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# Characterization of biochars to evaluate recalcitrance and agronomic performance

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ABSTRACT

Biochars ($n = 94$) were found to have ash contents from 0.4% to 88.2%, volatile matter from 13.2% to 70.0%, and fixed carbon from 0% to 77.4% (w/w). Greater pyrolysis temperature for low-ash biochars increased fixed carbon, but decreased it for biochars with more than 20% ash. Nitrogen recovery varied depending on feedstock used to a greater extent (12–68%) than organic (25–45%) or total C (41–76%) at a pyrolysis temperature of 600 °C. Fixed carbon production ranged from no enrichment in poultry biochar to a 10-fold increase in corn biochar (at 600 °C). Prediction of biochar stability was improved by a combination of volatile matter and H:C ratios corrected for inorganic C. In contrast to stability, agronomic utility of biochars is not an absolute value, as it needs to meet local soil constraints. Woody feedstock demonstrated the greatest versatility with pH values ranging from 4 to 9.

## 1. Introduction

Biochar, the solid product of biomass carbonization intended as a soil amendment, has attracted attention due to its ability for long term improvements in soil physical and chemical properties, with potentially important effects on soil biota. Specifically, biochar may improve water infiltration (Ayodele et al., 2009), soil water retention, ion exchange capacity and nutrient retention (Laird et al., 2010; Lehmann et al., 2003), pH (Van Zwieten et al., 2010a), and improve N use efficiency (Van Zwieten et al., 2010b). The substantial changes in bulk soil properties and around biochar particles have shown to influence soil biological processes with significant implications for soil biogeochemistry (Lehmann et al., 2011).

Thermochemical conversion during pyrolysis alters constituent carbon compounds to yield materials that are depleted of H and O (Küçükbayrak and Kadioğlu, 1989) and possesses a greater proportion of aromatic C in comparison with the biomass feedstock (Baldock and Smernik, 2002). These materials offer greater chemical recalcitrance and resistance to biological decomposition (Baldock and Smernik, 2002; Zimmerman, 2010), thereby ensuring that any beneficial effects of biochar endure. On one extreme, naturally occurring black C is able to persist for millennia (Lehmann et al., 2008; Skjemstad et al., 1996). This has promoted interest in biochar as a carbon sequestration tool (Lehmann et al., 2006).

Biochar yield (Williams and Besler, 1996), physical (Wildman and Derbyshire, 1991), and chemical properties (Shafidazeh, 1982) depend on the conditions during pyrolysis as well as the composition of the feedstock biomass. Furthermore, different soil constraints require different biochar properties by also recognizing the different crop needs for example of legume or cereal crops (Van Zwieten et al., 2010b). As a result, not all biochars have demonstrated improved crop yield in all instances (Deenik et al., 2010; Gaskin et al., 2010; Van Zwieten et al., 2010a), and there are significant differences in stability between biochars (Spokas, 2010; Zimmerman, 2010). In addition, biochar properties change over time in soil and these changes may also be affected by the initial properties of the biochars (Joseph et al., 2010). Therefore, the differences between biochar properties have to be well understood as a function of production conditions and feedstock type, in order to match soil needs with the appropriate biochar type.

Agricultural application of biochar would benefit from a characterization framework to identify which biochars produce increases in short and long term yields and improvements in soil health for a given crop and soil. From an agronomic standpoint it is important to determine if the biochar causes toxic effects, alters soil physical attributes at a specific application rate, improves nutrient availability and use efficiency, or changes the population and density of microorganisms and fauna. To date biochar characterization has mainly utilized tests developed for the power industry and for soils. For example, the so-called “proximate analysis” according to ASTM D1762-84 determines moisture, volatiles, and ash content of wood charcoal with regard to its use as a fuel. The volatile content may to some extent be informative to understand the stability of the material (Zimmerman, 2010) and effects on N availability

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