Manure Processing Fact Sheet Series

Biochar Production through Slow Pyrolysis of Animal Manure

MANURE PROCESSING for Farm Sustainability

Biological Systems Engineering
COLLEGE OF AGRICULTURAL & LIFE SCIENCES
UNIVERSITY OF WISCONSIN–MADISON

Joseph Sanford
Assistant Professor,
Soil and Crop Sciences,
University of Wisconsin–Platteville

Horacio A. Aguirre-Villegas
Associate Scientist,
Biological Systems Engineering,
University of Wisconsin–Madison

Rebecca A. Larson
Associate Professor,
Biological Systems Engineering,
University of Wisconsin–Madison

Mahmoud A. Sharara
Assistant Professor,
Biological and Agricultural Engineering,
North Carolina State University

Zong Liu
Assistant Professor,
Biological and Agricultural Engineering,
Texas A&M University

Linda Schott
Assistant Professor,
Soil and Water Systems,
University of Idaho

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Introduction

Biochar is a carbon-rich product resulting from pyrolysis, where biomass (such as wood chips, corn stover, and manure) is thermally treated at high temperatures under oxygen limited conditions (**Figure 1**). Pyrolysis produces syn-gas and bio-oil, fuels that can be used for heating or energy production, and a solid residual known as biochar. Biochar is porous, has a high carbon content, and low density (5 to 20 pounds per cubic foot) and has recently been used as a soil amendment to foster soil health. When integrated into fields it can sequester carbon, improve soil fertility and crop yield, decrease nitrous oxide emissions (a potent greenhouse gas), and improve nitrogen retention and reduce nitrate leaching (a groundwater contaminate) (Lehmann and Joseph 2015; Ahmed et al. 2019; Xu et al. 2016; Bradley, Larson, and Runge 2015; Sanford and Larson 2020a; 2020b)

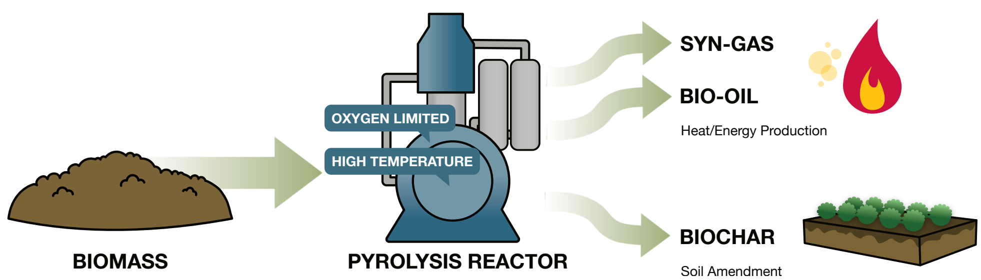

Figure 1. Pyrolysis process and products produced.

Industrial pyrolysis systems have primarily used woody biomasses as feedstocks. However, recent research highlights the potential of using agricultural residue, including manure, as a feedstock for slow pyrolysis. Converting manure into biochar reduces the mass and volume of manure (**Figure 2**, **Table 1**), which can be used to ease transportation for land application as a fertilizer compared to the original manure solids.

Figure 2. Mass and volume of separated manure solids before and after pyrolysis at 350°C.

Technology Basics

Pyrolysis is the process of converting an organic biomass at high temperature under oxygen limiting conditions to produce a syn-gas, bio-oil, and biochar. Any organic biomass can be used for biochar production, but moisture content should be less than 30%. If moisture content exceeds 30%, drying is suggested to decrease energy requirement to achieve desired temperature during pyrolysis (Tripathi et al. 2016). Moisture content also will impact bio-oil production, with higher moisture biomass resulting in more bio-oil production (Fonseca et al. 2019).

Pyrolysis reactors can be designed to optimize production of syn-gas, bio-oil, or biochar by varying the reactor temperature, heating rate, and holding time (Spokas et al. 2012). Slow pyrolysis technologies are used to optimize recovery of biochar and operate in a temperature range of 300 to 700°C (572 to 1292°F) with a slow heating rate typically below 10°C (50°F) per minute. The resulting process reduces the mass of the biomass by 20 to 50 percent, into a low-density carbon-rich product.

Slow pyrolysis reactors can be designed to operate as batch or continuous systems (Boateng et al. 2015). Batch systems, commonly called batch kilns, are typically lower cost units and used when recovery of biochar (and not the syn-gas and bio-oil) is a priority. In a batch system, the biomass is loaded into a reactor, which is then heated at a specified heating rate to the desired temperature and then allowed to cool. Continuous systems are designed to feed biomass continually into the system where the biomass will undergo drying, preheating, pyrolysis, and cooling at different stages within the reactor. Drum pyrolizers and rotary kilns are common continuous pyrolysis systems, in which biomass enters a cylindrical drum and is moved through different stages of pyrolysis using a paddle (drum pyrolysers) or rotational gravity (rotary kiln).

Table 1. Literature values for conversion of manure solids to biochar using slow pyrolysis.

Parameter	Range (%)
Mass Reduction [a, b, c, d, e]	42 – 82
Phosphorus Recovery [a, c, d, e]	93 – 99
Nitrogen Recovery [a, b, c, e]	18 – 62

[a] (Cantrell et al. 2012)
[b] (Cely et al. 2015)
[c] (Cao and Harris 2010)
[d] (Liang et al. 2014)
[e] Unpublished data from Sanford and Larson

Performance and End Use

Slow pyrolysis of feedstocks results in a variable mass and volume reduction dependent on pyrolysis temperature. Small scale batch pyrolysis test of dried manured solids results in a mass reduction ranging from 42 to 86% (**Table 1**). During the pyrolysis process complete recovery of manure phosphorus occurs, while only 18 to 62% of nitrogen is recovered due to losses through volatilization and emission of ammonia and nitrogen gases. Pyrolysis temperature will impact mass and nitrogen recoveries, with higher temperatures resulting is greater mass reduction and lower nitrogen recovery (Cao and Harris 2010). The process of converting manure solids to biochar results in a nutrient-rich manure by-product (**Figure 3**) that can be used as a fertilizer that has undergone significant mass and volume reduction. Manure-derived biochar can be land applied as a fertilizer and acts as a slow release phosphorus fertilizer (Jin et al. 2016; Liang et al. 2014; Subedi et al. 2016). To improve handling, storage, and transport of manure-derived biochar, manure can be pelletized (See UW–Madison Extension Publication A4192-003) prior to pyrolysis (**Figure 4**).

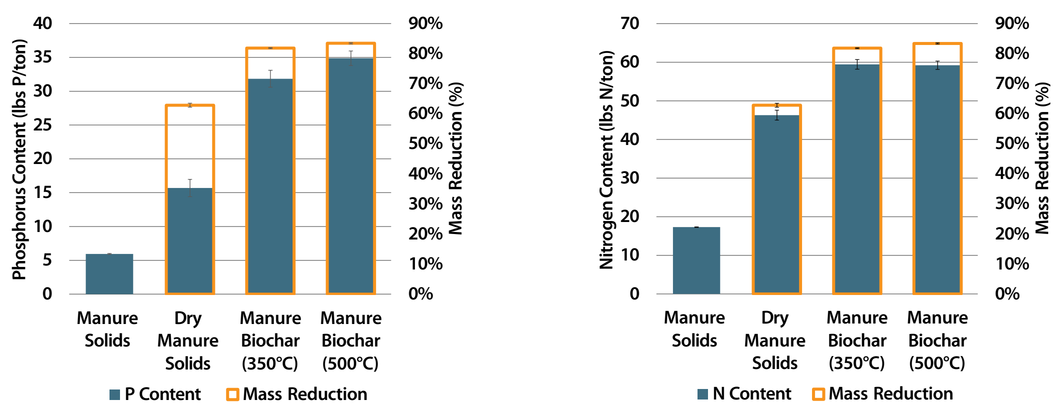

Figure 3. Nutrient content of phosphorus (left) and nitrogen (right) of manure solids when produced into biochar. Unpublished data from Sanford and Larson.

Conversion of biomasses to biochar and amending to soil can sequester carbon. Additionally amendment of biochars produced from wood has been shown to increase soil water-holding capacity and plant available water content (Pavuluri et al. 2019), reduce nitrogen leaching (particularly nitrate) in cropping system soils (Laird and Rogovska 2015), improving nutrient retention and decreasing pollution to groundwater. However, manure-derived biochar still needs to be evaluated to identify if similar soil amendment benefits will occur. Yield from amendment of biochar has varied across multiple studies, with some studies indicating increases in crop yield (Jeffery et al. 2015), while others found no or negative impacts on crop yields (Haider et al. 2017). However, manure-derived biochars have been found to generally increase crop yield (Subedi et al. 2016; Uzoma et al. 2011)

Figure 4. Unprocessed and pelletized manure solids following biochar production.

Cost

Implementation of pyrolysis reactors primarily have been on an industrial scale, but on-farm pyrolysis is limited. Capital cost of slow pyrolysis reactors will vary significantly based on type of system (continuous vs batch), size, and integration of an energy recovery system for syn-gas and bio-oil. Capital cost for pyrolysis plants from small-scale (2,000 tons per year) to large-scale (over 200,000 tons per year) plants range from $1M to $90M dollars (Shackley et al. 2015). Operating cost in literature varies drastically between $20 to $330 per ton of dry feedstock, which will vary based on system type, end product objective (i.e., syn-gas, bio-oil, or biochar), temperature range, and energy cost. In addition to pyrolysis reactors, manure will require pretreatment before biochar production (solid liquid separation and drying), and facilities will require biochar storage facilities, increasing the capital cost.

Limitations

Conversion of manure to biochar will require additional technologies for solid liquid separation and drying prior to pyrolysis as pyrolysis conditions require biomass to have a low moisture content (less than 30%). A solid liquid separation system, such as a centrifugation, screw press, incline screen, etc. will be required for preprocessing, and to decrease moisture content drying may be required.

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