Chapter 73
Automatic Estimation of Soil Biochar Quantity via Hyperspectral Imaging

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ABSTRACT

Biochar soil amendment is globally recognized as an emerging approach to mitigate CO2 emissions and increase crop yield. Because the durability and changes of biochar may affect its long term functions, it is important to quantify biochar in soil after application. In this chapter, an automatic soil biochar estimation method is proposed by analysis of hyperspectral images captured by cameras that cover both visible and infrared light wavelengths. The soil image is considered as a mixture of soil and biochar signals, and then hyperspectral unmixing methods are applied to estimate the biochar proportion at each pixel. The final percentage of biochar can be calculated by taking the mean of the proportion of hyperspectral pixels. Three different models of unmixing are described in this chapter. Their experimental results are evaluated by polynomial regression and root mean square errors against the ground truth data collected in the environmental labs. The results show that hyperspectral unmixing is a promising method to measure the percentage of biochar in the soil.

INTRODUCTION

Food security and climate change are two key global issues for the 21st century. With growing world population and rising living standard, global demand for agricultural products will rise 70% by 2050 (Food and Agriculture Organization, 2009), while agricultural productivity is facing emerging plateau and high exposure to climate change (Keating and Carberry, 2010). However, many conventional farming

DOI: 10.4018/978-1-5225-7033-2.ch073

practices are based on high resource inputs (e.g. fertilizer, irrigation and fuel), and tending to generate high greenhouse gas (GHG) emissions and exacerbate soil degradation, thereby unlikely to sustain the rate of productivity gain (Robertson, 2010). Thus, there is an imperative need for farming approaches that can efficiently use constrained resources (e.g. land and water) and effectively mitigate greenhouse gas emissions.

Soil amendment with biochar, a carbon (C)-rich product of burning biomass in the absence of oxygen (pyrolysis), is recognized globally as an emerging approach to improve soil fertility and increase soil C stock (Woolf *et al.*, 2010). Biochar has unique properties to improve soil chemo-physical and biological properties for crop growth (Chan and Xu, 2009, Bai *et al.*, 2015). The porous physical structure of biochar can improve soil bulk density and aeration (Alburquerque et al., 2014; Mukherjee and Zimmerman, 2014). The large surface area also creates a great sorption capacity to retain soil moisture and nutrients and improve soil cation exchange capacity (CEC) (Chan and Xu, 2009; Liu *et al.*, 2012; Novak *et al.*, 2012). The alkaline nature of many biochar makes such materials especially suitable for improving acidic soil (Novak *et al.*, 2009). Biochar made from specific feedstocks (e.g. manure) have high nutrient content and promotes plant growth (Hass *et al.*, 2012; Lentz and Ippolito, 2012; Uzoma *et al.*, 2011). These positive effects of biochar on crop yield are especially significant in degraded soils (Spokas *et al*., 2012, Xu *et al*., 2015). Many types of biochar also has high proportion of recalcitrant C with hundreds to thousands of years of durability, making it a potentially effective soil C sink to mitigate climate change (Cheng *et al*., 2008; Kuzayakov *et al*., 2009). Agronomic benefits of biochar and the potential of biochar for soil carbon sequestration have been widely demonstrated in many on-ground trials over the world (Atkinson *et al*., 2010; Spokas *et al*., 2012).

Agronomic and climate mitigation benefits of biochar are associated with the application rate and the stability of biochar in soil (Zimmerman and Gao, 2013). Therefore, accurately and cost-effectively measuring biochar in soil is critical for evaluating the benefits of biochar soil amendment, which is essential for justifying the integration of biochar into emission mitigation schemes and developing cost-effective biochar-based farming protocols (Koide *et al.*, 2011). In practice, routine and frequent measurement of biochar in soil is often required to achieve these purposes. However, biochar are subject to complex physical and chemical and biological changes after applying to soil. In soil, biochar experiences physical processes such as migration and dissemblance (Major *et al.*, 2010). Although C in biochar is generally assumed to be non-reactive, a proportion of C in biochars is actually decomposable, especially when fresh biochar is applied into soil (Lehmann *et al.*, 2009). Some components in biochar can be utilized by soil microbes and microbial processes can have stimulatory effect of on biochar degradation (Zimmerman and Gao, 2013). These changes of biochar in soil, combining with its heterogeneous and complex chemical composition, make it analytically challenging to accurately quantify biochar within soil.

Currently, major chemical analysis approaches used to quantify biochar in soils include the determination of (1) C chemical composition *in situ* via scanning calorimetry, NMR spectroscopy or infrared spectroscopy, (2) extractable compounds which are characteristic for biochar (i.e. molecular marker), (3) residual stable carbon after oxidizing reactive carbon with chemical or thermal approaches (by NMR, optical or mass spectroscopy), and (4) thermal decomposition behaviour of different carbon fractions in soil (see review, Schmidt and Noack, 2000; Manning *et al*., 2009; Koide *et al.*, 2011). In addition, other methods such as hand sorting (Kasin and Ohlson, 2013), combination of soil C and stable isotope (Major *et al.*, 2010), and loss of ignition of soil with and without biochar (Koide *et al.*, 2011) also have been applied to quantify biochar in soil. Most of these analytical approaches are laborious, time-consuming