The Potential for Biochar to Enhance Sustainability in the Dairy Industry

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EXECUTIVE SUMMARY

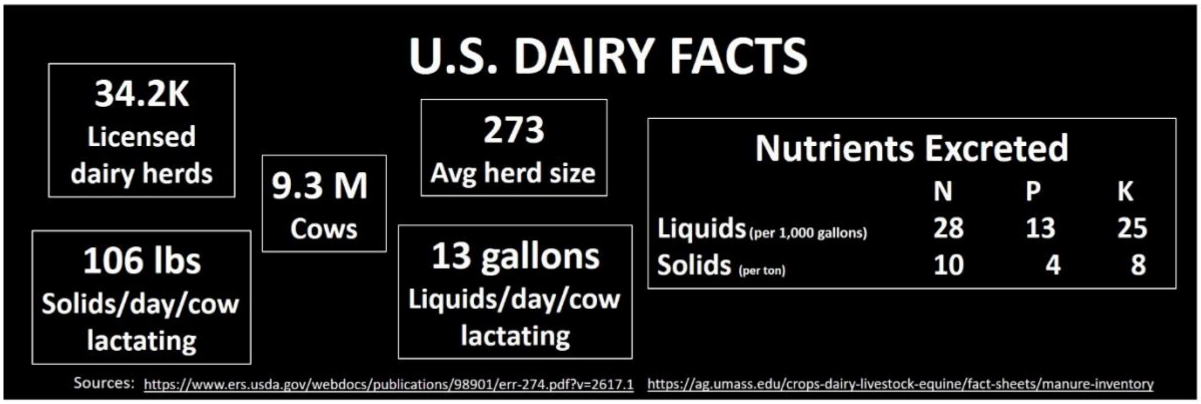
The US dairy industry launched a net zero initiative with the objective of becoming carbon neutral or even carbon negative by 2050 along with adoption of goals to optimize water use and improve water quality by recycling manure-based nutrients in dairy farms (ICUSD, 2020). Reducing impacts on air and water quality, and greenhouse gas (GHG) emissions such as methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) is increasingly urgent. Regulations are increasingly causing farmers to build larger facilities or buy more land to handle excess nutrients. At the same time, the industry has been hit hard by a number of different challenges.

New methods of reducing emissions on dairy farms include the production and use of biochar, a solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment. Biochar can be used as a product itself or as an ingredient within a blended product, to improve soil properties and/or resource use efficiency, to remediate and/or protect against environmental pollution, and as an avenue for GHG mitigation (IBI 2013). Biochar also offers the possibility of large-scale carbon sequestration which may lead to increased revenues for farmers of all types as carbon marketplaces begin to embrace biochar as a carbon removal product.

This paper reviews some ways that biochar is being or could be incorporated on dairy farms to improve overall economic and environmental impacts. While additional benefits and uses could accrue to the entire supply chain for milk, cheese any other milk-based products, this paper focuses solely on the dairy farm itself. It reviews different entry points for biochar from its use as a feed additive, to feed storage component, bedding additive, or manure management component. It also discussed converting manure directly into biochar as a manure management strategy that could reduce storage costs and GHG emissions.

The methodology used in this paper combines a review of the peer-reviewed literature with a survey of selected dairy and biochar demonstration projects in Australia, Canada, and the United States. Several project teams were interviewed, and project descriptions are included which outline preliminary results of using biochar within the context of dairy farming.

While a growing number of dairies are discovering the benefits of biochar, much work remains to help scale the production and use of biochar within the industry. Recommendations for future activities include benchmarking the GHG reductions for Thermochemical Conversion (TCC) compared to different manure management processes, optimizing TCC technologies for different sized dairies and those with existing infrastructure for manure management (e.g. anaerobic digesters), additional research on the impact of adding biochar to dairy feed on milk production, more biochar production demonstrations on dairy farms, and on-going coordination amongst dairy and biochar projects.



U.S. DAIRY FACTS

34.2K Licensed dairy herds

9.3 M Cows

273 Avg herd size

106 lbs Solids/day/cow lactating

13 gallons Liquids/day/cow lactating

Nutrients Excreted

	N	P	K
Liquids (per 1,000 gallons)	28	13	25
Solids (per ton)	10	4	8

Sources: https://www.ers.usda.gov/webdocs/publications/98901/err-274.pdf?v=2617.1 https://ag.umass.edu/crops-dairy-livestock-equine/fact-sheets/manure-inventory

CHALLENGING TIMES FOR DAIRIES

Dairy farmers have faced many challenges particularly over the last decade. Milk prices are falling (Reese 2019); equipment costs are on the rise, with some essential farm equipment more than doubling in cost since 1995 (Koenig 2016); and availability of labor for the dairy industry has steadily decreased (USDA "Farm Labor"). Although the average number of milking cows decreased in 2019, US milk productivity has more than doubled over the past several decades (Blayney 2004) resulting in more supply than demand leading to falling prices and losses that averaged $3 per hundredweight of milk produced in 2018 (Mercier 2019). This is an unsustainable situation which has forced an increasing number of dairies out of the industry.

Farmers are also facing increasing scrutiny about the environmental impacts of nutrients in land-applied dairy manure that can impact local and regional water bodies (Eagle 2017). For instance, the public often blames phosphorus runoff from dairy farms as the primary cause of harmful algal blooms (Guo et al. 2019).

USES & BENEFITS OF BIOCHAR ON DAIRY FARMS

Biochar, at its most basic, is carbonized organic material. It can be produced using a wide variety of thermochemical conversion technologies, and from a wide variety of feedstocks including wood, crop residues, and manure. Although most often biochar is intended for direct use in soils as a soil amendment to improve soil health and to reduce land degradation, additional benefits may accrue for the dairy industry both on-farm and for surrounding communities. These benefits are outlined below.

Feed Additive

Although the use of biochar as a feed additive for animals that enter the human food chain was removed from the Food & Drug Administration list of approved additives in the United States roughly a decade ago, at least one State has approved of its use for livestock. The California Department of Food & Agriculture allows the use of biochar (called charcoal in their regulations) in livestock feed. The Official California Code of Regulations for Food and Agriculture related to commercial feed states the following:

> *(e) Charcoal (vegetable) is charred hard or soft wood, nut shells, or fruit pits. If it is wood charcoal, it shall bear a designation indicating whether it is hard wood charcoal or soft wood charcoal. Charcoal from nut shells or fruit pits shall be designated as shell charcoal. When used in a mixed feed the maximum percent shall be stated on the label. (Barclay's Official California Code of Regulations)*

Feed biochar has been approved and used in many other parts of the world for many years including Europe, Australia, Canada, and Japan (Schmidt et al. 2019). In some of these areas, feed is a larger market for biochar than the soil amendment market. Significant interest and attention within the US biochar industry is focused on expanding biochar to the list of federally approved feed additives. In Europe, the certification criteria for feed biochar is more stringent than for soil use biochar. Currently biochar used as a feed additive in Europe is limited to biochar made using woody material only (EBC 2012).

Both academic and anecdotal studies are increasingly demonstrating the benefits that can be derived from adding small amounts of biochar to animal feed. Schmidt et al. (2019) summarized research on the use of biochar as a feed additive and found it offers the following benefits: improved animal health, increased feed efficiency and healthier atmosphere for animals, reduced nutrient losses and greenhouse gas emissions, and once the manure is applied to soils, increased soil organic matter content and soil fertility. While some studies suggest that using biochar as a feed additive may reduce enteric methane emissions from ruminants (Lang et al. 2015, Winders et al. 2019), others suggest negligible or no reduction of methane emissions (Teoh et al. 2019, Terry et al. 2019). Ultimately, this is an area of research that needs more standardized methods and further investigation (Kammann et al. 2017). Activated carbon, which is similar to biochar but undergoes more extensive processing and is often more expensive, acts as a binder when fed to livestock and has been shown to reduce certain mycotoxins that may be found in animal feed that contaminate milk and meat. Up to 93% removal efficiencies of aflatoxin in milk have been observed when high surface area activated carbons are added to dairy feed. In the same study bentonite, a commonly used binder, removed 80% of the aflatoxins (Di Natale et al. 2009).

Doug Pow, a cattle and avocado farmer in Western Australia, has been feeding his cows biochar mixed with molasses for the past seven years (IBI 2018). He has collaborated extensively with academic researchers who have studied and reported on his methods and outcomes. Originally, his goal was to add long lasting organic matter to his pastures by employing his cows as a low-cost delivery system in collaboration with dung beetles that would carry the biochar enriched dung further down into the soil profile. His pastures have become much more fertile while eliminating the need to purchase fertilizer or additional hay for feed. At the same time his cattle have become healthier even as he reduced or eliminated the use of insect sprays and drenches (Joseph et al. 2015).

Feed Storage

Storing large quantities of silage can generate leachate that contains biological oxygen demand (BOD) in the range of 12,000 – 90,000 mgL_{-1} (Sandford et al. 2020). As a point of comparison, the BOD from various wastewater treatment plants in the United States ranged from 101 – 437 mgL^{-1} (Sieple et al. 2017). Without proper controls nitrogen (N), phosphorus (P), and potassium (K) from silage runoff can contaminate groundwater or nearby water bodies. While the leachate can be added to manure storage facilities, this can produce dangerous hydrogen sulfide (H_2S), and must therefore be managed carefully.

One approach which is sometimes used to manage seepage is vegetated filter strips. Adding 2.5% (wt/wt) corncob biochar to a depth of 15 cm in vegetated filter strips surrounding horizontal bunker silos has been shown to reduce cumulative total nitrogen (TN) influent by 64% whereas the control reduced TN by 49%. While vegetative strips can reduce cumulative nitrate (NO_3^-) leaching, the addition of biochar reduced it by an additional 40% (Sandford et al. 2020). Once the biochar in the filter strips becomes saturated with these nutrients, it could be removed and applied to soils as a source of nutrients reducing the need to purchase additional fertilizers.

Bedding Additive

Few rigorous scientific studies have been published comparing the use of biochar in dairy or other livestock bedding to current bedding options and inputs (e.g. sand, sawdust, lime, gypsum, etc.). However, an increasing number of on-farm experimentation has shown that using biochar as a component of bedding could lead to numerous benefits including reduced odors, dryer stalls and improved hoof health.

An inoculated deep litter system (IDLS) developed as part of the Korean Natural Farming program includes a 6” layer of biochar at the bottom of the system, covered with deep layers of logs and green waste. Adding micro-organisms to this type of bedding results in lower odor, fewer flies and can significantly reduce labor related to cleaning as the systems can last for 10 years or more, according to Mike DuPonte, an Animal Specialist with CTHAR Cooperative Extension in Hawaii (DuPonte et al. 2012).

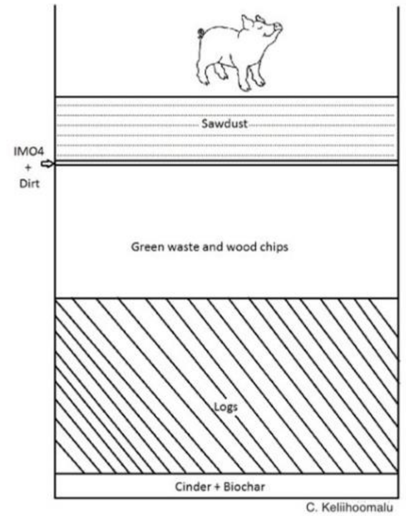


Diagram showing layers in IDLS pen.

MANURE MANAGEMENT

Dairy cows produce prodigious amounts of manure; daily manure production ranges between 52 to 67 kg per animal per day. Manure management for even small-scale dairies can thus be challenging, especially if there is insufficient land for spreading manure, or if regulations and weather prohibit spreading during certain months of the year.

Manure management strategies vary. Some of the most common include composting, slurries or lagoons, and anaerobic digestion for larger dairies. Biochar can be added to composting, slurries or lagoons, or manure can be converted directly into biochar via thermo-chemical conversion. Each of these are manure management strategies are discussed below.

Land Application of Manure

Dairy farmers have commonly applied manure or slurry to their land as a way to recycle the nutrients. However, this can lead to excess nutrient leaching, particularly of P, into nearby waterbodies resulting in eutrophication or harmful algal blooms (HABs) (Carpenter et al. 1998).

Emissions from land application of manure can also be significant (FAO 2010). Brennan et al. (2015) compared the impact of different types of slurry on emissions when being applied to land. The addition of biochar made from wood shavings pyrolyzed at 650°C for 4.5 hours significantly reduced nitrous oxide (N_2O), ammonia (NH_3), cumulative carbon dioxide (CO_2) (by 63%, 72%, and 84% respectively) and thereby reduced overall Global Warming Potential (Forster et al. 2007) of land application of dairy cattle manure.

When comparing direct land application of cattle manure to gasification of manure followed by land application, emissions varied from a positive emissions rate of 119 kg to negative emissions of -643 per ton of dry manure (Wu et al. 2013). This calculation assumes energy from the gasification process will be used to displace fossil fuel energy.

Composting

Composting dairy manure is a common manure management strategy though it has certain limitations in terms of pathogen removal and environmental issues, such as greenhouse gas (GHG) emissions and odors. The use of biochar in manure composting offers several potential advantages. Co-composting of up to 10% biochar by dry weight with manure or other organic material can provide several benefits including increased nutrient retention, reduced emissions of NH_3, N_2O and methane (CH_4), reduced bioavailability of heavy metals (e.g. copper (Cu), cadmium (Cd), and zinc (Zn)), improved water management and aeration and odor reduction (Sanchez et al. 2018). In addition, biochar provides a habitat for various microorganisms which enhance the composting process.

Biochar has been found to accelerate and improve the composting process when added at the beginning—for example by increasing temperature which stimulates microbial activity. This increased activity and higher temperatures can also reduce certain pathogens. Biochar addition has been shown in both research and commercial operations to reduce labor for turning piles and improve habitat for microorganisms, enhance moisture, aeration and nutrient availability thereby boosting microbial growth (Sanchez et al. 2018). This may have important economic implications since accelerated composting is a desirable effect, especially with organic materials that require long composting times and take up space.

Biochar addition to compost has been found to reduce emissions of N_2O, which result from the animal manure composting process (Akdeniz 2019), by 26% (Wang et al. 2013). Adding biochar to compost has also proven useful in reducing CH_4 emissions (Pandey et al. 2014, Chen et al. 2017). For instance, researchers at the University of Merced in California are investigating the impact biochar has on CH_4 from dairy manure and compost. They have hypothesized that it could reduce state-wide CH_4 emissions related to manure by 2.75 Mt CO_2e per year (Feedstuff.com 2019).

Biochar additions during the composting process can also reduce NH_3 gas losses by between 50 – 64% (Steiner et al. 2010; Malinska et al. 2014; Agyarko-Mintah et al. 2017*)* which can cause nuisance odors and is a major source of N loss (Eghball et al. 1997; Bernal et al. 2009). The ammonia gas retention can be enhanced with greater oxidation of the biochar (Hestrin et al. 2019).

Slurry/Lagoon

NH_3 emissions from manure slurries can cause various environmental problems, including poor air quality. After heavy precipitation events slurries may get overloaded and leak N, leading to eutrophication and algae blooms. Biochar used as a floating manure cover on slurries or lagoons can significantly reduce NH_3 emissions. Holly et al. (2017) found that woody biochar produced from low temperature pyrolysis (400°C) was able to reduce NH_3 emissions by 96% as compared to an uncovered slurry. Layering biochar on top of the slurry creates a barrier that reduces volatilization and related odors.

Daugherty et al. (2017) found that biochar made from bark and center wood pyrolyzed at 600°C could reduce NH_3 concentrations in head space between 72 – 80%, yet biochar made by gasifying Douglas Fir at 600°C did not significantly impact ammonia concentrations and associated odors, biochar covers can sorb nutrients such as N and P. Information on CH_4 emissions from lagoons to which biochar was added, are currently lacing and require further research.

Anaerobic Digestion

Larger dairy farms may use an anaerobic digester (AD) which is an oxygen-free environment that converts the organic material into CH_4, CO_2, and H_2S. While there are many benefits to AD systems, they can be expensive to install and maintain. The process provides renewable energy but does not significantly reduce the volume of material and farmers must still have storage facilities or markets for the fiber (digestate) and/or sufficient land to spread the nutrient-rich effluent.

Co-locating pyrolysis with AD may be able to offer a synergistic manure management system. Adding 10 g L^{-1} of biochar made from dairy manure pyrolyzed at 350°C was found to increase methane production by 25% while decreasing the lag phase from 2 days to 1.5 days (Jang et al. 2020).

Additional benefits of using biochar in an AD include a substantial reduction of H_2S production that could lead to improved biogas quality and reduced wear and tear on equipment. Wang (2018) observed a 78% reduction of H_2S using poplar woodchip biochar while Choudhury & Lansing (2019) found that iron (Fe) impregnated biochar had a 99% removal efficiency for H_2S.

Thermo-Chemical Conversion

Thermo-chemical conversion (TCC) are high-heat, low- or no-oxygen processes that convert organic matter into gases, liquids and solids, including biochar, a material that decomposes much more slowly than the original biomass. There are various technologies capable of carbonizing organic material, but the most common are pyrolysis and gasification (hydrothermal carbonization produces hydrochar and is not considered in this white paper). TCC has a number of advantages over other manure management processes including volume reduction, faster processing, heavy metal immobilization, and the ability to reduce certain toxins and odors in the material that is converted.

Larger livestock operations may increasingly be required to provide manure storage capable of safely containing significant amounts of manure during certain times of the year when regulations do not permit manure application to soil. Even large manure storage can be threatened by large amounts of rainfall causing spillage. Volume reduction between 75% to 95% of the separated solids of the manure can be achieved using thermo-chemical conversion, depending on the temperature used for pyrolysis.

While other manure management processes such as composting or AD may take several weeks to process per batch, TCC converts manure into more persistent carbon in seconds to hours depending on the technology and desired co-products (typically about 15-30 minutes for slow pyrolysis). A continuous TCC process can reduce the need for expensive manure management infrastructure.

Current manure management strategies may be hotspots for certain contaminants such as antibiotics. Pyrolysis (>400°C) is capable of eliminating antibiotics and immobilizing heavy metals such as zinc, copper, chromium, nickel, lead and cadmium that are sometimes found in manure, can accumulate in soil, and negatively impact soil fertility and food safety (Tien et al. 2019; Li et al. 2019). Carbonizing manure also reduces the risk of spillage and overflow of storage systems during storms, if the need for storage is reduced.

Processing manure through TCC may also help reduce or eliminate certain pathogens, particularly those that are susceptible to high heat such as *E. coli* and salmonella.

Under certain conditions and with certain types of organic materials and thermochemical conversion technologies, pollutants such as polycyclic aromatic hydrocarbons (PAHs) or dioxins may be produced (Hale et al. 2012). However, the amount of these toxins is typically below regulated levels and in a majority of biochars tested, these contaminants were tightly bound and only marginal bioavailability (Hilber et al. 2017). Biochar may actually be able to reduce the availability of PAHs found in other materials such as sewage sludge (Stefaniuk et al. 2018).

DAIRY WASTEWATER

The amount of water consumed within the dairy industry is estimated to be 2.5 times the volume of milk produced and is considered one of the largest generators of industrial food wastewater in the world (Kolev Slavov 2017). Farm dairy effluent results from cleaning, disinfection of equipment, cooling and heating and contains water, urine, dung, feed, cleaning chemicals and milk. While the dry matter content is generally very low, dairy effluent contains nutrients such as N, P, K, and other elements. Though these nutrients can be beneficial in soils, but they can also lead to groundwater pollution which has motivated many local and state authorities to restrict the timing and amount of land spreading of dairy effluent. Ghezzehei et al. (2014) found that low temperature hardwood biochar added to the wastewater can retain 20% to 43% of ammonium (NH_4^+) and 19 - 65% phosphate (PO_4^{3-}) (2.86 mg and 0.23 mg per gram of biochar, respectively) over a 24-hour period. Biochar made from digestate was found to sorb up to 32% of P from anaerobically digested dairy effluent which was predominantly plant available and filtered through the biochar (Streubel 2011). Other research has demonstrated that biochar used in a filtration system can significantly reduce total suspended solids and the chemical oxygen demand by 85% and 83%, respectively (Samkutty & Gough 2002). Information about biochar used as a cover for dairy waste water is not available.

ENERGY PRODUCTION

TCC technologies capable of creating biochar include pyrolysis and gasification. Pyrolysis thermally decomposes biomass without the presence of oxygen to create biochar at temperatures starting at 300°C. Gasification uses limited oxygen and higher temperatures (500°C to 1,500°C) (Brown et al. 2015). A co-product of biochar production is energy in the form of process heat, liquid fuel, or combustible gases that can be used to supply heat or electricity. Depending on the technology used, additional co-products of TCC may include syngas and bio-oil in addition to biochar and heat. Often when high moisture content materials, such as manure or sewage are used for biochar production, this heat is used to dry organic materials prior to carbonization.

BIOCHAR FROM DAIRY RESIDUES

Table 1 highlights a number of papers that analyzed various characteristics of manure-derived biochar.

A recent study in 2018 as part of a project funded by the Innovation Center for US Dairy (Enders et al. 2019) analyzed pyrolyzed dairy manure in New York State. They found the pH of the biochar produced from dairy manure to be 10.4. More importantly, it had a calcium carbonate equivalence of 3.3%. In other words, 100 pounds of the manure biochar could neutralize acid as well as 3.3 pounds of lime. The organic carbon content of the biochar derived from dairy manure was 43%, and the quality of the carbon in the biochar is such that roughly half is expected to persist over 100 years, compared to practically 0% in the original manure.

The Fertilizer Class of the dairy manure biochar, according to the IBI classification system, was 3 on a scale of 0-4. This is defined as providing adequate nutrition for corn at <4.5 tons/acre for 3 out of 4 nutrients (Figure 1).

As for nutrients, Enders et al. (2019) found that the dairy manure biochar contained 4.1% phosphorus, 2.2% potassium, and 4.4% magnesium (Table 1). They found that nutrient concentration in the biochar could be as much 2.6 times greater than in the original manure feedstock and that sulfur in the biochar was 50% less than in the feedstock (Table 2). In addition to increasing total nutrient contents, pyrolysis improved nutrient availability. For instance, the biochar provided 13% more plant-available phosphorus (per unit total P) than the manure feedstock. Interestingly, increased available phosphorus was coupled with a 10-fold decrease in leachable phosphorus (i.e. the plant available phosphorus was not water soluble). The biochar also demonstrated 59% more available potassium than the manure.

Table 1. Characteristics of biochar from pyrolyzed Dairy Manure, Digested Dairy Manure, Composted Dairy Manure, Raw Dairy Manure, or Cow Manure (unspecified if it was dairy) from several sources.

Feedstock	**Temperature (℃)**	**Total Ash Content (%)**	**Total C (%)**	**Total N (%)**	**H (%)**	**H:C ratio (mol:mol)**	**pH**	**Zinc (mg/kg)**	**Sodium (mg/kg)**	**Total P (mg/kg)**	**Calcium (mg/kg)**	**Magnesium (mg/kg)**	**Potassium (mg/kg)**	**Iron (mg/kg)**	***Source***
Dairy Manure	0	14.80	46.52	2.29	5.49	1.41	8.30	220	2510	5610	16000	6940	6700	2290	*Cantrell et al. 2012*
Dairy Manure	300	10.10	61.50	1.60	4.50	0.87	-	90	3270	1152	11094	3934	8986	208	*Enders et al. 2012*
Dairy Manure	350	10.20	64.10	1.80	4.10	0.76	-	98	3698	1810	10859	4278	10074	317	*Enders et al. 2012*
Dairy Manure	350	-	42.85	2.36	-	-	9.72	150	1040	5730	33700	6510	5030	8290	*Liu et al.2014*
Dairy Manure	350	24.20	55.80	2.60	4.29	0.92	9.20	361	5620	10000	26700	1220	14300	3640	*Cantrell et al. 2013*
Dairy Manure	400	11.50	67.10	1.40	3.30	0.59	-	87	3569	1466	12808	4258	10345	305	*Enders et al. 2012*
Dairy Manure	450	11.70	70.10	1.50	3.10	0.53	-	121	4009	2001	13473	5068	11756	349	*Enders et al. 2012*
Dairy Manure	500	12.40	72.50	1.40	2.60	0.43	-	80	2223	1754	12569	4610	9630	396	*Enders et al. 2012*
Dairy Manure	500	-	73.87	1.38	2.42	0.39	10.18	-	-	-	-	-	-	-	*Ouyang et al. 2013*
Dairy Manure	500	-	44.67	1.98	-	-	10.20	170	1170	6460	38000	7340	5670	9340	*Liu et al.2014*
Dairy Manure	550	13.40	72.30	1.50	2.30	0.38	-	142	4424	2358	25702	6357	13388	754	*Enders et al. 2012*
Dairy Manure	600	12.60	75.20	1.30	2.00	0.32	-	114	4538	2433	13997	5366	13236	398	*Enders et al. 2012*
Dairy Manure	700	39.50	56.67	1.51	0.94	0.20	9.90	423	8790	16900	44800	2060	23100	6480	*Cantrell et al. 2014*
Digested Dairy Manure	300	39.20	56.10	2.70	-	-	9.00	129	3808	5391	20185	8757	14954	1710	*Enders et al. 2012*
Digested Dairy Manure	350	12.70	57.70	2.40	-	-	9.20	-	-	-	-	-	-	-	*Enders et al. 2012*
Digested Dairy Manure	400	14.50	63.80	2.40	-	-	9.30	131	4405	6446	22552	9733	16604	1656	*Enders et al. 2012*
Digested Dairy Manure	450	17.80	60.40	2.50	-	-	10.20	-	-	-	-	-	-	-	*Enders et al. 2012*
Digested Dairy Manure	500	14.70	59.40	2.60	-	-	9.70	224	3861	5649	18505	8498	14937	2371	*Enders et al. 2012*
Digested Dairy Manure	550	17.30	60.90	2.20	-	-	10.00	-	-	-	-	-	-	-	*Enders et al. 2012*
Digested Dairy Manure	600	18.80	62.80	2.20	-	-	10.00	200	5051	8269	26518	11744	20852	2356	*Enders et al. 2012*
Composted Dairy Manure	500	50.10	37.80	2.00	-	-	10.30	172	1219	6011	38388	12534	12824	9119	*Enders et al. 2012*
Raw Dairy Manure	500	32.00	51.20	2.10	-	-	10.70								*Enders et al. 2012*
Cow Manure	450	-	29.50	1.39	0.95	0.38	-	-	-	-	-	-	-	-	*Sun et al. 2013*
Cow Manure	600	-	30.70	1.11	0.46	0.18	-	-	-	-	-	-	-	-	*Sun et al. 2013*
Cow Manure	500	67.50	43.70	-	-	-	10.20	52	-	646	3795	1569	1021	616	*Zhao et al. 2013*
Cow Manure	500	-	43.70	1.99	3.20	0.87	-	-	-	-	-	-	-	-	*Zhao et al. 2014*

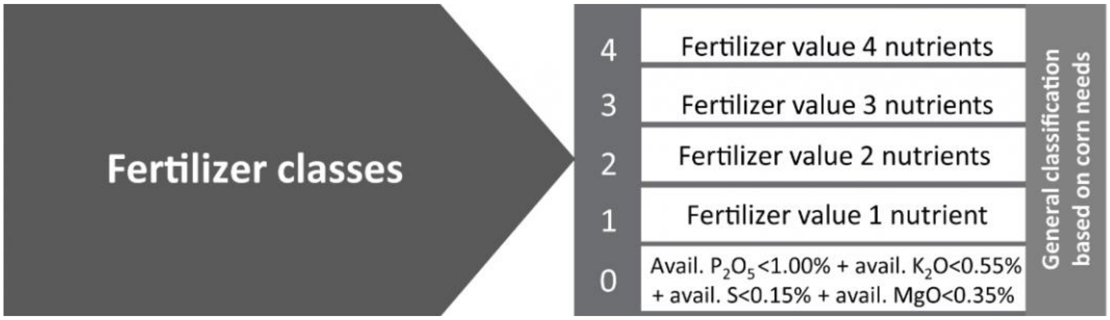
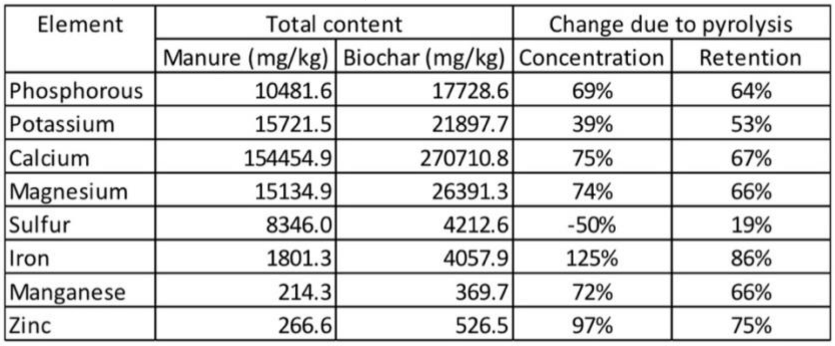


Figure 1. Fertilizer class based on the ability of P, K, S and Mg in a biochar to satisfy the expected yield and nutrient removal demands of corn. Courtesy of International Biochar Initiative https://biochar-international.org/biochar-classification-tool/

Table 2. Total nutrient contents and retention (i.e., the amount retained in the biochar as compared to the total amount in the original manure; full recovery would be 100%) of nutrients in uncharred manure and biochar made from the same manure (from Enders et al. 2019).



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%

Enders et al. (2019) also did a stringent IBI toxicant assessment and found the dairy manure biochar did not contain toxic levels of any investigated compounds and contained 30 times less than the threshold value for any single analyte. A germination trial also assessed possible biochar toxicity. Of the three species used (lettuce, ryegrass, and radish) germination in dairy manure biochar amended media was not different from the control.

Using high temperature pyrolysis (900°C), it is possible to design dairy manure biochar with high surface area (360 m^2 g^{-1}) and high cation exchange capacity (57.5 ± 16.1 cmol kg^{-1}) (Tsi et al. 2019) (Figure 2). This type of biochar may be a cost-effective way to remove pollutants. As with activated carbons, dairy manure biochar could be regenerated and reused for extracting heavy metals such as lead (Pb), Zn, and Cd (Wallace et al. 2019).

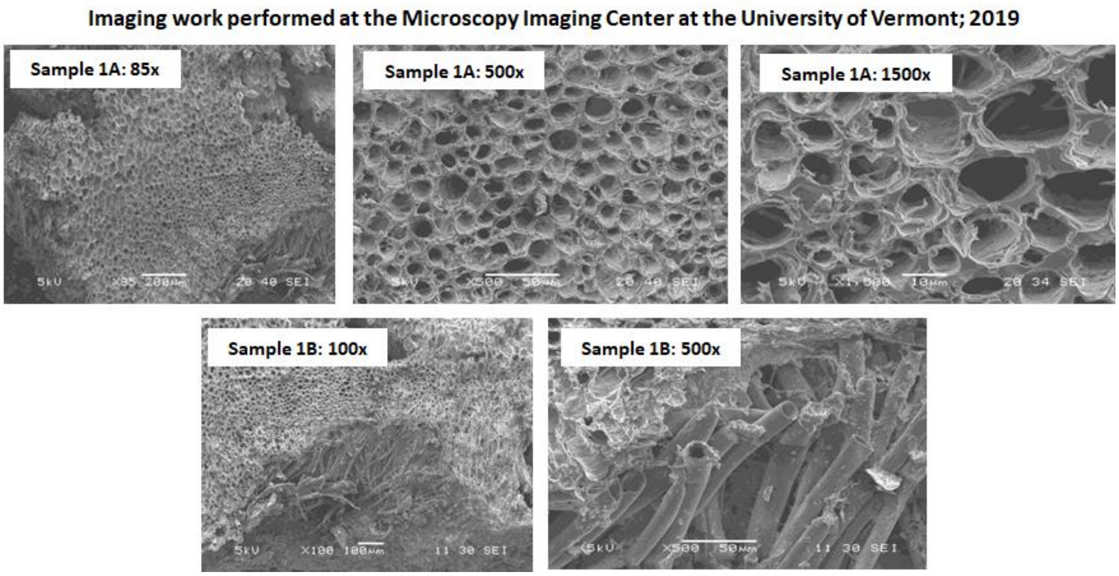

Imaging work performed at the Microscopy Imaging Center at the University of Vermont; 2019

Figure 2. Dairy manure biochar samples at different magnification levels highlighting different pore sizes and surface areas.

ROLE OF BIOCHAR IN DAIRY OPERATIONS FOR ADAPTATION TO AND MITIGATION OF CLIMATE CHANGE

In many farming scenarios the production and use of biochar can help farmers to both adapt to the impacts of climate change and reduce their emissions that contribute to climate change. Both adaptation and mitigation are considered below.

Adaptation

While climate change impacts vary significantly by region, many areas are experiencing increasing drought while others must cope with heavier rainfall and higher temperatures. For the dairy industry, higher temperatures can lead to heat stress that reduces feed intake and milk production. Pasture production and crop yields are increasingly variable and the need for improved water efficiency is becoming critical in dryer regions. Adding certain types of biochar, either on their own or, preferably in combination with manure, to pastures and crop land can improve the water retention in soils boosting resilience against drought (Rasa et al. 2018, Sanchez-Garcia et al. 2019; Razzaghi et al. 2020). Similarly, infiltration after rainfall events can be increased through biochar additions depending on biochar and soil properties (Wang et al. 2016b; Wang et al. 2017). It should be noted that the specific impact on plant available water holding capacity is highly impacted by both type of biochar and type of soils (Amonette et al. 2019). Wood shavings biochar has also been shown to improve the infiltration rate during simulated heavy rain events while also reducing soil erosion in arid or semi-arid climates (Abrol et al. 2016).

Mitigation

Dairy farmers are not only impacted by climate change, but they contribute to it through GHG emissions and have the opportunity to contribute to atmospheric carbon dioxide reductions through soil carbon sequestration. The sources and amount of emissions vary widely depending on various farmer practices. For instance, according to a study comparing eight organic dairies with eight conventional dairies in Germany, an organic dairy farm emits on average 995 g per kg of Energy Corrected Milk (ECM) while a conventional farm emits 1,048 g per ECM (Frank et al. 2019). The largest proportion of emission sources stem from enteric methane while the largest difference in emissions amongst dairy and conventional farms is related to carbon sequestration in soil. Organic farms achieved a net sequestration rate of (-57 g CO_2-eq (kg ECM)$^{-1}$) while conventional dairies produced 82 g CO_2-eq (kg ECM)$^{-1}$). Frank et al. (2019) concluded that GHG reduction plans require farm specific strategies based on current emission sources.

As discussed previously in this White Paper, the production and use of biochar could help to reduce GHG emissions and sequester carbon in a variety of ways, typically 0.5-1.5 t CO_2-e t^{-1} dry manure for slow pyrolysis (Cowie et al. 2015). A significant amount of emissions comes directly from cows in the form of enteric emissions (i.e. belching). Understanding how to reduce these emissions by changing diets or incorporating effective feed additives is critical. In addition to the benefits described previously in the Feed Additive section, preliminary research has shown that certain types of feed biochar can reduce enteric methane emissions in cattle by up to 18% as measured by dry matter intake (Winders et al. 2019). This may vary depending on the type of biochar, the feeding regimen and possibly the breed of dairy cow.

Biochar added to soils either directly or indirectly after having passed through the rumen, adds carbon to the soil that will persist for longer periods of time than manure alone (decades to millennia). In addition to direct carbon sequestration, biochar may indirectly improve carbon storage in soils through negative priming. This additional indirect sequestration could contribute nearly as much carbon as is contained in the biochar itself (Blanco-Canqui et al. 2019), but varies strongly with soil and biochar type, with reductions across studies lying around 4% (Wang et al. 2016a).

ECONOMICS OF BIOCHAR USE IN DAIRY FARMING

The financial impact of biochar use on dairies is heavily dependent on how and why it is used. As an example, a recent study in South Australia funded by the Dairy Industry Fund and carried out by the Climate and Agricultural Support Group found that a dairy with 250 cows netted AUS$71,000 in additional profits from increased milk production and reduced feed costs after the cost of biochar was deducted. If credits for carbon sequestration were added for the excreted carbon in the biochar or for reductions in GHG emissions from the soil, additional revenues would accrue.

Few scientific studies have been done to assess the cost impact of converting manure into biochar as compared to other manure management strategies. As pyrolysis can be done on a continuous basis and the reductions in volume are significant, smaller manure storage facilities would be required. Manure storage facilities can be very costly and can emit GHG emissions that may not currently be controlled by regulation but might be in the foreseeable future. Thus, carbonizing manure could save dairy farmers from needing to invest in larger facilities as well as avoiding carbon penalties.

Farmers may want to utilize the biochar on-farm for different uses, which have been described previously. Alternatively, some farmers, particularly larger dairies, may have excess biochar that could be sold.

According to Enders et al. (2019) the nutrient value of the biochar as a substitute for other organic fertilizers could equate to $240-340/ton. Analyses suggest that over half of the carbon in the resulting biochar will persist over the long term, to benefit soil fertility and carbon sequestration for over a century after application. Dairy manure biochar is an odor- and pathogen-free, nutrient-rich soil conditioner with approximately twice the nutrient content of the original manure by mass, and more than three times that by volume. A study by Krounbi et al. (2019) suggests there may be a significant market value for biochar produced from high moisture content waste products compared to compost. Additional economic values should be seen on farms with the use of biochar as an additive to bedding, manure pits, soil, and more. There is also an economic benefit in the reduction of storage, transportation and spreading costs.

DAIRY AND BIOCHAR DEMONSTRATION PROJECTS

Australia: Fleurieu Peninsula

Main Focus: Feed additive

Dairy farmers in the Fleurieu Peninsula in South Australia have found feeding biochar to their dairy cows not only improves milk production, but also improves feed conversion reducing the amount of feed farmers need to purchase or grow. Feeding wood-based biochar at a rate of 150 grams per day, increased daily milk production by 1.4 liters per head (McCallum 2020).

Canada: Poelman-Murray Ltd, Ontario

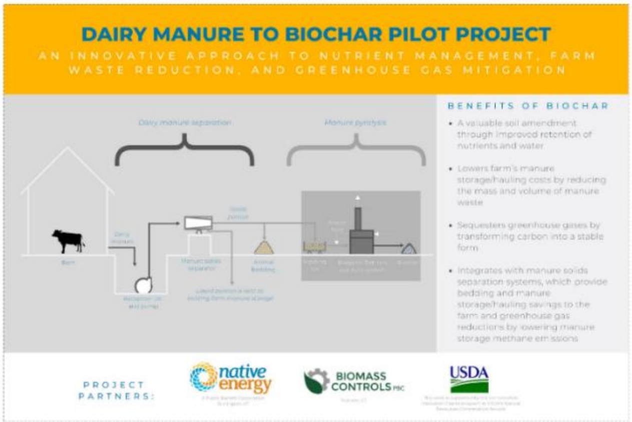
Main Focus: Feed additive

Holstein dairy farmer Thomas Murray began adding activated carbon to his 58-head herd in 2017 in an effort to reduce the impact from suspected silage contamination (Haines 2018). Affected animals were fed biochar which not only improved their health, it also helped boost production levels and a small increase in fat levels.

USA: Fairvue Farm, Connecticut

Main Focus: Pyrolysis of Dairy manure

The first of up to ten demonstrations of on-farm pyrolysis of dairy manure is located in Woodstock, CT at Fairvue Farms, a farm with 1,500 milking Holsteins that produce roughly 10 gallons of milk per cow per day. This collection of demonstrations is partially funded by USDA NRCS and uses Biomass Control's Biogenic Refinery (BR) to convert dairy manure into biochar. Native Energy, a carbon offset provider and project developer is identifying appropriate small farms for the project.



DAIRY MANURE TO BIOCHAR PILOT PROJECT

AN INNOVATIVE APPROACH TO NUTRIENT MANAGEMENT, FARM WASTE REDUCTION, AND GREENHOUSE GAS MITIGATION

BENEFITS OF BIOCHAR

- A valuable soil amendment through improved retention of nutrients and water
- Lowers farm's manure storage/hauling costs by reducing the mass and volume of manure waste
- Sequesters greenhouse gases by transforming carbon into a stable form
- Integrates with manure solids separation systems, which provide bedding and manure storage/hauling savings to the farm and greenhouse gas reductions by lowering manure storage methane emissions

PROJECT PARTNERS:

Much of the manure generated at Fairvue is land applied; however, there is an excess amount available. The current BR is able to process the manure from approximately 200 cows. Manure is collected from a storage pit below the milking barns and sent to either a separator shed or manure storage shed. A screw press reduces moisture from 90% to between 60 - 65%. Much of this dewatered manure is

Biomass Control unit in tractor trailer with feedstock augered in from bin outside of trailer.

used for bedding though there can, at times, be too much material for the farm’s needs. When running full time, the BR can produce roughly 1 m_3 of biochar per day from 5 m_3 of dewatered manure.

USA: Shelburne Farms, Vermont

Main Focus: Odor control from manure slurry

In an effort to reduce odors emanating from manure storage facilities at Shelburne Farms, a non-profit dairy farm in Vermont focused on sustainable farming education, a truckload of biochar was applied to a 1,325 cubic meter manure slurry. A noticeable reduction in odor was observed once the biochar developed a cake on top of the slurry. While no peer-reviewed studies were produced from this work, farm management was pleased with a new option for odor management (Gribkoff 2019).

USA: Ontario Agricultural Commodities, California

Main Focus: Co-composting with dairy manure

Ontario Agricultural Commodities, a commercial-scale composter, teamed up with the Local Carbon Network in 2019 to pilot co-composting of dairy manure and biochar. The biochar was produced using the All Power Labs gasifier and is certified both by IBI and is listed by the Organic Materials Review Institute (OMRI) (All Power Labs 2019). Using a blend of 10% biochar and 90% dairy manure the piles not only reached consistently higher temperatures but were finished eight days sooner than the control pile with no biochar, representing a 30% reduction in finishing time. Hotter temperatures can help eliminate pathogens that may reside in the dairy manure.

DISCUSSION AND FUTURE RESEARCH

A growing number of dairy farmers have demonstrated interest in using thermo-chemical conversion of manure and the resulting biochar in different ways in their dairy operations. Often their interest stems from the need to find more cost-effective and environmentally benign manure management practices. Even though these pioneers are showing various ways to produce and use biochar on dairies, significantly more work is needed to demonstrate how and why the dairy industry should adopt these practices.

Quantification of GHG reductions using biochar on Dairy Farms

Pyrolysis has been recognized by the Intergovernmental Panel on Climate Change (IPCC) as one of only a handful of negative emission technologies (NETs). In addition, biochar used in soils has recently been added to the IPCC’s list of mechanisms for countries to reach their Nationally Determined Contributions (NDC), or reduction commitments.

While the U.S. recently pulled out of the Paris Agreement and thus is not committing to reduction targets at the federal level, a growing number of States are committing to ambitious net-zero carbon targets. As an example, New York State has committed to reduce emissions by 40% by 2030 and become net zero by 2050. California's ambitions for net zero are targeted to occur even earlier (in 2045). Both States have large dairy industries and these targets can therefore not be met, unless dairy emissions are significantly reduced if not fully eliminated.

Calculating the GHG impact of using TCC and biochar in combination with current manure best-management practices and as a feed additive are critical for all U.S. states, as well as other countries, to assess the most cost-effective methods to achieving their goals. Benchmarking the emissions related to current practices against those that incorporate biochar through Life Cycle Assessments (LCAs), should be a top research priority.

Once LCAs are published, protocols can be developed for carbon markets that may help farmers finance a transition from current practices to lower emitting ones. States such as New York will start to de-emphasize carbon credits for renewable energy as 100% renewable is already part of the strategy for getting to net zero. This may also be the case with other emission reduction strategies. Carbon removal strategies may become much more valued in the near future. For this reason, understanding the carbon sequestration potential for manure biochar is also critical.

Optimizing TCC & Biochar in Manure Management

While the use of biochar in various manure management strategies has been researched and trialed at small scales, insufficient work has been done on the use of dairy manure biochar specifically for use in dairy manure composting, lagoon covers, or anaerobic digesters to understand how best to optimize these synergies on-farm. Understanding the optimal size pyrolysis unit on dairy farms that already have ADs but generate excess digestate and perhaps could benefit from increased CH_4 production, isneeded. Case studies that assess the capital and operating costs of co-locating different manure management processes with pyrolysis will enable farmers and other potential funders (e.g. carbon market brokers) to understand which combinations work on different sized dairies located in different parts of the U.S..

In addition, an assessment of different technologies available to carbonize manure would be helpful. This would include a review of the costs, capacities and co-products of different gasification and pyrolysis technologies that can handle manure as well as a closer look at the potential revenue streams and/or cost savings that farmers may achieve. Understanding any ancillary equipment (e.g. pre or post processing of feedstock and/or biochar) required as well as labor hours and skill sets is also necessary.

Research on the impact of feed biochar on milk production

While the benefits to animal health and to the environment from the addition of biochar to livestock feed is increasingly studied, few if any published papers exist on the long-term impact of feed biochar on milk production (the authors are aware of one on-going study in Australia on this topic as well as anecdotal discussions on dairies in the U.S. that implemented this approach with positive results but no published papers were found). It is critical to understand the impact on both volume and quality of milk production when dairy cattle routinely ingest biochar as a feed additive.

Until, or unless, extension agents, nutritionists, veterinarians and others are convinced of both the safety and benefits of adding biochar to daily feed, it may be challenging to scale its use on U.S. dairies beyond those dairies that are already pioneering these and similar efforts.

Demonstrations of biochar production & use on Dairy farms

Even though there are a growing number of dairies that are using and even producing biochar from manure or other organic sources, their numbers are still very small, and few people have access to these farms to learn from their experiences. Setting up on-farm pilot projects in different geographic locations, on farms of different sizes and manure management practices that others could visit would be helpful in demonstrating to other dairy farmers how the process works, what equipment and other assets are required and how the biochar can be used on-farm.

On-going coordination amongst dairy and biochar projects

In order for the lessons learned and best practices related to TCC and biochar use on dairies to be shared effectively within the industry, it is important to organize on-going coordination amongst dairy farmers that are piloting these practices. This would include outreach on a regular basis (e.g. semi-annual); scheduling virtual calls with other participating dairies; and documenting and sharing of issues, challenges, benefits, improvements and other feedback from dairies. In researching on-farm experiences for this white paper, most pioneering dairies venturing into the biochar space had little knowledge of other dairy farms involved with biochar. If there was some coordinating entity, new adopters of biochar-dairy approaches could potentially get up to speed quicker while avoiding challenges already overcome by others, thus further enabling scale.

CONCLUSIONS

As with most types of farming, the use of biochar and conversion of excess organics produced on farms is still at the earliest stages, though it is certainly beginning to garner more and more attention due to the multiple benefits offered. It is probably not over-stating the situation to say that a majority of those involved in the dairy industry, both in the production and processing have yet to have even hear about biochar. Still others that have heard about it may be skeptical as to the net benefit to the industry.

To date little, if any, targeted educational materials have been created and deployed to educate the dairy industry on the benefits and uses of biochar. This White Paper, a discussion with dairy specialists from Cornell Cooperative Extension as well as a webinar hosted by the International Biochar Initiative on this topic will help, but significantly more resources are required to educate extension agents, farmers, national, regional and state dairy associations, policy makers and others about the economic and environmental benefits which can be derived from pyrolyzing manure into biochar and using the manure biochar both on- and off-farm.

Attending and presenting at various industry gatherings, and more generally farming trade shows, professional conferences, and other events would help raise awareness and identify opportunities and hurdles to adoption. Writing articles and highlighting farmers that are already involved with TCC and biochar for different dairy publications, newsletters and journals would also be needed to reach as wide an audience as possible. Not only should producers be educated about these benefits, but buyers of milk products should also be more aware, particularly those that are focused on reducing their emissions throughout the supply chain. This includes both large buyers (e.g. fast food chains or ice cream, yogurt and cheese manufacturers) and small buyers that may be concerned about the carbon footprint of milk products.

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