BIOCHAR FOR SOIL REMEDIATION

Soybean producers–in fact, all crop producers–are constantly assessing the potential of soil amendments for increasing yield and/or economic return and for improving soil quality for crop production. However, some amendments that are touted as beneficial may not be beneficial enough to increase a producer's net return. Thus, all such soil additives should be assessed both agronomically and economically.

It is an established fact that most inorganic fertilizer and lime additions to soil are beneficial if/when applied according to established critical levels for a growing crop. Thus, there is a constant effort to determine the proper amount of these amendments that are needed to provide economic benefit because this can change with improved varieties and production practices.

In today's environment of issues associated with climate change and its perceived associated negative consequences, agricultural producers are expected to reduce their carbon [C] footprint in order to reduce the amount of C that enters the atmosphere. Thus, producers are faced with the quandary of the potential negative effects that arise from applying more inputs to produce more food, feed, and fiber, while also reducing the perceived adverse effects that may result from those increased inputs. And of course, all of this comes under the arguable intention of increasing the "sustainability" of agricultural production, which regrettably has been defined by those who are not faced with this quandary but who have the authority to impose their sustainability standards on those who are.

It is an established fact that irrigation of crops in the Midsouth 1) increases yields and net returns from crop production, and 2) has resulted in a declining water level in the Mississippi River Valley Alluvial Aquifer [MRVAA]. Thus, continued crop irrigation in the Midsouth is not sustainable using current practices on an ever-increasing irrigated acreage when the main water source is the MRVAA. Therefore, more attention should be given to sustainable dryland crop production in the region.

Promotion of dryland agriculture in the Midsouth is a worthy cause. However, less than 35% of the region's average annual rainfall is received during the growing season months of May through September. Also, the year to year vagaries in rainfall pattern during this period frequently result in extended periods of little or no rainfall, and this is exacerbated by high temperatures that are normal during this period [thus the frequent drought periods]. This compromises dryland crop production, and often results in poor yields from dryland cropping systems in the Midsouth.

Now back to the opening paragraph of this article. Biochar is being touted as a promising soil amendment to address the above challenges in sustaining dryland agriculture. Biochar is widely regarded as a soil amendment that will enhance water and fertilizer use efficiency in crop production because of its positive effects on soil pH, soil porosity and bulk density, cation exchange capacity [CEC], hydraulic conductivity, nutrient availability, soil water holding capacity, soil microbial activity/diversity/abundance, and sequestration of C into agricultural soils. This perceived enhancement of these soil properties should result in crop yield increases in dryland systems.

Before further narrative on this subject, the following definitions are needed.

- **Pyrolysis** is a process that uses the application of high temperatures [above the boiling point of water and other solvents and in an environment with negligible or limited oxygen] to organic compounds to cause chemical decomposition.
- **Biochar** is the product of pyrolysis of biomass waste materials such as crop residues, forestry/logging wastes, poultry litter, and animal manure. Biochar is a C-rich charcoal.
- **Biochar feedstocks** come from biomass waste materials such as crop residues [e.g. corn stover, sugarcane residue or bagasse–see below], forestry/logging wastes, poultry litter, and animal manures. The chemical composition of biochar–i.e. the amount of C, nitrogen [N], potassium, calcium, etc.–depends on the feedstock used in its production and the duration and temperature of the pyrolysis. Thus, any biochar product used as a soil amendment should be tested on a batch by batch basis to determine its specific chemical composition. The choice of biochar feedstocks also will be determined by their availability in the area of intended use–e.g. in the Midsouth, poultry litter, sugarcane bagasse, logging residue would be available feedstocks.
- **Bagasse** is the residue or fibrous matter that remains after sugarcane stalks are crushed to extract their juice. Most bagasse is used as a fuel for sugarcane processing, but the percentage that is not used for fuel can be used as a feedstock for biochar production. The amount of this material that would be available for biochar production on a large scale is not known.

Making biochar from its various feedstocks 1) should not compete for land used for crop production, 2) prevents these materials from being burned or left to decompose [thus releasing carbon dioxide (CO_2) and methane (CH_4) back into the air] and from polluting local ground and surface waters, and 3) can result as a byproduct of producing energy from various biomass feedstocks. A consistent supply of biochar feedstock will depend on availability both within and among years, and this will likely be related to producer planting decisions, weather vagaries, and government programs that may influence choice of crop to plant or diversity of a farming operation.

A thorough review [with cited references] of the basics of biochar production and benefits from its use in agriculture is in the White Paper titled "Biochar: An Overview" (Feb. 2018) by Woolley and Hallowell. Other selected references pertaining to biochar production and use are "Feedstock determines biochar-induced soil priming effects by stimulating the activity of specific microorganisms" by Yu et al [European J. Soil Science, Feb. 2018], "Change in nutrient composition of biochar from rice husk and sugarcane bagasse at varying pyrolytic temperatures" by Nwajiaku et al [Intl. J. Recycling of Organic Waste in Agriculture, Aug. 2018], "Chemical Properties of Biochar Materials Manufactured from Agricultural Products Common to the Southeastern United States" by Evans et al [HortTechnology Feb. 2017], and "The Potential of Biochar as a Fertilizer Supplement and Soil Amendment" by Burke et al. [Univ. of Ark. Coop Ext. Serv., FSA2196, Oct. 2021]. Important points from these articles follow.

- Biochar is the pyrolysis product which contains all of the non-combustible constituents of the selected feedstock.
- Biochar yield is maximized when a slow pyrolysis process is used, and conversely, biochar yield is minimized under high temperature/fast pyrolysis conditions.
- The chemical composition of biochars can vary widely. Biochar quantity and quality from a selected feedstock can vary based on the pyrolysis temperature, duration of the process, and exposure to oxygen during the process.
- Typically, as the peak pyrolysis temperature increases, biochar yield [by weight] decreases, and C content of the biochar [by weight] increases.
- A typical slow pyrolysis process achieves a 35% biochar mass yield, whereas a typical fast pyrolysis achieves a 12% biochar yield.
- The C and nutrient element content of biochar can vary widely based on the selected feedstock and pyrolysis conditions.
- Biochar nutrient concentrations are generally based on 1) they are significantly higher when feedstocks undergo pyrolysis at higher temperatures, and conversely, N concentrations often decrease as pyrolysis temperature increases, 2) pyrolysis temperature can be adjusted to optimize concentration of desired nutrients in the resulting biochar, 3) plant-derived feedstocks often produce biochars with a lower nutrient value than biochar derived from animal-derived feedstocks such as manures, and 4) initial nutrient concentrations in feedstocks should not be used to predict biochar's nutrient makeup.
- Increasing the pyrolysis temperature or exposure time for a feedstock increases the surface area and adsorption capacity of resulting biochar. This increased porosity enhances biochar's water retention capacity, nutrient retention, and microbial accumulation.
- The effect of biochar addition on soil and crop productivity varies widely. The greatest improvements often occurred when biochar was added to acidic or pH-neutral soils, and to soils with medium or coarse texture. The greatest improvements in crop yield were often associated with large amounts of biochar additions. Also, improvements were most notable when biochar was added in addition to fertilizer vs. when applied alone.
- The high variability in chemical composition among biochar feedstocks and their biochar products requires that users know the specific properties of any biochar product they use as a soil amendment. Therefore, biochar should not be referred to as a single entity, but rather recommendations for its use and predicted performance should be based on the specifics of the feedstock and its pyrolysis conditions.
- Studies have shown that biochar addition to soil can improve water retention ability, pH, CEC, nutrient retention, and soil biota. However, as stated previously, pyrolysis temperature, pyrolysis duration, feedstock, the amount of biochar added to soil, and the soil's inherent nutrient composition will all impact biochar's ability to positively affect soil qualities and crop yield.
- The bacterial and fungal populations in soil following the addition of biochar are affected by the feedstock source used for biochar production. This is apparently related to the proportion of cellulose and lignin in the feedstock. The lignin and cellulose contents of feedstock also strongly affect the pore structure of resulting biochar.
- Long-term studies are needed to properly assess biochar's impact on soil attributes before widespread biochar use is promoted.
- Optimized biochar production can significantly reduce greenhouse gas [GHG] emissions, and thus significantly contribute to C sequestration.
- Since biochar is obtained from waste sources, its production would not affect current land use or food production. However, biochar production as a major C sequestration technique would require mass pyrolysis of feedstocks on a global scale.

- Since biochar's C sequestration is based on its ability to slow the release of C into the atmosphere, its C stability must first be optimized. Again, this will require a major long-term research effort to determine the optimum feedstock(s) and the optimum pyrolysis conditions for the various feedstocks.
- There is not enough sound scientific evidence to support the widespread adoption of all biochars from all feedstocks. Also, research needs to be conducted to determine the long-term gains from applying biochar to soil used for agricultural production.
- The nutrients contained in biochar can be accessed by root hairs that come into contact with a biochar particle, which is similar to their accessing nutrients from a synthetic fertilizer particle.
- Biochar's longevity in the soil allows it to remain a stable source of nutrient retention for successive growing seasons.
- Biochar can improve soil structure by increasing the number of soil pores.
- The main limitations to biochar production and use as a soil additive in agricultural settings deal with economics, logistics, and demand.
- At this time, there is no recommended application rate for any particular biochar product due to the varying pyrolysis processes and the varying physical properties of the myriad biochar products.

Caveats. 1) While the above narrative gleaned from biochar-related literature paints a positive picture for the potential use of biochar as a soil amendment in agricultural production systems, it is doubtful if there are sufficient facilities for the production of a selected biochar product in an amount that would be required for its use on a large acreage in the Midsouth. So even if sufficient research determines its value for any or all of the above-stated potential benefits, it will likely take a number of years to ramp up to the required large-scale production of needed biochar from any feedstock. 2) If sufficient research determines biochar's value as a soil amendment in the Midsouth, there will be a need to determine if in fact production and use of a selected biochar product in the amount needed will be economical in the region.

MAR 2023 UPDATE

An article titled "A global synthesis of biochar's sustainability in climate-smart agriculture–evidence from field and laboratory experiments" by Huang et al. [Vol. 172, Feb. 2023, 113042] appears in the journal "Renewable and Sustainable Energy Reviews". The contents of this article highlight the effects of biochar in field experiments. Major points from the article follow.

- Results from 592 papers published before 2021 that reported GHG emissions, soil C stock, crop yields, and soil N loss resulted in a dataset that had 9970 observations for the subject variables.
- Research reported in the articles was conducted on cropland soils.
- The biochar in the studies was produced by pyrolyzing organic materials.
- Overall, crop yield response from soils with biochar addition were positive, but were greater in laboratory experiments [25.4% increase] vs. field experiments [15.7% increase]. Similar patterns were noted for soil organic carbon [SOC] and total N.
- Generally, addition of biochar to soil reduced CH_4 and nitrous oxide [N_2O] emissions in both lab and field experiments.
- The effects of biochar application on crop yield, SOC, GHG emissions, and N dynamics depended on multiple factors that included biochar properties and application methods, soil properties, climate, and agronomic management factors such as tillage, irrigation, fertilization, and residue addition.
- Biochar feedstock had a major effect on crop yield, with manure-based biochar increasing yield the most, followed by herbaceous-based biochar. The effect of feedstock type was greater in lab than in field experiments.
- Positive crop yield responses increased with increasing biochar application rates, and peaked at rates between 9 and 18 tons/acre in field experiments [these application rates likely are not economical in field settings].
- Biochar's positive effect on crop yield was more pronounced in fine-textured vs. coarse-textured soils in field experiments.
- In field experiments, biochar's positive effect on SOC was less in soils with a higher/increasing C content.
- N fertilizer did not affect biochar's effect on crop yield, CO_2 and N_2O emissions, or nitrate [NO_3] leaching in field experiments.
- The results of this meta-analysis showed that biochar addition to soil can increase SOC pools and crop yield.
- These results also show that the positive effects from biochar addition to soil are greater in lab vs. field experiments, and that biochar application rates in lab experiments were often unrealistically high. Thus, results from lab experiments with biochar likely lead to an over-estimation of the positive effects of biochar.
- **Overall, the findings from this meta-analysis reveal that 1) data derived from field experiments should be used when analyzing the effects of biochar soil amendment on crop yield, soil properties, and GHG**

emissions, 2) unrealistically high biochar application rates used in lab experiments are likely impractical under field conditions because of the high cost of feedstock and its transportation and pyrolysis, 3) long-term field experiments should be used to determine the legacy effects of biochar soil amendment on crop yield, soil properties, and GHG emissions, and 4) the costs associated with biochar production and its application to field sites, plus the potential impact of the chosen biochar product on crop yield, should always be considered and verified before deciding on biochar use as a soil amendment.

NOV. 2023 UPDATE

An article titled "Effect of biochar application on corn and soybean yield in Michigan and Ohio" by Silva-Pumarada et al. provides the following information about biochar addition to cropland.

- Pine-derived biochar was added to soils in the fall of 2020 at locations in Ohio and Michigan to test its effect on corn and soybean yields.
- Yield of both crops was unaffected by biochar additions.
- The authors concluded that 1) the positive environmental and soil quality benefits that may accrue from biochar soil amendment will not offset the short-term lack of its effect on corn and soybean yield because of the high cost of the biochar amendment and its application, and 2) biochar soil amendment may not be economically viable for corn and soybean farmers to use in the short-term.

These results further reinforce the conclusions about biochar use on corn and soybean production sites that have been alluded to previously in this article–i.e. the expense associated with biochar application to corn and soybean production sites will not likely be recouped in the short-term by yield increases of either crop.

APRIL 2024 UPDATE

An article titled "Biochar modifies soil physical properties mostly through changes in soil structure rather than through its internal porosity" by Zanutel et al. provides insight into just how biochar application rate and age affect physical properties of silt loam and sandy loam soils. Results from research reported in the article follow.

- Application of fresh biochar decreased bulk density about 17%, and increased saturated water content and macroporosity by 16% and 79%, respectively.
- The authors did not measure a consistent effect resulting from the two biochar application rates of 6 and 12 tons/acre.
- The improvement in soil physical properties in the short-term was related to the improvement in soil physical structure by biochar rather than the internal porosity of the biochar.
- "Old" biochar did not appear to affect soil physical properties in this study, probably because of clogging of biochar pores by clay particles in the soil over the long term.
- The authors concluded from their research that biochar can improve soil physical properties in the short-term, but the effects likely are not long-lasting due to clogging of biochar pores.

JULY 2024 UPDATE

Click here for an article on this website that provides a link to a report about a process that was developed by Korean scientists to provide a quick, on-site conversion of animal manure to biochar. The process described in the article is currently in the "pilot" phase, but it is anticipated that it can soon be operational on a scale that will allow it to be used in individual livestock operations in the U.S. The breakthrough technology described in the article can contribute to a 1) reduction in animal manure's contribution to some of the factors that are perceived to be associated with climate change, and 2) significant increase in biochar supply that will be available to crop producers to apply to fields as a beneficial and affordable soil additive.

MAY 2025 UPDATE

Hopefully, the above process can quickly be available for large-scale production of biochar from materials that are plentiful in the Midsouth. An article titled Application and residual effects of poultry litter biochar on cropping system yields provides a reason for this to occur.

- Poultry litter can supply plant-available nutrients to crop plants.
- Converting poultry litter to a biochar product should reduce nutrient losses from this animal manure product when it is added to the soil.
- The study in the above-linked article had three treatments [no phosphorus (P), inorganic P fertilizer, and P supplied as poultry litter biochar (PLB)] applied in two consecutive years at two Florida locations.
- Crop treatments were cereal rye from fall to spring, silage corn from spring through mid-summer, and forage sorghum from mid-summer to fall in both years of the study.
- PLB applied in an amount to equal the P supplied by the inorganic P fertilizer resulted in comparable or greater cumulative biomass as that resulting from the addition of

the inorganic P fertilizer.

- The positive effect of PLB addition was most evident in corn, probably because of corn's greater nutrient demand. **Thus, corn seems the obvious crop to test biochar efficiency**.
- Overall, PLB supplied residual P to the crops used in this system in an amount that was comparable to that supplied by the inorganic P fertilizer. This should be accounted for in future research that evaluates the effects of PLB on different crops.

The results from the study reported in the above-linked article support the use of biochar as a replacement P fertilizer for crops. **However, the expense associated with biochar production and its application to crop production sites that is alluded to above is an overriding deterrent to its use.** Thus, it appears that any future research that determines the effect of the addition of any biochar product to a crop must account for its expense relative to that of current P fertilizers that are available.

As stated in the opening paragraph of this update, it is hoped that a process to provide an economical conversion of any animal manure to biochar will be forthcoming. Such a process on a scale that will allow it to be used in individual livestock operations in the U.S. will contribute to a 1) reduction in animal manure's contribution to some of the factors that are perceived to be associated with climate change, and 2) significant increase in biochar supply that will be available to crop producers to apply to fields as a beneficial and affordable soil additive.

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