Biochar Feedstock Research Using a Two-Barrel Nested Retort

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Introduction

Biochar is a potentially beneficial natural product for use in pollution prevention, carbon storage, and as an enduring soil enhancement. Biochar is plant matter that has been heated under relatively low-temperature (<700° C or 1292° F) and low-oxygen conditions. It was a key factor in formation of the ancient *terra preta* (Portugese: "black earth") soils in the Amazon - soils that are uncharacteristically fertile and rich in organic matter (Fig. 1).

FIGURE 1. The soil on the right is *terra preta*. It is believed to have been heavily modified with charcoal from ancient cooking fires. The soil on the left is relatively untouched, found in the same area of the Amazon (Glaser and Birk, 2012).

Biochar is a possible solution for improving poor soils that have low productivity due to low amounts of organic matter. Soil organic matter is important for nutrient and water retention, microbial activity, and soil structure. Biochar functions like organic matter in soil, and may even surpass organic matter in providing some of these enhancement properties (Lehmann and Joseph, 2009). Most Oklahoma soils are low in organic matter, so enhancement with biochar may help boost productivity in this region.

Barrow (2012) has identified a long list of research questions about biochar that need to be answered so its use can be undertaken wisely and without unforeseen problems. One broad area needing investigation is the selection and suitability of various feedstocks for making biochar. Lehmann and Joseph (2009) identify feedstock differences, pyrolysis temperature, and rate of pyrolysis as major factors that can be adjusted to create a range of biochars for different purposes.

At Kerr Center, we examined eight biochars produced from eight different feedstocks - four crop residues, three forestry residues, and one "municipal solid waste" material (shredded office paper). All were processed at roughly the same temperature and rate of pyrolysis using a popular, low-cost, two-barrel nested biochar retort. The feedstocks were all obtained locally, either from the Kerr farm and ranch or from neighbors. The highest temperature our retort can reach is about 350° C (662° F). For the most part, we were interested in determining which feedstocks are most worthwhile for turning into biochar on our farm, with our style of retort.

Methods and Materials

Eight feedstocks were charred separately using a two-barrel nested retort (Fig. 2). We prefer this design because it emits minimal pollutants, is fuel efficient, and is relatively safe, having an enclosed fuel fire during most of the burning process. It is also inexpensive to build, using easily obtainable materials. The two-barrel nested design is already in use by a number of small scale farmers, gardeners, and investigators to make small batches of biochar.

The feedstock in the inner (charge) barrel is heated to about 350° C or 662° F by burning wood scraps stuffed into the space between the inner and outer barrels. The fire is lit at the top of the outer barrel. It burns down the gap between the two barrels, fed by air drawn in through slits at the bottom of the outer barrel. The burning is enhanced by wood gases that escape from the bottom of the inner charge barrel as it is heated. The fire is allowed to burn out and the retort cools naturally [1].

A "burn" typically takes about four hours from ignition until the barrels are cool enough to handle and open without the biochar spontaneously igniting. We took samples of the finished biochar of each feedstock and stored them in plastic zipper bags.

Each biochar sample was crushed to pass a 1 mm (0.04 in.) sieve. A 1.9 gram (0.067 oz.) subsample of each char was mixed with 16 ounces (by fluid volume measure) of store-bought sand. This was done to mimic an application of roughly 10,000 lbs. (five tons) of biochar per acre, to a depth of six inches. We used sand because of its low nutrient and organic content, and its low water holding capacity.

The sand-and-biochar samples were bagged and submitted for standard soil testing at A&L Laboratories (www.allabs.com). In addition, samples of pure biochar were submitted to Control Laboratories (www.compostlab.com), a separate lab specializing in biochar, in order to learn more about the quality of the biochar, and how well it would resist degradation in the soil. A slideshow of biochar production and application at the Kerr Center is found at http://www.slideshare.net/MauraMcDW/slideshare-biochar-trial.

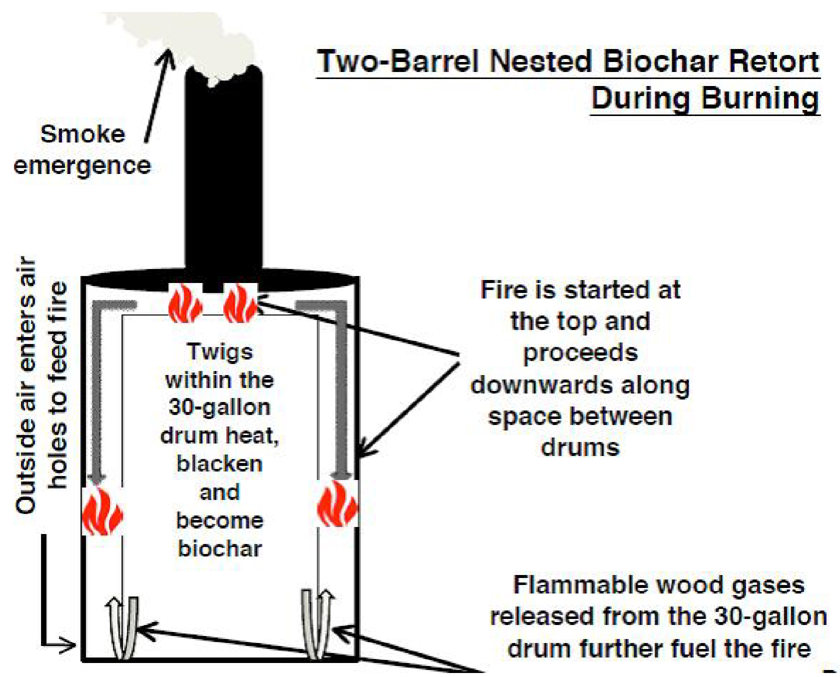
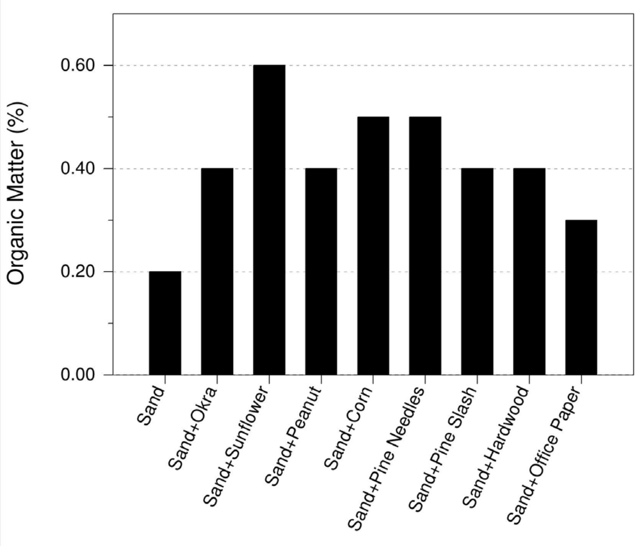


FIGURE 2. Two-barrel nested biochar retort

Results: Boost in organic matter, CEC, and pH

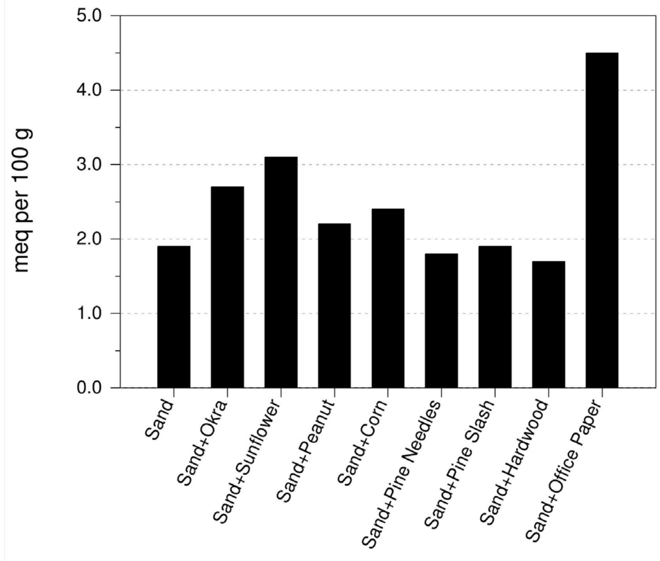
Soil test data generally aren't regarded as suitable for biochar evaluation due to consistency problems, so please view the following soil test graphs in that light. That said, a few indications may still be noted with reasonable confidence.

FIGURE 3. Organic matter



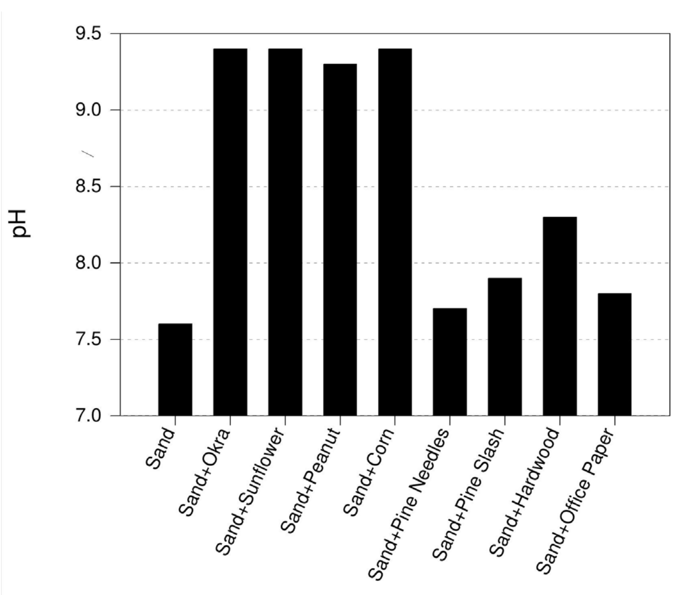
The organic matter percentage is increased with the application of biochar, no matter the feedstock. This was expected. On average, the biochar-amended samples contained 0.2 grams more organic matter per kilogram of soil than the sand-only control.

FIGURE 4. Cation exchange capacity (CEC)



The CEC (cation exchange capacity - the ability of soil particles to hold onto nutrients) was also boosted in most of the samples. This was also expected since it typically occurs when organic matter is added to the soil.

FIGURE 5. pH



Crop residue biochars clearly have a higher liming effect than forestry residues - that is, they can make soils more basic. This is probably due to their higher content of base cations - nutrients like magnesium, calcium, and potassium.

Results: Biochar quality feedstock comparisons

BIOCHAR SAMPLE	$H:C_{org}$	FEEDSTOCK CELLULOSE %
Okra	1.30	67.5
Sunflower	0.78	40.3
Peanut	0.63	45.0
Corn	0.88	40.4
Pine needles	0.67	42.6
Loblolly pine slash	0.79	40.4
Hardwood sticks	0.52	47.5

(Cellulose data: Phyllis2, 2012) IBI Standard: $H:C_{org}$ = 0.7 or lower. Uncharred material is ≈ 1.5.

The durability of biochar and its effects in the soil depend on the quality of the char. Proximate analysis supplies much of this information. The $H:C_{org}$ (ratio of hydrogen atoms to organic carbon atoms) value is the current International Biochar Initiative (IBI) standard for measuring how stable a sample of biochar will remain in the soil. IBI has determined that samples measuring greater than 0.7 on this scale are poor quality and likely to degrade quickly, thus having only a short-term effect on the soil.

Seven samples were ultimately analyzed. (Office paper presented difficulties in charring and was dropped from the experiment.) Of the seven samples, hardwood sticks produced the most enduring and promising biochar. We consider this fortunate for us, as downed limbs and similar wastes already seemed most suitable to charring at the Kerr Center. Crop residues can more easily be composted or incorporated into the soil in the field.

Biochars with $H:C_{org}$ ratios higher than 0.7 are still technically biochar, they just will not be as durable in the soil. Such biochars may boost productivity when properly applied to soil, but the benefit will be short-lived.

The cellulose content of the original feedstock is also listed in the above table. It correlates fairly well with $H:C_{org}$ [2]. This means that feedstocks with high levels of cellulose (>60%) will probably not produce good quality biochar when using a nested barrel retort. Feedstocks with high cellulose do not char well at 350° C (662° F) - first, because cellulose is a good insulator [3], and second, because it doesn't pyrolyze at temperatures below 300 - 315 °C (572 - 599°F; Lehmann and Joseph 2009; Williams and Horne 1994). Lignin and hemicellulose, the other major components in plant matter, pyrolyze at much lower temperatures than cellulose.

Conclusion

We believe high-cellulose feedstocks (>60%) should be avoided when using a double-barrel nested retort. Feedstocks with cellulose between 35% and 50% will probably make reasonable-quality biochar as understood by the IBI standard. However, hard–wood material seems to be the best feedstock for use with this retort; hardwood and other feedstocks with lignin contents over 20% are likely to do best. Identifying superior feedstocks to use with specific kinds of retorts can help in making better decisions about both waste management and the quality of soil amendment that one is producing.

Notes

1. A guide to building and using a nested barrel retort can be found at: http://www.kerrcenter.com/publications/biochar_sm.pdf.

2. The coefficient of correlation is 0.73, on a scale of -1 to 1, with 0 being no correlation.

3. It appears that high cellulose feedstocks may be insulating the inner core of the reaction chamber and may require higher temperatures or longer heating times in order to become quality biochar.

References

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