Feasibility Assessment of Dairy Biochar as a Value-Added Potting Mix in Horticulture and Ornamental Gardening

Akio Enders [a], John Gaunt [a, b], Johannes Lehmann [a], Rajesh Chintala [c]

a Department of Soil and Crop Sciences, Cornell University, Ithaca, NY 14853
b GreenTree Garden Supply, Ithaca, NY 14850
c Innovation Center for U.S. Dairy

The project enabled an assessment of the potential for upgrading anaerobically digested, screw-pressed dairy manure into a higher value biochar product. This research capacity was leveraged to apply for and receive both the Northeast Sustainable Agriculture Research and Education ($15,000) grant and a portion ($16,520) of a larger Soil Health ($400,000) grant. The SARE grant objective is creation of a 10-20% (%w/w) nitrogen fertilizer by fixing volatile ammonia from dairy manure to biochar using carbon dioxide. Our focus for the Soil Health grant is assessing farmer response to dairy manure biochar amended potting mix for production of vegetable starts.

Dairy manure biochar is a nutrient-rich fertilizer with approximately twice the nutrient content of the original manure by mass, and more than three times that by volume. Additionally, conversion to biochar stabilizes the carbon so that more than half will remain to benefit soil fertility and carbon sequestration for over a century after application.

Workflow

Anaerobically digested, screw pressed, dairy manure was sourced from a 3000+ head New York dairy farm. This feedstock was air dried to 11.8% moisture from an initial content of 58.8% and pyrolyzed at a highest heating temperature of 550 °C with a 30 minute total residence time. Biochar yield was 38% over the 209 pound production run.

Following production, analysis of Basic Utility Properties and a Toxicant Assessment were performed on the biochar according to the International Biochar Initiative (IBI) Standard Product Testing Guidelines v 2.1. The effect of pyrolysis on nutrient content was assessed through total elemental contents of both the manure and the biochar. Transformations in nutrient availability of the manure and biochar were investigated with three extractants. Leachable nutrients were determined with a 0.01 M calcium chloride extraction. Available nutrients were determined with a modified Morgan extraction, with exception to phosphorous where a 2% citrate extraction was employed as a fertilizer industry standard. These data were used by our commercial partner, GreenTree Garden Supply, to substitute dairy manure biochar for all of the commercial biochar as well as a portion of fertilizer they use in three of their commercial growing media. A total of 10 samples (manure, dairy manure biochar, 5 dairy manure biochar blends, 3 wood biochar blends) were analyzed as soil samples by an independent laboratory (Dairy One) to gauge fertility. The value of this material as both biochar and fertilizer was then calculated.

Basic Properties

The dairy manure biochar is a dry, dense, odor and pathogen free material with improved storage capability, compared to its manure precursor. The biochar is 178% more dense than the manure at 503 pounds / cubic yard, with ash content increased from 18 to 38%.

The IBI classification tool calculates the Carbon Storage Class of this biochar as 1, on a scale of 1-5 with 5 providing the highest carbon storage potential. This rating is based on both the quality and quantity of carbon present. The high ash content of this biochar downplays the quality of the carbon present, hence the low rating. However, the quality of the carbon is sufficiently condensed (i.e., low H/Corg ratio) that roughly half of the 43% organic carbon is expected to persist over 100 years, compared to practically 0% in the manure.

The pH of this biochar is 10.45. More importantly, it has a calcium carbonate equivalence of 3.30%. In other words, 100 pounds of biochar can neutralize acid as well as 3.30 pounds of lime. This falls under IBI Liming Class 1, rated on a scale of 0-3, with 3 relating to the highest lime equivalent. Therefore, this biochar is best suited for mildly acid soils that would benefit from increasing pH. Unlike biochar from biomass, this material possesses a moderate level of soluble salts with electrical conductivity (1:20 w:v) at 1.65 dS/m. For comparison, soil salinity begins to affect plant growth at levels over 2 dS/m.

The Fertilizer Class of this biochar, according to the IBI classification system, is 3 on a scale of 0-4. This means that < 4.5 tons/acre provides adequate quantities of 3 out of 4 nutrients to corn. The Fertilizer Grade specifies that phosphorous, potassium, and magnesium requirements for corn are provided by application of 4.0, 1.3, 1.3 tons/acre.

Toxicant Assessment

The IBI toxicant assessment is understandably quite stringent, screening for persistent organic pollutants: polyaromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), dioxins (PCDD) and furans (PCDF); toxic heavy metals including: arsenic, cadmium, chromium, lead, mercury; trace elements that become toxic at higher quantities including: copper, molybdenum, nickel, selenium, and zinc; and phytotoxic elements including: boron, chlorine, and sodium. The dairy manure biochar was non-toxic on all counts, and contained 30 times less than the threshold value for any single analyte. A germination trial also assessed biochar toxicity. Of the three species used (lettuce, ryegrass, and radish) germination in dairy manure biochar amended potting mix was essentially identical to the control.

Test species		Germination after 14 days (%)	
Common name	Latin name	Control	Dairy manure biochar
Lettuce	*Lettuca sativa*	92	96
Ryegrass	*Lolium perennium*	100	62
Radish	*Brassica rapa*	100	96

Total Nutrients

The total content of plant nutrients in the dairy manure biochar was on average 66% more than in the manure. Biochar contained 4.1% phosphorous as P_2O_5, 2.2% potassium as K_2O, and 4.4% magnesium as MgO. If nutrients were completely retained, however, concentration in biochar would be 163% more than in the manure. The difference here is due to gaseous losses of nutrients during pyrolysis. Sulfur is the most notable example where biochar had only 50% of the content of the feedstock.

Element	Total content		Change due to pyrolysis	
	Manure (mg/kg)	Biochar (mg/kg)	Concentration	Retention
Phosphorous	10481.6	17728.6	69%	64%
Potassium	15721.5	21897.7	39%	53%
Calcium	154454.9	270710.8	75%	67%
Magnesium	15134.9	26391.3	74%	66%
Sulfur	8346.0	4212.6	-50%	19%
Iron	1801.3	4057.9	125%	86%
Manganese	214.3	369.7	72%	66%
Zinc	266.6	526.5	97%	75%

Available Nutrients

In addition to increasing total nutrient content, pyrolysis improved nutrient availability, with exception of nitrogen and iron. The dairy manure biochar has a nitrogen content of 1.7%, however thermal treatment has converted this to forms unavailable to plants (likely pyrroles and pyridines) and is therefore considered insignificant.

Biochar provided 13% more available phosphorous than the manure feedstock with 1.2% of biochar mass as P_2O_5, i.e. as would be printed on a fertilizer label. This increase in available phosphorous was coupled with a nearly 10-fold decrease in leachable phosphorous.

The biochar also demonstrated 59% more available potassium than the manure with 1.6% of biochar mass as K_2O. It should be noted however that the IBI Standards consider available potassium equivalent to total potassium (which is an appropriate approximation).

Element	Manure		Biochar		Change due to pyrolysis	
	Leachable	Available	Leachable	Available	Leachable	Available
	mg/kg	mg/kg	mg/kg	mg/kg		
Phosphorous	409.8	4505.9	35.8	5088.2	-91%	13%
Potassium	7372.8	8114.2	9399.9	12891.2	27%	59%
Calcium	31257.5	80671.0	33720.8	142276.8	8%	76%
Magnesium	2785.9	6578.6	291.1	7654.5	-90%	16%
Sulfur	179.5	681.0	125.4	750.5	-30%	10%
Iron	1.6	41.7	0.0	8.9	-100%	-79%
Manganese	7.1	109.3	6.2	176.6	-13%	62%
Zinc	1.9	69.2	0.5	85.0	-74%	23%

Commercial Value

When all nutrient and carbon content is accounted for, the dairy manure biochar has a value between \$0.91 - \$0.96/lb (or \$1,828-\$1,912). This is calculation is based on the weighted average wholesale price for individual components in commercially available organic fertilizers as below. The majority of value, \$0.79/lb, arises from the biochar carbon.

The product evaluation performed by GreenTree Garden Supply substituted all of the commercial biochar (80% C) with dairy manure biochar (43.3% C) on a carbon basis. This provided nutrient content that reduced materials cost for two products by 2.26% and 0.19% of their wholesale price.

	Rock phosphate *1			Bone char *2			Bone meal *3			Manure biochar		
	%	individual value	biochar $/lb	%	100% $/lb	biochar $/lb	%	100% $/lb	biochar $/lb	%	biochar $/lb	
Wholesale price		$ 0.39			$0.32			$1.43				
Total P_2O_5	20%	$ 0.15	$ 0.03	32%	$0.13	$ 0.02		$ -		4.1%	←	
Available P_2O_5	4%	$ 0.03	$ 0.01	16%	$0.06	$ 0.00	29%	$0.69	$ 0.03	1.2%	←	
Total K_2O	2%	$ 0.01	$ 0.02		$ -			$ -		2.2%	$ 0.04	*4
Total Ca	25%	$ 0.19	$ 0.01	34%	$0.13	$ 0.01	31%	$0.74	$ 0.04	1.6%	←	
Total Mg	1%	$ 0.01	$ 0.02		$ -			$ -		2.6%	$ 0.05	*5
Total S		$ -			$ -			$ -		0.4%	$ 0.01	*5
Organic C										43.3%	$ 0.79	*6

*1 https://norganics.com/index-12/index-11/fertilizers/old_phosphate-rock/
*2 https://norganics.com/index-12/index-11/fertilizers/bone-char/
*3 https://norganics.com/index-12/index-11/fertilizers/porcine-bone-meal/
*4 Potash ($0.83/lb) https://www.norganics.com/label/SulPotash.pdf
*5 Magnesium sulfate ($0.48/lb)
*6 GreenTree Biocore wood biochar ($1.45/lb)

Outreach

Container media and dairy manure biochar were featured at the Cornell Pyrolysis Facility opening celebration. Samples labeled to note collaboration with the Innovation Center for US Dairy were provided free of charge to interested parties. Additionally, the project is featured on the Pyrolysis Facility website at https://pyrolysis.cals.cornell.edu/projects/innovation-center-for-us-dairy/ .

The Pyrolysis Facility was featured in the following Cornell Chronicle articles:

http://news.cornell.edu/stories/2018/05/trash-treasure-cornells-pyrolysis-kiln-opens-may-24

http://news.cornell.edu/stories/2018/06/opening-pyrolysis-kiln-offers-waste-reward-reality

Future Outlook

A practical challenge to biochar production is reducing manure feedstock moisture content. Fortunately, biogas combustion could fulfill this requirement given the proper infrastructure. Where biogas is used to generate electricity, pyrolysis coproduct gases could be upgraded and then used as additional fuel. In this model, the electricity produced could be used to power on-farm pyrolysis. Biochar application to farm fields would increase soil fertility and reduce nutrient inputs. Large-scale dairy operations would benefit from engineering solutions incorporating anaerobic digestion, electricity generation, and manure drying and pyrolysis.

Organic farming presents a feasible commercial application for dairy manure biochar, as it is cost competitive with other organic phosphorous sources and organic farmers are accustomed to spreading a larger bulk of material as fertilizer. Additional fertilizer (especially N) would be blended with the biochar to achieve a desired nutrient balance and concentration and the final product would contain biochar to benefit soil fertility in the long term.

metric	threshold	actual	units	method [IBI category]
moisture	declaration	1.46	%	ASTM D1762-84 [A]
ash	declaration	38.42	%	
Corg	> 10	43.27	%	Dumas combustion; ASTM D4373 [A]
H : Corg	< 0.7	0.42	molar	
N	declaration	1.73	%	Dumas combustion [A]
pH	declaration	10.45	pH	1 : 20, 90 minutes (Rajkovich et al. 2011) [A]
EC	declaration	1.65	dS/m	
liming	declaration	3.30	% CaCO3	AOAC 955.01 [A]
particle size distribution	declaration	0.0	> 50 mm	progressive dry sieving [A]
		0.0	50 - 25 mm	
		0.0	26 - 16 mm	
		0.0	16 - 8 mm	
		2.2	8 - 4 mm	
		29.0	4 - 2 mm	
		39.8	2 - 1 mm	
		18.4	1 - 0.5 mm	
		10.6	< 0.5 mm	
germination inhibition	pass/fail	pass		(VanZwieten et al. 2010) [B]
PAH	< 300	1.83	mg/kg	EPA 8270 via EPA 3540 [B]
PCDD / PCDF	< 17	bdl	ng/kg	EPA 8290 [B]
PCB	< 1	0.01	mg/kg	EPA 8082 or EPA 8275 [B]
As	< 100	bdl	mg/kg	EPA 3051 or EPA 3050B [B]
Cd	< 39	0.29	mg/kg	
Cr	< 1200	1.44	mg/kg	
Co	< 100	1.39	mg/kg	
Cu	< 6000	39.67	mg/kg	
Pb	< 300	7.60	mg/kg	
Hg	< 17	bdl	mg/kg	EPA 7471 [B]
Mo	< 75	0.00	mg/kg	EPA 3051 or EPA 3050B [B]
Ni	< 420	2.18	mg/kg	
Se	< 200	0.52	mg/kg	
Zn	< 7400	219.49	mg/kg	
B	declaration	73.65	mg/kg	
Cl	declaration	0.00	mg/kg	
Na	declaration	4366.55	mg/kg	
total P	declaration	8644.93	mg/kg	dry ashing (Enders & Lehmann 2012) [C]
total K	declaration	21897.70	mg/kg	
total Ca	declaration	147171.00	mg/kg	
total Mg	declaration	12449.50	mg/kg	
total S	declaration	1658.85	mg/kg	
available P	declaration	5088.15	mg/kg	2% formate (Wang et al. 2012) [C]
volatile matter	declaration	27.27	%	ASTM D1762-84 [C]

Carbon Storage Class	1	sBC_{+100} = 217g kg^{-1}
Fertilizer Class	3	P_{9t} K_{3t} Mg_{3t}
Liming Class	1	$CaCO_3$ - eq = 3.303%
Particle Size Class	Pd	Blended Powder
Fertilizer Grade	Total N = 1.73% Total P_2O_5 = 1.98% Total K_2O = 2.64% Total S = 0.17% Total MgO = 2.06% Total CaO = 20.58%	Avail N / Total N = 0.00 Avail P / Total P = 0.59 Avail K / Total K = 0.92 Avail S / Total S = 0.45 Avail Mg / Total Mg = 0.61 Avail Ca / Total Ca = 0.97

courtesy of International Biochar Initiative https://biochar-international.org/biochar-classification-tool/

Carbon Storage Class

H/C_{org}	0.42		
C_{org}	%	43.3	total mass, dry basis

Fertilizer Class

Total N	%	1.73	mass basis	Avail. N	%	0	mass basis
Total P	%	.864	mass basis	Avail. P	%	.509	mass basis
Total K	%	2.189	mass basis	Avail. K	%	2.006	mass basis
Total S	%	.166	mass basis	Avail. S	%	0.075	mass basis
Total Mg	%	1.245	mass basis	Avail. Mg	%	.765	mass basis
Total Ca	%	14.71	mass basis	Avail. Ca	%	14.23	mass basis

Liming Class

$CaCO_3$	%	3.303	equivalent

Particle Size Class

<0.5mm	%	10.6	2 - <4mm	%	29.0	16 - <25mm	%	0.0
0.5 - <1mm	%	18.4	4 - <8mm	%	2.2	25 - <50mm	%	0.0
1 - <2mm	%	39.8	8 - <16mm	%	0.0	≥50mm	%	0.0

courtesy of International Biochar Initiative https://biochar-international.org/biochar-classification-tool/