendments based on the principle of adsorption is often considered as a cost-effective alternative for remediation of pesticide-polluted soils (Lehmann and Joseph, 2009). One of the most popular amendments is biochar, which is environment-friendly and has a vast range of raw material sources.

Biochar is a carbon-rich and porous solid produced from biomass via pyrolysis in the absence of oxygen (Lehmann et al., 2006). The most common application of biochar is soil amendment to improve soil quality, increase crop yield, reduce irrigation and fertilizer requirements (Chan et al., 2007; Drake et al., 2015; Liu et al., 2016; Prendergast-Miller et al., 2014; Sika and Hardie, 2014), and mitigate greenhouse gas emissions (Sohi, 2012; Steinbeiss et al., 2009; Xu et al., 2012). Moreover, relatively recently, biochar has gained attention for its ability in sorption and immobilization of heavy metals and organic contaminants in the soil (Bornemann et al., 2007; Chun et al., 2004; Martin et al., 2012; Mukherjee et al., 2016) resulting from the presence of highly porous structure and various functional groups (e.g., carboxyl, hydroxyl, and phenolic groups). Heavy metal behavior in soils with biochar amendment has been well investigated (Inyanga et al., 2016; Li et al., 2017; Liu et al., 2018). Also, there are large numbers of studies on the impact of biochar application in agricultural soils on the sorption-desorption and degradation of pesticides. Yu et al. (2006) found that soil amended with biochar derived from pyrolysis of red gum chips enhanced the sorption of diuron, and increased the non-linearity of the adsorption isotherm and the extent of sorption-desorption hysteresis. Incorporation of about 1% biochar in soils has shown decreased biodegradation of benzonitrile due to enhanced sorption (Zhang et al., 2005), reduced microbial degradation of diuron and its herbicidal efficacy on barnyard grass (Yang et al., 2006), and decreased uptake of chlorpyrifos by Chinese chives and Spring onion (Yu et al., 2009; Yang et al., 2010). As a result, in recent years, biochar as a soil amendment is progressively gaining attention among policy makers and scientific communities.

However, to better understand the impact of biochar amendment on the fate of the pesticides in the soil, it is necessary to systematically characterize the effects of biochar application on pesticide behavior in agricultural soils, which will be most helpful for assessing the risk and modeling the fate of the pesticides in the environment. Present reports either put focus on one or several specific pesticides (Cabrera et al., 2014; J.W. Jin et al., 2016; Yu et al., 2011), or one aspect of pesticide behaviors for example sorption (Yavari et al., 2015), or lose sight of the systematic review of biochar characteristics (Khorram et al., 2016; Zhang et al., 2013). Therefore, the objective of this review was to assess the potential effects of biochar amendment on the environmental fate of pesticides based on sorption, desorption, and degradation in soils. We placed emphasis on: (Acosta et al., 2016) the dominant characteristics of biochar, (Agrafioti et al., 2014) the effects of biochar on pesticide sorption-desorption in the soil, and (Ahmedna et al., 2004) the effects of biochar on pesticide degradation in the soil. Priority areas of future research are also put forward in this review.

2. Dominant characteristics of biochar

Biochar generally has strong sorption capability for pesticides in the soil environment, due to its specific physicochemical properties which largely depend on its feedstock (such as, pinewood, wheat straw, rice husk, dairy manure, sugar beet tailing, and sewage sludge) and the pyrolysis conditions (such as temperature, heating rate, and residence time) (Yavari et al., 2015). The dominant properties affecting pesticide