6th Annual

Driftless Region Beef Conference

Proceedings

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Cover crops and manure nutrient management

Morgan Hayes, Paul Davidson, Eric Dahlke

Recently the Midwestern US has seen a push has seen a movement to improve water quality for waters eventually reaching the Gulf of Mexico; this is in an effort to reduce the hypoxic zone. Cover crops show effectiveness at reducing nitrogen and phosphorus loads in waters leaving fields. One concern with cover crops is their impact on grain production following the kill of the cover crop as they tend to tie nutrients into organic forms, which are not immediately plant available. This study looked to identify if manure would act differently than a commercial fertilizer (urea) when interacting with a cover crop (cereal rye). Overall, during the 2015-2016 season, there was no significant differences in how the manure and urea interacted with the cereal rye.

Timeline for the study

In early October 2015 cover crops were planted. Soil samples were taken in early November 2015, prior to manure application. The manure was injected in late November after soil temperatures dropped below 50 °F. A manure sample was pulled at the time of sampling and sent to a commercial lab for analysis. Soil columns to measure nutrient lost into field tiles were taken following manure application but prior to any precipitation. When manure results were returned, urea was applied to the cover crop non-manure treated columns and field plots to achieve the same nitrogen application rate. Unfortunately, December 2015 had high precipitation totals (~7.5 inches, 4.75 inches above normal) and it was not possible to apply the urea to the field until January 2016. In April 2016, an herbicide mixture of 2 oz/acre Sharpen, 16 oz/acre Outlook and 24 oz/acre Roundup was applied to the field plots and columns to kill the cereal rye. While cereal rye likely did not need such an aggressive herbicide program, other cover crop field plots like annual ryegrass were more of a concern See Figure 1 below for the layout of the plots. The field used in this study has traditionally been tilled, so the decision was made to disk the cover crop into the soil one week after the herbicide mixture was applied. The columns were also turned to provide a similar treatment to running a disk through the field. Following this turning of soil, rain delayed planting for approximately 10 days. Corn was planted in early May 2016. Spring starter fertilizer application of 22 kg ha^{-1} (20 lb acre^{-1}) was adjusted based on manure test results to ensure 200 kg ha^{-1} (180 lb acre^{-1}) nitrogen was applied to all treatments. Corn was harvested the first week of October 2016 and final soil samples taken the following two weeks.

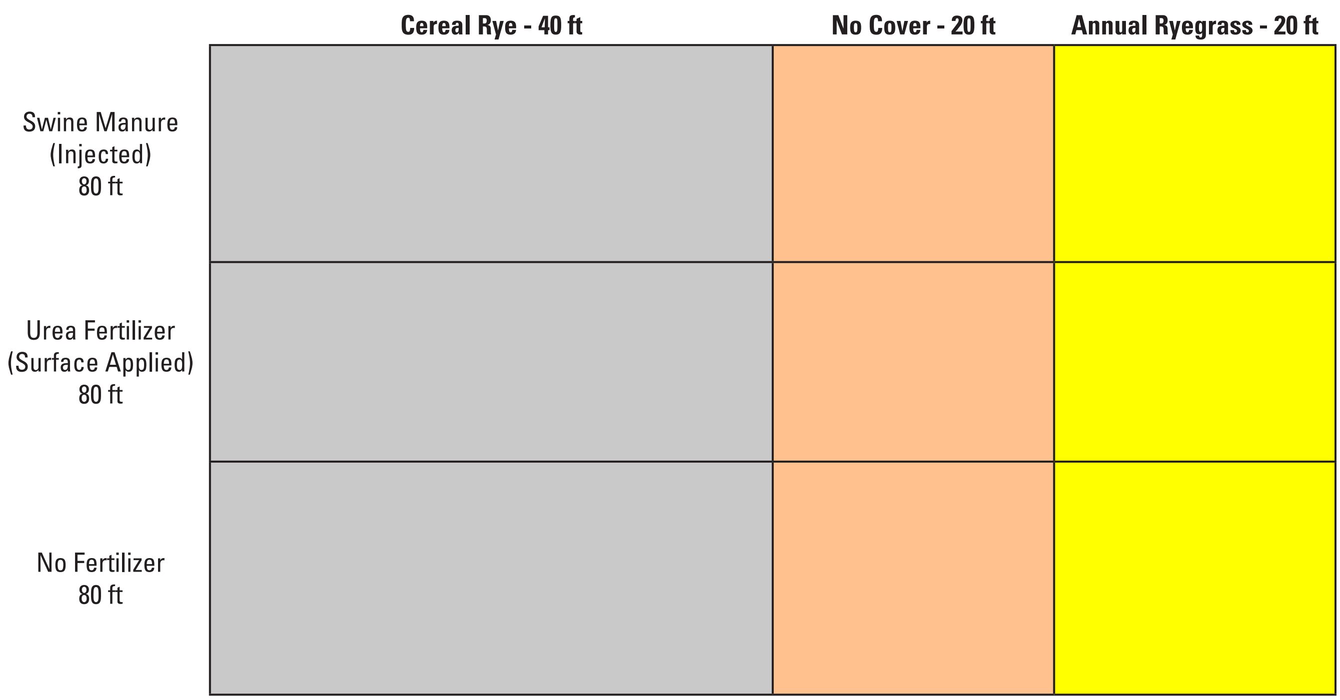

Figure 1. The layout of the field plots used in the experiment. Cover crops and corn were planted in rows with fertilizer applied perpendicular to the crop plantings.

Weather conditions

Fall 2015 was a near ideal season for growing cover crops. The fall was warmer than average with average to above average rainfall totals. During this water collection period of the study (Figure 2), monthly rainfall was typically average or above average. During this water collection period of the study, monthly rainfall was typically average or above average. December 2015 had a very high precipitation total leading to the majority of the water collected from the soil columns.

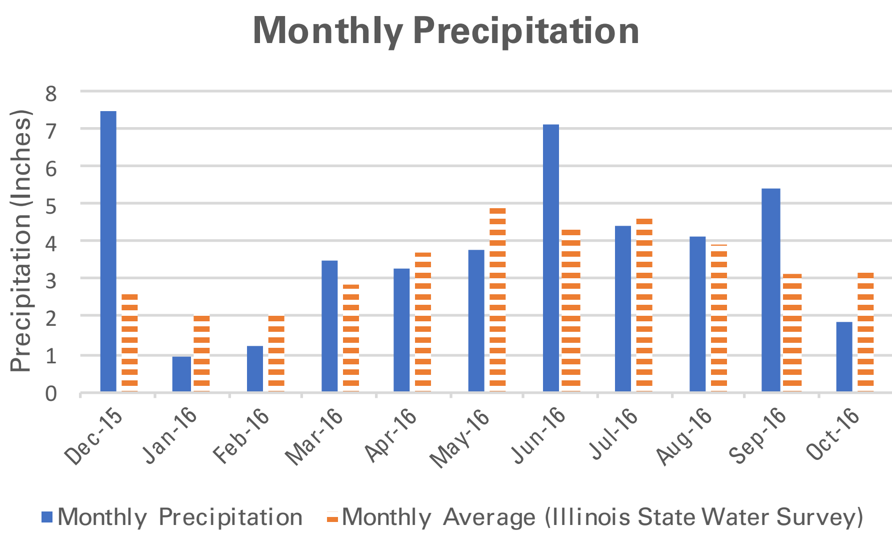

Figure 2. Monthly precipitation for the months when water could be collected from the soil columns. Final water collection actually occurred in May 2016.

Results

This study found that cereal rye was effective at reducing total nitrogen and nitrate that leached from soil columns treated with both manure and urea, with no significant difference by fertilizer source (Figure 3). Throughout the study, there were only a handful of total phosphorus and phosphate samples above the detection limit. With the limited number of samples and rarely samples from multiple treatments during the same precipitation event there are limited options for analysis. Some recent literature has indicated the importance evaluating phosphate in tile drainage however in the study no significant drained phosphorus was found.

The second way to evaluate nutrient leaching is to determine the total mass of the nutrient lost over the season. The mass of nitrogen lost from the columns were adjusted to reflect a lb/acre basis to make results applicable to field conditions. The highest loss of nitrate (20.7 lb/acre) and total nitrogen (22.3 lb/acre) came from the treatment of manure without cover crops. This loss was significantly greater than the other two treatments. The cover crop with manure treatment (10.5 lb/acre nitrate and 10.6 lb/acre total nitrogen), was nominally higher than the cover crop with urea treatment (7.6 lb/acre nitrate and 8.9 lb/acre total nitrogen) for nitrogen loss; both cover crop treatments were approximately half of the total nitrogen and nitrate lost without a cereal rye cover over the monitoring period.

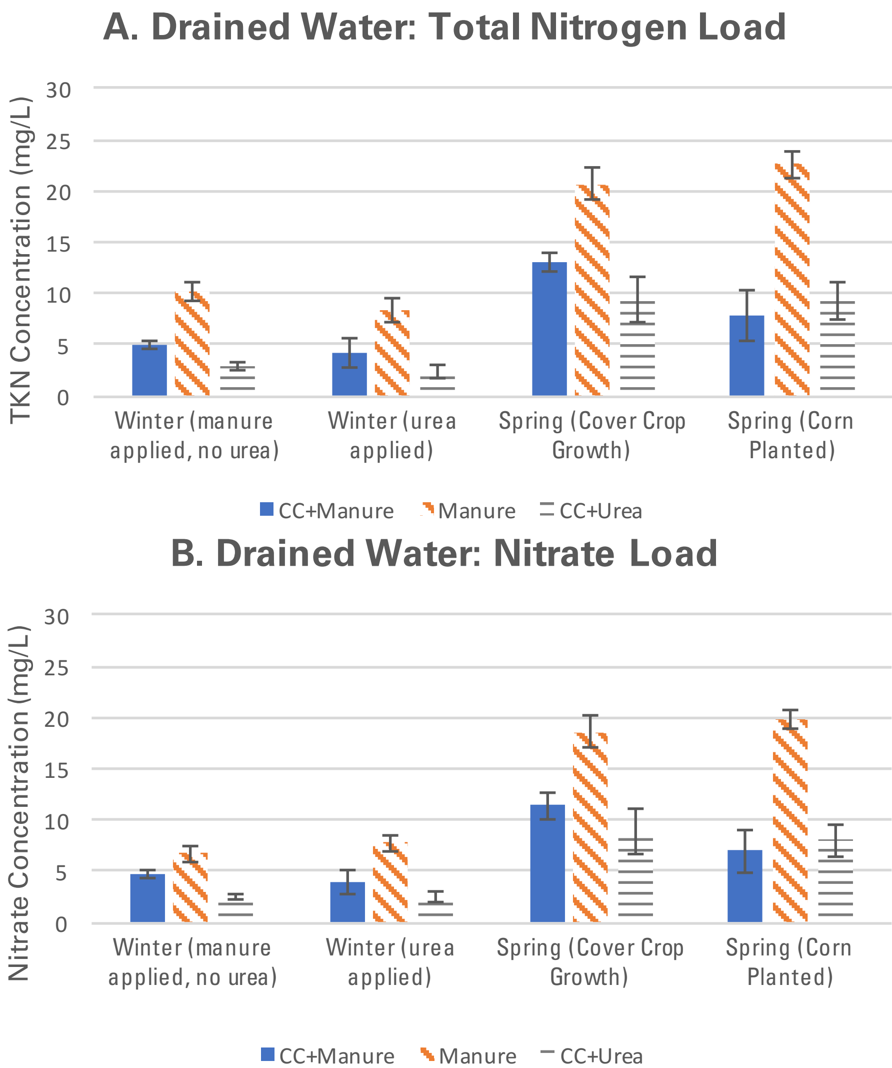

Figure 3. Concentrations of total nitrogen (A) and nitrate (B) in water samples drained from the soil columns for three treatments: cereal rye with manure, manure without cereal rye, and cereal rye with urea fertilizer. Error bars demonstrate one standard error.

The cereal rye produced 20% more biomass when a surface application of urea was used instead of injected manure. This difference in biomass is not unexpected since injecting manure does disturb the soil and plant roots for the cover crop material. This loss of plant material with manure injection is often an expressed concern for producers, however the cereal rye's nitrogen uptake per acre was similar and phosphorous uptake was higher when manure was applied (Table 1).

Table 1. Cereal rye biomass yield, nitrogen and phosphorus uptake with three fertilizer treatments with cereal rye cover for the fall 2015- spring 2016 growing season.

	Dry Matter	**N Uptake**	**P Uptake**
	tons/acre	lbs/acre	lbs/acre
CC + Manure	1.03	82.0	11.5
CC + Urea	1.21	82.6	9.9
CC + No Fertilizer	0.55	28.2	6.2

Corn yield was measured with a 4 row combine. Because the field plot for cereal rye was double width, two yields were determined. There were not replicates were available for statistical analysis, but some trends are noted (Table 2). Manure had slightly higher yields than urea with cereal rye, similarly with annual ryegrass, however when no cover crop was planted the urea treatment performed better than the manure treatment. Also, it should be noted that the annual ryegrass did not show reduced yield compared to no cover crop. In the plots with no fertilizer, both no cover and annual ryegrass produced about 40 bushel per acre. The cereal rye plots produced less than 10 bushels per acre. This is likely indicative of the bound nutrients from the cereal rye impacting corn yield. The annual rye had less biomass and a lower carbon to nitrogen ratio, likely increasing the rate of decomposition (and therefore making the nutrients available sooner).

Table 2. Average corn yield in the field with three cover crops (cereal rye, annual ryegrass, and no cover) and three fertilizer treatments: manure, urea, and no fertilizer.

Cover Crop	Treatment	Field Plot Corn Yield (bu/acre)
Cereal Rye 1	Manure	89.2
	Urea	73.3
	No Fertilizer	8.3
Cereal Rye 2	Manure	65.0
	Urea	49.4
	No Fertilizer	0.0
No Cover	Manure	128.8
	Urea	145.4
	No Fertilizer	41.8
Annual Rye	Manure	167.9
	Urea	143.5
	No Fertilizer	41.2

Final thoughts

Overall, the cereal rye performed as was expected. The cereal rye bound up nitrogen and phosphorus that was applied or was already available in the soil. While the manure injection did appear to disturb the soil and the cereal rye's root structure and therefore reduce biomass, it did not appear to reduce the amount of nutrients bound by the rye in this year. If the main goal of using a cover crop is to bind nutrients, the cover crop did complete its expected task. Additionally, the cereal rye was effective at reducing total nitrogen and nitrate in the water which drained from the columns.

In terms of corn yield, a reduction was noted for both cereal rye with manure and cereal rye with urea. This would indicate that starter N applied at planting was not adequate for the nitrogen bound by the cover crop. Higher starter application or a sidedress application may be needed to overcome this issue. It was also interesting to observe that the second cover crop used on the field plot (annual ryegrass) did not show this same issue as cereal rye. The better characteristics for decomposition with the ryegrass appear to have eliminated this decline in corn yields. This may suggest that finding the right cover crop is critical to having nutrients cycle as desired.

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AG NEWS & VIEWS

CROPS

Cover Crops: A Tool in Agricultural Production

by Jim Johnson, soils and crops consultant | jpjohnson@noble.org
and Bryan Nichols, livestock consultant | bmnichols@noble.org

There are many variables to consider when deciding if cover crops fit into a cropping system. For the purposes of this article, a cover crop is defined as a crop grown between cash crops with the primary intent of noncash benefits, such as soil heath, erosion control, weed suppression, etc. Following are three topic areas relative to cover crops that are discussed frequently among Noble Research Institute consultants.

continued on next page

Cover crops are a tool in agricultural production just as tractors and herbicides are tools. When used correctly and with purpose, they can be effective.

Water Use

Cover crops do use water. However, bare soil will also evaporate water. Trade-offs must be examined between water used by a growing plant and its benefits versus water lost through evaporation. Other management practices can be employed to reduce, but not eliminate, water loss on fallow ground through evaporation, such as eliminating tillage and maintaining good residue cover. Even though a cover crop does use water, it also has the potential to increase infiltration when subsequent rains occur, which can offset the amount of water used by the growing plant. Obviously, there are risks in this equation. If the rains do not come in a timely manner, soil moisture may not be restored soon enough and the following crop will be affected. In some environments, a growing cover crop using water may be seen as a positive when wet conditions that prevent field work exist.

Climate

Climate varies according to location, and our farming practices should and do vary accordingly. Amount of rainfall is not the only underlying climatological factor in agricultural production. Temperature, evapotranspiration (the sum of evaporation from the land plus transpiration from plants), timing of rainfall, growing season, etc., must also be taken into account. It is important to look at research conducted in a similar environment to determine the effect of cover crops in a cropping system.

Economics

Integrating cover crops must be an economical proposition. In some areas, economic benefits may be seen immediately through yield increases or reduced erosion, which reduces machinery costs, etc. Others may not see benefits for an extended period of time. Most of the proponents of cover crops tout the long-term benefits more than the short-term. This is an area where very little, if any, research is available. Each operator must ask themselves whether the short-term costs are worth the real and/or perceived long-term benefits.

Cover crops are a tool in agricultural production just as tractors and herbicides are tools. When used correctly and with purpose, they can be effective. When used incorrectly or with unrealistic expectations, they can be harmful. Agricultural producers do not make a living by growing cover crops; rather, they make a living by producing a saleable product. Focus on the system that does this in the most efficient and profitable way while maintaining and improving the land resource for generations to come.

Cover Crop Videos Online

The Noble Research Institute is testing dozens of cover crop species with potential to help build soil health in the Southern Great Plains. Watch for an upcoming video series featuring the cover crops we've grown on our Headquarters Farm in southern Oklahoma. We'll share our thoughts on establishment and growth, ground cover potential, and weed control. Look for them soon at youtube.com/nobleresearchinstitute.

A common sunflower, like other types of sunflowers, attracts pollinators. Typically, black oil sunflowers (not pictured) are used as cover crops.

Additional resources

Jim Johnson, Soils and Crops Consultant, Noble Research Institute

Related publications

Includes links to publications, news and articles.
https://www.noble.org/staff/jim-johnson/

Noble Research Institute Legacy issue focused on cover crops.
https://www.noble.org/news/publications/legacy/2017/winter/

Related videos

Playlist of cover crop videos.
https://www.youtube.com/playlist?list=PLIIQw8FHFtX88btL12rdFmjANlm8d-mtJ

Video for calibrating a drill to plant cover crop

https://www.noble.org/videos/seed-drill-calibration/

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Mycotoxins in cattle feed: Detection, consequences and preventive strategies

Trevor K. Smith, adjunct professor, Dept. of Animal Biosciences, University of Guelph

Introduction

Mycotoxins are toxic compounds produced by fungi (molds). It appears that the frequency of mycotoxin challenges in animal production globally is increasing. One causative factor may be increasingly common extreme weather conditions. Excess rainfall and flooding during the growing season and at harvest can promote mold growth and mycotoxin contamination of feedstuffs preharvest. Drought can also result in mycotoxin contamination as cracking or shriveling of grains can result in mechanical damage to outer protective layers of grains permitting easier colonization by fungal spores. A factor that increases the severity of response of cattle to a given concentration of mycotoxins in feeds is the complex nature of modern rations with many different potentially contaminated feed ingredients including grains, protein sources, by-products, silage and hay. This means that cattle routinely face a multiple mycotoxin challenge when considering the total ration. There can often be ten or more detectable mycotoxins although many may be in very low concentrations. There is the potential, however, for additive and possibly synergistic effects which result in increased severity of responses compared to what might be expected if equivalent amounts of individual mycotoxins were ingested.

On a global basis, the mycotoxins of greatest significance in cattle production include aflatoxin and the many *Fusarium* mycotoxins (Smith and Korosteleva, 2010). Aflatoxin is produced mainly by *Aspergillus flavus*, which is a tropical or semi-tropical fungus that thrives under conditions of high temperature and humidity. Aflatoxin is a potent carcinogenic hepatotoxin and the tolerance of cattle to aflatoxin has been described thoroughly in the scientific literature. Analyzing feeds for aflatoxin is relatively simple as only four main metabolites, aflatoxins B1, B2, G1 and G2, have been identified. *Fusarium* fungi thrive in more temperate climates. Our understanding of the toxicity of *Fusarium* mycotoxins in cattle is much less complete because of the large number of compounds, several hundred have been identified, which have a wide range of chemical structures. It is not practical, therefore, to exhaustively analyze cattle feeds for *Fusarium* mycotoxins. Only a few compounds are routinely analyzed for including, for example, deoxynivalenol (DON, vomitoxin) and fumonisin. This is not a very precise estimate of the hazard posed by contaminated feeds, however, as the response of cattle to a given dose of these compounds will depend on the nature and relative amounts of co-contaminants. An additional challenge in cattle production is mycotoxin contamination of silages. These can also contain many *Aspergillus* and *Penicillium* mycotoxins many of which have antibiotic properties which can reduce rumen function as well as having other specific toxicities.

Analyzing cattle feeds for *Fusarium* mycotoxins

A relatively new complication in analyzing cattle feeds for *Fusarium* mycotoxins is the concept of conjugated or "masked" mycotoxins (Berthiller et al., 2013). Mycotoxins are produced by fungi which can invade plants. The plant, however, can chemically modify the mycotoxin in what is thought to be plant detoxification reactions. The result is conjugated or "masked" mycotoxins. An example is the conversion of DON into DON-3-glucose. Such conjugated forms of mycotoxins have been reported for many compounds including DON, zearalenone, fumonisin, T-2 toxin, ochratoxin, fusarenon-X, fusaric acid and nivalenol. There is some evidence that conjugated forms of mycotoxins may be hydrolyzed by microbial enzymes in the digestive tract to yield free mycotoxins. This would render the conjugated forms toxic. In the absence of chemical standards for the conjugates, however, and with minimal cross-reactivity in ELISA test kits, the conjugated forms are non-detectable, hence the term "masked". A survey of Canadian corn samples has shown that including conjugated DON in analysis of total DON increased the detectable DON by up to 43% (Tran et al., 2012). It can be concluded, therefore, that our current analytical procedures are likely significantly underestimating the true concentrations of many mycotoxins thereby complicating quality control procedures and increasing the chances of exposing cattle to contaminated feeds.

The significance of immunosuppression in mycotoxicoses

Immunosuppression is likely the most economically significant consequence of feed-borne mycotoxins. When cattle are immunosuppressed we see lingering health problems in the herd, animals that do not respond to medications and potential failure of vaccination programs. The result is uneven growth rates and increased mortalities. The lesions seen post-mortem are, moreover, not lesions typically caused by mycotoxins. They are lesions caused by the infectious organisms which took advantage of the mycotoxin-induced loss of immunity. The losses are, therefore, only indirectly caused by mycotoxins. To further complicate diagnosis, the mycotoxin concentrations in feed are likely underestimates of the true levels of mycotoxin contamination due to the presence of undetected conjugated mycotoxins. The incorrect conclusion, therefore, is often that mycotoxins are not a causative factor in losses.

Categories of fusarium mycotoxins

Fumonisins

The fumonisins are a small family of relatively recently discovered Fusarium mycotoxins. The most common is fumonisin B1. The chemical structure of fumonisin is such that it can specifically inhibit the synthesis of sphingolipids resulting in impaired membrane function. Corn and corn by-products are the most common sources of fumonisin. Horses are particularly sensitive to fumonisin and as little as 3 mg/kg of feed can be fatal due to equine leukoencephalomalacia, an atrophy of the brain. The feeding of rations containing 440 ppm fumonisin had little negative effect on Holstein steers (Baker and Rottinghaus, 1999). Such concentrations are very high and it would be very unlikely to encounter such levels under field condions. This does not mean that fumonisin is irrelevant in cattle production, however, because fumonisins also contribute to immunosuppression.

The Trichothcecenes

The trichothecenes are a large group of several hundred structurally-related compounds of which DON is likely the most common contaminant of livestock feeds. Other common trichothecenes include nivalenol, T-2 toxin, H-T2 toxin, diacetoxyscirpenol and fusarenon-X. The trichothecenes are pharmacologically active and can increase brain concentrations of serotonin. Elevated serotonin results in behavioral changes such as loss of appetite, loss of muscle coordination and lethargy. The trichothecenes also inhibit tissue protein synthesis causing them to be dermal necrotic agents. The tissues first affected, therefore, by ingestion of contaminated feeds are the epithelial lining of the digestive tract. In cattle this may contribute to hemorrhagic bowel syndrome. The trichothecenes are also immunosuppressive, however, and can contribute to reduced herd health status.

Zearalenone

The mode of action of zearalenone is simpler than that of most other *Fusarium* mycotoxins. Zearalenone has no effect on behavior or immunity. Zearalenone is estrogenic and can influence reproduction. The geometry of the zearalenone molecule allows it to bind to estrogen binding sites in the reproductive tract. This mycotoxin is anabolic and promotes tissue growth in target organs. Uterine enlargement is seen thereby displacing other internal organs and causing a characteristic rectal and vaginal prolapse easily seen in pigs. Increased frequency of infertility and abortions are seen in mammalians.

Fusaric acid

Fusaric acid is a common contaminant of livestock feeds but has received relatively little attention from researchers because it has a relatively low acute toxicity. The significance of fusaric acid, however, is that it is pharmacologically active. Fusaric acid inhibits the activity of brain dopamine-beta-hydroxylase which catalyzes the synthesis of norepinephrine from dopamine. The physiological effect of reduced brain epinephrine concentrations is lowered blood pressure causing edema and poor blood flow to key organ systems. This can be seen in swelling of feet and the udder. A second mode of action of fusaric acid is that it can also increase brain serotonin concentrations and in this manner fusaric acid can cause a toxicological synergy with DON to magnify the effects of low concentrations of DON in livestock feeds (Smith et al., 1997). In addition to pharmacological effects, fusaric acid is also immunosuppressive and can contribute to reduced herd health status.

Strategies for minimizing the harmful effects of mycotoxins

There are numerous strategies that can be employed to minimize the harmful effects of feed-borne mycotoxins both pre- and post-harvest (Jouany, 2007). Diluting contaminated grains with grains of lower contamination can reduce the mycotoxin concentration below the threshold of biological activity. Mycotoxin concentrations are usually greatest in small, broken fractions of grain. The removal of screenings can decrease grain mycotoxin concentrations by 20-25%. Feed additives known as mold inhibitors can stabilize high moisture content grains in storage. These are weak organic acids, such as propionic acid, which can be applied to grains in storage. Such acids kill live mold spores by lowering the pH of the grain. This will prevent the synthesis of new mycotoxins but such acids are too weak to inactivate mycotoxins already present in the grain as these are very chemically stable. Silage inoculants can have a similar effect. Specialized feed grade enzymes of microbial origin can be added to livestock feeds and can inactivate mycotoxins in the digestive treact of the animal and thereby prevent uptake into blood. This approach is complicated by the specificity of different enzymes for different chemical structures. Multiple co-contaminants will require multiple matching enzymes to ensure detoxification. It is also not clear that the enzyme that can inactivate DON, for example, can also inactivate the various forms of conjugated DON. To use the enzyme approach effectively, therefore, it would be necessary to have an array of enzymes that matched the array of free and conjugated contaminants. Such a sophisticated array of enzymes, however, is not yet commercially available. Where the enzymes are very specific, the opposite approach is the use of mycotoxin adsorbents. The adsorbents are high molecular weight, highly-branched polymers which are non-nutritive, non-digestible and non-fermentable (Ramos et al, 1996). These polymers can pass down the digestive tract intact and adsorb small molecules to prevent absorption from the digestive tract. Adsorbents can be inorganic, silica-based materials such as zeolites, bentonite and diatomaceous earth. Organic adsorbents can contain activated charcoal, lignin and glucomannan polymers extracted from the inner cell wall of yeast. The non-specific nature of the adsorbents makes them well suited to multiple co-contaminants with differing chemical structures in both free and conjugated forms. The lack of specificity, however, means that the adsorbents are also capable of adsorbing other small molecules including vitamins, minerals, amino acids and bile salts. The level of inclusion of the adsorbent must, therefore, be appropriate for the degree of mycotoxin contamination in the feed in question.

Studies of the feeding of blends of grains naturally-contaminated with *Fusarium* mycotoxins to cattle

A series of experiments have been conducted feeding cattle blends of corn, wheat, silage and hay naturally-contaminated with *Fusarium* mycotoxins. Multiple mycotoxins were detected including DON, zearalenone, fusaric acid and 15-acetyl DON and these would be present in both free and conjugated forms. The objective of the studies was to mimic conditions seen in the field.

Dairy cows

A TMR containing a blend of feedstuffs naturally-contaminated with *Fusarium* mycotoxins including corn, wheat, hay and silage was fed for 56 days to 18 midlactation Holstein cows with DON concentrations of 3.6 ppm (Korosteleva et al., 2007). Dry matter intake, body weight, milk production and milk composition were not affected by diet. There was a significant elevation in blood urea concentration for cows fed the contaminated TMR compared to controls. There was also a significant reduction in blood immunoglobulin A concentrations. It was concluded that the feeding of contaminated diets impaired immunity and reduced nitrogen utilization in dairy cows. A subsequent study examined the effects of contaminated diets on immunity in more detail (Korosteleva et al., 2009). Neutrophil phagocytotic activity was significantly reduced when contaminated diets were fed while specific antibody response to ovalbumin injection was also altered. These studies confirmed the sensitivity of dairy cattle immunity to feed-borne mycotoxins.

Veal calves

Thirty-two grain-fed veal calves were fed diets containing corn naturally-contaminated with *Fusarium* mycotoxins for 84 days (Martin et al., 2010). Dry matter intake and blood glucose concentrations were decreased compared to controls when contaminated diets were fed as were hot carcass weight, back fat and longissimus muscle area. It was concluded that carcass characteristics can be adversely affected by exposure of cattle to mycotoxin-contaminated feed and this may be related to reduced appetite.

Conclusions

It can be concluded that cattle are sensitive to the feeding of diets naturally-contaminated with mycotoxins. Economic losses are incurred due, in part, to mycotoxin-induced immunosuppression. The best defence against this is rigorous quality control procedures to ensure that cattle are not exposed to contaminated feeds. This is complicated, however, by the presence of non-detectable conjugated mycotoxins. Until advances are made in analytical procedures, the use of an appropriate mycotoxin adsorbent in recommended.

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Grazing supplementation for pastured stocker cattle

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Summary

Four purposes for supplementation of pastured stocker cattle are as follows. It is a method for providing 1) additional nutrients when nutrients available from forage biomass are insufficient, 2) an additional feed resource for the purpose of reducing forage intake and thereby extending the grazing season, 3) feed additives such as ionophores, and 4) dewormers, thereby avoiding the need to individually restrain animals for dose administration. The evidence strongly suggests that supplementation of an energy source, rather than a protein source, yields a growth response by stocker cattle. The literature dataset analyzed here resulted in the following estimate for a supplement substitution effect. For high quality forage, forage dry matter intake (DMI) declined linearly with increases in supplementation level. Each increase in 1% body weight (BW) of supplement DMI resulted in 0.65% of BW decrease in forage DMI. This is the reason why supplementation can be used to extend the supply of forage. For low quality forage, the substitution effect is evident at supplementation levels greater than 0.23% BW. The dataset also revealed that there was no evidence for a negative effect of supplementation on in vivo digestibility of plant cell walls. In conclusion, when supplementation is implemented, the feed should be an energy source. When a feed carrier for a supplemented additive is chosen, an energy source is recommended because it will also contribute to an animal performance response. Thereafter, the next decision criterion would be cost per unit energy, so that the animal performance response is most cost effective. Supplementation of P seems unnecessary for stocker cattle grazing summer forages in the Driftless Region.

Introduction

The role of ruminant animals in food production is to convert humanly indigestible plant cell walls into humanly digestible and palatable protein and energy sources. This role is eminently displayed by stocker cattle. The stocker cattle segment of the U.S. beef cattle industry involves weaned calves that have recovered from the stresses of castration, dehorning, weaning and co-mingling. Producers who have forage resources of sufficient quality and quantity to support modest growth rates to achieve 100 to 150 kg of gain by these young cattle purchase them. (One kilogram equals 2.2 lb.) A common example of stocker grazing is fall-born, weaned calves purchased in the spring and then grazed until fall on cool-season grass pastures. A second example is spring-born, weaned calves purchased in fall and then grazed over winter on winter wheat until March or May. The latter example is common in western Kansas, Oklahoma and the Texas Panhandle. The former example is typical of stocker grazing operations in the Midwest and therefore will be the focus of this paper.

Since the stocker cattle production system aims for cattle growth on grass, lightweight steers or heifers are turned out for grazing so that heavyweight cattle can be sold for placement into feedlots for finishing. This means that quantity of forage nutrients needed increases during the grazing season due to growth of the cattle. Of course, the intent of the grazier is for the entire herd to remain intact and graze until the season concludes. To do otherwise would mean that some of the cattle are sold before the end of the grazing season to reduce grazing pressure, and selling cattle after a short period of ownership increases the risk that the revenue received will not cover the cost of gain if the feeder cattle market declines. The challenge to the grazier's intention is compounded in the Upper Midwest by suppressed productivity of cool-season pasture forage species during the warmth of summer. By mid-summer, the cattle have grown from their turn-out weight in spring and therefore their nutrient requirements have increased but the nutrient supply from pasture biomass has declined. Consequently, the forage nutrient supply is deficient compared to the need for nutrients by the cattle. How does one satisfy this deficiency? The answer is to provide supplemental nutrients.

Purposes for supplementation

Feed supplementation for grazed cattle could have four purposes. First, supplemental feed could be provided to satisfy the nutrient deficiency that develops during the grazing season between cool-season pasture biomass supply and cattle nutrient requirements. This leads to the question, 'which nutrient(s) should be supplied by the supplemental feed?' This question will be addressed in the next section. Secondly, feed supplementation could be done for the purpose of reducing the consumption of forage thereby extending the number of days during which the forage resource could be grazed. In other words, supplementation extends the duration of the grazing season because supplemental feed substitutes for forage consumption. Thirdly, supplemental feed could be the carrier for delivering a performance-enhancing additive, such as an ionophore, to pastured cattle on a daily basis or for a specified duration. Lastly, feed-grade dewormers can be conveniently administered via a feed carrier, which therefore is supplementation. Young cattle are more susceptible to worm infestations as a result of grazing than are adult cattle. In addition, rotationally grazed young cattle are even more likely to experience worm infestations because the moist, summertime conditions beneath the pasture forage canopy are more conducive to development of the infective stage of worm larvae. In all four situations, the logical follow-up question is 'which feed should be supplemented?' It seems logical that the answer should be a kind of feed that provides the least-cost stocker gain or least-cost forage substitution.

Which nutrient to supplement?

We have used two approaches to address the question of which kind of feed to supplement. The first approach was a series of experiments in which a variety of nutritional or management treatments were applied to grazed Holstein steer calves. Our second approach was to review the supplementation research published during 1998 to 2013. The latter approach encompasses a variety of pasture forages, climates, management scenarios and years. Importantly, more treatments and cattle are involved, thus increasing confidence in the resulting conclusions. Many of the management scenarios involved grazed beef cattle but some involved harvested forages fed to cattle in confinement.

Lancaster supplementation trials – Screening for the growth-limiting management practice

A 6-yr project was conducted at the Lancaster Agricultural Research Station (LARS) to determine the growth-limiting management practice for Holstein steers grazing pastures typical of the Driftless Region (southwest Wisconsin, southeast Minnesota, eastern Iowa, and northwestern Illinois). The first 3 yr of this project received some financial support from Hoffmann-LaRoche Inc and Equity Cooperative Livesock Sales.

Typical animal and pasture management procedures were as follows. Holstein steers (400 lb) were purchased from a variety of states, unloaded at LARS in April, vaccinated against respiratory pathogens and pink-eye, dewormed, fitted with transponders and trained to use Calan headgates, and rotationally grazed on perennial cool-season grass-legume pastures. Pasture swards included blue-, brome-, orchard-, fescue, and quack grasses, as well as red and Kura clovers. Nitrogen fertilizer was applied in mid-April, late June and early August. One acre paddocks were grazed with rest periods that were 12-20 days early in the season and 45 days late in the season. When forage growth exceeded animal consumption, additional cattle or mechanical harvesting equipment were used to remove excess growth and ensure that immature forage was available for grazing. Prior to steer entry into a paddock, quadrat samples were collected by clipping and then analyzed for crude protein (CP), acid detergent fiber (ADF) and neutral detergent fiber (NDF). Insecticide-impregnated fly tags were installed for fly control. Four steers were randomly assigned per treatment replicate, and there were three replicate groups for each treatment. Steers in the control or Synovex-S treatments had access to the same pasture as supplemented steers, but received only trace mineralized salt and water. All dietary supplements were hand-fed daily via Calan feeding gates. Calan feeding gates and associated feed troughs were rotated with the cattle through the paddocks. Initial and final weights were unshrunk weights collected on two consecutive mornings.

During 1995-1997, the experimental design included five treatments with 12 steers per treatment. The experimental design compared the effects of ground corn supplementation at 1% of body weight (BW), Synovex-S implant administered on d 1 and 84, Bovatec (200 mg/hd daily provided in 1 lb of wheat middlings), and two-way or three-way combinations of these treatments as shown in Table 1. The amount of corn supplement (i.e., 1%

BW) was based on initial and 28-d interim BW. Duration of the grazing trials was 91 d in 1995, 125 d in 1996, and 162 d in 1997. Inexperience in trial conduct accounted for the short duration in 1995. Drought shortened the grazing season in 1996. Normal temperatures and above-average rainfall accounted for very good pasture forage availability and longer grazing season in 1997.

Forage available at entry into a paddock was typically 2000 lb DM per acre. There was incomplete consumption of the corn and corn-containing supplements in all three years, especially in May and early June. Supplement consumption increased during the grazing season but was typically 70-80% of the amount offered to the steers. In 1997, forage composition was 19% CP, 31% ADF and 49.7% NDF. Large quantities of high quality forage were available during the 1997 season and perhaps this played a role in reducing appetite by cattle for corn. Across the five treatments, ADG was 1.89 lb/d in 1995, 2.38 lb/d in 1996, and 2.71 lb/d in 1997 (Table 1). Slow growth rates in 1995 are partly attributed to loss of body condition by these steers which had been raised on a high-grain regimen prior to their purchase for this trial. Growth of the control steers was faster in 1996 and 1997. It is unlikely that CP content of the pasture forage limited cattle ADG since the dietary CP requirement for these steers is 14-15% CP. All treatments including corn (C) resulted in improved ADG ($P < 0.05$), which indicates that energy was the limiting nutrient for growth.

Table 1. Summary of treatment effects on average daily gain (ADG) by grazed Holstein steers during 1995-1997 grazing seasons.

	ADG (lb/d)		
Treatment	**1995**	**1996**	**1997**
Control	1.55^{a}	2.05^{a}	2.38^{a}
Synovex-S (S)	1.66^{a}	2.21^{a}	2.68^{b}
Corn, ground (C)	1.92^{b}	--	--
S + C	2.14^{c}	2.44^{b}	2.92^{c}
S + Bovatec (B)	--	2.48^{b}	2.57^{ab}
S + C + B	2.19^{c}	2.74^{c}	2.99^{c}

^{a,b,c} Means within the same year with different superscripts are different ($P < 0.05$).

Corn supplementation increased ADG in all years, but the conversion of corn to weight gain was relatively inefficient and ranged from 7.7 to 21.4 lbs corn consumed per additional pound of weight gained. Efficiency of corn conversion to weight gain was better in the weather-shortened grazing seasons of 1995 and 1996. Our methods did not allow us to quantify the effect of corn supplementation on forage intake or pasture carrying capacity. The Synovex-S implant improved ADG numerically in each of the 3 yr, but only in a statistically significant manner in 1997 when control ADG was 2.38 lb/d. Since implants function by increasing muscle growth at the expense of fat deposition, it is to be expected that the implant benefit would occur when fat deposition occurs. In Holstein steers with initial weights of 173-223 kg (380-490 lb), a significant advantage due to implanting and re-implanting with Synovex-S only occurred when unimplanted steers gained in excess of 2.3 lb/d. Bovatec supplementation resulted in a significant benefit only in 1996 ($P < 0.05$) and not in 1997. In summary, corn supplementation consistently demonstrated that digestible energy was the limiting nutrient for growth of these cattle.

The objective of the succeeding project was to test the effect of supplemental CP, degradability of the supplemental protein, and frequency of paddock rotation on steer ADG. During 1998-2000, there was a factorial arrangement of six treatments – no supplemental CP vs normal soybean meal (SBM) vs SoyPlus soybean meal and 2-d vs 4-d paddock rotation frequency. SoyPlus had a ruminal degradability of 40% whereas conventional SBM had a ruminal degradability of 65%. The hypothesis was that steer ADG may be limited by intestinal supply of amino acids. If so, then SoyPlus should increase ADG. All steers were implanted with Synovex-S on d 1 and 84. SBM and SoyPlus were provided at 1 lb/steer daily and the trials began in late April to early May and continued to mid-September. There were two replicate groups of steers for each treatment, but each control (no supplemental CP) treatment replicate was populated by 8 steers while each SBM or SoyPlus treatment replicate was populated by 4 steers. Thus, in each of the two replicates there were 8 control steers, 4 SBM steers, and 4 SoyPlus steers. Each of two groups was rotated on a 2-d frequency while the other two groups were rotated on a 4-d frequency.

The results of this 3-yr project indicated that neither rotation frequency nor protein supplementation or source affected ADG. The results are shown in Table 2. There were no differences in ADG among treatments. These results mean that the pasture supplied sufficient CP to the steers and not even SoyPlus with its reduced ruminal protein degradability improved ADG.

Table 2. Summary of treatment effects on ADG by grazed Holstein steers during 1998-2000 grazing seasons.

Rotation Frequency, d	Protein Supplement	ADG, lb/d
2	Control	2.19
2	SBM	2.25
2	SoyPlus	2.23
4	Control	2.14
4	SBM	2.25
4	SoyPlus	2.28
Frequency x Protein	P value	0.83

There are two macro-nutrients in the diet DM of grazed cattle, digestible energy and protein. In each instance during 1995-1997 when corn was supplemented, ADG increased. The consistency of this response is interpreted to mean that digestible energy is the growth-limiting nutrient for grazed cattle.

Mineral - Phosphorus

It has often been stated that supplemental phosphorus (P) is needed for grazed cattle, yet very little research has been conducted in the Upper Midwest to assess macro-mineral supplementation for pastured beef cattle. Since elevated soil P concentrations may contribute to high P concentrations in sediment runoff and thus contribute to decreased surface water quality, and since P is a relatively expensive mineral, it is appropriate to assess the need for supplemental P by grazed cattle.

This was the motivation for the phosphorus supplementation project reported by Brokman et al. (2008). A 2-yr study was conducted with 248-297 kg (546-653 lb) Holstein steers that were supplemented with trace mineralized salt or a mixture of 67% trace mineralized salt and 33% dicalcium phosphate which contained 6.2% P, 7.4% calcium and 0.16% magnesium and was consumed at the rate of 45-50 g (1.6 ounces) daily. Calcium consumed in pasture forages satisfies cattle growth requirements. Steers rotationally grazed fertilized cool-season grass and legume pastures that contained at least 0.29% P (DM basis). Provision of supplemental P did not improve ADG. This was explained on the basis that the steers had a daily P requirement of 17 g P and their forage DMI was 2.7% BW which provided 23-31 g P per day. This was at least 126% of the P requirement. In summary, the grazed forage alone provides sufficient P intake to meet the P requirement of growing cattle.

Mineral – Magnesium

Magnesium (Mg) is commonly associated with grass tetany, a muscle contraction problem experienced by spring-calving, lactating cows that graze spring pastures which have been fertilized with potassium. High potassium and low Mg content of the spring forage is associated with cows that lose their muscle coordination, fall over on their side, convulse and eventually die. The counter-measure is to add magnesium oxide to the salt supply as an attempt to increase voluntary Mg consumption. The Mg requirement for early lactation cows is 0.20% while for gestating cows it is 0.12% (diet DM basis). The higher requirement for lactating cows is due to the additional need for Mg due to Mg output in milk.

This Mg disorder is not typically associated with grazed steers or heifers. However, my (DS) experience is that sick steers have been diagnosed with low blood Mg concentrations and the Mg concentration of spring pasture forage has been observed to decline to near the dietary requirement for growing cattle which is 0.10%. Symptoms of magnesium deficiency in calves are excitability and frothing at the mouth, which advance to convulsions. Mg disorders are due to reduced Mg absorption from the rumen, which can be due to high potassium intake, high ruminal ammonia concentrations, and certain plant chemicals (NASEM, 2016). Yet from a grazier's perspective, supplementation of Mg in the trace mineralized salt is about the only practical preventive step that can be taken to prevent a Mg deficiency. Stocker cattle at the Arlington Beef Grazing farm receive a trace mineralized salt containing 12% Mg to reduce this risk during spring grazing season.

Meta-analyses of grazing supplementation literature

A meta-analysis is a method for systematically combining pertinent qualitative and quantitative study data from several selected studies to develop a single conclusion that has greater statistical power. Two analyses were conducted to investigate the effects of beef cattle supplementation on feed intake and growth. In the first analysis, we investigated the effect of different types of supplements (Energy, Protein and Protein+Energy) on the ADG (kg/d), supplement intake (% BW and kg/d) and supplement CP intake (kg/d) within low and high quality forage diets. The response was expressed as the difference in ADG (kg/d) between the supplemented and control treatments (i.e., supplemented minus control), which resulted in one observation per treatment-and-control pair. The types of supplements were classified according to CP concentration. Three categories were used: Energy: CP < 15%, Protein: CP > 30%, and Protein+Energy: CP between 15 and 30%. In the dataset, the most common feed used as an Energy supplement was corn, while soybean meal was the most common feed used as a Protein supplement. Additional feeds that were used in the dataset were citrus pulp, cottonseed meal, soybean hulls, corn gluten meal, wheat meal and urea. The forages were classified as low or high quality when the CP concentration was less than or greater than 9%, respectively. The second type of analysis involved regression analysis of the effects of level of supplementation on the forage DM intake (% BW), total DM intake (% BW), total tract organic matter digestibility (OMD, %), in vivo total tract NDF digestibility (TTNDFD, %) and ruminal pH.

Dataset and analyses

Three databases were searched: Web of Science, Scielo and Scopus, with the following combination of search terms used: beef cattle, supplementation, grazing, forage, concentrate, intake, performance, protein, energy, supplement, source, digestibility, and ruminal pH. To be included in the dataset, the study must have reported the forage and total DMI, ADG, and number of observations.

In order to evaluate the effect of source of supplement on animal performance, 44 studies reported in 34 peer-reviewed published papers (Barbosa et al., 2007; Baroni et al., 2000; Cabral et al., 2008; Fernandes et al., 2010; Jung et al., 2009; Leão et al., 2005; Nascimento et al., 2009; Paulino et al., 2006; Porto et al., 2009; Simoni et al., 2009; Goes et al., 2005a; Gomes et al., 2002; Zervoudakis et al., 2002; Silva et al., 2010; Porto et al., 2008; Ruas et al., 2000; Nascimento et al., 2010; Wheeler et al., 2002; Figueiredo et al., 2011; Porto et al., 2011; McLennan et al., 2012; Marsetyo et al., 2012; Matheus et al., 2011; Pavan and Ducket et al., 2008; Elizalde et al., 1998; Moreira et al., 2003; Santos et al., 2004; McDonald et al., 2007; Casagrande et al., 2011; Sales et al., 2008; Zanetti et al., 2000; Valente et al., 2011; Cabral et al., 2012; Couto et al., 2010), 4 PhD dissertations (Correia, 2006; Acedo, 2008; Casagrande, 2010; Vieira, 2011), and 2 Master theses (Ramalho, 2006; and Costa, 2007) were compiled. These studies were published between 1998 and 2013, totaling 126 treatment comparisons (mean response = supplement – control), derived from 2,591 beef animals. Statistical analysis was conducted to test the fixed effect of source of supplementation on animal performance response and supplement intake. In addition, the mean weighted responses were tested if they differed from zero. Descriptive statistics for the dataset are shown in Table 3. Across both forage quality categories, there is much similarity for means and ranges for body weight (BW), supplement TDN, and forage neutral detergent fiber (NDF). The BW of cattle consuming low and high quality forages was 279 kg (614 lb) and 296 kg (651 lb), respectively. There appears to be greater variability in the CP content of the supplements used in the low quality reports. As expected from the sorting process, forage CP ranges do not overlap and the mean CP for low and high quality forages is 6.5 and 13%, respectively.

Table 3. Descriptive data for studies used in the animal performance analysis (*n* = 44 studies) sorted by forage quality (low: CP < 9% DM, and high: CP > 9% DM)

	Low quality (< 9% CP)				High quality (> 9% CP)			
	Average	**SD**	**Min**	**Max**	**Average**	**SD**	**Min**	**Max**
n	40	24	12	116	70	58	16	214
BW, kg	279	93	140	473	296	90	130	546
Supplement TDN, % DM	77.0	9.3	45.0	93.4	80.0	6.0	69.3	90.0
Supplement CP, %	34.4	18.0	10.3	91.0	25.1	10.6	6.4	40.0
Forage CP, % DM	6.5	1.7	3.4	9.0	13.0	3.9	9.1	20.8
Forage NDF, % DM	70.4	6.6	58.3	84.3	65.3	5.7	56.0	72.7

A regression analysis to investigate the relationship of level of supplementation with feed intake was performed using a dataset set from 45 studies published between 1974 and 2011 (Lake et al., 1974; McCollum and Galyean, 1985; Caton et al., 1988; Guthrie et al., 1988; Stokes et al., 1988; Pordomingo et al., 1991; Koster et al., 1996; Hess et al., 1996; Elizalde et al., 1998; Mathis et al., 2000; Ruas et al., 2000; Barbosa et al., 2001; Brokaw et al., 2001; Detmann et al., 2001; Wheeler et al., 2002; Bodine and Purvis, 2003; Moreira et al., 2003; Santos et al., 2004; Detmann et al., 2005; Góes et al., 2005b; Freitas et al., 2005; Ribeiro et al., 2005; Richards et al., 2006; Barbosa et al., 2007; MacDonald et al., 2007; Loy et al., 2007; Figueiredo et al., 2008; Pavan and Ducket, 2008; Sales et al., 2008a,b; Wickersham et al., 2008; Morais et al., 2009; Nascimento et al., 2009; Simoni et al., 2009; Casagrande, 2010; Dórea, 2010; Figueira et al., 2010; Morais et al., 2010; Nascimento et al., 2010; Paula et al.,2010; Bohnert et al., 2011; Costa et al., 2011; Figueiredo et al., 2011; Paula et al., 2011; Porto et al., 2011;and Vieira, 2011). Descriptive statistics for this dataset are shown in Table 4. The means and ranges are similar for BW, level of supplementation, forage DMI, total DMI, and forage NDF. There appears to be a greater average CP and more variable CP content in the supplements used in the low quality reports. As desired, the forage CP means and ranges are different due to sorting.

Table 4. Descriptive data of studies used in the forage and total dry matter intake analyses (*n* = 45 studies) divided by pasture forage quality (low: CP < 9% DM, and high: CP > 9% DM)

	Low quality (< 9% CP)				High quality (> 9% CP)			
	Average	**SD**	**Min**	**Max**	**Average**	**SD**	**Min**	**Max**
BW, kg	323	113	191	580	343	103	130	580
Level of supplementation, % BW	0.24	0.32	0.00	1.00	0.35	0.25	0.00	1.32
Forage DMI, % BW	1.66	0.39	0.61	3.42	2.13	0.53	1.09	3.49
Total DMI, % BW	1.91	0.39	0.61	3.42	2.48	0.53	1.63	3.49
Forage CP, % DM	6.0	4.2	1.9	9.0	13.2	1.8	9.5	23.6
Forage NDF, % DM	73.0	7.0	48.5	80.9	67.9	6.0	53.5	80.8
Supplement CP, % DM	33.2	16.4	19.2	92.4	18.8	10.2	10.9	46.1

To evaluate the effect of supplementation on OMD, TTNDFD and ruminal pH, a subsample of the dataset was used, since few studies in the dataset reported these variables. The studies compiled to evaluate OMD, TTNDFD and ruminal pH were Porto et al., 2011; Valente et al., 2011; Cabral et al., 2012; Nascimento et al., 2009; Nascimento et al., 2010; Wheeler et al., 2002; Figueiredo et al., 2011; Sales et al., 2008; Couto et al., 2010; Bodine et al., 2003; Lake et al., 1974; Brokaw et al., 2001; Martin and Hibberd et al., 1990; Richards et al., 2006; Hess et al., 1996; Carey et al., 1993; Elizalde et al., 1998; Pordomingo et al., 1991; Chase Jr. et al., 1987; Caton et al., 1988; Lardy et al., 2004; Pavan and Ducket, 2008; Faulkner et al., 1994, Franco et al., 2002; Franco et al., 2004, Goes et al., 2005; and Paulino et al., 2006.

Response of ADG to different type of supplements

Average daily gain and supplement intake (Table 5) were evaluated using the mixed procedure of SAS (SAS Inst. Inc., Cary, NC), with type of supplement (Energy, Protein and Protein+Energy) included as a fixed effect in the model and "study" as a random effect (St. Pierre, 2001). The ADG and supplement intake responses were weighted by the number of observations used in each study. The data were evaluated for leverage and influence using the DFFITS and DFBETAS procedures (Belsley et al. 1980).

Regression analysis

The response variables included in the models were total DMI (% BW), forage intake (% BW), OMD (%), TTNDFD (%), and average ruminal pH. The explanatory variable was the level of supplementation (% BW). The models included the fixed effect of level of supplementation (explanatory variable) and the random effect of "study" (St. Pierre, 2001). The models were weighted by the number of observations used in each study. Estimation for all models was carried out using the method of maximum likelihood assuming that the covariance structure was unstructured. All models were analysed using the mixed procedure of SAS. The regressions were also evaluated for leverage and influence as described in the previous section.

Results and discussion

The effect of type of supplemental feed was determined by analysis of the differences between supplement and control means for each supplement type (Table 5). All three types of supplements resulted in greater ADG ($P < 0.01$), regardless of low or high quality forage. For the high quality forages, there was no difference in the effect of Energy, Protein or Protein+Energy. However, for the low quality forage, Energy and Protein+Energy resulted in greater improvements in ADG ($P < 0.03$). Further analysis of the results (Table 5) for low quality forage reveals that Protein supplement intake, expressed in terms of percentage of BW and kilograms per day, was lower than for Energy and Protein+Energy supplements ($P < 0.001$). However, intake of supplemental CP was not different among the three supplement types ($P < 0.79$). Thus, the lower ADG effect associated with Protein supplements was apparently due to the lack of digestible energy in the supplement. With regard to high quality forage, the improvement in ADG by Energy and Protein+Energy was apparently less than when low quality forage was consumed. The fact that the ADG improvement due to Protein was equal to the ADG improvements induced by Energy and Protein+Energy may be because 1) the high quality forage may also have provided a higher plane of digestible energy intake, thus making the differential effects of Energy and Protein less evident, and 2) supplemental CP intake was the greatest ($P < 0.001$) for Protein (453 g/d). Protein can also serve as a source of digestible energy. Thereby, the ADG improvement by Protein was equal to that of Energy probably because of additional digestible energy derived from supplemental CP. To conclude, the results of this analysis of 44 studies which involved supplemental Energy or Protein indicate that the observed improvements in ADG could be attributed to improved digestible energy intake.

Table 5. Average daily gain (ADG) and supplement intake of beef cattle fed with Energy, Protein and Protein+Energy supplements when fed two forage qualities (low: CP < 9% DM, and high: CP > 9% DM). Forty-four studies were evaluated. A treatment mean was the difference resulting from supplement mean minus control (no supplement) mean. Statistical analysis was conducted to test null hypothesis that treatment mean = 0. (n = 126 treatment means).

	Low quality (< 9% CP)			P-value[4]	High quality (> 9% CP)			P-value
	Energy[1]	Protein[2]	Protein+ Energy[3]		Energy	Protein	Protein+ Energy	
n	8	44	23		12	21	18	
ADG, kg/d	0.25	0.143	0.254	0.03	0.175	0.150	0.171	0.89
SE	0.05	0.04	0.04		0.03	0.04	0.03	
P-value[5]	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	
Supplement intake, % BW	0.81	0.27	0.61	<0.001	0.42	0.40	0.37	0.76
SE	0.08	0.05	0.06		0.06	0.07	0.05	
P-value	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	
Supplement intake, kg/d	2.04	0.77	1.60	<0.001	1.11	1.27	0.94	0.47
SE	0.29	0.19	0.20		0.20	0.23	0.18	
P-value	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	
Supplement CP intake, kg/d	0.300	0.332	0.351	0.79	0.105	0.453	0.226	<0.001
SE	0.08	0.05	0.06		0.04	0.05	0.03	
P-value	<0.01	<0.01	<0.01		<0.01	<0.01	<0.01	

[1]Energy = supplement with CP concentration (% DM) lower than 15%.
[2]Protein = supplement with CP concentration (% DM) greater than 30%.
[3]Protein+energy = supplement with CP concentration (% DM) between 15 and 30%.
[4]Probability that the effects of the supplement types were not the same.
[5]Probability that advantage of the supplemental feed type was greater than zero.

The next initiative of the literature analysis was to evaluate the relationship of level of supplementation, expressed as supplement DMI divided by BW times 100, with grazed forage intake and total DMI. The relationship between level of supplementation and total DMI was similar for low (Figure 1A) and high (Figure 1B) quality forages. As level of supplementation increased, there was a linear increase in total DMI; however, the slopes of the relationship were different (0.90 for low quality vs 0.35 for high quality). This means that supplementation at 1% of BW to cattle consuming low quality pasture forage resulted in greater increases in total DMI (0.90%) than for cattle supplemented while consuming high quality forage (0.35%). The fact that both slope values are less than 1.0 means that when supplemental feed is provided there is a reduction in forage DMI. This is called the "substitution effect" of supplemental feed. The substitution effect of supplemental feed was greater for high quality forage (slope = 0.35) than low quality forage (slope = 0.90).

Evaluation of the relationship between level of supplementation and forage DMI is shown for low (Figure 1A) and high (Figure 1B) quality forages. First, note that at zero supplementation, forage DMI is 1.63 and 2.35 % of BW for low and high quality forages, respectively. Cattle are capable of eating more high quality than low quality forage. Second, intake of forage DM eventually decreases as supplementation level increases, but the shapes of these relationships are different. For low quality forage (Figure 1A), there is an increase in forage DMI for supplementation up to 0.23% BW. Thus based on our dataset, there is no substitution effect in this situation! There is an advantage; the small amount of supplement stimulates the cattle to eat more forage. At supplementation levels greater than 0.23%, forage DMI is reduced as supplementation increases. For high quality forage (Figure 1B), forage DMI declines linearly with increases in supplementation level. Each increase in 1% BW of supplement DM results in 0.65% of BW decrease in forage DMI.

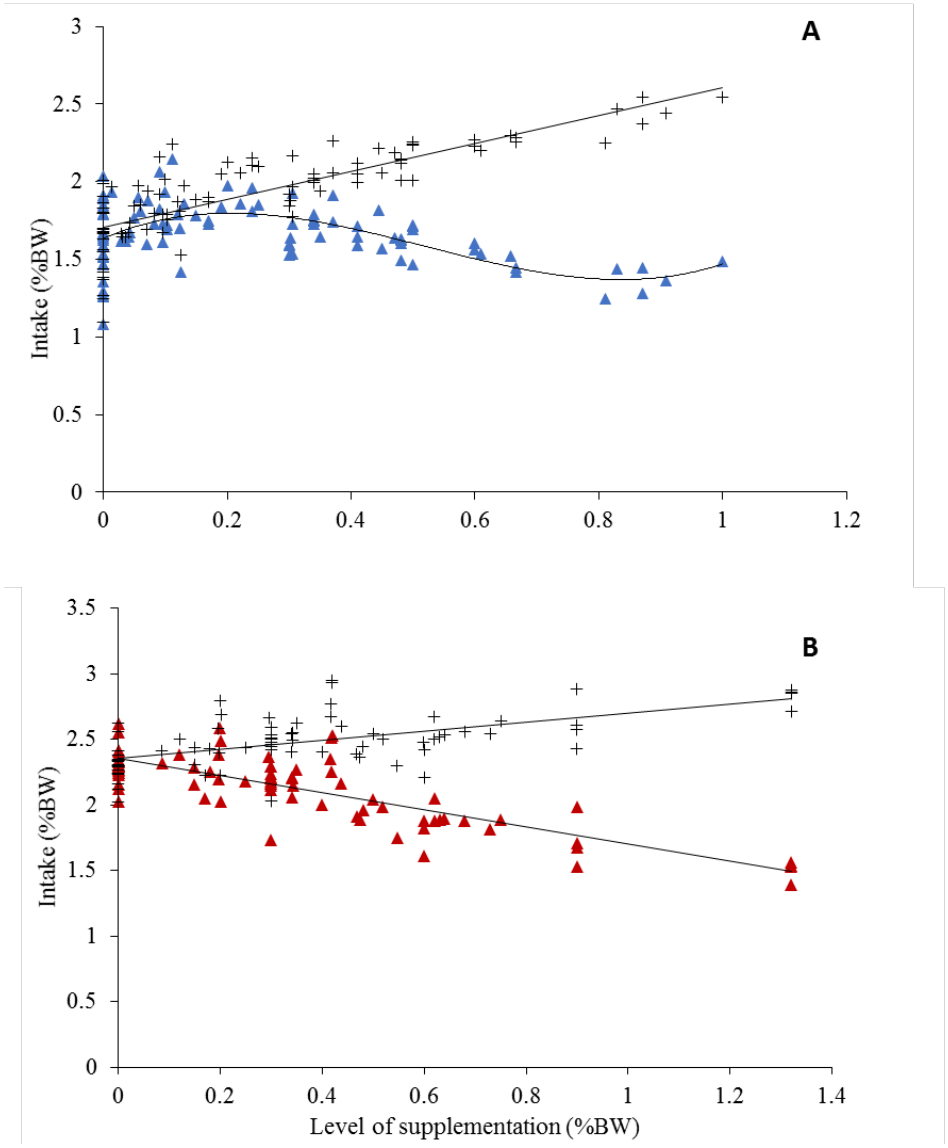

Figure 1. Relationship between level of supplementation (LS) and total (+) and forage (▲) DMI in beef cattle, all expressed as percentage of BW. Panel A: Low quality forages: total DMI = 1.70 + 0.90 × LS, R2 = 0.65, forage DMI = 1.63 + 1.73 × LS - 5.28 × LS2 + 3.38 × LS3, R2 = 0.33. The intercept and slope presented P < 0.01. Panel B: High quality forages: total DMI = 2.35 + 0.35 × LS, R2 = 0.35, forage DMI = 2.35 – 0.65 × LS, R2 = 0.66. The intercept and slope presented P < 0.01.

Decreases in forage DMI are undesirable if one aims to maximize conversion of forage DM to cattle BW. On the other hand, decreases in forage DMI are desirable to the grazier who wishes to sustain grazing as the method of feeding the herd but faces a shortage of pasture forage DM. In that case, the substitution effect decreases forage DMI and thereby extends the duration over which the available pasture forage is grazed.

The studies in the dataset also allowed an evaluation of total digestive tract OM and NDF digestibility (Figure 2). As level of supplementation increased, there was a slight increase in OM digestibility. This is expected because the digestibility of OM in supplemental feeds is presumed to be greater than OM digestibility of forages. This is why certain feeds are chosen to serve as supplements. Of greater interest is the relationship between level of supplementation and NDF digestibility. There is no evidence for supplementation resulting in a decrease in NDF digestibility. There has been longstanding concern among ruminant nutritionists that supplementation of digestible energy sources results in decreased digestibility of plant cell walls, which is the NDF fraction. This review of forage supplementation does not support this dogma.

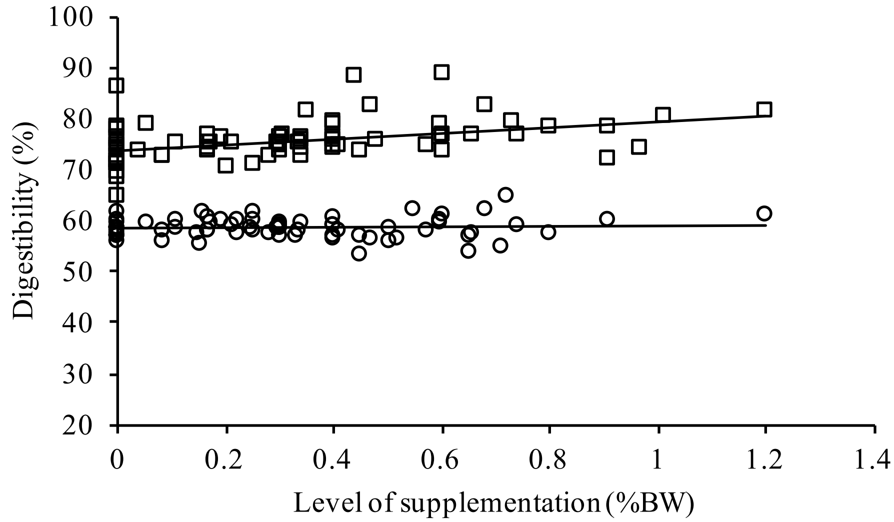

Figure 2. Relationship between level of supplementation and total tract OM (□, *n* = 76) and NDF (○, *n* = 73) digestibility in beef cattle. Regression equation for OM digestibility: y = 74.9 (± 3.7) + 5.65 (± 3.24) × level of supplementation, R2 = 0.16. The intercept is different from zero (P < 0.01), and the slope tends to be different from zero (P = 0.08). Regression equation for NDF digestibility: y = 58.2 (± 2.6) + 0.20 (± 1.23) × level of supplementation, R2 = 0.01. The intercept is different from zero (P < 0.01), but the slope is not (P = 0.86).

The literature review delved further into the supplementation effect on fiber digestibility by evaluating its effect on average ruminal pH (Figure 3). Level of supplementation did not affect average ruminal pH (P = 0.35). Even for supplementation at 1% of BW, ruminal pH was still greater than 6.0. Ruminal pH less than 6.0 is considered to be detrimental to cell wall (NDF) digestion. Admittedly, average ruminal pH does not reveal pH minima, which may fluctuate to pH < 6.0. For this reason, additional investigation of this relationship is needed. Nevertheless, pH evidence in this dataset did not support the notion that supplementation reduces ruminal pH, and this lack of effect is consistent with the results in Figure 2 in which level of supplementation did not adversely affect NDF digestibility.

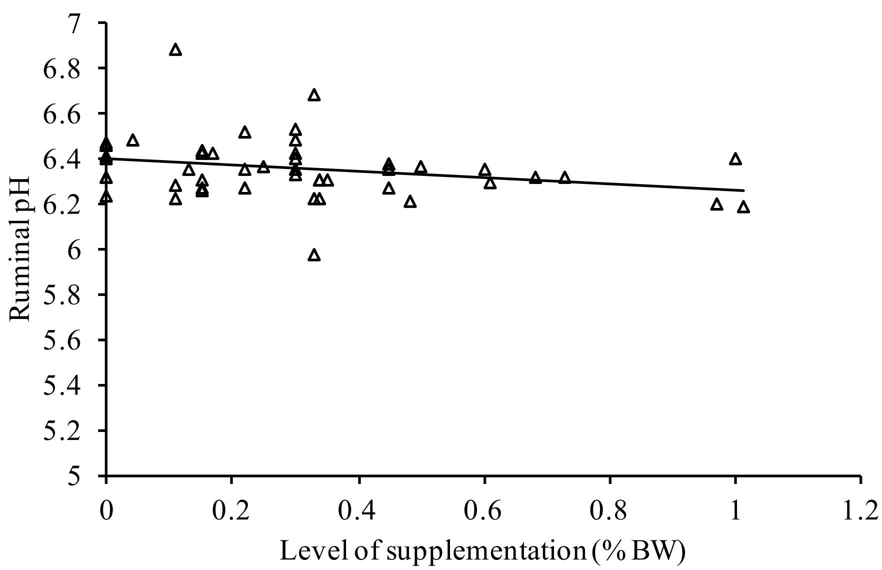

Figure 3. Relationship between level of supplementation and ruminal pH in beef cattle (n = 50). Regression equation: y = 6.40 (± 0.08) – 0.11 (± 0.12) × level of supplementation, R2 = 0.07. The intercept is different from zero (P < 0.01), but the slope is not (P = 0.35).

Practical application

There is sufficient knowledge regarding supplementation of grazed cattle to allow one to implement the practice thoughtfully and for economic gain. The process begins by knowing the nutrient composition of grazed forages and of the available supplemental feeds. In the Driftless Region, forages are of high quality, though an exception is corn stover. This review advocates that money be spent on an energy feed rather than protein or phosphorus. Next, the energy feed chosen should be one that is of low expense per unit of energy. Lastly, realize that when an energy supplement is fed, it decreases forage DMI by cattle. This is a good outcome when forage supply is insufficient. It is an undesirable outcome when one aims to convert grazed forage to beef.

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Confining cows during the calving season

Morgan Hayes

This calving barn presentation will cover the basics of cow-calf confinement focusing on the spacing and ventilation needs for these barns. Moving cow-calf pairs from pasture to a barn requires more intensive management. Ultimately, the goal in managing these barns should be to keep the inside of the barn dry. I would define a dry barn as one with no tagging on the cattle. Stocking density, bedding management, and ventilation all interact in the moisture management of barns. The intensity of this management style includes not only more rigorous management of the cows and calves themselves, but also balancing stocking density, bedding and ventilation for this moisture management concern as well. The higher the stocking density the more moisture the barn receives from the animals. Additionally, higher stocking densities reduce open square footage on the floor from which moisture can be evaporated. Adding bedding is the simplest and likely most expensive way to rectify issues with moisture in a barn. Bedding should be used to manage short term moisture loads like seasonal heavy rains; however, if bedding is becoming cost prohibitive on an annual basis either stocking density or ventilation will need to be adjusted. Ventilation is defined as how much fresh air is entering the barn. Higher ventilation rates allow for more moisture to be removed from the barn. Since cow-calf barns are typically naturally ventilated, proper siting and barn design are critical for developing adequate ventilation

Spacing requirements

Animals need less square footage in a barn then they need on an open lot and animals on a slatted floor barn need less square footage than those on a bedded pack floor. However, a slatted floor is not recommended for cow calf pairs, because the slats spacing required for calves and cows are different. Below is table 1 showing square footage requirements for cows with calves on their side, dry cows, and weaned calves in a bedded barn. Calving or maternity pens for individual cows are often 12 ft by 12 ft or occasionally 12 ft by 10 ft.

Table 1. Spacing requirements for cow and calves from various resources

	Spacing Bedded Barns	
Cows with calves on the side	80-120 ft^2 (Iowa State)	
Dry cows	25-30 ft^2 (MWPS)	40 ft^2 (dairy NRCS)
Calves after weaning	20-25 ft^2 (MWPS)	20-25 ft^2 (NRCS)

In addition to square footage, spacing consideration is also needed with regards to space at feeders and waters. Recommendations for feed bunk space for cows range anywhere from 24 to 36 linear inches per cow. One benefit of raising cow calf pairs in a barn is that calves adjust to bunk feeding early. Likely the higher end of the range described above is necessary if calves are not provided creep feeding areas elsewhere in the barn. A more common issue with the bunks is the volume of space available for feed. Cows typically are fed a higher roughage diet then feeders. Many feed troughs do not hold the volume of feed farmers want to provide.

Ensuring enough space at the waters is also very important for cow calf pairs. Typically, the higher the dry matter intake the higher the water need of the cow, so cows in the barn will need to drink more water than cows on grass in a pasture. Limiting water to a lactating cow will also have an impact on milk production and therefore the calf's performance. When determining the number of cows at a waterer recommendations from the manufacturer can vary; if there is a range of cows which can be supplied, use the smaller of the range or average between the dairy and beef cattle.

One final consideration with both feeders and waters is the height over which the animals must reach to get to the feed/water. Calves have a shorter neck reach and typically do better with a lower bunk or water height (Table 2). One option to allow calves to reach the feed and water is to put a small 6 to 8-inch curb around the feed bunk and waterer so the calves can step up, but the cows can stand behind the lip and reach the feed and water comfortably as well.

Table 2. Heights at which various size cattle feel comfortable eating or drinking

Recommended Bunk Height	
Cows	22-24 inches
Calves	18 inches
Feeders	20-22 inches

Ventilation requirements

Natural ventilation is driven by buoyancy and wind. Buoyancy is based on the concept that warm air rises (like a chimney). It is critical that eaves and ridge be opened for this method to work. Wind driven ventilation requires proper location so wind can move across the barn from sidewall to sidewall. For the Midwest, this means sidewall need to be oriented to the north and south typically. One major concern with siting new barns to take advantage of wind driven ventilation is the location of the barn with respect to other barns. At a minimum 2 barns should have 75 to 100 feet between them, a common equation to determine separation distance is as follows:

Separation Distance= 3 * Ridge Height

Below is a table showing ventilation needs for winter, spring/fall and summer conditions. Typically, in the winter buoyancy can be used to achieve proper ventilation, however in the summer it is critical to have the barn set up to take advantage of wind to achieve the desired ventilation rates.

Table 3. Ventilation requirements per animal for summer and winter conditions for cows and calves

	Ventilation Requirements (cubic feet per minute)		
	Cold Weather	**Mild Weather**	**Hot Weather**
Cows	50	170	470
Calves	15	50	100
Feeder	30	80	180

Hydrogen Sulfide Safety – Monitoring

Importance of hydrogen sulfide safety

Sulfur content in manure has increased over the past ten years from three pounds per 1,000 gallons to nine pounds per 1,000 gallons in swine manure because of increased use of distiller's dried grains with solubles (DDGS) and improved water conservation. Similar dietary changes driven by DDGS and corn glutton meal have increased sulfur in cattle manure. This has led to an increase in hydrogen sulfide (H_2S) concerns when agitating and pumping manure.

Exposure to hydrogen sulfide, even at low concentrations, can have serious health impacts. At high concentrations, exposure to the gas can cause nearly instant death. Symptoms of hydrogen sulfide exposure can be found in Table 1.

Table 1. H_2S exposure impacts (humans)

Concentration	Symptoms/effects
0.01-1.5 ppm	Odor threshold; can first smell it
2-5 ppm	Prolonged exposure may cause nausea, tearing, or headaches
20 ppm	Fatigue, loss of appetite, headache, dizziness
100 ppm	Coughing, eye irritation, loss of smell, death after 48 hours
500-700 ppm	Staggering, collapse, damage to eyes, death after 30-60 minutes
700-1000 ppm	Rapid unconsciousness, collapse within 1-2 breaths, death within minutes
1000-2000 ppm	Nearly instant death

2016 usage of monitors

During the 2016 Manure Applicator Certification program, participants were asked about hydrogen sulfide monitor usage. At the time, five percent of commercial applicators and one percent of confinement applicators had monitors. Additionally, applicators were asked about the likelihood of purchasing a monitor in the future, with 25 percent of commercial applicators and 31 percent of confinement applicators saying it was likely they would. A summary of responses can be found in Figures 1a and 1b.

Have H_2S monitoring equipment

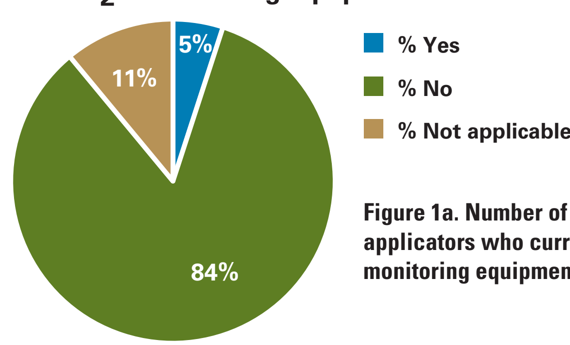

Figure 1a. Number of commercial applicators who currently have monitoring equipment.

Likelihood of purchasing H_2S equipment

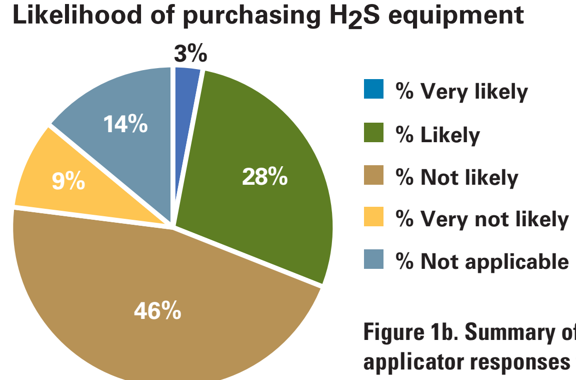

Figure 1b. Summary of confinement applicator responses to how likely is it that they will purchase an H_2S monitor.

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Hydrogen sulfide monitors

ALERTS VERSUS REAL-TIME MONITORS

Instruments are available to perform as just an alarm or as a real-time monitor. Instruments that take readings in real time display the current concentration being measured on the screen, whereas instruments that are only alarms sound an audible beep when the certain concentrations are reached but don't display the current reading. Though slightly more expensive, real-time monitors are preferred as they provide feedback on what concentrations the operator is experiencing and as a result can be used to make informed decisions about when supplemental ventilation is required or feedback on when agitation practices need to be modified.

Most manufacturers have both types of monitors available for purchase. For example, the Gas Clip Technologies H_2S Monitor SGC-H serves as an alarm, supplying an audible signal when certain hydrogen sulfide concentrations are reached. This instrument needs to be connected to the Gas Clip Technologies IR Link GCT-IR-Link to be used as a monitor and provide real-time measurements.

MONITORS AVAILABLE

One way to stay safe is by using a hydrogen sulfide monitor. Monitors, which range in price from $99-$800, will sound an alert if a certain hydrogen sulfide threshold is reached. The monitors are small enough to wear and can be purchased online.

Single gas monitors for consideration:

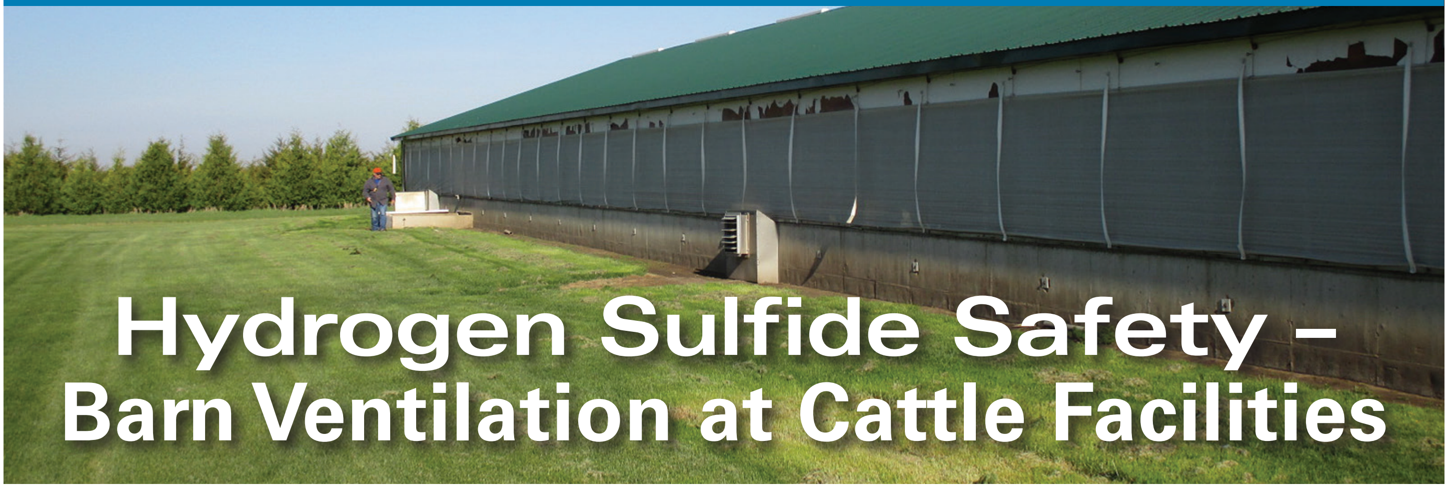
- BW Honeywell GasAlertMax XT II
- BW Honeywell – 2 Year H_2S Clip BW Honeywell
- Gas Clip SGC Plus
- Draeger Pac 3500 H_2S Monitor
- Gas Clip Technologies Single Gas Clip
- Industrial Scientific T40-Rattler
- Industrial Scientific GasBadge Pro
- MSA Altair
- RKI 03 Series H_2S
- RAE Systems ToxiRAE II
- RAE Systems ToxiRAE Pro

No endorsement is intended by Iowa State University Extension and Outreach of companies or their products mentioned nor is criticism implied of similar companies and their products not mentioned.

In addition to purchasing a monitor, other practices to follow when agitating or pumping manure include:

- Verify all fans are working and air inlets are open,
- Place a tarp over pump-out to help protect applicator,
- Communicate with farmer and crew,
- Listen for animal distress,
- Be aware and alert as dangerous conditions can develop quickly.

Prepared by Daniel Andersen, assistant professor and extension agriculture engineering specialist with Iowa State University.



Hydrogen Sulfide Safety – Barn Ventilation at Cattle Facilities

Importance of hydrogen sulfide safety

Hydrogen sulfide levels can spike quickly and without warning during pit pumping. Barn ventilation is necessary to remove gasses released from the manure and to dilute concentrates with fresh air entering the facility. As agitation will release gasses from the manure, obtaining adequate ventilation is essential for animal and human safety.

People should **NEVER** enter a building or facility while agitation is occurring. Use yellow caution tape to mark barn entrances and alert everyone that manure agitation and pumping is occurring. Consider lockout tags during pumping.

When possible, remove animals from the portion of the barn in which manure agitation and removal is occurring. If not possible, only use subsurface agitation and consider reducing agitation intensity.

Ventilation strategy

- Barn ventilation should be maximized; back wall curtains should be completely opened.
- A cross wind (through the barn) of at least five mph is necessary. Wind velocity must maintain at this level and be directed through the barn.
- If wind direction is at an angle to the barn, ten mph wind speed is recommended.
- Watch for changing weather conditions; wind conditions can change quickly especially as evening approaches. Many times night time air is more still than daytime air.
- If removing manure during calm wind conditions, consider using power take-off (PTO) driven fans to provide extra ventilation (Figure 1). This ventilation should be directed at animals if present. Additional ventilation should be directed at the operator.
- If possible set up agitation equipment on the up-wind side of the facility to provide pump operator with cleanest air possible.

Figure 1. Example of PTO driven fan that can be used to increase barn ventilation.

- If present, turn on stir fans in the barn. This moves air around and will decrease the chance of air "dead zones" where inadequate ventilation exists.

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- Consider adding pump out curtains (tarps) around manure agitation areas to limit escape of hydrogen sulfide gas near the agitator (Figure 2). This curtain blocks some of the pit air from swirling back toward the pump operator.

Figure 2. Example pump out curtain. Weight (PVC pipe with some gravel in it or a piece of metal) should be attached to the curtain to hold it at the manure surface.

Prepared by Daniel Andersen, assistant professor and extension agriculture engineering specialist with Iowa State University.

Management and vaccination strategies to produce healthy calves

Chris Clark, DVM, Iowa State University Extension and Outreach Beef Specialist

The epidemiologic triad refers to the complex interactions between host, pathogen, and environment. The concept is that each component of the triad affects the other two and ultimately, the interaction of these three factors determines whether disease occurs. The take-home message is that there are many ways to promote health and protect animals from disease. Producers can work to strengthen hosts, improve environments, and minimize pathogens. Vaccination, for instance, is a great tool but is just one piece of the puzzle. There are many other ways to promote the health and vigor of host animals and producers can work to reduce pathogen load and create healthy, low-stress environments for livestock.

The importance of proper nutrition and animal husbandry cannot be over emphasized. Proper nutrition is critical to health, performance, and productivity of beef cattle. Diets must be formulated to provide adequate energy, protein, effective fiber, vitamins, and minerals. Diets must also be affordable, palatable, and readily available. Beyond nutrition, basic animal husbandry is extremely important. Producers should strive for excellence with all the basics of animal husbandry: shelter, bedding, low-stress handling, shade, identification of sick animals, facility design, biosecurity, etc. Years ago, I met a veterinarian that described his clinic motto as “Doing the ordinary things extraordinarily well.” This phrase is very applicable to cattle production. Cattle producers can prevent many problems by doing the ordinary things extraordinarily well. We live in an age of amazing technological advances…growth promotants, artificial insemination, embryo transfer, in vitro fertilization, genomically enhanced EPDs, and the list could go on. Despite this technological explosion, successful livestock production usually comes down to the basics and in many cases, technology cannot be used to full potential without a solid foundation of proper nutrition and excellent animal husbandry.

Parasite control is an important component of a cattle health program. Parasites harm hosts in many ways. Internal parasites such as worms steal nutrition from the host, impair digestion, and cause inflammation and tissue damage. External parasites such as flies irritate and annoy hosts, spread disease, and cause blood loss. Numerous studies describe production benefits of deworming cattle and Lawrence and Ibarburu (2007) described dewormers as the most valuable pharmaceutical technology for the cowherd. Fly control is also important given the potential impact of horn flies and face flies. A comprehensive parasite control program must be a component of the overall management plan.

Vaccination is a common and important tool to protect livestock from disease. There are several principles of vaccination that are worth mentioning before discussing vaccines against specific diseases. First, timing and host condition are extremely important factors. As a preventive measure, vaccination should obviously be given prior to exposure or disease challenge. Upon primary vaccination, it may take at least 7-10 days and up to several weeks for animals to mount a fully protective immune response. Upon administration of boosters, animals should respond more quickly. Host condition is also a big factor in how animals respond to vaccination. Livestock should be on good plane of nutrition, be in adequate body condition, be at a relatively low stress level, etc. in order for them to best respond to vaccination. It should also be noted that not all animals will respond with protective immunity. Even when everything is done properly, some, hopefully small percentage of vaccinates will not respond with an adequate immunity.

There are a few additional principles of vaccination that are worth mentioning prior to discussion of specific vaccination protocols. Veterinarians, producers, cowboys, and anyone handling vaccines should review vaccine-handling guidelines and strive follow them appropriately. Vaccines, especially modified live viral vaccines (MLV), are sensitive to extreme temperatures, direct sunlight, freeze / thaw cycle, etc. Handlers must strive to follow the label guidelines for storage temperatures and conditions. Furthermore, MLV vaccines should be used shortly after being mixed. The usual recommendation is that handlers not mix more vaccine than will be used within one hour. When vaccinating against Infectious Bovine Rhinotracheitis (IBR) and Bovine Respiratory Syncytial Virus (BRSV), modified live intranasal (IN) vaccines should be considered. Intranasal vaccines stimulate local immunity on mucosal surfaces, which should be a great first line of defense upon natural exposure. When vaccinating highly stressed calves producers may want to avoid using modified live Bovine Viral Diarrhea (BVD) vaccines. Modified live BVD vaccines can have some residual pathogenicity, which means that they have the potential to cause disease. Using these products in highly stressed animals may actually induce some clinical signs of BVD.

Producers should work closely with their regular veterinarians to formulate vaccination protocols. Specific vaccination strategies will vary depending on location, disease pressure, and management system. In terms of vaccine protocols for cows, the focus is usually on reproductive diseases. Fertility is an extremely important factor in determining profitability of a cowherd. In order to have a chance at profitability, the vast majority of cows need to have a calf every 365 days. Nutrition and other management factors are a big part of reproductive success. Additionally, vaccination against reproductive disease is an integral part of most cow-calf operations. Diseases of concern would include Brucellosis (Bang's Disease), Infectious Bovine Rhinotracheitis (IBR), Bovine Viral Diarrhea (BVD), Leptospirosis, Campylobacteriosis (aka Vibriosis), Tritrichomonas foetus, and Neospora. Vaccination is used regularly to aid in prevention of many of these diseases.

It is still advisable to vaccinate against Brucellosis, which must be done by a veterinarian while heifers are between 4 and 12 months of age. This is a unique vaccine in that it is administered only one time. Heifers should receive IBR and BVD vaccines 30 to 60 days prior to breeding. MLV products stimulate better immunity and are usually combined in multivalent vaccines to include IBR, BVD (types 1 and 2), BRSV, and Parainfluenza 3 virus (PI3). Timing is important here because MLV IBR and BVD vaccines can cause transitory infertility. The recommendation to allow 30-60 days between vaccination and breeding allows some time for resolution of this vaccine-induced infertility. Lepto / Vibrio vaccines should also be given 30 to 60 days prior to breeding. Following a solid pre-breeding vaccine program, adult cow vaccine protocols often simply include annual boosters of Lepto / Vibrio, and a multivalent viral vaccine. Veterinarians and producers should think carefully about vaccine timing and choice of MLV versus killed products. MLV vaccines can cause abortion and label directions must be followed carefully to safely administer these products to pregnant females. Additionally, producers may use vaccines against scours pathogens late in gestation to stimulate greater antibody production to be shared with calves through colostrum.

Calf health management starts with parturition. USDA NAHMS, 2007- 2008 data indicates that of those calves that are born alive but die prior to 3 weeks of age, 25.7% die from calving-related problems, 25.6% die from weather-related problems, 18.6% die of unknown causes, 14.0% die of GI disease, 8.2% die of respiratory disease, and 6.2% die of injury or predation. It seems plausible that calving-related problems and weather-related problems might contribute to a few of those infectious diseases, injuries, and unknown causes of death. The take-home message is that proper management of parturition and protection from weather extremes can save a tremendous number of newborn calves.

Vaccination should be delayed because newborn calves, for a variety of reasons, are not able to respond well to vaccinations. Chase et al. (2008) described the development of the neonatal calf immune system and its impact on vaccine response. At branding time or grass turnout time (sometime early summer when spring born calves are approximately 2-4 months of age) is a good time to administer a 7-way Clostridial (blackleg) vaccine. If there is a history of summer pneumonia with specific pathogens, viral respiratory vaccines may be given at this time. Care should be taken to choose products that have been shown to be safe and effective for young calves. This might be a good time to utilize IN vaccines. This may also be a good time to castrate and dehorn. These painful and stressful procedures should be done early in life rather than at preconditioning / weaning. Preconditioning / pre-weaning vaccines should include a 7-way Clostridial booster and a multivalent viral vaccine to combat bovine respiratory disease. Ideally, calves would receive a viral respiratory booster prior to weaning approximately 3 weeks following the primary vaccination.

Management of the weaning period can have a huge impact on animal health, welfare, performance, and profitability. Weaning involves many potential stressors that can negatively affect beef calves: separation from dam, new environment, diet change, and new social dynamics just to name a few. Minimizing the stress of weaning will give your calves greater opportunities to thrive, perform, and reach their genetic potential. Producers should consider low-stress weaning strategies such as two-step weaning, fence-line weaning, pasture weaning, etc. Nutritional management of the newly weaned calf is critical to success. Rations must be carefully formulated to be palatable and to include adequate nutrients. Producers should strive for excellence with animal husbandry to minimize stress as much as possible. Finally, cattle should be observed closely for signs of bovine respiratory disease.

The final point of emphasis is biosecurity. Biosecurity simply refers to management practices that help to minimize the risk of disease transmission. Biosecurity usually revolves around thoughtfulness and cleanliness. Signs can be posted indicating that all visitors should check in with the producer. New animals should be quarantined for a period before introducing them to the primary herd. Producers should buy virgin bulls or bulls that have been tested for Tritrichomonas foetus. Ear notches can be used to test for BVD status to avoid keeping persistently infected animals. Care should be taken to minimize vector and fomite transmission of disease.

Many important factors play a part in determining success and profitability on a cow-calf operation. The principles and suggestions outlines in this article should help producers manage and vaccinate to produce healthy, vigorous, and valuable calves.

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New insights on rumen health for profitable feedlot cattle

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Introduction and recent trends

Economic and genetic factors have altered common cattle feeding practices in recent years. From 2010 to 2016, average hot carcass weight increased from 835 lbs to 880 lbs (USDA) with greater days on feed and moderating feed prices. Over the same time span, the occurrence of liver abscesses increased 25% up to 19% of slaughter cattle evaluated using industry monitoring services. With additional regulations on feeding tylosin to feedlot cattle in the Veterinary Feed Directive and a host of new, "natural" feed additives being released, priorities within the cattle feeding sector have led to a renewed interest on rumen and lower gut health. The importance of the rumen and its microbes to cattle nutrition and production efficiency has long been established. However, our newfound understanding of the rumen microbiome and gut physiology has generated new emphasis in this area of livestock production. To make profit-driven management decisions in this changing landscape, cattle feeders must understand the basics of rumen function that underlie best feeding practices to evaluate the consequences of market-based choices affecting cattle management.

Importance of rumen function and health

Fermentation in the rumen is responsible for harvesting the majority of the energy for the ruminant animal. When it is functioning well, the rumen is the ideal place for anaerobic bacteria to efficiently digest feed; it is warm, properly mixed, appropriately buffered, regular provision of a substrate (feed), and free of oxygen. Indicators of rumen function can include rate of absorption, motility patterns, rumen papillae histology, and microbial digestion of feed and fiber. Beyond the digestive contributions of the rumen, it also serves an immune function as a protective barrier from microbial inhabitants. In the context of feedlot cattle, the rumen will experience more challenges to the natural equilibrium of rumen function. This is because maximizing gain potential by greater energy intake and minimizing of digestive upsets are antagonistic goals. To achieve both goals, a balanced diet must be complemented with proper feeding management.

Common challenges to rumen health

The feedlot sector has historically focused on gut health by preventing rumen-related maladies. Common challenges to rumen health include acute and subacute acidosis, bloat, laminitis, rumen ulcers, and liver abscesses. These conditions are often not observed in isolation but are often interrelated. Acidotic conditions in the rumen are driven by the rapid production of organic acids that exceed the rate of absorption by the rumen wall to result in a depressed ruminal pH. Generally, acute acidosis is defined by a pH below 5.0, while subacute acidosis is defined by a pH between 5.0 and 5.6. When ruminal pH is above 5.6, rumen health will be improved by greater motility, increased fiber degradation, and improved barrier function by the rumen wall. The difficulty of measuring pH in a production setting can make diagnosis more challenging. Acute acidosis results in more noticeable symptoms; these may include large decreases in feed intake, recumbent animals with their head in their flank, an absence of ruminal contractions, and severe dehydration. Lactic acid accumulates in the rumen during acute acidosis and further reduces pH while increasing osmolality. The osmolality gradient concentration causes water to diffuse from tissues into the rumen resulting in dehydration and diarrhea. The rapid influx of water can also damage the rumen wall and lead to a rumen ulcer or rumenitis. In contrast, subacute acidosis would typically only cause a moderate reduction in feed intake, loose stools, and some signs of colic. The long-term occurrence of subacute acidosis will likely decrease performance and fiber digestion, but this has been difficult to document the magnitude of effect in a research setting.

Although commonly described as two distinct conditions, acidosis exists as a continuum of symptoms with greater severity often causing subsequent ailments. When acidosis disrupts the barrier function of the rumen wall, liver abscesses can occur. A breach of the rumen epithelium allows bacteria to enter into the bloodstream to be transported to the liver. While not a predominant bacteria in the rumen, *Fusobacterium necrophorum* is an opportunistic pathogen found in liver abscess infections. Tylosin is a feed grade antibiotic fed to the majority of feedlot cattle (80%; Samuelson et al., 2017) to prevent liver abscesses. Tylosin is effective at reducing liver abscesses, but it does not change the precursor events that lead to the development of liver abscesses including a decreased rumen pH and damage to the rumen wall. Beyond the health implications of an active infection, severe liver abscesses decrease growth performance and cost slaughter facilities $20-80 in carcass value per animal (Brown and Lawrence, 2010). The recent implementation of the Veterinary Feed Directive and continued public pressure on the use of feed-grade antibiotics in livestock production will continue to impact nutritional management of cattle in the future.

Bloat is the easiest form of digestive upset to diagnose in feedlot cattle. An accumulation of gases trapped within the rumen causes distension on the left side of the animal that can range from mild to severe. Although several variations of bloat exist, frothy bloat is the most commonly observed in the feedlot and frequently occurs from 100-120 days on feed (Vogel et al., 2015). The formation of stable foam prevents eructation from expelling the gases from the rumen. Treatment of bloat includes passage of a stomach tube, administration of mineral oil, or use of a trocar for a rumenotomy. Because acidosis can affect ruminal contractions, saliva production, and the bacterial community, the stagnation of rumen can lead gas accumulation and bloat (Meyer and Bryant, 2017).

Recent research findings

Reducing the incidence of digestive upsets in the feedlot will increase cattle performance and health to drive profitability, but many challenges exist. The latest National Animal Health Monitoring System survey indicated 71% of feedlots were affected by digestive problems. However, it also described the greatest challenge with these issues: diagnosis prior to death. The ratio of mortality to morbidity for digestive problems was 159% compared with pneumonia which was 3.79%. Prevention of digestive upsets is critical considering our poor ability to detect their early onset.

One of the primary risk times during the feeding period for digestive upsets is when animals are being transitioned to a finishing diet. Calves are typically adapted to a finishing diet during the 14 to 28 days after arrival. The goal of this period is to slowly adapt the rumen microbes to a higher concentrate inclusion in the diet. This can be successfully achieved by making moderate increases in feed calls while also making small dietary adjustments. Recent research has also investigated the long-term consequences of different transition strategies on overall finishing performance. If cattle are truly more adapted for the finishing diet, then they should exhibit an advantage that extends beyond the transition period. Work conducted at the University of Illinois has shown that coproducts can replace most of the forage in transition diets to increase the energy content without adding starch and greater risk of digestive upset (McCann, unpublished). Multiple experiments from the University of Nebraska support the fact that management and nutritional decisions over this adaptation period can have long-lasting effects during the remainder of the finishing phase. Huls et al. (2016) observed that cattle adapted to a silage-based finishing diet using corn gluten feed (Sweet Bran, Cargill Corn Milling) had increased growth performance and feed conversion compared with cattle adapted using primarily alfalfa. Another experiment evaluated the ability of a complete starter feed (RAMP, Cargill Corn Milling) to adapt cattle to the finishing diet (Schneider et al., 2017). Cattle performance increased when fed RAMP compared with a more traditional, alfalfa-based adaptation diets. Collectively, this body of work indicates nutritional strategies during the transition period can improve the adaptation of the rumen microbiome and translate to a performance advantage.

It is well established among nutritionists that most of the problems with digestive upsets are rooted in management rather than the diet formulation. Although their opinion may have some level of bias, many implementation steps do alter the diet composition from the formulation to what is actually consumed by the cattle. In essence, variation or change is the enemy when feeding cattle a high concentrate diet. A range of management factors can reduce the risk of digestive upsets if done well and include bunk calls, ration mixing, ration delivery, feedstuff management, grain processing, and monitoring of cattle sickness. These are the primary opportunities to reduce man-made variation and prevent it from compounding the animal-to-animal variation that already exists. The level of individual animal variation in cattle on feed can be evaluated using the GrowSafe feed bunks that measure each animal's feed intake. While feed intake may remain consistent for a large group of cattle on feed, within the group, feed intake changes significantly on a day-to-day basis. Research at the University of Illinois has indicated some cattle may be particularly inconsistent, fluctuating more than 30% in dry matter intake on nearly 50% of the evaluated days. Recognizing the inherent animal variation further emphasizes the need for consistent management practices.

The transition to the finishing diet was historically considered the time with the greatest risk for acidosis. However, recent findings have indicated that the occurrence of acidosis increases with additional days on feeds (Castillo-Lopez et al., 2014). While the study was not large scale, it was able to collect consistent ruminal pH measurements throughout the finishing phase. Cattle are clearly adapted to the finishing diet near the end of the feeding period, so there must be a different factor initiating the acidotic events. During the finishing phase, minor acidotic insults accumulate and appear to condition the microbial community and the ruminal epithelium. Additional days on feed also increase the opportunity for an off-feed event to occur. A repeated subacute acidosis challenge was conducted at the University of Illinois to further understand the etiology of the acidotic events (McCann et al., 2016). During the initial two challenges, only one of the 12 cattle actually acquired acidosis despite different levels of challenges implemented. However, during the third challenge, all but one animal experienced subacute acidosis. The results indicate that minor events can prime the system over time for an acidotic event to occur later.

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Keys to a successful pasture system

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If you grow corn or soybeans, variety selection is an important component of your management plan. As a pasture-based producer, you may believe that a particular forage species or new variety will solve all your problems, and you'd be right in some situations. Some forage species are simply not suited to certain soil types or climate zones, and planting a better-adapted species may make a large difference in pasture productivity. Plant breeding and selection have also produced improved forage varieties with greater yield, disease resistance, quality, and persistence than older varieties. But before you decide to renovate a pasture to add or change species, the manner in which you manage your pastures needs to be carefully considered.

A number of management practices contribute to successful, well-managed pastures. While these practices are routinely presented at producer meetings and in trade publications and scientific papers, they are worth reviewing. First, what is managed pasture? Most print and electronic sources share a common definition of "managed pasture" – a rotational system of grazing that systematically moves livestock to new (rested) areas of pasture (paddock). The length of time a paddock is grazed will depend on paddock size, forage species and yield when grazing begins, number and class of livestock, and management objectives. The benefits that result from appropriate rotation may include improved annual yield and distribution of forage, greater control of forage quality and forage utilization, better distribution of manure nutrients, less need for conserved forage feeding, and improved livestock health and productivity. Whether pastures are grazed at a vegetative stage or a mature stage, appropriate rotation is critical to realizing these benefits.

Rotational grazing means, of course, that livestock will return to a paddock that has been grazed previously. The period of time before livestock graze a paddock again (length of rotation) and the number of times a paddock is grazed during the grazing season (frequency) is primarily a function of forage growth rate and the maturity at which the pasture is grazed. Soil physical and chemical characteristics and climate have a major impact on forage growth rate throughout the growing season, but other than fertility, a producer has relatively little control over these factors. The maturity at which the pasture is grazed is largely determined by the nutritional requirements of the livestock. The producer does control, however, a management element that impacts forage growth rate more than any other decision – residual sward height, or the amount of forage remaining on the pasture after livestock are moved to the next paddock. Adequate residual sward height means the grass has enough leaf area remaining to keep the plant's photosynthetic engine running to initiate growth of new leaves and tillers. If too much leaf area is removed by grazing too short, new growth is dependent on energy stored in stem bases or rhizomes, which reduces growth rate and increases the time required for the paddock to reach a desired forage mass. If a pasture is routinely overgrazed, the number of times a paddock can be grazed during a growing season is reduced by one or two events. Overgrazing during a drought has the most detrimental effect on pasture productivity.

Repeatedly overgrazing pastures and leaving insufficient residual sward height not only reduces forage growth rate in the current grazing season, but in the next growing season as well. Our research demonstrated that when pastures were grazed to a 3-inch residual sward height compared to a 6-inch height, pasture growth the following spring was delayed one week. Grazing to a 1½-inch residual sward height delayed pasture growth the following spring by an additional week. The bottom line of overgrazing pastures the previous year is that livestock must be fed stored forage longer the following spring until pastures are ready to be grazed.

Routine overgrazing eventually results in the death of more productive, tall-growing grasses. Kentucky bluegrass, which is less productive but is well-adapted to short residual sward height, usually becomes the dominate component of the pasture. Pasture productivity and resiliency to drought are further diminished as weeds invade and runoff increases. The producer is left with something that bears little resemblance to "managed pasture".

Which brings us back to the first point of this paper – improving pasture with the right species and improved varieties.

Improved varieties of orchardgrass, meadow fescue, smooth bromegrass, and tall fescue have the potential to increase annual yield and forage quality, improve seasonal distribution of production, and extend the grazing season. Orchardgrass is one of the most productive cool-season grasses available and has good uniformity of seasonal yield distribution. Meadow fescue was rediscovered in the Driftless Region and is gaining popularity throughout the Midwest due to lower fiber concentration and greater fiber digestibility than other perennial grasses. The primary advantage of smooth bromegrass is early, consistent spring growth. And even though tall fescue still suffers from the bad reputation of its endophyte-infected relative, Kentucky 31, improved varieties have greater palatability, retain their excellent tolerance of environmental stress, and are the best-suited grass for fall stockpiling. All of these grasses can be successfully established by drilling directly into suppressed, existing sod in early spring.

Still greater improvements in pasture productivity, quality, and animal performance can be gained by introducing legumes. The nitrogen fixation capacity of legumes also reduces reliance on purchased nitrogen fertilizer. Alfalfa is the most productive legume on near neutral pH, well-drained soils. Red clover and white clover are better adapted to poorer soils, and red clover is particularly well-suited to frost seeding. Although "variety-not-named" legume seed might be less expensive, named varieties provide an assurance of measured performance.

But before a single pound of these improved species or varieties is purchased and planted, a producer must decide to implement management practices that optimize growth and persistence after establishment. Setting an appropriate rotation, and most importantly, making sure that livestock leave adequate residual sward height are the keys to a successful managed pasture program incorporating improved species and varieties.