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# BIOCHAR USAGE: PROS AND CONS

**Jim Ippolito, Rick Lentz, Jeff Novak, Kurt Spokas, Hal Collins, and Jason Streubel**
Research Soil Scientist, USDA-Agricultural Research Service, Northwest Irrigation and Soils Research Laboratory, Kimberly, ID; Research Soil Scientist, USDA-Agricultural Research Service, Northwest Irrigation and Soils Research Laboratory, Kimberly, ID; Research Soil Scientist, USDA-Agricultural Research Service, Coastal Plains Soil, Water, and Plant Research Center, Florence, SC; Research Soil Scientist, USDA-Agricultural Research Service, Soil and Water Management Research Unit, St. Paul, MN; Research Microbiologist, USDA-Agricultural Research Service, Vegetable and Forage Crop Research Laboratory, Prosser, WA; Ph.D. Candidate, Washington State University, Pullman, WA.

## ABSTRACT

Soil fertility benefits of charcoal application have been reported as early as 1847 indicating that plant nutrients are sorbed within charcoal pores. The use of biomass-derived black carbon or biochar, the solid byproduct from the pyrolysis processing of any organic feedstock, has garnered recent attention as a potential vehicle for carbon sequestration and a beneficial soil conditioner. However, most of the past biochar research has focused on improving the physico-chemical properties of tropical (i.e. *terra preta*) and highly weathered soils, while little research has focused on improving arid or semi-arid soils of the USA. Here, we present an overview of the potential benefits and drawbacks of biochar usage in western US agro-ecosystems based on research performed at multiple USDA-Agricultural Research Service locations (Washington, Idaho, Minnesota, and South Carolina).

## INTRODUCTION

Soil fertility benefits of charcoal application were reported in the mid-1800s when Allen (1847) suggested that plant nutrients were sorbed within charcoal pores. Increased attention has recently been given to the use of biochar (biomass-derived black carbon), a byproduct from the pyrolysis processing of organic feedstock (Antol and Grønli, 2003), as a beneficial soil conditioner in tropical and highly weathered soils. However, depending on the type of process (slow, fast, or flash) and the pyrolysis conditions (e.g. temperature, pressure, time, heating rate, and biomass material), the yields and characteristics of the biochar vary dramatically (Bridgwater et al., 1999).

Researchers have noted that charcoal applications by pre-Colombian farmers to infertile Amazonian soils have caused fertility improvements observed today. Glaser et al. (2004) studied anthropogenically-modified soils (Anthrosols), reporting that greater effective cation exchange capacity, base saturation, and nutrient availability were present in biochar amended soils as compared to unamended soils (Ferrolsols). Lehmann et al. (2003) showed that an Anthrosol increased cowpea (*Vigna unguiculata*) shoot and root biomass as compared to a Ferrolsol, with the growth increase attributed to greater Ca, P, Mn, and Zn availability due to the presence of biochar. Lima et al. (2002) further suggested that the increase in Anthrosol Ca and P content was due to the presence of bone apatite, and the increased Mn and Zn content due to presence of pottery remains added during the pyrolytic process of animal and other organic residues.

Other researchers have extended this concept, using biochar to improve the fertility status of soils outside of the tropics; results have been mixed. Asai et al. (2009) studied biochar produced from a combination of teak (*Tectona grandis* L.) and rosewood (*Pterocarpus macrocarpus* Kurz) and applied increasing quantities (up to 7 tons per acre) to a highly-weathered Laotian soil, noting a decrease in rice yield with increasing biochar application. The authors attributed the yield decrease to a decline in available N, likely due to microbial immobilization. However, Deenik et al. (2010) hypothesized that the volatile content of the biochar could be partly responsible for the observed decreases in plant growth and yield (Deenik et al., 2010). Kimetu et al. (2008) applied Eucalyptus (*Eucalyptus saligna* Sm.) biochar (2.7 tons per acre per season for three seasons) + inorganic fertilizer to several Kenyan Ultisols degraded by years of continuous corn production. Biochar + inorganic fertilizer application in the most degraded soils doubled corn yield as compared to inorganic fertilizer applications alone. However, post-application investigations revealed that plant nutritive values changed little, suggesting that improvements in soil cation exchange capacity, plant-available water status, or microbial dynamics associated with biochar application were likely causes for the yield response. Gaskin et al. (2010) applied up to 10 tons per acre of peanut hull (*Arachis hypogaea* L.) biochar to a Tifton loamy sand (a highly-weathered Ultisol) and then grew corn. Biochar application increased soil base cation concentrations during the first cropping year, but the result was not present during the second cropping year likely due to crop uptake and leaching losses. Novak et al. (2009b) produced biochars, at varying pyrolysis temperatures, from peanut hulls, pecan shells (*Carya illinoensis*), poultry litter (*Gallus domesticus*), and switchgrass (*Panicum virgatum* L.). In a lab experiment, biochars were applied to a Norfolk loamy sand (a highly-weathered Ultisol) at a rate comparable to 20 tons per acre. The authors found that most biochars increased soil pH and extractable P concentration as compared to the control soil. The above findings are specific to highly weathered Ultisols receiving a one-time application of biochar.

Biochars are known to typically improve the fertility of highly weathered soils, but there is a void in the literature for its effects in arid soils. Asai et al. (2009) applied a teak/rosewood derived biochar (0 and 3.6 tons per acre) to rice grown in an alkaline Laotian soil. The authors noted an increase in rice yield at two of three locations with the 3.6 tons per acre biochar application, possibly due to biochar increasing plant-available P content. Van Zwieten et al. (2010) mixed 4.5 tons per acre of two separate paper mill waste biochars into an Australian calcarosol. Other than an increase in total C content, the authors did not observe a change in extractable soil nutrient concentrations. This was speculated to be in response to the initial soil pH (7.7), free soil $Ca^{2+}$ content (21.7 meq per 100 grams), and alkaline pH of both biochars (8.2 and 9.4).

North America contains approximately 6 million acres of Aridisols and are frequently found in desert ecosystems (Nettleton and Peterson, 1983). These soils can easily become infertile if overused. However, improvements in fertility levels may be possible using biochars. Improving or rebuilding fertility characteristics of Aridisols is important because these soils are used extensively for and can be very productive in agronomic settings (Missouri Cooperative Soil Survey, 2010). The objective of this manuscript is to briefly describe how biochars might affect arid soils in a positive or negative manner.

## BIOCHAR USAGE IN WESTERN US AGRO-ECOSYSTEMS: PROS AND CONS

The literature has shown that biochar can improve the physico-chemical properties in highly weathered soils, and so it follows that biochar may also improve arid soil characteristics. In, 2008, Lentz and Ippolito (unpublished data) initiated a field plot study with CQuest$^{tm}$ biochar (Dynamotive; pyrolyzed at 930°F) applied to calcareous soils in South Central Idaho. Treatments included a control (only N was added to supply the needs of the crop; ~180 lbs per acre), cow manure at 20 tons per acre, biochar at 10 tons per acre, and manure + biochar at 20 and 10 tons per acre, respectively. Corn was planted in the spring of 2009. Following the Fall 2009 harvest, as compared to the other treatments, the soil total C content was greatest in the biochar amended plots, biochar alone increased soil Mn availability, and manure + biochar produced a synergistic effect by increasing soil Zn and P availability. This fact should benefit arid, alkaline soils containing low Zn or P concentrations due to precipitation with soil carbonate phases. In spite of the increase in nutrient availability there were no significant differences in corn yield between treatments.

In a pot study, Ippolito et al. (2010) investigated the effect of low or high temperature pyrolyzed (480 or 930°F) switchgrass (*Panicum virgatum* L.) biochar application on the fertility status of two Aridisols. Biochar was added at 2% (w $w^{-1}$) to either a Declo loam (Xeric Haplocalcids) or a Warden very fine sandy loam (Xeric Haplocambids) and then incubated at 15% moisture for 127 days; a control (no biochar) was also included. Soils were leached with 1.2 to 1.3 pore volumes of deionized $H_2O$ on days 34, 62, 92, and 127, and cumulative leachate nutrients were quantified. After the incubation period, soils were destructively sampled for extractable nutrients, total C, inorganic C, organic C, and pH. For both soils, leachate Ca and Mg decreased with the 480°F switchgrass biochar likely due to binding on biochar negative surface functional group sites. Both biochars caused an increase in leachate K, while the 930°F biochar increased leachate P concentration. The 480°F biochar reduced $NO_3$-N concentrations to the greatest extent. The authors speculated that the easily degradable C, associated with the 480°F biochar's structural make-up, stimulated microbial growth thus promoting $NO_3$-N immobilization. Soil extractable K, P, and $NO_3$-N followed a pattern similar to the leachate observations. Soil extractable Mn and Ni content increased with the 480°F biochar application as compared to the control, likely due to an increase in negative exchange sites. Total soil C content increases were linked to an increase in organic C from the biochars. These findings suggest that the 480°F could improve the fertility status of calcareous soils with minimal reduction in environmental quality.

Droughts in the arid western US can be exacerbated by poor rainfall distribution and poor soil water storage. Because biochars contain hydrophilic organic groups and internal pores, it may sorb water or be involved with micro-aggregate formation resulting in more soil water retention. To test this concept, Novak et al. (2010) performed research concurrent to the Ippolito et al. (2010) study, determining gravimetric and volumetric soil moisture contents after free drainage had ceased, and 2 and 6 days after leaching. Relative to the controls, adding 2% switchgrass biochar to the Declo and Warden soils resulted in moisture content increases of about 3 to 6%. The most significant increase in soil moisture content was obtained after the first leaching event on day 34, and it declined with the ensuing three additional leaching events on days 62, 92, and 127. This decline was correlated to an increase in bulk density, thereby reducing pore space for water storage. However, even after the fourth leaching event, the moisture contents associated with 2% switchgrass application were still 5 to 7% greater than the controls. Biochars enhanced the moisture storage capacity of Aridisols, and thereby could potentially reduce the on-set of crop moisture stress and benefit irrigation management.

The dairy industry is becoming more prevalent in Western US agroecosystems. Idaho typically ranks third in total number of dairy cows in the US, with ~ 550,000 head (USDA

NASS, 2008), while the dairy industry in Eastern Washington State has recently been growing by ~8% per year (Collins and Struebel, 2010). In Washington, dairy and cattle manure produce ~ 1.7 million tons of manure per year and thus finding a suitable, year round use for the material can be a challenge. Collins and Struebel (2010) performed proof-of-concept research aimed at answering the question: is the addition of biochar to dairy effluent an efficient and cost effective method of capturing nutrients? The researchers pelletized dry, anaerobically digested manure fiber and then pyrolyzed the material at 930°F. The biochar was then placed in 100 gallon tubs with anaerobically digested manure effluent passed over the biochar, with the aim of capturing excess solution P. In a 15 day period, the biochar was able to remove 68% of the effluent P (initial and final effluent P was ~ 450 and 140 ppm, respectively). In a laboratory study, Collins and Struebel (2010) placed the P-loaded biochar in a Quincy Sand (Xeric Torripsamments) and incubated the soil for 21 days, after which Olsen extractable P was determined. Based on P sorbed onto biochar, the authors concluded that ~ 13% of the P was readily available and could potentially supply P for crop needs.

The above results suggest that biochar use in western US agro-ecosystems may be beneficial. However, one may question the longevity and lasting effects of biochar when applied to arid soils. Spokas (2010) suggested that the biochar O:C molar ratio may be a reliable predictor of biochar stability in soils. Figure 1, presented by Spokas (2010) shows the combustion product continuum as related to the O:C molar ratio within the product. Graphite and soots contain no discernible structures of the original biomass and have relatively low O:C molar ratios; these materials resist degradation within the soil. On the other hand, biomass contains high O:C ratios and degrades relatively quickly within soils; charcoals and chars lie in between. Based on studies from previous researchers, Spokas (2010) concluded that biochars with O:C molar ratios less than 0.2 are likely the most stable, with estimated half-lives greater than 1000 years. Biochars with an O:C molar ratio between 0.2 and 0.6 would have intermediate half lives of between 100 and 1000 years, while biochars with O:C ratios greater than 0.6 would likely possess half lives of less than 100 years. The actual longevity of biochar in soil is dependent on many complex parameters, but these results show that a simple biochar characteristic, O:C, may serve as an index of its resistance to degradation.

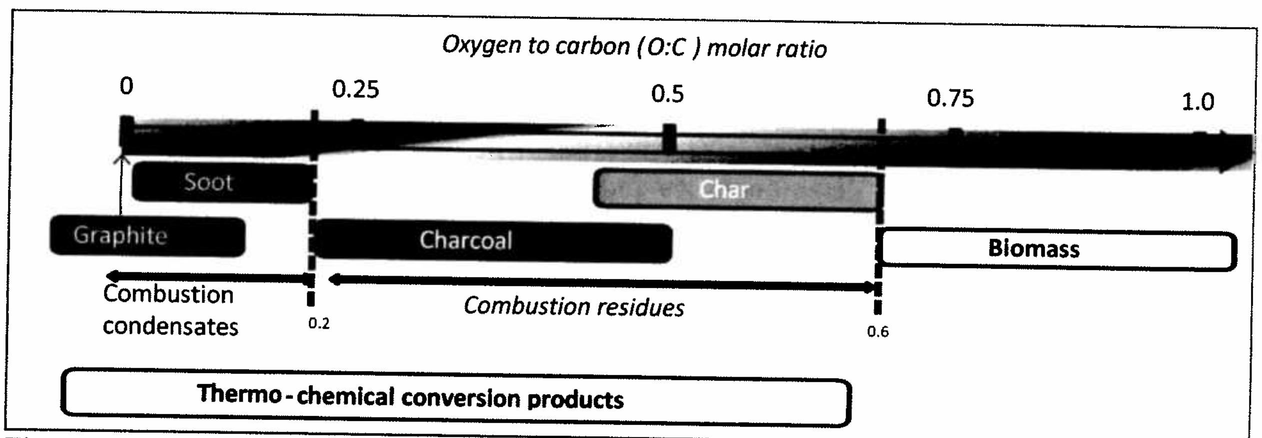


Figure 1. The spectrum of combustion product continuum as related to product O:C molar ratio. Redrawn from Spokas (2010), which was originally adapted from Hedges et al. (2000) and Elmquist et al. (2006).

## SUMMARY

Although currently limited, the above results suggest that biochar application to and usage in western US agro-ecosystems could benefit arid soils. It has been shown that Dynamotive CQuest^tm^ biochar co-applied with manure could increase Zn and P availability in alkaline soils where these two essential plant elements are typically bound to soil carbonate phases. Switchgrass biochar prepared at 480°F could improve the fertility and water storage capacity of calcareous soils with minimal reduction in environmental quality. This biochar could also be used to help immobilize excess soil $NO_3$-N, likely reducing leaching in the short-term. Biochar created from anaerobically digested cattle manure can be used to sorb excess P from anaerobically digested wastewater lagoon effluent. Subsequently, the P-loaded biochar can be used as a P fertilizer in arid soils. The length of time a biochar may be viably active in soils, and thus supplying or sorbing nutrients, can be estimated based on the biochar O:C molar ratio. Ratios below 0.2 would suggest half-lives greater than 1000 year, while ratios greater than 0.6 suggest half-lives less than 100 years. Thus, biochar reaction in soil will likely differ between various biochars. Caution should be used when applying the above findings to soils, as biochars do vary based on biomass source, type of pyrolysis, and pyrolysis temperature and time.

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