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Biochar as Feed Supplement for Cattle

Introduction

Interest is growing in using biochar or charcoal as an animal feed supplement. This interest stems from two major concerns: the potential to reduce production costs by improving animal feed efficiency and the need to reduce methane emissions from ruminants to slow climate change. Feed efficiency and methane emissions are related, making it more likely to find integrated solutions that address both problems. Biochar is such a solution. This paper summarizes information about past and current cattle feed supplements containing charcoal and looks at different impacts charcoal may have on cattle health. We survey current research efforts using biochar, while explaining the mechanisms of rumen fermentation and how biochar might work to achieve the benefits observed. We conclude with a list of priorities for further investigation.

History

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. The first written accounts of charcoal as medicine are found in Egyptian papyri dating to around 1500 BC. Hippocrates, Pliny and Galen all wrote about the curative properties of charcoal for digestive ailments, wound healing and other uses.¹

Animals in the wild and in the barnyard have been observed self-medicating with charcoal. Colobus monkeys eat charcoal to help them digest leaves that have high levels of tannins. The leaves are otherwise nutritious and high in protein but the tannins interfere with protein digestibility, and charcoal binds the tannins. A National Geographic video report illustrates this well: youtu.be/qFzVdfozISo

A textbook on animal husbandry dating from 1906 observed: "Swine appear to have a craving for what might be called 'unnatural substances.' This is especially true of hogs that are kept in confinement, which will eat greedily such substances as charcoal, ashes, mortar, soft coal, rotten wood, etc. It is probable that some of the substances are not good for hogs, but there is no doubt that charcoal and wood ashes have a beneficial effect, the former being greatly relished."²

19th century and early 20th century agricultural journals have many discussions of the benefits of various "cow tonics," mostly 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.³

Charcoal was considered to be a superior feed additive for increasing butterfat content of milk. Cow's milk was tested for butterfat content in competitions and top-producing cows could win a prize. Farmers took great care in formulating the feed ration for such tests:

"The grain mixture fed during the test consisted of 100 pound of distillers dried grains, 50 pounds of wheat bran, 100 pounds of ground oats, 100 pounds of hominy, 100 pounds of cottonseed meal.... Charcoal is seldom if ever left out the test ration by many of the breeders." ⁴

Charcoal Feed for Health

Current interest in use of charcoal as a feed supplement for animals is not entirely based on the emerging interest in biochar, but rather is a carryover of traditional uses of charcoal in feed. Several companies offer feed supplements that contain varying amounts and types of charcoal. Some of these are summarized here, along with the claims that are made for these products:

Company: Agri-dynamics

website: www.agri-dynamics.com—livestock.html

product name: HEMOCEL BULLETS™

product contents: Probiotic Cultures (viable and non-viable fermentation product), Herbs (the "Bitters"), Yeast Cultures, Charcoal, Organically Bound (chelated) Minerals, B-complex Vitamins, Digestive Enzymes, Ocean Kelp

use instructions: Cattle 500 - 1,000 lbs: Administer 1-2 (14 gm) capsules daily as needed.

Cattle over 1,000 lbs: Administer 2 (14 gm) capsules daily as needed.

claims: HEMOCEL BULLETS™ is the product to use when appetite and digestion are a consideration. It's critical to keep cattle on feed without interruption if you want to maintain peak milk production and healthy rates of gain. Feed or weather changes, shipping, calving, etc. can all affect a cows ability to consume and digest adequate levels of energy.

Company: Charcoal House LLC

website: <http://www.buyactivatedcharcoal.com/>

product name: VetDtox™

product contents: pure activated charcoal

use instructions: Dosages for diarrhea: Horses, cattle 50 - 200gm. Dosage for poisoning: 0.75 g per kg body-weight.

claims: Use in animal feeds as an antidote for poisoning and to control diarrhea - e.g. as a result of food poisoning. It is vegetable-based and able to adsorb numerous harmful or undesirable substances that may be present in the gastro-intestinal tract. Added side benefit is its ability to help control animal odors.

Company: Agrilabs

website: <http://agrilabs.com/>

product name: Cryptex

product contents: Targeted egg-yolk proteins, combating common pathogens that cause malnutrition and scours. Lactic acid-producing bacteria, glutamine and inulin, combining to crowd out harmful bacteria in the gut, support intestinal health and foster the growth of beneficial bacteria. Cryptex, a precisely formulated polysaccharide and thermally-activated carbon mixture, gives ACHIEVE its characteristic black color.

use instructions: Depending on severity of stress, feed 20 g, 40 g or 60 g orally on the back of the tongue.

For best results, start feeding ACHIEVE PRO 24 hours after birth. Repeat as needed. Do not provide to animal without swallowing reflex. If condition persists, consult a veterinarian.

claims: It removes pathogenic toxins from the intestine and creates a hostile environment for pathogens such as Cryptosporidium, a major cause of protozoal diarrhea. All-natural formula developed to bolster the ability of newborns to withstand disease stressors such as scours, the leading cause of neonatal loss accounting for up to 46 percent of calf deaths.

Company: Fine Fettle Feed

website: <http://www.finefettlefeed.com/default.asp>

product name: Happy Tummy Gold

product contents: 100% pure hardwood charcoal sourced from sustainable woodlands

use instructions: Happy Tummy® charcoal should be fed in small amounts continually. FEEDING GUIDE using 5g / 15ml scoop: Recommended daily amount - in every case the amount is divided / split into two feeds:

Equines: 16HH+ 8-10 scoops; 14-15HH 6-8 scoops; 12-13HH 4-6 scoops; 11HH and under 2-4 scoops; Minatures 1-2 scoops. The recommended amount can be reduced by half, once the condition/problem has significantly improved and this reduced amount used as an aid to full recovery. For maintenance and prevention, about a 1/3 of the recommended amount should be given.

claims: The principal way in which Happy Tummy charcoal works is by re-balancing the acid/alkaline of the digestive system. It is comparable to passing a superb biological filter through the system where it adsorbs toxins and re-balances without adding anything to, or burdening, the system in any way. Its role is a passive one. The re-balancing of the pH facilitates an environment where minerals, vitamins and nutrients are utilised at their optimum. The trickle feeding of Happy Tummy to equines on a daily basis helps maintain condition, good temperament and excellent performance all round. Happy Tummy charcoal does not take out vitamins and minerals from the system. References which allude to this concern the regular use of 'activated' charcoal, which has superadsorbent properties. In fact, field experience has shown that because it re-balances the system, Happy Tummy charcoal facilitates the uptake of nutrients, enabling animals that weren't 'doing well' to gain weight and improve condition. Testimonials from customers at:

www.finefettlefeed.com—testimonials.asp

Company: Pancosma

website: www.pancosma.com—vegetal-charcoal

product name: Carbovet®

product contents: thermo-structured (non-activated) vegetal charcoal made from specially selected French oak.

use instructions: can be used in all animal feed and whatever the age of animal.

claims:

Company: Swiss Biochar

website: www.swiss-biochar.com—carbonfeed.php

product name: Carbon Feed

product contents: Wheat bran (40%), biochar [charcoal] (15 %), sugar cane molasses, linseed, alpine herbs, corn flakes, wheat flakes, barley flakes, minerals

use instructions: Dairy cows: 200g per day; Calves: 50 g per day. You can either mix Carbon Feed with the usual feed or administer it on its own. You should withhold the feed for five days after every 14 days – i.e. on a 19-day cycle.

claims: Carbon Feed increases uptake both of foodstuffs and of the energy contained within them, keeping animals' digestive systems healthy and thus reducing the amount of nutrients lost into excrement and manure. They also improve the overall stall environment. By using malolactically fermented wheat bran, Carbon Feed keeps the microbial balance in digestive tracts, whilst the biochar element binds toxins such as dioxins, glyphosates, mycotoxins, pesticides and PAH toxins. This leads to improvement in health, activity levels and wellbeing of livestock, thus improving their overall output. Illness due to mutagens and pathogens also becomes less common, reducing the risk of an epidemic. Transferrable diseases are also reduced, protecting the farmers who use this feed.

Research Support for Health Claims

A variety of studies have looked at the impact of charcoal or activated carbon on animal health. One recent study⁵ was a large scale observational study of cows fed biochar supplements that was managed by veterinarian Adam Gerlach. Results are copied here:

21 farm managers, each with an average herd of 150 cows, gave their impressions of the effects they had observed during and after the administration of biochar. It should be noted that biochar administered as treatment for dysbiosis was concomitantly supported in about 1/3 of the farms by sauerkraut brine (acetylcholine, lactobacilli, enterococci, B-vitamins, vitamin C). Observations of initial effects (1 – 4 weeks after starting biochar administration):

- Generally improved health and appearance
- Improved 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)
- Minimisation of hoof problems
- Stabilisation of post-partum health
- Reduced diarrhoea within 1-2 days, faeces subsequently generally 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
- Slurry not smelling as bad as it used to”

Biochar Impact on Diseases

Several studies further demonstrate the impact of biochar or charcoal on specific disease or toxic conditions, as 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

Botulism is a recurrent disease of cattle caused by the *Clostridium botulinum* bacteria. The bacteria 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."⁶ Cattle sicken from ingesting the toxins produced by the bacteria, and activated charcoal is a recommended treatment option for sorbing the toxins.⁷

Swiss and German researchers conducted an experiment in a dairy that was experiencing a number of common health problems: reduced performance, movement disorder, fertility disorders, inflammation of the urinary bladder, viscous saliva, diarrhea. Animals were fed different combinations of charcoal, sauerkraut juice or humic acids over periods of 4 to 6 weeks.⁸ Experimenters found that oral application of charcoal, 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 could have a tonic effect on cow health.

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.⁹

Biochar can potentially reduce the spread of *E. coli*. 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.¹⁰

A study *in vivo*,¹¹ testing the ability of activated charcoal to bind E. coli in sheep, showed no effects. The researchers speculated that a significant time delay between inoculation with the E. coli and the dosing of AC was a factor or that the contents of the GI tract interfered. Dosage could also have been a factor as Naka *et al* (2001) found the effects were dosage dependent.

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.^{12,13,14}

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.¹⁵

Parasites

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.¹⁶

Acidosis

Acidosis is a chronic nutritional disorder in feedlots where cattle are transitioned from forage diets to grain diets. Acidosis is caused by explosive growth of *Streptococcus bovis* when grain is suddenly introduced. *S. bovis* produces large amounts of lactate, acidifying the rumen. It can kill the cow. Acidosis is not one disorder but rather a continuum of degrees. 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."¹⁷

One study also found that charcoal can help prevent acidosis. Sheep were feed two diets, roughage-based and concentrate-based. Activated charcoal was added at 0.3% of dry matter to the diet. The AC had no marked effects on feed intake, daily gain or feed conversion, likely due to the low levels of AC provided: "However it was observed that the animals provided with AC in the concentrate diet did not suffer from diarrhea and easily adjusted to high concentrate feeding."¹⁸

Toxics in feed

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. Those on good quality forage showed no difference in feed intake, milk production or milk fat and also showed no preference for feed containing AC.¹⁹

Ochratoxin is another toxic compound that is commonly produced by two species of fungi, *Penicillium verrucosum* Dierckx and *Aspergillus ochraceus*. Researchers found that adding 10% charcoal to the diet of pigs decreased the concentration of ochratoxin in blood, liver, kidney, spleen, and heart by 50 to 80%.²⁰

Pesticides

Pesticide residues of all kinds are present in animal feed. Biochar has been shown to sorb a number of pesticides and herbicides. Activated carbon has been used specifically for the purpose of removing organochloride pesticides from cattle. 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."²¹

Researchers in India also found that feeding charcoal to dairy cows could reduce the excretion of organochloride pesticide residues in milk.²²

Charcoal and Plant Secondary Metabolites

Animals that are fed charcoal on a regular basis are likely to experience better health and digestion as a result of charcoal's ability to neutralize pathogens and pathogenic toxins, as well as environmental sources of toxins. This will naturally result in better weight gain and feed conversion. Another potential benefit of feeding charcoal is the mitigation of Plant Secondary Metabolites (PSM) such as tannins that are present in many forages.

Tannins are a complex and highly variable group of compounds that have some benefits and some detriments to ruminant digestion. Tannins tend to bind protein in the rumen, but that can have benefits to weight gain as some tannins will then allow protein to pass through the rumen to be digested in the hindgut where it has more nutritional benefit to the animal (it is not degraded for energy to feed bacteria in the rumen). However, not all tannins have this effect. 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.^{23,24,25}

Tannins also have the potential to reduce methane emissions. An *in vitro* study found that tannins from tropical tree leaves could suppress CH₄ production in rumen fluid without adverse effects on digestibility. The authors hypothesized that "methane reduction without significant reduction in VFA in most of the samples in our study was the result of the direct effect of tannin on methanogens."²⁶

Essential oils are another group of PSM that have been used in cattle feed supplements for benefits to health and feed conversion. Some researchers think they have good potential for reducing CH₄ emissions as well, and should be more thoroughly researched.²⁷ Biochar could be combined with essential oils or other PSM and tested to see if they have additive effects on weight gain or CH₄ reductions.

Feed Additives to Reduce Methane Emissions and Increase Feed Conversion

Recently, there is significant interest in feed supplements that can not only increase feed conversion but also reduce enteric emissions of CH₄. CH₄ is produced in the rumen because microorganisms that digest fiber produce hydrogen gas as a waste product. H₂ gas combines with carbon as the terminal electron acceptor in the reaction, producing CH₄. Firstly, this reaction represents an energy loss to the animal as the CH₄ is purely a waste product that must be eliminated through eructation. Secondly, ruminant CH₄ emissions are increasingly recognized as a target for GHG emissions reductions.

Many attempts have been made to find alternative electron acceptors to lower CH₄ production, but the only alternatives in the anaerobic environment are nitrogen or sulphur, producing ammonia or hydrogen sulfide, both of which are toxic to animals at certain levels.

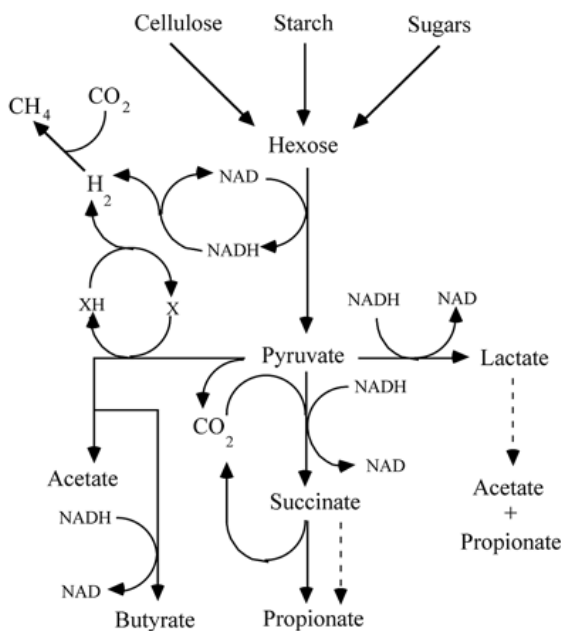


Figure 2. A schematic showing the major pathways of carbohydrate fermentation by ruminal bacteria. "X" denotes alternative electron carrier (e.g., ferredoxin). In some ruminal bacteria, pyruvate decarboxylation is coupled to formate production, but most of this formate is converted to hydrogen and carbon dioxide by hydrogen formate lyase. The dashed lines show pathways that occur in other organisms.

From Russell, J. B., & Rychlik, J. L. (2001). Factors that alter rumen microbial ecology. *Science*, 292(5519), 1119-1122.

However, some feed supplements can alter the microbial balance in the rumen, selecting for microbes that produce less H₂ in their metabolism and make more efficient use of food energy. One widely used supplement that both reduces CH₄ and increases weight gain is a class of antibiotics called ionophores. Ionophores (at a newly prescribed higher dosage) are specified by the American Carbon Registry (ACR) as the only feed technology that directly reduces enteric CH₄ emissions.²⁸

Ionophores affect the ion concentration gradient across microorganism cell walls, causing them to enter a futile ion cycle. Greatest impacts are to the metabolism of Gram-positive bacteria and protozoa in the rumen. These are the organisms most involved in methanogenesis. 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.²⁹ Their effectiveness is also limited over time as gut bacteria adapt to their presence. For feedlot cattle with short lifespans, this is not so significant.

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.³⁰

Ionophores are also associated with increased shedding of *E. coli* O157:H7,³¹ 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."³²

Biochar to Reduce Methane Emissions and Increase Feed Conversion

Supplementation with biochar may become a viable alternative to ionophores for achieving the dual objectives of reduced methane emissions and increased weight gain. 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.

Researchers Leng, Inthapanya and Preston began with the hypothesis that biochar promotes growth of methanotrophs in anaerobic systems. The hypothesis is based on the observation that biochar applied to rice paddy reduced methane emissions by providing habitat sites for methanotrophs that consumed the methane gas. They speculated that a similar phenomenon could occur in the rumen, as previous studies had isolated methanotrophs living in the rumen fluid. They further speculated that two factors normally limit the number and effectiveness of methanotrophs in the rumen:

- 1) Methanotrophs grow slowly in anaerobic environments where they are limited by the energy availability. Rumen fluid has a short turnover time that prohibits substantial growth of methanotrophs. If biochar provides a favorable habitat for methanotrophs, it could support their proliferation.
- 2) Methanotrophs are normally attached to rumen epithelium, but to be effective in capturing methane, they would have to be spatially distributed close to the site of methane production on the biofilms that are closely attached to feed particles. Biochar might provide the means to bring them in closer proximity.

These researchers began with a series of *in vitro* studies. One study found that biochar lowered methane production by 12.7%. When supplemental nitrogen was added (the feeds used were low protein), methane production was reduced by up to 49%.³³

Further work revealed that different biochar materials had different effects on methane reduction.³⁴ The researchers speculated that one reason for these differences could be related to recent studies that show "the possibility of promoting direct interspecies electron transfer with activated charcoal through a high conductivity of biochar providing better electrical connections for inter-species electron transfer than those forged in the biofilm on feed particles." Biochar materials are likely to vary in conductivity and other characteristics, thus having different levels of electron transfer.

The researchers followed up their *in vitro* work with a 4-month *in vivo* feeding trial with young tropical cattle. Biochar was added as 0.62% of the dry matter (DM) fed. Two types of nitrogen were supplemented to the low protein cassava diet. Biochar was responsible for 25% increase in live weight gain without causing any change in DM intake, and a 22%

decrease in methane emissions. Additive effects of biochar and nitrate combined reduced methane emissions by 41%.³⁵

The reduction in methane emissions could be explained by the mechanisms described in the *in vitro* studies - the proliferation of methanogens. Or there could be other mechanisms that might account for both reduced methane and increased feed conversion. The researchers hypothesized that the increases in weight gain could result from biochar improving "microbial habitat where microbial consortia can come together for mutual benefits and efficient use of each of their metabolic end products." The right combination of bacteria can utilize more of the H₂, "producing more reduced end products of feed break down such as propionate." The result would be less formation of methane.

Finally, the researchers also looked at differences in the rumen fluid from animals both with and without biochar in their diet. They found that rumen from biochar fed animals produced less methane in an incubation than the rumen from non-biochar adapted animals. This indicates that the biochar-adapted animals had different consortia of microbes in the rumen microbial community that was responsible for the reductions in methane emissions.³⁶

Researchers in Denmark recently published results from an *in vitro* study of several different biochars incubated in rumen fluid that confirms a reduction of methane in the presence of biochar. They found reductions of 11% to 17% compared to the control. They also observed no differences in the digestion of fiber; leading them to conclude that biochar supplementation would have no detrimental effects on feed conversion.³⁷

A research group in New Zealand has a paper in press³⁸ describing results from their inoculation of rumen fluid with biochar. In that case, no effect of biochar on methane emissions was found. They speculate that differences with the Leng study may arise from the different biochar materials used.

Areas for Further Research

In order to realize the promise of biochar as a cattle feed supplement, a program of basic science research is needed to prove the benefits and better understand the mechanisms involved. Better understanding of fundamental mechanisms will enable a robust R&D program to produce ideal formulations of biochar products for different feeds and production systems. Research and development should focus initially on those benefits of greatest economic importance to beef and dairy producers. Good quality scientific research and strong results will be required if biochar is to compete for market share with feed supplements such as ionophores.

Outlined below is a beginning list of priorities for an R&D program that would address the most fundamental science questions and the top concerns of producers. Some additional prospects for further work are also listed, along with a potential task list for addressing marketing and policy questions.

Basic science questions

1. How does biochar change the rumen ecology, especially the functioning of biofilms?
2. Does biochar promote growth of methanotrophs in the rumen?
3. Does the rumen ecology adapt to biochar so that its beneficial effects increase or decrease over time?
4. What kinds of biochar and/or post treatments are most effective in reducing CH₄?

5. Does biochar bind essential nutrients, minerals or vitamins and make them unavailable to animals?
6. What are the best practices for feeding rates and duration? Is it best to program a regular hiatus in the feeding schedule?

Top producer concerns

1. How does biochar feed affect average daily gain (ADG)?
2. How does biochar feed affect carcass quality?
3. How does biochar affect milk production output?
4. How does biochar affect milk solids quality?
5. How does biochar feed affect overall animal health?
6. What are the metrics to determine health impacts?
7. Does biochar reduce the death rate at feedlots (current industry average - 2%)

Future prospects

1. Are there PSM additives such as herbal essential oils that can work synergistically with biochar to improve performance and reduce CH₄ emissions?
2. Can biochar be used with microbial inoculants to manipulate rumen ecology for desired ends?
3. How does biochar impact manure management in feedlots and dairies?
4. Can biochar improve pasture when fed to grazed cattle?
5. Can biochar be used in grain storage to inhibit spoilage?
6. Can biochar be used in silage for improved quality and reduced spoilage?

Marketing and policy questions

1. Will regulators accept biochar as a feed additive?
2. Can biochar qualify as a valid GHG mitigation under the American Carbon Registry fed cattle protocol?
3. Can biochar compete with ionophores for market share?

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, but we still do not know if it provides enough benefits to be economically viable in today's production systems. A focused effort is needed to quantify 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 producers can clearly show the benefits of biochar feed products, there is a chance that producers will be willing to try it.³⁹ Economic stability makes a big difference, because in hard times, producers are rarely willing to take risks on new products.

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