

BIOCHAR GUIDELINES FOR AGRICULTURE APPLICATIONS

Practical insights for applying biochar to annual and perennial crops



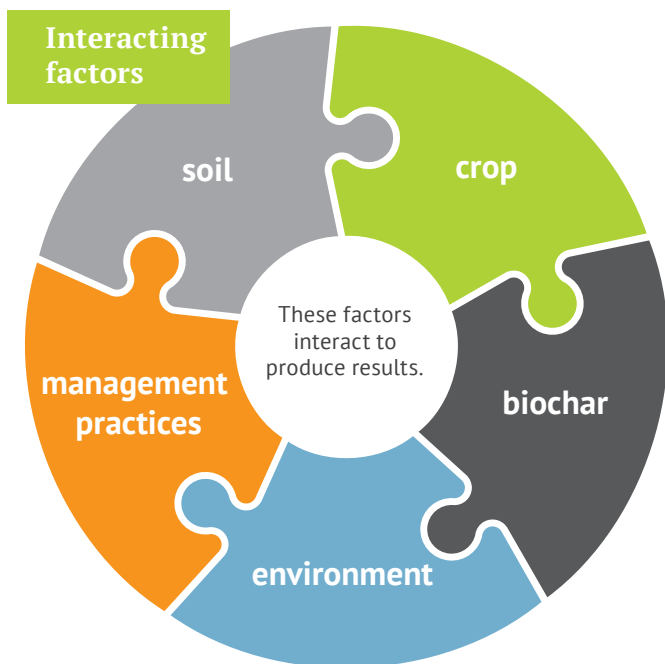
Photo by Britt Fossum



Photo by David Laird

A sustainable soil amendment that:¹⁻⁴

- builds soil organic carbon and soil health
- increases crop yields and soil moisture
- improves nutrient retention
- boosts microbial activity
- alleviates compaction
- reduces soil acidity
- sequesters carbon



expensive. Biochar quality and availability are important factors to consider in your decision to use it. Farmers should consult with an ag professional or their local extension office for help selecting and applying biochar.

The best applications occur when the right biochar is applied at the right rate to address an identified resource concern. Feedstock and pyrolysis conditions influence the resulting biochars physical and chemical properties.⁶

Resource concerns or limiting factors that biochar might help address include soil compaction, water retention, nutrient use efficiency (NUE), soil organic matter levels, and pH. Other objectives could be to sequester carbon⁷ or generally improve soil health.

Right place

Applying biochar to the soils that need it⁸

As national supply has increased, the cost of biochar has declined (\$350/ton on average), and carbon credits can make it more affordable. Not all soils and crops will see a yield benefit from biochar applications, making it essential to know which soils will likely generate a positive crop yield response. Soil maps can help identify soils that would potentially benefit the most from biochar applications.

In horticultural applications, biochar can replace non-renewable potting materials including peat, vermiculite and perlite.⁹ Biochar can also be a key component in many

FOLLOW THE 4RS

Biochar application to soils requires a similar strategy as the 4Rs of nutrient stewardship: right source, right place, right rate, and right timing.⁵ When biochar is used appropriately it can help farmers achieve maximum crop productivity and improve soil health, while minimizing environmental impacts.

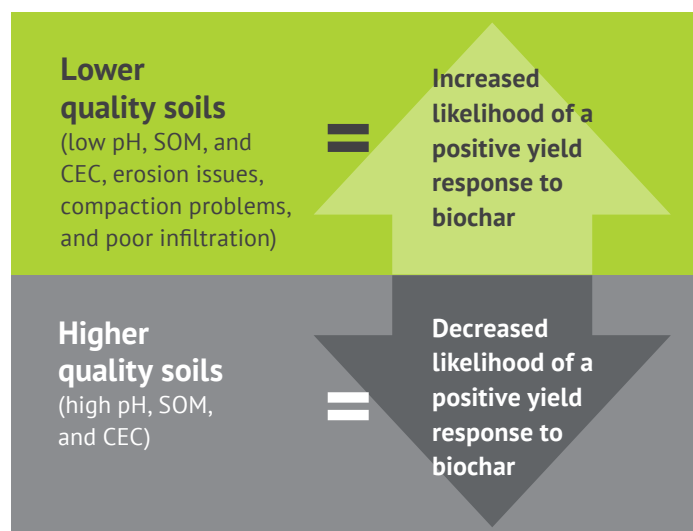
The physical and chemical properties of biochar differ based on the original feedstock and production conditions. Using the 4Rs improves the efficacy of soil biochar applications.

Right source

Selecting the best biochar for your crop

The best source of material for making biochar is local, available and would otherwise be a waste product (sustainable). Depending on where a farm is located some feedstocks to produce biochar include poultry litter, manure, switchgrass, rice hulls, corn stover, vine/tree prunings, coconut husks, woodchips, straw, sugarcane bagasse, etc.

Biochar is also produced from biosolids, construction waste and other materials that may pose a contamination risk when applied to soils. To select the ideal biochar, know the original feedstock and also have the biochar analyzed prior to use. Sometimes the best biochar may be far away, making it very



SOM = soil organic matter, CEC = cation exchange capacity

different conservation practices or management strategies. For example, if installing a field border or grassed waterway, biochar can improve the soil condition and assist with vegetation establishment and plant growth.

Right rate

Applying the right amount

There is no one-size-fits-all answer regarding the amount of biochar to apply. Application rates are site-specific and should be determined to correct or improve a production constraint or resource concern. Soils vary in their deficiencies and needs, and application rates are determined on a field-by-field basis to address a specific issue.

Field application rates of between 1–10 tons/acre have shown consistent positive impacts in numerous studies.³ A good starting point for field applications is 1 ton/ac or 4 cu yd/ac as the lowest effective rate to improve soil organism habitat and 3 ton/ac or 12 cu yd/ac to improve soil organic matter levels. For container production or tree planting holes, 5–25% by volume maintains good plant performance.¹⁰

Economics are often a factor. Higher rates of the ideal biochar are usually better, but they typically are not cost-effective. Financial assistance from USDA programs may supplement costs (contact your local NRCS service center: nrcs.usda.gov/contact/find-a-service-center).

Right time

Identifying when to apply

Biochar can be applied at any time of year except when the ground is frozen (state laws often prohibit application of amendments on snow-covered or frozen ground due to higher runoff potential).

Spring application is the most common time to apply biochar. But often, a better time to apply biochar is after harvest and with a cover crop. This provides time for the biochar to equilibrate in the soil. However, it would be imperative to have a cover crop in this situation to prevent runoff and utilize excess nutrients from the biochar amendment.

Applying biochar with other amendments or during other management operations may save farmers time and money and reduce the risk of erosion loss. Most common examples are mixing and spreading biochar with manure, chicken litter or compost.

IMPORTANCE OF POST-PROCESSING

Charging/inoculating/blending

Biochar, a relatively inert material, serves as the backbone or carrier of nutrients and shelter for microorganisms. Inoculating, charging, activating, blending or mixing essentially fills biochar surface functional groups with nutrients and microbes to initiate surface reactions.

When applied to the soil, inoculating biochar is critical to minimize the potential for nutrient immobilization (tying up of nutrients), which can lead to a yield drag or loss, particularly in the first year of application. Filling the pore spaces in biochar with nutrients, fertilizers or microbially active substrates minimizes a potential yield loss and improves the efficacy and potential for positive impacts from biochar.¹¹ Mixing biochar with manure, compost or other amendments may also improve the efficiency of those amendments.¹²

Many different sources can be used to inoculate biochar – compost, manure, compost tea, fertilizer, urine, microbial inoculants. Selecting one depends on availability, scale and farmers' fertility practices.

The time needed to activate before use varies; 1–3 weeks has been recommended.

The benefits of charging biochars led to the development of biochar-based fertilizers (BBFs) that take advantage of the opportunity to produce biochars tailored for specific needs and use different pre- or post-pyrolysis methods to load biochar with nutrients.¹³ Farmers can speak directly with biochar suppliers to create customized biochar blends to meet their fertility needs or purchase formulated BBFs directly from fertilizer companies. (See pelletized/prilled biochar text on page 6.)

For more information, see manure fact sheet: <https://go.unl.edu/biochar>.

CASE HISTORY: GADY FARM

Improved wheat yield

CHALLENGE/OPPORTUNITY: Gady Family Farm, a >300-acre operation in Rockford, WA, grows mostly grass seed and small grains on fine silty textured soils. The farm struggles with issues of soil acidity, requiring regular applications of agricultural lime.

SOLUTION/APPROACH: Biochar can replace lime while simultaneously providing nutrients. In the early 2000s, in cooperation with Farm Power, an on-farm gasifier was built to produce both power and biochar from straw and seed cleaning residues to increase the farm's sustainability.

At 650-750°C and with a feed rate of 60-82 kg h⁻¹, ~ 50 pounds of biochar are generated per hour. The resulting seed screened biochar has a high ash content (17.7%), liming equivalence 12% (calcium carbonate equivalent), and nutrient value of 2.2% N, 3.4% P, and 6.1% K.

In 2013, the USDA-ARS established trials at the Gady Farm to compare the impacts of the seed cleaned



The growth of wheat in Eastern Washington in soils amended with biochar vs. unamended soils. *Photo by Kristin Trippe*

biochar versus lime on wheat yields and other soil parameters. Each treatment was replicated four times in two seasons (2013 and 2014). Biochar was applied at 8 ton/acre (equivalent to 1.2% by mass in the top 4 inches, or 6% by volume) and lime at 1 ton/acre. A lime spreader application was followed by rototilling to a 4-inch depth before winter wheat was planted in the fall.

RESULTS: Biochar plots increased wheat yields, soil moisture levels, and fungal community abundance relative to both the no amendment control and lime treatments in 2013. Soil pH increased by a similar amount for both amendments. In 2014, both amendments increased wheat yields relative to the no amendment control. Overall, biochar increased yields by 280% (lime by 200%) over both years.¹⁶

Biochar being incorporated after broadcast application to an Iowa corn field. *Photo by David Laird*



SINGLE VS. REPEATED APPLICATIONS

Because biochar resists decomposition in soil, single applications can provide beneficial effects over many growing seasons.¹⁴ Thus, biochar does not usually need to be applied annually, like manures, compost, synthetic fertilizers, and other amendments.

Yet repeated or incremental applications can be made with current management practices (e.g., fertilizer or compost applications). Considering economics, logistics or mechanization in no-till systems, smaller amounts of biochar can be applied on a more frequent basis. One tradeoff is that changes to soil properties may take longer to be realized.

In perennial cropping systems (e.g. vineyards, orchards and ornamentals), applying biochar at the time of planting directly into the planting row ensures incorporation into the soil profile and within the root zone. For existing plantings repeated surface applications can be made in-row or between rows, though it is best to mix with compost or fertilizer to reduce risk of loss.¹⁵

In pasture or range systems, applying biochar before grazing can be advantageous to incorporation, but forage height and livestock type play a role in that decision. The best time to apply biochar in pasture settings is right after livestock have rotated through a paddock, so biochar is combined with residual manure and urine.

CASE HISTORY: SIEMBRA FARM

Improving sandy soil

CHALLENGE/OPPORTUNITY: Siembra Farm is a 15 acre farm located outside of Gainesville, FL. They grow vegetables, herbs, and fruit for retail, CSA shares (community supported agriculture) and wholesale markets. Their goal is improving sandy, low-quality soil on the farm.

SOLUTION/APPROACH: Managers learned that biochar could improve soil biological activity and nutrient and water holding capacity. They needed a cost effective method to produce biochar. Since the farmer regularly clears brush from the surrounding forest, they started making biochar from this material.

They pile woody material, which includes oak stumps, vines, branches and saplings, (~15ft. diameter and 6-7ft. tall), then ignite the pile from the top down with occasional monitoring over 6-8 hours. Once the pile is reduced to charcoal, it is quenched with soil or water. This relatively hands-off method produces ~1 cubic yard of biochar, which they apply to ~1 acre of land.



Photo by Roy Smith

If the biochar is produced near the intended use area it is spread in place using a front-end bucket loader, then disked or rototilled into soil. Otherwise, biochar is shoveled into buckets and applied by hand around crops or mixed with compost and spread using a compost spreader at 2 cubic yards/acre.

RESULTS: Visually there are significant differences in cover crop performance in areas that received biochar compared to areas that did not. The plants are taller, greener, and lusher. Soil tests indicate that the addition of biochar to the newly cleared planting sites improves the sandy soil's nutrient and organic matter levels. Approximately 51% of farms in the US are <81 acres in size, so biochar can help small farms improve yields while lowering their input costs.¹⁷

APPLICATION EQUIPMENT AND METHODS

Equipment common on farms can be used to apply biochar including compost/manure spreaders, lime spreaders, broadcast seeders, tillage implements, seed drills and liquid injection. Which piece of equipment is used will depend on the cropping system, biochar particle size, size of the farm and other management practices.

Methods

Broadcast applications + incorporation

Biochar can be broadcast applied to the soil surface by hand (small scale) or using a lime, manure, or compost spreader (larger scale). Biochar is ideally applied in combination with other amendments, as discussed above, to reduce risk of wind erosion. Incorporate the biochar into the soil when possible using available tillage implements to minimize any further losses.

Liquid injection, fertigation and top dressing

For farms where liquid manure injection is common (dairy and field crops), micronized biochar (0.02mm particle size) can be incorporated into the liquid slurry before application to fields or initially added to manure lagoons to provide a variety of benefits. See manure fact sheet: go.unl.edu/biochar

Micronized biochars can be suspended in water and injected into the root zone of perennial crops or fertigated, which could provide a slow but steady method of adding biochar to the root zone via irrigation water.



Biochar slurry application using a sprayer. Photo by Kristin Trippe

The micronized biochar suspended in water can also be used to top-dress turfgrass, fields, golf courses and lawns. This also helps decrease the likelihood of losses due to wind or water erosion.

Trenching in perennial crops

Targeting biochar to the planting row or planting hole where the roots will have access to the nutrients is ideal. Also, adding biochar to the planting hole is more economical than applying it to the entire row.¹⁸

Drilling/banding in pastures and no-till fields

Biochar can be mixed with seed and/or fertilizer in no-till drills and banded into the soil with minimal disturbance to the soil surface. Ensure the biochar is dry (<20% moisture) before mixing to prevent caking in the drill.

Other considerations:

- Pelletized biochar is produced by compacting residual biochar into small pellets with or without a binder.¹⁹ Pelletizing biochar with chicken litter, hay or another appropriate binder makes application easier with existing equipment. The denser pellets minimize potential loss when biochar is top-dressed. The type of binder varies, but using a urea ammonium sulfate is a good option to supply additional N and balance the C:N ratio.
- Prilled biochar – A product like prilled urea with biochar can offer the most compatible substrate for farmers to use in existing fertilizer application equipment. Over 20 studies revealed a 15-69% delay in N release and 25-65% improvement in fertilizer use efficiency with prilled biochar-based N fertilizer.²⁰
- Incorporate biochar into the soil, when possible, using tillage implements, which is often the most practical method of application. Moistening biochar can further reduce losses due to wind at the time of application. However, biochar that is too wet may be difficult to spread depending on equipment used. Mixing with manure or compost aids in spreadability. Biochar by itself is very dry and dusty, so appropriate personal protective equipment (e.g., dust mask, goggles, and gloves) may be required. It is best to apply biochar during calm weather conditions.

CASE HISTORY: SHAMROCK CHRISTMAS TREE FARM

Minimizing nutrient leaching

CHALLENGE/OPPORTUNITY: Located on the east end of Long Island in Mattituck, NY, Shamrock Christmas Tree Farm is a 20-acre operation that specializes in the production of Douglas fir trees. The sandy soils and low organic matter (OM) levels (1.7%) mean water and nutrient retention are an issue, leading to problems such as chlorosis. Owner Joe Shipman was interested to see if biochar could help address these issues.

SOLUTION/APPROACH: In 2019, a 3-year field trial²¹ was initiated to evaluate the impact of biochar application rate on nutrient availability, soil water retention and plant response in commercial field production of Douglas Fir (*Pseudotsuga menziesii*) Christmas trees. Biochar, inoculated with compost tea, was applied at rates of 5, 10, and 15 tons/acre, plus a no biochar control. Each treatment plot was 10 trees, replicated 5 times (200 trees total in the study). The biochar was surface applied and raked into the top 4 inches of the soil within the future herbicide strip (see image).

Lysimeters were installed to monitor nitrogen leaching, while time domain reflectometer (TDR) probes and water

potential sensors were installed to record soil moisture, electrical conductivity and soil temperature data. The grower followed their standard practices for weed and fertility management.

RESULTS: During the 2019 growing season, all biochar treatments resulted in lower nitrate (NO₃⁻) levels compared to the no biochar control. Data was more variable for NO₃⁻ leaching in the 2020 and 2021 growing seasons but were on average lower across all biochar treatments compared to the control. Averaged across depth, soil moisture levels in 2020 showed no difference between the 15 tons/acre treatment and the control. No data was collected in 2021 due to sensor issues.

Over the 3-year study, no differences were found between treatments on the number of leader buds and tree height for the Douglas fir trees. However, no symptoms of chlorosis were observed in the biochar amendment trees. All biochar treatments increased OM levels compared to the control (>2%). Findings support the need to incorporate or trench the biochar into the planting row to ensure the biochar is in the root zone and minimize losses from wind or water erosion.



Photo by Debbie Aller

References

- 1 Biederman, L.A., and Harpole, W.S. 2013. Biochar and its effects on plant productivity and nutrient cycling: A meta-analysis. *GCB Bioenergy*, 5(2), 202–214. <https://doi.org/10.1111/gcbb.12037>
- 2 Dai, Y., Zheng, H., Jiang, Z., and Xing, B. 2020. Combined effects of biochar properties and soil conditions on plant growth: A meta-analysis. *Science of The Total Environment*, 713, 136635. <https://doi.org/10.1016/j.scitotenv.2020.136635>
- 3 Schmidt, H.P., Kammann, C., Hagemann, N., Leifeld, J., Bucheli, T. D., Sánchez Monedero, M. A., and Cayuela, M. L. 2021. Biochar in agriculture – A systematic review of 26 global meta-analyses. *GCB Bioenergy*, 13, 1708– 1730. <https://doi.org/10.1111/gcbb.12889>
- 4 Singh, H., Northup, B.K., Rice, C.W., and Prasad, P.V.V. 2022. Biochar applications influence soil physical and chemical properties, microbial diversity, and crop productivity: a meta-analysis. *Biochar*, 4(1). <https://doi.org/10.1007/s42773-022-00138-1>
- 5 Fixen, P.E. 2020. A brief account of the genesis of 4R nutrient stewardship. *Agronomy Journal*. 112: 4511-4518. <https://doi.org/10.1002/agj2.20315>
- 6 Ippolito, J. A., Cui, L., Kammann, C., Wrage-Mönnig, N., Estavillo, J. M., Fuertes-Mendizabal, T., Cayuela, M. L., Sigua, G., Novak, J., Spokas, K., and Borchard, N. 2020. Feedstock choice, pyrolysis temperature and type influence biochar characteristics: A comprehensive meta-data analysis review. *Biochar*, 2(4), 421–438. <https://doi.org/10.1007/s42773-020-00067-x>
- 7 Blanco-Canqui, H. 2019. Biochar and Water Quality. *J. Environ. Qual.*, 48:2–15. <https://doi.org/10.2134/jeq2018.06.0248>
- 8 Dokoohaki, H., Miguez, F. E., Laird, D., and Dumortier, J. 2019. Where should we apply biochar? *Environmental Research Letters*, 14(4). <https://doi.org/10.1088/1748-9326/aafcf0>
- 9 Zulfiqar, F., Allaire, S.E., Akram, N.A., Méndez, A., Younis, A., Peerzada, A.M., Shaikat, N., and Wright, S.R. 2019. Challenges in organic component selection and biochar as an opportunity in potting substrates: a review, *Journal of Plant Nutrition*, 42:11-12, 1386-1401. <https://doi.org/10.1080/01904167.2019.1617310>
- 10 Allaire, S.E., and Lange, S.F. 2017. Report: Horticultural substrates containing biochar: Performance and economy. CRMR-2017-SA-3. Centre de Recherche sur les Matériaux Renouvelables, Université Laval, Québec, Canada, 40 p.
- 11 Schmidt, H.-P., Kammann, C., Hagemann, N., Leifeld, J., Bucheli, T. D., Sánchez Monedero, M. A., and Cayuela, M. L. 2021. Biochar in agriculture – A systematic review of 26 global meta-analyses. *GCB Bioenergy*, 13, 1708– 1730. <https://doi.org/10.1111/gcbb.12889>
- 12 Major, J. 2010. Guidelines on practical aspects of biochar application to field soil in various soil management systems. International Biochar Initiative.
- 13 Melo, L.C.A., Lehmann, J., Carneiro, J.S., and Camps-Arbestain, M. 2022. Biochar-based fertilizer effects on crop productivity: a meta-analysis. *Plant Soil* 472, 45–58. <https://doi.org/10.1007/s11104-021-05276-2>
- 14 Major, J. 2010. Guidelines on practical aspects of biochar application to field soil in various soil management systems. International Biochar Initiative.
- 15 Genesio, L., Miglietta, F., Baronti, S., and Vaccari, F.P. 2015. Biochar increases vineyard productivity without affecting grape quality: Results from a four year field experiment in Tuscany. *Agriculture, Ecosystems & Environment*, 201: 20-25. <https://doi.org/10.1016/j.agee.2014.11.021>
- 16 Philips, C.L., Trippe, K., Reardon, C., Mellbye, B., Griffith, S.M., Banowetz, G.M., Gady, D. 2018. Physical feasibility of biochar production and utilization at a farm-scale: A case-study in non-irrigated seed production. *Biomass and Bioenergy*. 108:244-251. <https://doi.org/10.1016/j.biombioe.2017.10.042>
- 17 US Department of Agriculture - National Agricultural Statistics Service (USDA – NASS). 2022. Farms and Land in Farms 2021 Summary. https://www.nass.usda.gov/Publications/Todays_Reports/reports/fnl0222.pdf
- 18 Sales, B. K., Bryla, D. R., Trippe, K. M., Scagel, C. F., Strik, B. C., and Sullivan, D. M. 2022. Biochar as an Alternative Soil Amendment for Establishment of Northern Highbush Blueberry, *HortScience*, 57(2), 277-285. Retrieved Apr 10, 2023, from <https://doi.org/10.21273/HORTSCI16257-21>
- 19 Mohammadi A. 2021. Overview of the Benefits and Challenges Associated with Pelletizing Biochar. *Processes*, 9(9):1591. <https://doi.org/10.3390/pr9091591>
- 20 Gao, Y., Fang, Z., Van Zwieten, L., Bolan, N., Dong, D., Quin, B.F., Meng, J., Li, F., Wu, F., Wang, H., and Chen, W. 2022. A critical review of biochar-based nitrogen fertilizers and their effects on crop production and the environment. *Biochar*, 4, 36. <https://doi.org/10.1007/s42773-022-00160-3>
- 21 https://projects.sare.org/sare_project/lne19-384r/



Suggested citation: Aller, D., Trippe, K., Smith, B., Seman-Varner, R., Delaney, M., Miles, T. 2023. Biochar Guidelines for Agricultural Applications: Practical insights for applying biochar to annual and perennial crops. United States Biochar Initiative.

For more information, please visit US Biochar Initiative: biochar-us.org

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Published by: USBI in partnership with Nebraska Forest Service.

Thanks to the US Forest Service for funding support.

