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Costs and Returns of Biochar Use in Dairies

1. Introduction

Biochar is a form of highly stable charcoal that is compatible with biological systems of all kinds. Biochar is porous and has a large surface area that retains water and nutrients, making them available to beneficial soil microbes and plant roots. Biochar is also used as an animal feed supplement that can remove toxins, promote digestive health and control pathogens. Biochar is especially beneficial when fed to cattle because it supports a healthy rumen ecology, improving feed conversion efficiency and overall health.

Biochar or charcoal has a long history of medical use in both people and animals, primarily as a poison control and to cure a variety of digestive upsets. 19th century and early 20th century agricultural journals have many discussions of the benefits of various "cow tonics" composed of charcoal and a variety of other ingredients that could be called spices, such as cayenne pepper, but also including digestive bitters like gentian. Manufacturers of these tonics claimed they would reduce digestive disorders, increase appetite and improve milk production. Farmers found that charcoal was a superior feed additive for increasing the butterfat content of milk. In milk butterfat competitions, the prize-winning cows were almost always fed charcoal.[1]

2. The Swiss Experience

The use of biochar in modern dairy operations is being pioneered today by dairy farmers and consultants in Switzerland and Germany[2]. Based on the traditional uses of charcoal, Swiss and German farmers were confidant enough in the benefits to trial biochar at large scale in their operations. Under the guidance of veterinarian Adam Gerlach, twenty one farm managers, each with an average herd of 150 cows, gave their impressions of the effects they had observed during and after adding biochar to feed rations (in about 1/3 of the farms biochar was supplemented with sauerkraut brine, a source of probiotic lactic acid bacteria).

Observations of initial effects, 1 – 4 weeks after starting biochar administration, were as follows:

- Generally improved health, appearance and vitality
- Improved udder health
- Decreased cell counts in the milk (interrupting the administration of biochar leads to higher cell counts and a drop in performance)
- Fewer hoof problems
- Stabilization of post-partum health
- Reduced diarrhea within 1-2 days, feces subsequently more solid
- Decline in the mortality rate
- Increase in milk protein and/or fat
- Combining biochar and sauerkraut brine has proved worthwhile
- Marked improvement of slurry viscosity, with less stirring needed and less scum on the surface, and slurry "not smelling as bad as it used to”

The Swiss and German researchers then conducted a controlled experiment[3] in a dairy that was experiencing a number of common health problems: reduced performance, movement disorder, fertility disorders, inflammation of the urinary bladder, viscous salivas, diarrhea. Animals were fed different combinations of charcoal, sauerkraut juice or humic acids over periods of 4 to 6 weeks. Experimenters found that oral application of charcoal (from 200 to 400 g/day), sauerkraut juice and humic acids influenced the antibody levels to C. botulinum, indicating reduced gastrointestinal neurotoxin burden. They found that when the feed supplements were ended, antibody levels increased, indicating that regular feeding of charcoal and other supplements had a tonic effect on cow health.

3. How Biochar Works

Biochar has many beneficial uses in the dairy. It is important to remember that biochar does not degrade easily and it will persist and provide additional benefits throughout the system. For instance, biochar added to feed will pass through the animal and have subsequent effects on manure and manure treatment. The application of biochar at one point in the system initiates a flow of benefits that cascade through the operation as a whole.

Biochar impacts the whole dairy system by supporting the beneficial micro-organisms that are essential to dairy functions, whether they are found in the rumen, manure treatment systems, soil or silage. Although the benefits of biochar in soil are well-documented, researchers are still learning about the details of biochar-microbial interactions in soil and other biological systems.

In the soil, biochar particles form micro-sites that accumulate resources like nutrients and water that microbes need. Similar sites have been described in charcoal added to aqueous environments like waste water treatment systems.[4] It is likely that biochar works in the rumen in the same way: by providing a habitat for colonies of diverse microorganisms that can feed efficiently by using each other's waste products.

When dairies have problems with pathogens and disease, the first response is often to bring in an anti-biotic, whether it is a pharmaceutical or a disinfectant. But more and more, dairy managers are using a different approach that relies on probiotics instead. It can be cheaper and less stressful for animals to increase populations of beneficial bacteria that can then outcompete the pathogens. Biochar is a valuable addition to this probiotic approach that will enhance its effectiveness and save money.

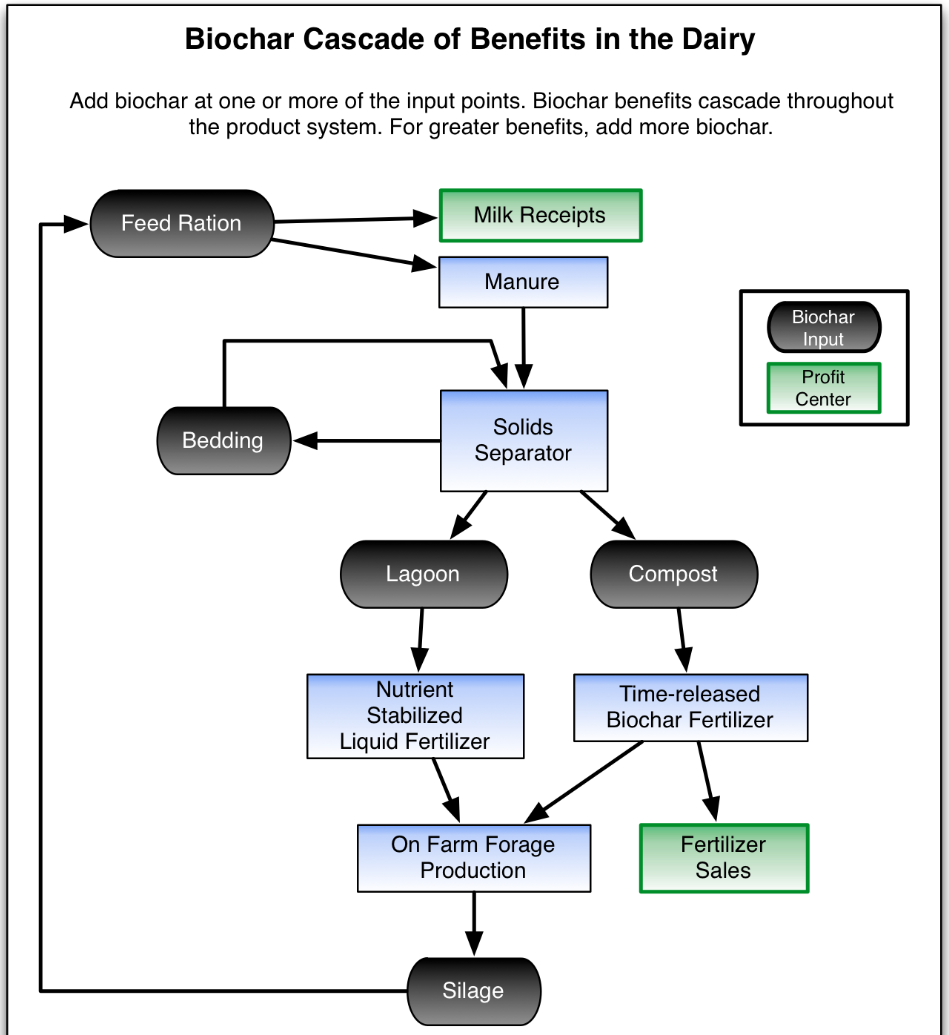
4. Dairy Margins Require Focus on Fundamentals

In the US, extreme market volatility in both milk and feed prices has pushed dairies to the edge of profitability. Dairymen are looking for ways to cut costs without cutting production. The California Department of Food and Agriculture (CDFA) looked at production cost trends and found that the cost per cow has increased, but since milk yield has also increased, the cost per cwt ("hundred weight," or 100 lbs) of milk has decreased. Improving feed efficiency is a top priority for cost reduction as feed costs continue to rise. In addition, CDFA recommends that producers "focus on fundamentals, such as cow comfort," while taking advantage of economies of scale.[5] Biochar can address fundamentals of dairy production, including feed efficiency, cow comfort and manure handling costs. This paper considers two main dairy profit centers that can benefit from biochar: milk production and manure nutrient capture as a biochar-manure fertilizer:

- Milk Production: Biochar added to feed and bedding is a low cost way to improve dairy margins. Biochar improves feed efficiency as well as cow health and comfort. In fact, biochar has the potential to dramatically improve herd health and longevity and reduce herd replacement costs.

- Biochar-Manure Fertilizer Production: In manure handling systems, biochar retains nutrients and reduces emissions and odors. Biochar enables better nutrient capture from manure and also adds to dairy profits by reducing cost of feed production and/or by sales of biochar-manure fertilizer.

Figure 1 is a flow diagram showing the points where biochar can be added and how benefits will cascade throughout the dairy.



5. Biochar Dairy Model - Milk Production Profit Center

Figure 2 illustrates how costs were distributed at the average dairy in California in 2012. Cost categories that can be improved by use of biochar are in the areas of Feed, Herd Replacement and Operating Costs. Biochar can also improve returns by improving milk quality. Specific milk production bottlenecks that are effectively addressed by biochar include:

- Feed efficiency
- Cow health, comfort and longevity
- Milk quality

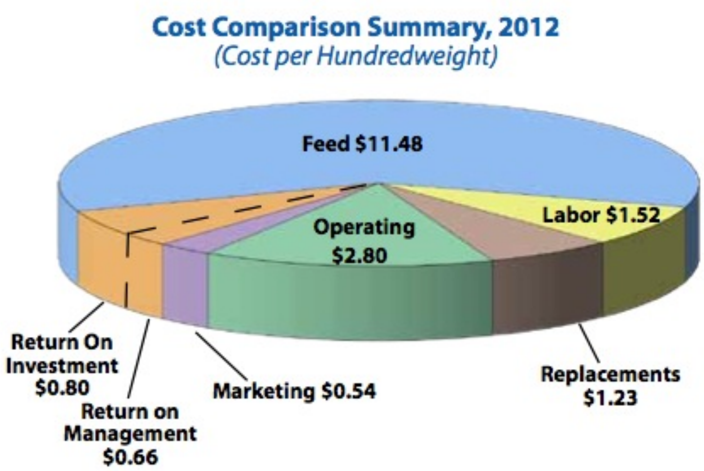


Figure 1. Dairy Cost Comparison Summary from *California Costs of Production 2012*, CDFA[6]

Table 1 gives parameters for a Biochar Dairy Model that will be used to quantify benefits. The Biochar Dairy Model is modular, with separate Benefit Cost Ratio calculations for four different dairy subsystems: feed, bedding, silage and processing of manure to a biochar fertilizer product.

Table 1. Biochar Model Dairy: 2500 head Holstein, freestall, dried solids bedding	
head	2,500
average animal weight per head, lbs	1,350
animal units per herd	3,375
milking percent	87%
dry percent	13%
milk produced per cow/day, lbs	75.54
annual milk/head, lbs	27,572
total annual milk, lbs	68,930,000
total annual milk, CWT	689,300
adjusted milk price/CWT	$16.00
total annual milk receipts	$11,028,800
herd replacement cost, $/CWT	$1.23
feed DM-milking cows, pounds	55.00
feed DM-dry cows, pounds	44.00
biochar price/ton	$1,000
Total biochar used in dairy, tons/yr	879

Before developing the biochar feed module, we reviewed the literature on biochar in animal feed and the use of biochar for disease suppression. This literature, along with basic dairy facts and statistics, forms the basis of the Biochar Dairy Model. The complete model is attached to this report as an Excel spreadsheet.

Literature Review: Feed Efficiency - Ionophores Compared to Biochar

Ionophores are commonly used to improve feed efficiency and can save as much as $.20/cow per day in feed costs, at a cost of $.02-$.04 per day.[7] Ionophores alter the microbial balance in the rumen, selecting for microbes that produce less H_2 in their metabolism and make more efficient use of food energy, while reducing methane emissions. Ionophores promote increased production of the fatty acid propionate that is associated with better lean muscle weight gain. Ionophores may interfere with production of butterfat in milk, so they are not as beneficial for dairy animals.[8] Their effectiveness is also limited over time as gut bacteria adapt to their presence. Ionophores have other problems that limit their use. They have a narrow dosage window for safe use, so they can only be used in veterinarian approved feed mixtures, and are not approved for use at all in Europe. Ionophores are toxic to humans and other livestock animals, such as horses. Ionophores are also toxic to young calves. When combined with antibiotics present in a ration of dried distillers grains (DDG), ionophores sickened and killed hundreds of cattle at feedlots in Kansas.[9] Ionophores are also associated with increased shedding of human pathogen, E. coli O157:H7,[10] with researchers concluding: "These results indicate that the use of growth-promoting agents and antibiotics in beef production may increase the risk of environmental contamination by E. coli O157."[11]

Supplementation with biochar is a viable alternative to ionophores for achieving the dual objectives of reduced methane emissions and increased feed efficiency. A series of studies by researchers working in Laos looked at the effects of different biochars on enteric emissions and weight gain in tropical cattle. The researchers conducted a 4-month *in vivo* feeding trial with young tropical cattle. Biochar was added as 0.62% of the dry matter (DM) fed. Biochar was responsible for 25% increase in live weight gain without causing any change in DM intake, and a 22% decrease in methane emissions.[12] In another study, these researchers found that rumen fluid that was already adapted to biochar reduced methane production even more.

Table 2 compares the advantages and disadvantages of biochar vs. ionophores. While the price of biochar is higher than the price of ionophores, it may be more effective in achieving the desired results, with fewer side effects and greater benefits. In the Biochar Dairy Model, we assume that the dairy is replacing ionophores with biochar and that the feed efficiency gains will be equivalent. We also credit biochar with additional cost reductions and increased returns due to additional benefits of biochar related to milk quality, cattle health and comfort, and herd replacement costs.

Table 2. Ionophores and Biochar Compared

	Ionophore (Rumensin)	Biochar
mode of action	anti-biotic: alters microbial balance in rumen by killing methanogens and protozoa	pro-biotic: alters microbial balance in rumen by promoting methanotrophs and biofilms; sorbs toxins
feed utilization efficiency	increases	increases
enteric CH4 emissions	reduces	reduces
safe dose window	narrow	wide
toxic to calves	yes	no
toxic to other animals, eg: horses, dogs, humans	yes	no
milk fat	tends to decrease	tends to increase
ecoli shedding	increases	reduces
acidosis	reduces	reduces
bloat	reduces	reduces
coccidiosis	reduces	reduces
mastitis	may increase	reduces
heat and conception	may decrease	may increase
compatible with direct fed microbials (DFM)	inhibits	promotes
interactions with pharmaceuticals	Cattle deaths reported when combined with antibiotics in DDG.	Could sorb some pharmaceuticals and reduce their effectiveness. More study needed
sorbs tannins, pesticides, alfatoxin and other toxics	no	yes
dietary adjustment needed	yes	no
term of effectiveness	effectiveness declines as microbes adapt	effectiveness increases as rumen ecology stabilizes

Literature Review: Biochar to Improve Cow Health and Comfort

Biochar can improve feed efficiency in the healthy cow. At the same time, it addresses critical cow health and comfort issues that bear on milk production, milk quality and herd replacement costs. Healthy, comfortable cows in an environment with low pathogen loading will produce more clean milk, more of the time. Improved health and comfort also improve calf survival and cow longevity, resulting in lower herd replacement costs. Some studies that demonstrated the impact of biochar or charcoal on specific disease or health conditions are summarized below. In most cases, the mode of action was sorption of a toxic compound or immobilization of a virus or bacterium, or both.

- Botulism can multiply in bad silage and large outbreaks have occurred in the dairy and other livestock industries. According to Iowa State: "Botulism seems to be increasing in cattle, possibly due to the increased use of plastic packaged grass silage, and these outbreaks can cause significant economic losses."[13] Cattle sicken from ingesting the toxins produced by the bacteria, and activated charcoal is a recommended treatment option for sorbing the toxins.[14] The Swiss study cited above showed that biochar in feed greatly reduced prevalence of C. botulinum.
- Mycotoxins are secondary metabolites of fungi and are a common contaminant of cattle feed, both grain and silage. Fungal growth can start in the field before harvest or develop in storage due to poor silage or inadequately dried grain. Charcoal and activated carbon can sorb these mycotoxins effectively and prevent toxic impacts on animals. Erickson *et al* (2011) fed two groups of cows with contaminated silage or clean forage and supplemented both groups with 0, 20 or 40 g of activated carbon per day. Cows on contaminated silage that received AC tended to improve intake and had higher butterfat content in milk compared to those that did not get AC.[15]
- E. coli - Cattle digestive systems are a reservoir of E. coli, including strains like O157:H7 that are pathogenic to humans. Feedlot and dairy systems that shift feed from forage to grain, cause acid tolerant strains of E. coli, like strain O157:H7 to predominate over less acid-tolerant nonpathogenic strains. Fecal shedding of E. coli O157:H7 in cattle can infect water and soil and also result in carcass contamination, spreading the disease to the human food supply. [16] An *in vitro* study added activated charcoal to a nutrient broth inoculated with E. coli O157:H7. The AC was effective in absorbing both the bacteria itself and the toxin it produced. The study also tested AC sorption of normal intestinal flora and found that the AC showed lower binding capacity to these organisms.[17] Biochar also has potential to reduce the spread of E. coli in water and soil. Several studies have found significant reductions in transport of E. coli through soils that contained biochar. Since E. coli infection within a herd seems to spread through water troughs, adding biochar to water troughs should also be studied.[18,19,20]
- Viral infections. A study looked at various sorbents used *in vitro* to control bovine rotavirus. One kind of charcoal and various clays were each found to sorb greater than 99.0% of bovine rotavirus. However, only the charcoal and one specialized clay were found to actually reduce the infectivity of the virus.[21]
- Protozoal parasites are a major cause of diarrhea and loss of young calves. Researchers in Japan tested a novel compound of activated charcoal containing wood vinegar liquid, as a treatment for infection with Cryptosporidium parvum. They found that the charcoal sorbed the oocysts and the wood vinegar killed the oocysts *in vitro*. Live calves were then infected with oocysts and half the calves were given the charcoal and wood vinegar treatment. Those calves recovered quickly while the control calves developed severe diarrhea.[22] Several "calf starter" products currently on the market include charcoal as an essential ingredient for prevention of diarrhea and easing young calves onto the adult diet.[23,24]

- Acidosis is caused by explosive growth of Streptococcus bovis when grain is suddenly introduced to the diet. S. bovis produces large amounts of lactate, acidifying the rumen. Effects of acidosis can manifest as a small reduction in feed intake or the death of an animal. According the Merck Veterinary Manual, "administration of activated charcoal (2 g/kg) is believed to protect the ruminoreticular mucosa from further injury by inactivating toxins."[25] One study also found that charcoal can help prevent acidosis. Sheep were fed two diets, roughage-based and concentrate-based. Activated charcoal was added at 0.3% of dry matter to the diet. The animals provided with AC in the diet did not suffer from diarrhea and easily adjusted to high concentrate feeding.[26]
- Tannins are often present in high protein forages such as legumes, and their strong taste can put animals off their feed, lowering weight gain. Several studies have looked at the impact of supplementing with charcoal to counteract the effects of tannins and found that animals on a high tannin diet that were fed charcoal ate more, and gained more weight.[27,28,29]
- Pesticide residues of all kinds are present in animal feed. Biochar has been shown to sorb a number of pesticides and herbicides. Cook & Wilson (1971) reported at the conclusion of a trial that examined various alternatives: "The method that is effective as an antidote for pesticide poisoning in cattle is a combination of activated carbon and phenobarbital feeding. This method proved successful in a large-scale field trial involving 105 lactating Holstein cows that had been contaminated with aldrin."[30]
- Biochar added to bedding can help prevent environmental mastitis and other cattle diseases by slowing the spread of pathogens. Researchers in Switzerland attribute a large part of the success in improved dairy conditions to adding 10% biochar to bedding material. They found that biochar sorbs moisture in bedding and inhibits ammonia emissions. Reduced odor in dairy facilities benefits both cows and workers.

Cost Benefit Ratio - Biochar in Feed

The first module we consider is the use of biochar as a feed supplement. Specific parameters and values used in the Biochar Dairy Model are discussed in detail below.

Feed Application Rate

We start with a feed application rate of 200 grams/head, based on the Swiss study discussed above. For our 2500 head Holstein dairy, this amounts to .8% of dry matter fed. This value is in line with reports that showed feed efficiency gains in cattle when biochar was added at .6% to 2.0% of dry matter.[31] A study of the impact of charcoal feed on general nutrition found that charcoal fed at these rates and higher did not reduce nutritional attributes such as serum protein, urea, nitrogen, albumin and globulin as well as serum trace minerals.[32]

Contagious Mastitis

Mastitis is the number one dairy health problem in modern dairies. Nationally, mastitis is estimated to cost dairy producers $1.8 billion, about 10 percent of the total value of farm milk sales. Approximately two-thirds of this loss is from subclinical infections that result in reduced milk production.[33] Mastitis is divided into two categories: Contagious Mastitis and Environmental Mastitis. Biochar feed can reduce contagious mastitis by reducing the internal pathogen load in animals, as shown in the Literature Review above. The Swiss researchers found an improvement in udder health as a result of biochar. A technical bulletin from Taiwan also recommends that charcoal in cow feed can "prevent mastitis".[34] To estimate the productivity increase gained by using biochar feed to help control contagious mastitis, we use a starting value of 2% of the annual milk production of the Biochar Model Dairy.

Herd Replacement Cost

Herd replacement cost is a complex item in the dairy budget. It includes the cost of breeding, calving and raising heifers, balanced against revenues from sale of cull cows and the cost of disposing of mortalities not suitable for beef. It is affected by milk cow longevity, which continues to decline as herd size increases and cow comfort and sanitation become more challenging.[35] Cull rates in US dairies average greater than 40%. Death or culling early in lactation is a large loss, estimated to cost between $500 and $1000 per cow, as most of the investment to raise a heifer to first calving and lactation is lost. An economic decision model made by de Vries showed that reducing the death rate by 50% during the first 3 months of lactation increased annual profits by $37 per head. Effects on milk production and fertility were not included in these calculations.[36] De Vries reported that the reasons for culling are: death, 21%; reproduction problems, 18%; injury or other reason, 14% and low production and mastitis, both 12%. Biochar in feed has the potential to reduce deaths from mastitis and other kinds of infections. It can also improve milk production and reduce the number of animals culled for low production.

A 2007 survey by the National Animal Health Monitoring System (NAHMS) found that 23.9 percent of pre-weaned calves had diarrhea and 17.9 percent of calves are treated with antibiotics for diarrhea.[37] Diarrhea is caused by bacteria and viruses as well as parasites. As discussed in the literature review above, biochar is effective in preventing and curing diarrhea caused by parasites and by bovine rotavirus. Biochar has also been shown to reduce the prevalence of e. coli, a major bacterial cause of diarrhea. Prevention of diarrhea is important because even when calves recover, their long-term future health and productivity may be reduced.

Because biochar can have a profound impact on major causes of cow and calf morbidity and mortality, such as mastitis, low production and calf diarrhea, we estimate that using biochar in the dairy can result in a 5% reduction in herd replacement costs.

Milk Quality Premiums

Dairy processors will pay premiums for desired milk qualities such as high butterfat content and low Somatic Cell Count (SCC). Mastitis infections are a major cause of both low butterfat and high SCC.[38] Given the historic accounts of the ability of charcoal in feed to increase butterfat, and the projected ability of biochar to reduce mastitis, it is likely that using biochar will improve milk quality by both measures. According to Hoard's Dairyman, an industry magazine, "Milk quality premiums can range up to 77 cents per hundredweight for an SCC of 100,000 compared to no premium for 400,000. That gives a significant advantage to operations striving for a low SCC."[39] Milk pricing is complex and differs regionally, but component pricing allows for premiums for butterfat content above an average of about 3.5 percent. We assume that biochar feed will increase butterfat content by an extra quarter pound of butterfat per CWT of milk. The CDFA Class 1 butterfat price for February 2014 was $1.75/lb.

Table 3 includes all the parameters and default inputs for the Biochar in Feed module.

Table 3. Benefit Cost Ratio - Biochar in Feed	
Biochar Feed Increased Costs	
biochar feed, per head, grams	200
biochar feed, per head, pounds	0.44
biochar fed as % DM (milking cows)	0.8%
annual biochar required, tons	201
annual biochar cost	$200,750
cost per head per day	0.22
cost per CWT	0.29

Biochar Feed Reduced Costs	
avoided ionophores - $per head per day	0.03
Annual cost, avoided ionophores	$27,375
avoided Contagious Mastitis, % of total CWT	2%
avoided Contagious Mastitis, increased CWT	13,786.00
total Contagious Mastitis avoided milk loss	$220,576
herd replacement cost reduction (%)	5%
avoided herd replacement cost, $/CWT	0.0615
Total herd replacement cost savings	$42,392
Biochar Feed Increased Returns	
butterfat premium, $/ CWT	$0.44
low Somatic Cell Count premium, $/CWT	$0.50
total premium value	$647,942
BCR Biochar in Feed	
Total Biochar Cost	$200,750
Total Cost Reductions+Increased Returns	$938,285
BCR	4.67

Cost Benefit Ratio - Biochar in Bedding

All of the biochar benefits discussed above result from adding biochar to cattle feed. However, as shown by the Swiss experiments, additional benefits to cow health can be had by adding biochar to bedding. Clean and comfortable bedding is one of the fundamentals of cow comfort and health. Bedding often carries a high pathogen load and biochar can be very effective in reducing the amount of bacteria that the animals are exposed to. In fact, researchers estimate that about half of mastitis cases are "environmental," that is, the disease is contracted by exposure to pathogens on dairy surfaces, mostly bedding.[40] Bedding is the highest source of ammonia emissions in the dairy. Ammonia volatilization affects respiratory health of exposed cows and dairy workers. Ammonia emissions also lose nitrogen from the system, reducing the nutrient value of manure.

Many studies have compared bedding materials to determine best choices for materials that might reduce pathogens. The National Animal Health Monitoring System found "The use of coarse sand or dried or composted manure was associated with better hygiene compared with the use of other bedding types."[41] However, even non-organic materials such as sand will become contaminated with pathogens soon after cows use them. Sanitized materials may actually be "too clean". Researchers found that, "In some cases, those that started out with "clean" bedding tended to have significantly higher levels of bacteria in used bedding, indicating that the bedding may have started out too clean (i.e., no competition from other bacteria)."[42]

We assume that adding 10% biochar to bedding materials will significantly reduce pathogens and odors. A probiotic lactic acid culture should be added along with the biochar for pathogen control and acidification. Mild acidity helps control the breakdown of urea into ammonia. Reducing ammonia and odors help improve cow comfort and increase production. We assume that adding biochar to bedding will increase productivity by an additional 3% of annual milk production by increasing cow comfort and reducing mastitis and other infectious diseases.

Adding biochar to bedding will also improve manure handling as the biochar flows through the system. Biochar will get the composting process off to a good start as it supports strong populations of beneficial microbes that suppress E. coli and other pathogens that can pass into the human food supply through use of manure on crops. Biochar in bedding also improves nitrogen capture and retention. Table 4 includes all the parameters and default inputs for the Biochar in Bedding module.

Table 4. Benefit Cost Ratio - Biochar in Bedding	
Biochar Bedding Increased Costs	
fresh bedding/day-head, lbs	5
percent biochar added	10%
annual biochar required, tons	228
annual biochar cost	$228,125
Biochar Bedding Reduced Costs	
avoided environmental pathogens, ammonia, % of total CWT	3%
avoided environmental pathogens, ammonia, increased CWT	20,679
Total environmental pathogens, ammonia avoided milk loss	$330,864
BCR Biochar in Bedding	
Total Biochar Cost	$228,125
Total Cost Reductions	$330,864
BCR	1.45

Cost Benefit Ratio - Biochar in Silage

Feed spoilage is a costly problem in dairy management, especially as feed costs continue to rise. Current figures for silage use and costs in California are about 30 lbs fed per head per day at a cost of $67.36 per ton.[43] Silage dry matter shrinks during fermentation, but poor conditions increase both shrinkage and spoilage. According to experts, dry matter loss with fermentation should be less than 10%, but losses can be as great as 25% or more.[44] Biochar can prevent spoilage and improve the quality and nutritional value of forage when added to silage after forage is harvested. US extension agents have recommended charcoal to prevent spoilage.[45] Several Swiss and German farmers are currently adding 1% biochar to their silage production by automatic injection, whether in silage towers or in silage balls. Biochar buffers moisture in silage, reducing the formation of fermentation juices that promote higher levels of butyric acid.[46] An *in vitro* study that added biochar to silage found that "increasing doses of biochar in the silage seemed to enhance the quality of the silage. Acetic acid tended to decrease, lactic acid tended to be stable and butyric acid was very low. "[47]

Table 5 includes all the parameters and default inputs for the Biochar in Silage module.

Table 5. Benefit Cost Ratio - Biochar in Silage	
Biochar Corn Silage Increased Costs	
silage fed per head-year, lbs/head-day	30.4
total annual silage, tons	13,870
percent DM in silage	35%
percent biochar added, by DM weight	1%
total biochar added, tons	49
annual biochar cost	$48,545
Biochar Corn Silage Reduced Costs	
cost of silage/ton	$67.36
percent shrinkage/spoilage savings	15%
Total Cost Reductions	$140,142
BCR Biochar in Silage	
Total Biochar Cost	$48,545
Total Cost Reductions	$140,142
BCR	2.89

6. Biochar Dairy Model – Biochar-Manure Production Profit Center

Increasingly, there is interest in viewing manure production in the dairy as a potential profit center rather than a waste disposal problem. Anaerobic digesters are one capital-intensive path toward dairy manure profits. Producing nutrient-rich biochar-manure fertilizer is an alternative path to profitability that is less capital intensive and also provides environmental benefits by reducing emissions of nitrogen and greenhouse gases. In commerce, the carbon and the nitrogen cycles are coming under regulation and being added to financial accounting and bottom lines. Biochar-manure fertilizer addresses these regulatory pressures. For farmers, the carbon and nitrogen cycles also involve the recycling of essential resources and inputs that have immediate impacts on profitability.

Nutrient and carbon cycle impacts that are effectively addressed by biochar include:

- Nitrogen loss from manure handling and application
- Environmental pollution costs from nitrogen
- Soil carbon for improved crop yield and water use efficiency
- Soil carbon storage for climate mitigation

Several authors have investigated the potential for using biochar to manufacture a new type of slow-release fertilizer, based on its ability to sorb nitrogen.[48,49] Biochar can solve two major problems with the current use of manure as fertilizer: by preserving N it preserves the correct ratio of nitrogen to phosphorus. Due to N loss, manures have too much phosphorus so when applied at appropriate N rates, too much P is added to soil where it can leach into groundwater. The other problem biochar can solve is pathogens. Composting manure with biochar inhibits pathogens like E. coli.

Cost of Production – Biochar-Manure Fertilizer

Dairies use a wide variety of manure handling systems, but most dairies use a combination of flushing and scraping to move manure from facilities into lagoons and piles for storage or composting. Often, solids are separated from liquid slurries in settling ponds and various types of mechanical separators can remove more moisture from solids. Tracking the material flow of dry and wet manure is difficult. Tracking the nitrogen content is difficult as nitrogen continually volatilizes and is lost as ammonia and other N-containing gasses.

Researchers in California have examined the problem of nutrient retention and nitrogen pollution from dairy manure. Most of the information and benchmark figures discussed below come from a 2003 report by the Committee of Experts on Dairy Manure Management at UC Davis.[50] Because mass balance of manure flows is complex and variable, it is most useful to track the nitrogen content of the manure. Nitrogen input into the dairy comes from feed and output to manure can be calculated on the basis of feed conversion efficiencies. Tracking N as it flows through the manure system requires the following parameters:

- Manure solids output per head – 17.6 lbs/day
- N output per head – 1.1 lbs/day
- Percent of recoverable solids. This is the amount of solids that is scraped or separated from liquids – 50%
- Percent N in solids versus liquid – a high percentage of N is in small particles that remain in flush water and end up in lagoons. This percentage is usually greater than 50%, but assuming that biochar is used in bedding, more N could be retained in larger particles and less will volatilize, allowing for 50% recovery of N in solids.

Before the manure solids reach the composting area, biochar is added at the rate of 10% by mass. The material is composted for 90 days to produce the biochar-manure fertilizer. Several studies have shown that 10 to 20% biochar added to compost reduces nitrogen loss by 50 to 65%.[51,52,53] Current estimates for total ammonia N losses in dairy manure are 35%. We assume that using biochar in the dairy for feed, bedding and compost will reduce N losses to 10% before composting and to another 10% during composting. Biochar is likely to increase composting temperature for better pathogen control, while reducing composting time. Compost shrinks as it matures, by compaction and mass loss through respiration and gas emissions. We assume a shrinkage of 40%, slightly less than mass loss of dairy manure that was composted with sawdust.[54]

Biochar added to compost reduces emissions of greenhouse gases: N_2O, CH_4 and CO_2. Biochar also retains more dissolved carbon and increases the humic fraction of compost.[55] Biochar itself has a certain portion of carbon that is "recalcitrant" and not easily mineralized. This fraction of stable carbon is the basis for carbon accounting methodologies that assign carbon offset value to biochar placed in soil. Using the American Carbon Registry's draft Biochar Protocol, we use a value 50% of biochar mass for the stable carbon component.[56]

The price of the biochar-manure fertilizer is based on the cost of the biochar additive, offset by projected payments – nutrient credits and carbon credits – for retaining N and C. The projected price of around $30-$40 a ton is not too much more than current prices of dairy manure compost of $25/ton. Processing costs are not included.

Table 6. Costs to Produce Biochar-Manure Fertilizer	
manure solids, lbs/head-day	17.60
N, lbs/head-day	1.10
N lost to volatilization	10%
total N, lbs	903,375
percent N in solids	0.40
percent solid recovered for compost	0.50
total manure solids in compost, tons	4,015
total N in starting compost	180,675
percent biochar added, by weight	0.1
annual biochar added to compost, tons	402
total cost of biochar added	$401,500
compost mass shrinkage factor	0.6
tons of finished biochar fertilizer	2,650
percent biochar in finished fertilizer	0.15
percent N retained	0.9
total N retained - lbs/ton	61.4
Biochar recalcitrance factor	0.5
total C retained -lbs/ton	200.8
Nutrient Credit, per ton of N retained	$0.25
Carbon Credit, per ton of C retained	$0.50
total cost of finished biochar fertilizer/ton	$35.80

Cost Benefit Ratio – Biochar-Manure Fertilizer to Grow Corn

As the final step in the cascading flow of benefits from adding biochar to dairy operations, we look at using the biochar-manure fertilizer to grow feed corn. Baseline costs and returns are drawn from the University of California Cooperative Extension report, *Sample Costs to Produce Corn Silage.*[57]

Biochar has documented benefits in increasing water use efficiency and crop yield. We will not review these here, but assume that adding 8 tons per acre of biochar-manure fertilizer with 15%

biochar content will provide 1.2 tons of biochar per acre and will increase WUE by 20% and crop yield by 20%. This application rate will also provide about 400 lbs of N per acre. This is more than needed by the crop, but some portion of the N is in slow-release form, bound up in microbial life forms that will multiply in the soil providing many benefits to nutrient cycling and plant growth.

Using biochar-manure fertilizer avoids the cost of all other fertilizers. It also saves water. If water is valued at $200 an acre-foot, then biochar application returns a benefit cost ratio of 2.24.

Table 7. Benefit Cost Ratio - Growing Feed Corn with Biochar-Manure Fertilizer	
Feed Corn Current Costs & Returns	
cost of chemical fertilizers/ac	$232.00
water price, ac-ft	$200.00
water used per acre, ac-in	48
cost of water used	$800.00
crop yield per acre, tons	32
crop price per ton	$45.00
crop receipts per acre	$1,440.00
Feed Corn Biochar Fertilizer Increased Costs	
biochar fertilizer application rate,tons/ac	8
total cost of biochar fertilizer/ac	$303.06
Feed Corn Biochar Fertilizer Reduced Costs	
water savings	20%
water cost reduction/ac	$160.00
Feed Corn Biochar Fertilizer Increased Returns	
yield increase	20%
yield increased receipts/ac	$288.00
BCR Biochar Fertilizer in Feed Corn	
Total increased costs	$303.06
Total increased returns + cost reductions	$680.00
BCR	2.24

7. Conclusion

Biochar used as a cattle feed supplement is both an old and a new idea. Traditional uses give us confidence that biochar is safe and effective to use as a feed supplement, and this analysis demonstrates that biochar provides enough benefits to be economically viable in today's production systems. Further effort is needed to verify the benefits of top interest to producers. The timing is good now for bringing biochar to this market. With strong exports and feed prices trending lower, cattle and dairy producers are likely to be more economically stable for the next few years. If CPES can clearly show the benefits of its biochar feed product, there is a chance that producers will be willing to try it.[58] Economic stability makes a big difference, because in hard times, producers are rarely willing to take risks on new products.

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