2010 Proceedings of the 8th ANNUAL MID-ATLANTIC NUTRITION CONFERENCE

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Timonium, Maryland

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University of Pennsylvania Veterinary School
University of Delaware
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Conference Note: The Mid-Atlantic Nutrition Conference is a regional meeting that evolved from the Maryland Nutrition Conference for Feed Manufactures. Program content and format remain the same.
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*These manuscripts were received in a timely manner, were reviewed, and edited by the General Program, Equine Nutrition, Poultry Nutrition, and Dairy Nutrition Program committees. Others were formatted for style and printed as they were received.

We thank the program participants for their cooperation in providing the material in this document.

**SAVE THE DATES: MARCH 23-24, 2011**

9**TH** MID-ATLANTIC NUTRITION CONFERENCE
ANIMAL AGRICULTURE FOLLOWING THE PASSAGE OF PROPOSITION 2 IN CALIFORNIA

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Abstract

In November 2008, California voters approved Proposition 2, a ballot initiative that placed new mandates on how egg farmers house their egg-laying hens, banned gestation crates for sows and veal crates for veal calves. The ballot measure passed with 63.5% of the vote. Florida and Arizona previously passed legislation eliminating sow and veal crates, however PROP 2 was the first time voters were asked to address egg-laying hens.

There are nearly 20 million hens located in California – the fifth largest state relative to egg production. There are no veal operations located in the state and a relatively small number of pork producers.

In the aftermath of PROP 2, the Humane Society of the United States moved their economist and PROP 2 campaign manager, Jennifer Fearing to California. She is now working in Sacramento as a registered state lobbyist. Additionally, in January 2009, California State Senator Dean Florez, announced the “revamping” of the Senate Agriculture Committee forming the Senate Committee on Food and Agriculture. The “revamped” Committee’s focus is on “critical issues of sustainability and food safety, as well as animal welfare reforms”. In 2009 the Committee addressed among other issues tail docking of dairy cows, the use of antibiotics in food animal production, and a mandatory spay and neuter legislation.

A united animal agricultural community effort based on sound science defeated the antibiotic bill and the mandatory spay and neuter bill as well as many other bills. Over 50 animal welfare bills were introduced in California in 2009.

Additionally, in May of 2009 the University of California announced the establishment of the University of California Animal Welfare Advisory Council. The Council’s mission is to review animal welfare issues relative to animal agriculture and to promote the development of recommendations based on sound science to improve the welfare of livestock and poultry. Members on the Council include veterinarians, animal scientists including Temple Grandin from CSU and Joy Mench, UC Davis, and other experts from the University of California system, the California State University System, and the private sector. The UC Animal Welfare Advisory Council also formed a Stakeholder Panel made up of representatives from animal agriculture as well as representatives from the animal rights community including HSUS.

In January 2010 Senator Florez announced the formation of the “Animal Protection Caucus”. The current make-up of the caucus consists of Senators Florez (D) and Strickland (R), and Assembly members Smyth (R) and Nava (D). HSUS stated the new Animal Protection Caucus is the first state legislative caucus focused on boosting efforts to pass “humane legislation”.

Since the passage of PROP 2 in 2008 the voters in Michigan have passed similar legislation. Voters in Ohio passed a constitutional amendment forming an Ohio Animal Care Standards Board and are now facing the possibility of a PROP 2 type initiative directing their Animal Care Standards board to adopt PROP 2 language.
In the aftermath, California egg farmers formed the Association of California Egg Farmers to specifically address PROP 2 compliance. The vagueness of PROP 2 language as stated below and the fact that a violation of PROP 2 is a criminal offense that calls for fines of up to $1,000 per violation and/or a jail sentence of up to six months makes it imperative that California egg farmers have clear-cut housing standards and guidelines to determine how they can comply with the law and continue to produce eggs in California under Proposition 2. They need to know exactly how much space to provide for an egg-laying hen and what housing systems will comply with the initiative. California egg farmers are willing to make the investment to comply with the law but they need clear cut standards that clarify Proposition 2.

Proposition 2 says neither farmers nor their employees may confine any egg-laying hen “for all or the majority of any day, in a manner that prevents” the hen from “lying down, standing up, and fully extending” her “limbs” and “turning around freely.” The initiative also says a hen must be able to fully extend “all limbs without touching the side of an enclosure, including, in the case of egg-laying hens, fully spreading both wings without touching the side of an enclosure or other egg-laying hens.” It defines an enclosure as “any cage, crate, or other structure” which is “used to confine” a hen.

Since the passage of PROP 2 California animal livestock groups are acutely aware of the need to work together to address animal welfare issues and to educate the general public about the livestock community in general. Great strides have been made by the animal agriculture relative to public outreach. We remain vigilant in our efforts to educate.
ANIMAL AGRICULTURE FOLLOWING THE PASSAGE OF ISSUE 2 IN OHIO

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Summary

The passage of “Issue 2” in Ohio was a landmark victory for Ohio agriculture and provides a blueprint for other states to follow in proactively addressing the animal welfare issue. Not only have farmers strengthened their bond with consumers, the state’s agricultural community demonstrated what could be accomplished when it unites around shared values. “Issue 2” was a state constitutional amendment to create the formation of an Ohio Livestock Care Standards Board, which sets standards for livestock and poultry care that take into account issues of food safety, local availability and affordability, best farm management practices for animal and worker well being and societal expectations.

This presentation will summarize 1) What lead to this initiative, 2) An overview of the campaign to pass “Issue 2”, 3) Lessons learned, and 4) Where are we today with the implementation of the Care Standards Board. In addition, I will discuss some of the reactions of animal activist groups, such as HSUS, and their current activities in Ohio to control the animal welfare/care issue and instill their views on the citizens of Ohio and the agricultural community.
THE UNWANTED HORSE ISSUE IN THE UNITED STATES AND ITS IMPLICATIONS

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Horses in the United States no longer wanted have been sold or discarded by their owners throughout history, but it is only in the last few years this subset of the horse population has been designated “unwanted”. To many, the horse is a symbol of beauty, grace, and the American West. A study of American attitudes toward animals in 1980, found the horse to be one of the top 3 most beloved animals (Kellert, 1980). Public sentiment and misinformation provided by animal activist groups have greatly complicated the unwanted horse issue and the discussion of end-of-life decisions for horses. Adding to the divisiveness in the unwanted horse debate is the fact the American horse industry and the Federal government classify horses as “livestock” whereas the non-horse owning public considers the horse a “companion animal” or pet.

U.S. horse population numbers increased gradually from their introduction into North America, peaking in 1910 at 19.8 million head. That number decreased dramatically with the start of industrial mass production of motorized vehicles and reached an all time low of 1.6 million head in 1974 (U.S. Department of Agriculture, 2008). Because most horses no longer had value as work animals and the interest in horses as recreational animals had not yet surfaced, horse surplus reduction occurred at dozens of horse processing plants across the country where they were processed for both human and animal consumption. Later, as the number of surplus horses dwindled and pet food manufacturers turned to cast off products from beef and hog processing plants, the number of horse processing plants dwindled to a very few. American consumers never developed a preference for horse meat and as their economic situation improved in the post-war years, horse meat largely fell out of favor. As these events were occurring in the United States, post-World War II European and Asian populations were being encouraged to eat horse meat that was considered lean and a good source of iron (Reece et al., 2000). The result was the development of a U.S. horse meat export market to European and Asian countries for human consumption. The U.S. horse slaughter industry steadily grew to meet that demand and in the late nineteen eighties was processing over 300,000 horses per year on average. Overtime, the number of horses processed gradually declined and reached a low of only 42,303 head in 2002 before stabilizing at approximately 100,000 head per year over the last few years.

Today, over one billion people, or 16% of the world’s populations, eat horse meat. According to the Food and Agriculture Organization of the United Nations (FAO) total production of horse meat for human consumption world-wide in 2007 was 1,040,450 tons, roughly five million horses (Food and Agriculture Organization of the United Nations, 2006). This is an increase of 27.6% in consumption since 1990. The top five leading horse meat producing countries in 2007 were China, Mexico, Kazakhstan, Mongolia, and Argentina (Food and Agriculture Organization of the United Nations, 2008). Generally, English speaking countries, such as the United Kingdom, Australia and the United States, do not consume horse meat, yet often export it to countries that do. The horse processed for meat represents the lowest economic level of the U.S. horse population and epitomizes the unwanted horse. Therefore, when addressing the unwanted horse problem, the issue of processing horses for human consumption and its welfare implications must be considered. Unfortunately, the debate over the processing of horses for human consumption has polarized the U.S. horse industry and non-horse owning public. Segments of each have strong, emotional opinions on the subject and share little common ground. This may be due to the change in modern American culture, which is two to three generations removed from the ranch or farm, toward animal advocacy and away from viewing animals as a food or labor source. That coupled
with increased costs in boarding, farriery, hay, fuel, and veterinary care has made it harder and more problematic to keep a horse until its natural death. When age, physical disability, or behavior decreases the horse’s value below a certain point, it often ends up at a slaughter plant. And therefore, the issues of the unwanted horse and the horse processed for meat cannot be separated.

Until the Bovine Spongiform Encephalopathy (BSE) outbreak in Europe in 2000 and the Foot and Mouth disease epidemic that occurred in the United Kingdom in 2001, Americans, both the horse owning and non-horse owning public, were not aware horses were being processed in the United States and their meat shipped to foreign markets. In addition, both disease outbreaks were responsible for changing many European consumers’ preferences from beef to horse meat (Helm, 2000). This change drew American media attention to the fact horses were being processed for meat in the United States and their meat exported to Europe for human consumption. Media coverage of the issue not only drew the attention of the horse owning public, but also equine breed associations, animal rights/welfare organizations, veterinary associations and the non-horse owning public. Because of the resultant focused lobbying efforts of many animal activist groups and some horse owners, federal legislation was introduced in the U.S. Congress in 2001 to prohibit processing of horses in the United States for human consumption. The legislation sparked aggressive debate on equine welfare and initiated a series of unintended horse industry welfare and financial consequences.

The term “Unwanted Horse” was first coined by the American Association of Equine Practitioners (AAEP) at a horse industry meeting in Washington D.C. in 2005. Unwanted horses are defined as “those no longer wanted by their current owner because they are old; injured; sick; unmanageable; fail to meet their owner’s expectations; or the owner can no longer afford to keep them” (American Association of Equine Practitioners Hosted Unwanted Horse Summit, 2005). Generally, these are horses which are geriatric, incurably lame, have behavior problems, or are dangerous. They also include un-adoptable feral horses and horses that fail to meet their owner’s expectations because they are unmarketable, unattractive, not athletic, unmanageable, have no color, are the wrong color, or cost too much to maintain. Normal healthy horses of varying ages and breeds may also become unwanted (Messer, 2004). In many cases, these animals have had multiple owners, have been shipped from one sale barn, stable or farm to another, and have ultimately been rejected. In 2007, approximately 58,000 horses were processed for meat in the United States, ±35,000 horses were exported to Canada for processing, ± 45,000 were exported to Mexico for processing (T. Cordes, USDA, personal communication). In 2008, after closure of the U.S. horse processing plants, ± 57,000 horses were exported to Mexico and ±50,000 were exported to Canada for slaughter. In addition, ± 21,000 un-adoptable feral horses were kept in Bureau of Land Management (BLM) funded long-term sanctuaries, ± 9,000 feral horses were in the BLM adoption pipeline and an undetermined number of unwanted horses were potentially abandoned, neglected or abused. As of February 2008, there are approximately 29,500 wild horses and 3,500 wild burros roaming free on BLM-managed range lands. Because feral horses have few predators, the herds double in size every four years unless animals are captured and removed. Since 1971, 235,000 wild horses and burros have been removed from federal lands and adopted (Lofholm, 2008). Feral horses that are over ten years of age when captured or have been put up for adoption three times and not adopted are placed in long-term BLM funded refuges where they live out the rest of their lives. In 2007, BLM spent $26 million to support wild horses and burros kept in short and long-term holding facilities (U.S. Department of the Interior, 2008). That is well over three-fourths of the BLM’s 2007 fiscal budget of $38.8 million. The BLM is authorized under a 2004 amendment to the 1971 Wild Free Roaming Horses and Burro Act to sell “without limitations” unadoptable horses and burros, but pressure from animal activists and public sentiment has not allowed these animals to be euthanized or sold for slaughter.

Initially, there was debate in the horse industry on what type of horses were primarily represented and who was responsible for creating the significant number of unwanted horses in the U.S. However, U.S. Department of Agriculture (USDA) export records on U.S. horses shipped to Canadian processing
plants in 2002-2005 reveal 42.8 percent were geldings, 52.1 percent were mares, 3.41 percent were stallions, and the gender was not recorded on 1.70 percent. In addition, 70 percent were western type horses, 11 percent were English or Thoroughbred type horses, 3.6 percent were draft type horses, and the rest included various breeds or types of horses or mules (Cordes, 2008). Observational studies conducted in 2001 reveal that “riding” horses make up 74% of the horses processed for meat as opposed to draft or other horse types (Mcgee et al., 2001). In general, these types of horses reflect the demographics of the U.S. horse population with no specific type or breed of horse standing out as the quintessential unwanted horse. On average, over the past 10 years, 1-2% of the 9.2 million head (75,000 – 150,000 horses) domestic equine population in the United States has been deemed unwanted and sent to processing plants (U.S. Department of Agriculture, National Agriculture Statistics Service, 2007; American Horse Council, 2003). According to the 2005 USDA National Animal Health Monitoring System survey, ±167,000 (1.8 percent) horses in the United States 30 days of age or older were euthanized or died that year. In addition, ± 112,000 (1.3 percent) horses were processed for meat (U.S. Department of Agriculture, Animal and Plant Health Inspection Service, 2005). Therefore, the total mortality for horses in the United States in 2005 was approximately 3 to 4 percent of the horse population of 9.2 million. These percentages have varied little during the last decade (U.S. Department of Agriculture, Animal and Plant Health Inspection Service, 1999). The question facing the horse industry is if the option of annually removing many of the unwanted horses from the general horse population via euthanasia at a processing plant is legislated out of existence, will the horse industry be able to provide adequate care and accommodations for these animals or will it be forced to absorb the additional cost of their euthanasia and carcass disposal?

In recent years horse rescue/adoption/retirement organizations have, to their credit, made a conscientious and concerted effort to provide care, funding or suitable accommodations for unwanted horses in both the private and public sector. The number and capacity of these facilities can only be estimated as they function relatively independently and do not have a national organization. The American Horse Council’s National Assessment of Contributing Factors Surrounding the Unwanted Horse Problem found the average maximum capacity of rescue/retirement/retraining facilities is 42 horses or an estimated total of 18,060 horses per year (Lenz, 2008). Due to the long natural life span of twenty five to thirty years for most horses, rescue/adoption/retirement facilities face a potentially long, costly care period for each horse, and have placed funding as the critical, limiting factor for those striving to provide an adequate standard of care. In addition, there is a strong need for the formation of a national oversight organization that could inspect and register equine shelters that meet humane husbandry standards in order to prevent animal hoarders and unscrupulous horse traders from taking in horses under false pretenses. According to the American Horse Council study, rescues reported the cost to maintain a horse for one year to be $2,300 on average. If the horses sent to processing plants in 2008 had been rescued, it would have cost the industry $343 million (Lenz, 2008). This annual cost, however, understates the total cost required because unwanted horses that would have been processed in previous years will now remain in the horse population.

There are a number of options for horses that are unwanted or no longer considered useful. Some can be retrained for other uses. This is common in racehorses that often find second careers in dressage or hunter jumper competition or cutting horses that find second careers in team penning or as pleasure horses. Some are donated to university animal science departments, law enforcement agencies, veterinary teaching hospitals or therapeutic riding programs. As has been discussed earlier, some are simply euthanized at the request of their owners or sent to processing plants. Whenever there are large numbers of unwanted horses, there is always concern for their welfare and the reality for many unwanted horses is that they become a burden and are potential candidates for abuse, neglect or abandonment.

For those responsible horse owners who do not want to burden others with the disposition of a horse that is old, lame or no longer useful, the option of euthanasia and carcass disposal is available. The term euthanasia is derived from the Greek terms eu meaning good and thanatos meaning death (American
A good death occurs with minimal pain and at the appropriate time in the horse’s life to prevent unnecessary pain and suffering. According to the American Veterinary Medical Association’s 2000 Expert Panel on Euthanasia Report, there are three acceptable forms of euthanasia for horses: an overdose of barbiturate anesthetic, gunshot and penetrating captive bolt (American Veterinary Medical Association, 2001). Sodium pentobarbital is the most commonly used barbiturate for euthanasia in the horse and, when administered intravenously, depresses the central nervous system, causing loss of consciousness and deep anesthesia progressing to respiratory and cardiac arrest (Hullinger and Stull, 1999). Unacceptable injectable agents include strychnine, nicotine, caffeine, magnesium sulfate, cleansing agents, solvents, disinfectants and other toxins and salts (American Veterinary Medical Association, 2001). Physical methods of euthanasia include gunshot and penetrating captive bolt. When properly applied, both cause trauma to the cerebral hemisphere and the brainstem, resulting in immediate unconsciousness and a painless, humane death. A non-penetrating captive bolt only stuns animals and should not be used for euthanasia of horses (Hullinger and Stull, 1999).

After euthanasia, it is important the horse’s carcass is properly disposed of in a safe manner that does not pose a hazard to people or animals. However, approved methods vary widely with animal species and regulatory authority. There are a number of carcass disposal options available including burial, composting, incineration, rendering and bio-digestion (Bagley et al., 1999). Rendering plants that supply by-products to dog and cat food companies will not accept horses euthanized with sodium pentobarbital. Recent studies at West Texas A&M demonstrate that when Sodium Pentobarbital is used to euthanize horses and the horse is composted, residues remain in the compost (Cotter, 2009). Further studies will be required to determine if this is a potential health risk to people and animals. Many landfills will not accept carcasses of horses that have been euthanized with barbiturate overdose. In addition, many counties and municipalities will not allow burial of horses chemically euthanized.

A review of the unwanted horse issue would not be complete without a brief review of anti-slaughter legislation and the effect it has had on the horse industry. The term euthanasia has already been defined, but because the term slaughter is used frequently in the proposed legislations it is important to understand its meaning. In North America, slaughter is used to describe the humane ending of an animal’s life under strict federal regulations and is used only when the carcass is processed at a licensed meat plant for food purposes. In the European Union, slaughter is used by authorities to describe humane animal death, no matter the end result of the carcass (Alberta Farm Animal Care, 2008). The 1996 Farm Bill gave the USDA’s Animal and Plant Health Inspection Service (APHIS) regulatory responsibility for the humane commercial transport of horses to processing plants. APHIS oversees the requirements on access to food, water and rest during shipment, as well as the types of horses that cannot be shipped. In addition, the regulations phased out the use of double-decker trailers in 2006 and require that origin/shipper certificates accompany each shipment that document identifying marks, breed, color and gender (U.S. Department of Agriculture, Animal and Plant Health Inspection Service). A major concern by proponents of the anti-slaughter legislation is they believe horses, despite USDA oversight, suffer during transportation to the processing facilities. In a study reported in 1999 and conducted at the two Texas horse processing plants, a total of 1,008 horses in sixty-three trailer loads were observed during unloading. Conditions considered severe welfare problems in horses were body condition scores of 1 to 2 (emaciated) of 9; recumbency or the inability to walk; fractured limbs; and severe wounds. Ninety-two percent of the horses arrived in good condition. Fighting was the major cause of the injuries that occurred during transport and marketing. Abuse or neglect by the owner, not transportation, was the cause of 77% of the severe welfare problems observed (Grandin et al., 1999). In a study conducted by Stull, nine trailer loads of horses (n=306) transported to slaughter facilities with distances ranging from 596 to 2,496 kms were observed to characterize the physiological responses and number of injuries due to transportation under summer conditions. The percent of horses injured was greater for two-tiered “potbelly” (29.2%) compared to straight-deck (8%) trailers (Stull, 1999).
In 2001, the first proposed law to outlaw horse slaughter was introduced into Congress. The bill was never taken up by the full House, however, it did strike an emotional chord within both the horse industry and the non-horse owning public and started a debate that continues today. Proponents argued the ban on slaughter would eliminate pain and suffering of those horses shipped to processing plants and the surplus of unwanted horses that would result could easily be absorbed by the horse retirement/rescue industry. Opponents to the bill argued that banning the slaughter of unwanted horses would result in unintended consequences that would include increased neglect, abuse and abandonment. They also argued that unwanted horses, which in the past could have been sold for a profit, will now become a cost to the horse owner who must pay for care or euthanasia and carcass disposal (Ahern et al., 2006). They believed this would most severely impact the approximately 45% of U.S. horse owners that have an annual household income below $75,000 per year (American Horse Council, 2003). They also pointed out the bill did not provide funding, an infrastructure or enforcement authority to address the welfare of unwanted horses no longer processed for meat. There was also concern voiced that if the processing plants overseen by USDA veterinarians were closed, horses would be transferred longer distances to foreign processing plants. The bill was not passed, but in subsequent years bills have again been introduced in Congress to prohibit the slaughter of horses for human consumption. Independent inspections of processing plants in the U.S., Mexico, and Canada by AAEP veterinarians verified that animals at the plants were handled properly and their use of captive bolt and gunshot were acceptable forms of humane euthanasia for the horses being processed (Grandin, 2004).

Federal legislation to stop horse processing for meat became a moot point when in 2007 a 1949 Texas law that prohibits the slaughter of horses for human consumption (Texas Agriculture Code, Section 149.002) was discovered and enforced, closing the two horse processing plants in Texas (State of Texas). In that same year, Illinois Bill H.B.1711 was passed and amended the Illinois Horse Meat Act, thus making it unlawful for any person in Illinois to slaughter a horse if that person knows that any of the horse meat will be used for human consumption (State of Illinois). Now that there are no longer horse processing plants operating in the U.S., activists have turned their attention to introducing federal legislation to prevent the export of U.S. horses to processing plants in foreign countries.

Although the Unwanted Horse issue appears to be a U.S. only problem, animal activists in Canada and Europe are beginning to stimulate discussion on banning horse slaughter in their respective countries. From the U.S. experience with both the horse slaughter and unwanted horse issues it can be predicted that such activities will have a negative affect on the horse industry and equine welfare in countries where it occurs. The U.S. unwanted horse issue coupled with a dramatic downturn in the economy has produced several negative affects on the horse industry. The cost of caring for horses has increased and the amount of money available to owners has decreased. This has resulted in an increased sell-off of horses and the inability of owners to adequately care for them if they will not or cannot sell them. Because the processing plants in the U.S. have been closed, horses are currently shipped to Mexico or Canada for processing. The resultant high cost of transporting the horses has lowered the price buyers are willing to pay to only a few hundred dollars for a standard-sized horse in good flesh. Horses that have traditionally been sold at sale barns for 50 to 60 cents per pound are now bringing 10 to 15 cents per pound. As a result, the lowered price being paid for low-end horses has lowered the sale price of all U.S. horses. In addition, the number of horses abandoned and neglected has significantly increased. In a recently conducted national survey, over 90% of those polled indicated the number of neglected and abused horses is increasing. Eighty seven percent indicated the issue of the unwanted horse has become a “big problem”, compared with only 22% who felt it was important three years ago. Sixty-three percent of rescue/retirement/retraining facilities surveyed reported they are currently at or near capacity and, on average, turn away 38% of the horses brought to them (Lenz, 2008). Other problems created by the issue include a push by animal activists to reclassify the horse as a companion animal rather than livestock. The general public supports this initiative because they no longer view horses as working animals, but rather a luxury item to be treated as a pet. If horses were to be officially reclassified as companion animals, the
The horse industry would lose all federal and state funding for disease control, equine research, and disaster relief. The debate over horse processing and the unwanted horse has also fragmented the U.S. horse industry and created strong, emotional divides in an industry that traditionally collaborates.

The horse industry will never be able to completely eliminate unwanted horses. Horses will always age, sustain career-ending injuries, not perform up to owner expectations or not be attractive enough. However, the horse industry has turned its attention to the unwanted horse issue and is developing strategies to both reduce the number of unwanted horses on the front end through responsible breeding as well as on the rear end through rescue-retirement facilities, retraining for alternative careers, and low-cost euthanasia options. It is the responsibility of all horse owners to learn the facts about the unwanted horse issue and to own responsibly. They must be aware of how their actions affect the welfare of the horses they own and consider the consequences before they breed, buy, or discard a horse at the local sale barn. The unwanted horse issue will not be resolved over night and over time will extend to other countries. Concerted efforts to reduce the number of unwanted dogs and cats in the United States have been underway for decades, yet millions of dogs and cats are still euthanized at animal shelters and veterinary clinics each year (http://www.americanhumane.org). Key equine stakeholders are now working together to develop effective strategies to improve the quality of life of unwanted horses and to reduce their numbers.

References


ENZYME SUPPLEMENTATION AND EFFICACY WITH DIVERSE FEEDSTUFFS- A COMMENTARY

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Summary

Enzymes commercially available when combined compares favorably with the array released by microbes for nutrient recovery in the fowl’s ceca. Coprophagy of cecal excreta likely enables a continuance of overall microbiological activities under anerobic terms within the crop. Enzymes digesting NDF avails encapsulated nutrients as would supplemental xylanase then form less complex CHO’s that subsequently facilitate cecal function. Amylase digests starch to facilitate fermentation to yield organic acids and low pH. As a result, increased phytin solubility enables phytase to avail phosphorus while diminution of divalent complexing minimizes complications to digestion. Variable improvements in gastric and pancreatic enzyme effectiveness together with a favorable mucin character at the intestinal surface can be rationalized as suppressed sequestering of Ca that would destabilize their structures. Mucin has an inordinate need for glycine, serine, and proline which are not readily synthesized. Proteases in the ceca like those commercially available are oriented to poorly digestible connective tissues where these AA are abundant. Supplementing amylase, phytase, protease, and xylanase to feed essentially creates a parallel to enzymes encountered with coprophagy. Although enzyme supplements are oriented to corn-soybean meal, overlap in specificity and concurrent contributions by microbes with coprophagy likely support consistent responses when using diverse secondary feedstuffs.
EQUINE METABOLIC SYNDROME, LAMINITIS AND CARBOHYDRATE NUTRITION

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Summary

It has long been recognized that obesity and insulin resistance are associated with increased risk of laminitis in horses and ponies. Furthermore, in a recent informal survey of equine practitioners these metabolic/endocrine abnormalities were listed as the most common predisposing factors for clinical cases of laminitis within their practices. These anecdotal impressions are supported by the results of observational studies that demonstrate a link between an insulin resistant phenotype and predisposition to laminitis, particularly the pasture-associated form of the condition. Recently, the term equine metabolic syndrome (EMS) has been used to describe the clustering of obesity (generalized and/or regional), IR and prior or current laminitis. Diet appears to play an important role in the triggering of laminitis in horses or ponies with this phenotype, particularly the ingestion of pasture forage or other feeds (e.g. cereal grains or sweet feeds) high in nonstructural carbohydrates (NSC; simple sugars, starches and/or fructans). Dietary NSC appears to modulate risk for laminitis in susceptible animals via gastrointestinal disturbances and/or exacerbation of insulin resistance.

This presentation will review current understanding of EMS, with emphasis on 1) the impact of carbohydrate nutrition on clinical expression of the syndrome, and 2) dietary countermeasures for reduction in risk of laminitis in susceptible animals. Alterations in diet and feeding management can be helpful in the management of obesity and IR in horses and ponies with EMS. Caloric restriction, ideally combined with increased physical activity, to promote weight loss and improve insulin sensitivity is indicated for management of obese animals. In insulin resistant animals with or without obesity strict control of dietary NSC, with elimination of grains and sweet feeds from the ration and restricted access to pastures that may be rich in NSC is currently recommended. Medical treatment with levothyroxine or metformin may be indicated in obese or insulin resistant animals that do not respond to conservative dietary management.
DIVERGENT IMMUNE DEVELOPMENT IN FOALS AND IMPLICATIONS FOR SUSCEPTIBILITY TO DISEASE

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Summary

The immaturity of the immune response during the neonatal period contributes to increased susceptibility to infectious diseases. Foals, in particular, are born with few circulating antibodies and must rely on maternal antibodies obtained through colostrum during the perinatal period. While most cellular components of the immune system are present at birth, in many cases these cells can be considered immature or lacking full functional capability. The mechanisms involved in this immaturity are numerous and incompletely understood. Combined these deficiencies contribute to the susceptibility of neonates to certain infections. As the foal ages it steadily acquires increased functionality of its immune system both through its own production of antibodies and the maturation of the cellular components of the immune response. The age-related maturation correlates with increased resistance to intracellular organisms. While the mechanism responsible for this maturation process remains unknown, it is likely that exposure to environmental antigens is a key component of this response. Further, the nature of this environmental stimulation may be important in shaping the developing immune system and its subsequent ability to respond appropriately to different antigens.
GROWING MORE DURABLE EQUINE ATHLETES

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Summary

Osteochondrosis is currently thought to be the result of a failure of endochondral ossification that may affect articular epiphyseal cartilage or the metaphyseal growth plate. Studies in other species as well as the horse suggest that initial lesions are derived from growing cartilage and are associated with cartilage thickening and subchondral bone defects (Hurtig and Pool, 1996; Neidel et al., 1995; Philipsson et al., 1992; Pool, 1993; Reiland et al., 1978; Reiland, 1978), thus dyschondroplasia may be considered to be a more accurate description of the condition (McIlwraith, 2001). However, observations during surgery have indicated separation of cartilage and bone without cartilage thickening or defect in subchondral bone. It has been suggested that until the pathogenesis of DOD and the correlations with research models and clinical observations are better understood, the use of osteochondrosis would be most appropriate (McIlwraith, 2001).

The term osteochondritis dissecans was used as early as 1887 in association with human knee injuries (Barrie, 1987). Osteochondrosis, osteochondritis and osteochondrosis dissecans have often been used interchangeably and with some confusion. Osteochondrosis can be considered the disease specifically associated with the bone cartilage condition, osteochondritis the inflammatory response and osteochondrosis dissecans the condition when a piece of cartilage is actually avulsed from the surface of a joint (Pool, 1992; McIlwraith, 2001; Poulos, 1978). Further classification of osteochondrosis is proposed as osteochondrosis lateens (focal cartilage necrosis of the epiphyseal cartilage), osteochondrosis manifesta (microscopic and / or radiographic evidence of focal failure of endochondral ossification) and osteochondrosis dissecans (a loose or avulsed flap of necrotic cartilage) (Ytrehus et al., 2007). In 1986 the term developmental orthopedic disease (DOD) was introduced as a heading for all orthopedic problems in growing horses (Hurtig and Pool, 1996; McIlwraith, 2001). Today osteochondrosis, acquired limb deformities, physitis, subchondral cystic lesions, flexural deformities, cubiodal bone malformation and juvenile arthritis can all fall under the general heading DOD.

We must continue to define what degree management decisions effect the horse during different stages of its growth. It would seem logical that the most profound influence would occur during the most rapid periods of growth. Therefore, concerns have been directed toward the last third of gestation and the possible indirect effect brood mare management has on fetal development. The early postnatal period is another period of rapid growth; thus, the effect of brood mare management on lactation may affect the growth of the foal. Management also will have a direct effect on growth and development from the initiation of creep feeding programs through maturity. Thus, management concerns regarding growth should start at conception and continue through maturity.
Introduction

From a pathogenic standpoint osteochondrosis has been associated with various factors and interactions among these factors. Incomplete angiogenesis resulting in ischemic necrosis of subchondral bone has been one factor initially considered (Adams, 1974; Rejno and Stromberg, 1978). Other evidence suggested no association with cartilage necrosis and incomplete vascularization (Reiland, 1978). However, studies in swine show a significant association with reduced blood supply and the pathogenesis of osteochondrosis (Carlson et al., 1991). Some of these differences in observed pathologies may be due to the site of the lesion as well as the age of the animal. In addition, the influence of physical trauma that may shear vessels and thus contribute to cartilage necrosis and subsequent osteochondrosis lesions can also confound the issue regarding reduced blood supply and the pathogenesis of osteochondrosis (Henson et al., 1997; Philipsson et al., 1992; Pool, 1992; Rooney, 1975). More recent work in swine suggest damage to defined local temporal vessels, only present during a specific phase of growth, as the primary contributor to disruption of blood supply and subsequent focal osteochondrosis (Ytrehus et al., 2007; Ytrehus et al., 2004). This type of pathogenesis also has been shown in horses (Olstad et al., 2008).

Although much knowledge has been gained regarding the nutrient requirements, health and management of the young growing horse, there are still many questions concerning optimum nutrition and management for growth and the avoidance of (DOD). What degree, if any, of DOD can be considered normal? If any DOD is abnormal, then what degree can be considered acceptable or recoverable, such that future athletic performance will not be compromised? Is there a perceived increase in the incidence due to a greater ability to detect DOD, or due to changes in management practices that predispose horses to the disease, or both? Our ability to recognize and detect DOD certainly has increased, which leads back to the question of how much of what we detect is normal or inconsequential regarding the development, maturity and soundness of the tissue. Whether changes in management practices have affected the incidence of DOD is difficult to ascertain. Since DOD can potentially be influenced by many variants of confounding factors of genetics, environment, nutrition and other management actions. For the sake of discussion in this article I will summarize all of these variants with the term “management” unless specifically identified otherwise. Thus it is the complexity of these different management interactions that make the establishment of accurate and precise recommendations to avoid DOD complex and difficult. The end goal is to grow individuals that will be more durable during their athletic career. So we will continue to work toward management practices that will help to develop horses with improved skeletal strength and integrity.

Genetics

Heritability for osteochondrosis has been established in the horse and can vary depending on specific joints and breeds (Grondahl and Dolvik, 1993; Grondahl and Dolvik, 1992; Philipsson et al., 1992; Ytrehus et al., 2007). As a population, feral horses have significantly less radiographic incidence of DOD than the domestic population (Valentino et al., 1999). This difference may be related to natural selection pressures as well as management differences between feral and domestic horses. More recent research in horses is focused on specific quantitative trait locus associated with osteochondrosis (Lampe et al., 2009; Wittwer et al., 2008) In pigs, associations have been made to the heritability of specific anatomical conformation and the incidence and severity of DOD (Ytrehus et al., 2004). Selection against specific anatomical features may result in significant reductions in the incidence and severity of specific types of DOD. Pieramati etal., (2003) reported that simulated active genetic selection in Maremmano horses over a five generation period indicated a 87.5% reduction in the frequency of osteochondrosis dissecans (reduction in frequency from 16% to 2%).

As genetic research progresses we will better understand the interactions of genetic and non-genetic factors, as well as the implications of genomics. Such knowledge may already be implemented in
breeding selection and also could provide insight to the possible genetic predisposition of a particular horse, which then may allow adjustment to management programs in order to reduce the risk of DOD.

**Maternal Influences on Growth**

Linear increase in fetal body weight occurs after 200 days of gestation, and increases in length are greatest during mid-gestation. Growth in length of the cannon bones continues rapidly until eight to nine months of gestation and then slows; however, the pastern bones reach almost adult length by the time of birth. In general the more distal the bone the sooner it reaches its mature size and shape. At birth the third phalanx no longer has an active growth plate and post-natal growth proceeds perichondral.

Concerns regarding the maternal effects on foal growth and development should include the prenatal period, particularly during the last two thirds of gestation. Evidence suggest neuroendocrine control of growth hormone secretion in the horse may occur before parturition, which is earlier than in other species and may emphasize the importance of broodmare nutrition during gestation and lactation. At this time no research has been done to examine the role of brood mare nutrition on fetal growth hormone secretion. A series of studies have shown copper supplementation in the mare is reflected in increased copper concentrations in the liver of the foal and also resulted in reduced radiographic indices for physitis in the distal third metatarsal (Pearce *et al.*, 1998a; Pearce *et al.*, 1998b; Pearce *et al.*, 1998c). However, more recent research showed no difference in the incidence of osteochondritic lesions in foals from mares given injectable supplementation of copper compared to mares not receiving copper supplementation (Gee *et al.*, 2005).

Increasing the amount of nutrients available to the broodmare during the last third of gestation and during lactation is well accepted. Such increases help insure proper fetal growth and development. In the mare it provides for adequate milk production and maintains broodmare body condition, which enhances rebreeding efficiencies. However, we do not know how the intricacies of broodmare nutrition may affect the skeletal soundness of the foal in-utero, during growth and throughout adulthood.

**Growth Rate**

The association with rapid rates of growth and OCD has been long recognized in several species including the horse (Grondahl and Dolvik, 1993; McIlwraith, 2001; Reiland *et al.*, 1978). Several studies have reported height and weight measurements of a horse’s growth rate when compared to estimated mature body size. At 6 months of age a horse has obtained approximately 83% of mature height and 46% of mature weight, at 12 months 90% and 67%, and at 18 months 95% and 80%. Much of the growth in length from the knee and hock to the ground has occurred by 4 to 6 months of age. Growth data shows that Thoroughbreds from 1989 to 1990 grew slightly heavier and taller compared to Thoroughbreds from 1958 to 1976 (Thompson and Smith, 1994). This may be related to genetic selection for larger, faster growing horses and/or increased nutrient intake, better defined nutrient requirements, improved nutritional management and improved health management. Data from 1979 showed that colts of the same age were heavier and taller than fillies and this difference persisted to maturity. However, data from Quarter horses showed no difference in height between colts and fillies after 48-60 months of age. Interestingly, growth patterns of horses seem to be similar across breeds, geography and diet (Green, 1969). Studies in Thoroughbreds and Standardbreds indicate an increased incidence of OCD lesions, particularly in the shoulder, stifle and tibiotarsal joints in horses with greater than average weight gains. Lesions in the fetlock were not associated with weight gain prior to weaning (Pagan and Jackson, 1996; Sandgren *et al.*, 1993). It has been suggested that DOD lesions occur in the first three months of life, which is the most intense postnatal growth phase (Jeffcott, 1991). In addition, the hind limbs of the horse tend to grow at a more accelerated rate that the front limbs and there is a greater frequency of DOD associated with the hind limbs (Goyal *et al.*, 1981). Also, timing may play a role in the development of
DOD in that there may be a “window of opportunity” along some point of the growth curve or at some transition period that allows for a greater susceptibility to DOD. In swine there is much contradictory data regarding growth rate and predisposition to DOD. Associations with a genetic predisposition for DOD may be more related to anatomical conformation as it relates to specific joints rather than rate of growth (Ytrehus et al., 2007).

Although genetic predisposition, as it relates to anatomical form and perhaps growth rate, is the primary determinant of DOD, nutrition may be a contributing factor in horses predisposed to such conditions. The effects of supplemental feeding programs for young, growing horses may be most profound during the transition period when the young horse begins receiving most of its nutrients from feed sources rather than mare’s milk. This transition period is usually associated with weaning (3 to 5 months of age), a period of rapid growth that may compound the effects of feeding programs on growth. Creep fed foals (at approximately 1.5% of body weight) generally show a greater growth response than non-creep fed foals. However, differences in weight and height between creep and non-creep fed horses that may be evident at the weaning to yearling stage are not maintained provided the non-creep fed horses receive adequate nutrition for growth until maturity. Growth in the foal has been expressed in a curvilinear fashion as it relates to age. Studies in other species have shown that daily growth is variable and may not follow a precise growth curve. Growth in children has been suggested to be a series of 0.5 to 1 centimeter spurts, each approximately lasting less than twenty-four hours and separated by periods of stasis (Daughday, 1981). Growth curves for horses may represent a more stair step type of pattern with a negative rate of gain for 2-3 days post weaning. Where on the growth curve a horse should be at a given point in time is dependent on breed, the growth potential of the individual horse, and the desired growth rate. It is generally accepted that moderate or less rates of growth contribute less to the incidence of DOD than rapid rates of growth. Horses that may be predisposed to DOD (i.e. large framed individuals with an apparent potential for rapid growth) may benefit from diets of lower caloric density. This is sometimes confused with nutrient deprivation (starvation), which is counter-productive to reducing the potential for DOD. Protein, vitamins and minerals are needed to insure sound tissue development, but do not accelerate growth rate. Even protein concentrations at 126% of 1989 NRC recommendations have not been shown to result in an increased incidence of DOD (Savage et al, 1993; Schryver et al., 1987). Furthermore a review of studies in humans shows a positive association between protein intake and bone mineral density, bone mineral content and reduced bone resorption makers (Darling et al., 2009). Deficiencies of these nutrients will certainly retard growth rate and may affect quality of growth. Managing the growth rate of predisposed horses is best achieved by reducing calories while still providing recommended amounts of protein, vitamins and minerals to maintain quality of growth.

The other aspect of the growing horse’s diet that is often neglected is the forage component, which can vary from 30% of the diet or less to 70% or more. Depending on the quality of the hay or pasture, this aspect may have a greater impact on the amount and quality of nutrients consumed than the concentrate portion of the diet and thus should be considered in the overall management of predisposed horses.

**Exercise / mechanical stress**

Proposals have been made to reduce the incidence and severity of DOD by eliminating athletic events and strenuous training regimens to which young horses are subjected. Although such proposals may be effective it is not a realistic solution given the current industry focus. In addition, several studies actually support the reverse contention that early training and competition are beneficial to healthy bone and cartilage development (Bramlage, 2008). Exercise effects bone density and those effects can be dependent on the intensity and duration of exercise (Brama et al., 2009b; Raub et al., 1989; Stromberg, 1979). Exercise may have a dual role in its effects on cartilage and subchondral bone (SCB) depending on the condition of the tissue when exercise is introduced as research suggests that non-clinical lesions
present at an early age manifest into clinical signs with the increased trauma of exercise (Barrie, 1987; Jeffcott, 1991; Stromberg, 1979). However, exercise during the growth phase appears to be of much benefit to the development of a healthy skeletal system. Early research showed young growing horses subjected to forced exercise increased bone mineral density without an increase in DOD, and that such exercise may actually serve as a potential prophylactic to the development and severity of DOD (Anderson, 1991; Raub et al., 1989; van Weeren and Barneveld, 1999). More recent research has examined the potential benefit of exercise to the development of a healthy skeletal system in the young growing horse. Growing horses maintained in a stall confinement system and subjected to short intense bouts of forced exercise resulted in negative consequences to skeletal health (Barneveld and van Weeren, 1999). In 2008 and 2009 a series of articles were published that were the result of an extensive and collaborative effort to examine in detail short and long term effects of exercise conditioning in young growing horses (Rogers et al., 2008a; Rogers et al., 2008b; van Weeren et al., 2008). In order to determine the long term effects on skeletal health of young growing horses subjected to forced exercise programs Rogers et al. (Rogers et al., 2008b) subjected young growing horses to a controlled exercise program and continued to assessed skeletal health through their 2-3 year old racing careers. Phase one consisted of one of two groups of horses in a pasture management system being subjected to a controlled exercise program beginning at approximately 3 weeks of age and continuing until the initiation of race training at approximately 20 months of age. No negative effects of forced exercise were observed through this period. During Phase two yours from phase 1 were entered into race training at approximately 20 months of age and maintained a normal race training and race event schedule through 3 years of age. No negative effects were observed in horses subjected to exercise conditioning programs as young growing horses prior to the initiation of race training. Horses that did receive exercise conditioning at an early age tended to respond better to initial race training and in general were better able to compete (Rogers et al., 2008a). A detailed assessment of the biochemical composition of the articular cartilage extra cellular matrix showed that the cartilage degeneration index was not different compared to control (van weeren). Although the exercise group had a lower glycosaminoglycans (GAG) and collagen content at one of two sites assessed, GAG distribution reflected a more mature profile. The lower collagen content may be a result of an early maturation process. Other barometers of collagen remodeling were higher in the exercise group indicating a more advanced stage of maturity. In total, early exercise seems to facilitate an accelerated process of maturation in articular cartilage extra cellular matrix components (6Brama et al., 2009a; 69van Weeren et al., 2008). Few statistical differences were observed in articular calcified cartilage thickness, mineralization density and tidemark count and linear accretion rate between exercise and non-exercise growing horses (Firth and Rogers, 2001). An observational study indicated a greater risk for DOD in foals reared in large pasture areas at a young age (< 2 months of age) (Lepeule et al., 2009) In addition to the effects of exercise on articular cartilage, subchondral bone mineral density is also influenced by early exercise. Foals subjected to exercise programs had significantly greater subchondral bone density than non-exercised controls. Exercised foals continued to have a greater bone density than non-exercised controls even 6 months after the cessation of the forced exercise program (Brama et al., 2009b). These results support observations from earlier studies regarding bone mineral density and exercise in young growing horses (Raub et al., 1989).

In contrast to the potential benefits exercise may have on bone and articular cartilage, no significant differences were observed in tendon properties between exercised and non-exercised growing horses reared under pasture management (Moffat et al., 2008; 62Stanley et al., 2008). Although no positive associations were observed for early exercise and tendon properties it is important to note that early exercise did not result in any negative consequences to tendon structural properties.

Several factors may contribute to variability in specific results of studies associated with exercise in young growing horses and the effect on skeletal health. There may be limitations of benefit based on time of implementation of an exercise program as it relates to extra cellular matrix (Brama et al., 2009a). Nutritional programs also may influence outcome. The most common variable that could have the most
profound effect on outcome is an accurate assessment of locomotor activity not related to specific controlled exercise programs. Use of the cumulative workload index (Firth and Rogers, 2004) will provide an accurate reflection for controlled exercise regimens but can only provide approximate assessment of activity of horses in pasture or stalled environments. Moderate variations in exercise may have significant effects on articular collagen properties and bone density. In addition, the difference may be relatively narrow between a beneficial or detrimental amount of exercise applied to young growing horses. A system utilizing a global positioning satellite (GPS) device may provide for more accurate and precise recommendations and control of exercise programs in young growing horses in order to benefit skeletal health. (Williamson et al., 2010).

Hormonal interactions

Different growth factors acting in a complicated orchestration, systemically and locally, regulate the growth of cartilage. Currently it is thought that chondrocyte proliferation and differentiation is influenced by cell location and density via a feedback loop involving parathyroid hormone-related peptide (PTHrP), Indian hedgehog (IHH) and transforming growth factor beta (TGF-Beta) (Goldring et al., 2006; Kronenberg, 2003). In addition, other systemic and local growth factors like IGF-1 may have effects on this regulatory process (Provot and Schipani, 2005). In addition, IGF-1 and TGF-beta also may play a role in changes of cartilage protein and proteoglycan seen in osteochondritic lesions in the horse (Henson et al., 1997; Neidel et al., 1994; Semevolos et al., 1999).

Initial research regarding nutrition suggested higher starch and sugar diets were a predisposing factor due to an increased insulin response to feeding which precipitated episodic transient hypothyroidism (Glade and Belling, 1986). Subsequent research suggested that increased concentrations of insulin in response to dietary induced elevations in blood glucose may be more directly associated with DOD than the hypothesis of transient hypothyroidism. Increases in glycemic response measurements have been associated with increased incidence of DOD (Ralston et al., 2001). Increases in glycemic response may affect directly and indirectly hormonal responses that may affect cartilage metabolism. How nutrition interacts with various growth related hormonal theories associated with DOD is not completely understood. It has been suggested that feeding diets higher in starch and sugar may contribute to hormonal interactions that facilitate DOD issues in growing horses. However, such interpretations may be complicated since glycemic response may be affected by rate of consumption, physical form of the diet, diet composition and activity level. Substituting fat and fiber calories for sugar calories has been shown to effect systemic concentrations of IGF-1 in foals (60Slough, 2001). Other studies addressing the effect of added fat and/or reduced starch and sugar diets did not see any significant effects on systemic IGF-1 or TGF-beta (Baldock et al., 2003; Noweisky et al., 2009; Slough, 2001), or TGF-beta in synovial fluid (Weber, 1991).

The optimal amount of calories and the form in which they are presented to reduce the potential of DOD is not known at this time. To date the relative weak association of nutrition and DOD, may suggest a diminished role of nutrition as it relates to the etiology and pathogenesis of DOD. However, an old management rule of thumb that may be very applicable regarding nutrition and DOD would be: “the more of the nutrient requirements of a horse that can be met with long stem roughage the better will be their overall health”. In addition, what is not met with roughage should be compensated for with a well formulated, research based, high quality concentrate. When feeding with such concentrates their nutritional balance and quality should not be compromised with added supplements.

Other nutrient considerations

There has been little work addressing possible connections to vitamin status and DOD. The pathology of the various forms of DOD does not suggest a vitamin deficiency or excess issue. Mineral
nutrition for the growing horse seems to be well established as it relates to object deficiencies, particularly for minerals of primary concern such as calcium, phosphorus, zinc and copper (Cymbaluk and Smart, 1993; Knight et al., 1985). Additional research in this area may be warranted as we continue to learn more about the intricate relationships of vitamins and minerals and growth physiology. However, consideration should be taken that deficiencies of vitamins and minerals are associated with systemic disease conditions and not reflective of localized growth cartilage osteochondrosis. Furthermore, supplementation of minerals should not be considered a prescription for DOD.

References


THE IMPACT OF THE RUMEN MICROBIOTA ON FEED UTILIZATION AND HEALTH OF DAIRY COWS

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Summary

Ruminants are strict herbivores that consume fibrous diets with the main energy component being cellulose and hemicellulose of plant cell walls. Lacking the enzymatic capabilities to digest these carbohydrates ruminants are dependent on their microbial symbionts in order to obtain energy from the diets they consume. Favorable phenotypes such as high feed efficiency in dairy cattle may be regulated not only by the genetics, diet, and environment of the host, but also by their unique rumen and intestinal microbiota. Microbes in the reticulorumen include bacteria, protozoa, fungi, archaea, and viruses. Bacteria are generally categorized according to their preferred substrate, such as cellulolytic, amylolytic, and proteolytic types, which preferentially digest structural carbohydrates, non-structural carbohydrates, and protein, respectively. Protozoa ingest other microbes, as well as degrading feed components, generally non-structural carbohydrates and protein. Ruminal fungi are capable of hydrolyzing ester linkages between lignin and hemicellulose or cellulose thereby breaking down feed particles. Rumen archaea utilize the hydrogen produced by fermentation to reduce carbon dioxide to methane and thereby promote fermentation by removal of end-products. The wide diversity of microbes and their complex interactions are essential for efficient degradation of complex carbohydrates in the rumen. The end-products of microbial fermentation, mainly acetate, propionate and butyrate, are available to the host and can contribute up to 80% of the energy requirement of the ruminant. The microbes also use the available proteins and non-protein nitrogen in the feed to produce ammonia and ultimately incorporate the nitrogen into their cells as protein. The microbial protein is then available to the animal for digestion and absorption in the intestine. Another dietary advantage of this symbiosis is that the B-vitamins and vitamin K required by the animal are synthesized by the microbes. Ruminants are dependent on their ruminal and intestinal microbiota not only for nutritional contributions but also for their immunological, physiological and health protective contributions. As the microbes are the first to encounter the feed before host digestion they are also the first line of defense against anti-nutritional compounds in the diet such as phytotoxins and mycotoxins. Certain compounds can be transformed or degraded into less harmful products by microbial action. For instance, dihydroxypyridine degrading bacteria prevent toxicity when ruminants feed on the legume *Leucaena*. Not all the microbe-host interactions are beneficial to the host. Rumen microbes are associated with digestive problems such as bloat and acidosis, generally due to dietary changes resulting in changes in the microbial populations. Polioencephalomalacia, a neurological disorder, is associated with increased hydrogen sulfide production in the rumen. Improving dairy production by manipulating the rumen microbial ecosystem has been the goal of nutritionists and microbiologists for decades and requires an understanding of the microbes and their roles in order to have a positive impact on ruminant health and nutrition.
RECENT ADVANCEMENTS IN GAINING A DEEPER UNDERSTANDING OF RUMEN MICROBIAL ECOLOGY

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Summary

Culture-independent, molecular-based methods for characterizing microbial populations have revolutionized the field of microbial ecology. Application of these methods to the study of rumen microbiology has indicated that the rumen, like most other habitats, is inhabited largely by bacterial species that have resisted laboratory cultivation. Quantitative (real-time) PCR (qPCR) has proven particularly useful for quantifying individual species having known sequences of particular marker genes. qPCR studies using species-specific primers have revealed that the 13 most studied ruminal bacterial species comprise <10% of bacterial 16S rRNA gene copy number (a proxy for relative population size). However, qPCR using genus-level primers suggests that a single genus, the metabolically versatile \textit{Prevotella}, accounts for half or more of the total bacterial 16S rRNA gene copy number. qPCR is also useful for tracking changes in abundance of individual taxa in response to dietary change, and has revealed responses to monensin which challenge the notion that this feed additive has a selective effect against Gram-positive bacteria. Because qPCR requires prior knowledge of gene sequences from known organisms, it cannot capture the full spectrum of diversity of the microbial community. By contrast, community fingerprinting techniques (ARISA, T-RFLP, or DGGE), when combined with multivariate statistical methods, allow comparison of entire bacterial communities between cows, and allow tracking of changes in bacterial community composition (BCC) within individual cows over time and across dietary treatments. These methods have revealed that BCC changes substantially during the feeding cycle and differs substantially between solid and liquid phases of ruminal contents. Most striking, perhaps, is the observation that individual cows fed the same diet differ substantially in BCC, and that dietary changes that elicit specific performance responses (e.g., milk fat depression) are associated with specific changes in BCC. Moreover, experiments involving cross-inoculation of ruminal contents between cows suggest that the BCC of individual animals is host-specific and is not easily altered in the absence of specific selective pressure. In cases where specific microbial inoculants are aimed at filling targeted niches within the rumen, molecular-based methods are ideal for tracking populations of introduced microbes.
A REVIEW OF THE USE OF DIRECT FED MICROBIALS TO MITIGATE PATHOGENS AND ENHANCE PRODUCTION IN CATTLE

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Summary

Direct fed microbials (DFM’s) or probiotics have been employed in ruminant production for over 30 years. Originally, DFM’s were used primarily in young ruminants to accelerate establishment of the intestinal microflora involved in feed digestion and to promote gut health. Further advancements led to more sophisticated mixtures of DFM’s that were targeted at improving fibre digestion and preventing ruminal acidosis in mature cattle. Some of these outcomes have undoubtedly contributed to improvements in milk yield, growth and feed efficiency that have been observed in some, but not all production studies with DFM’s. More recently, there has been an emphasis on the development of DFM’s for cattle that exhibit activity against potentially zoonotic pathogens such as Escherichia coli O157:H7, Salmonella sp. and Staphylococcus aureus. Regulatory requirements has limited the number of microbial species within DFM’s with most products containing lactic acid producing bacteria (i.e., Lactobacillus and Enterococcus sp.) or yeast (i.e. Aspergillus oryzae; Saccharomyces cerevisiae). Development of DFM’s of rumen origin has also being explored using lactate utilizers (i.e., Megasphaera elsdenii, Selenomonas ruminantium, propionibacteria) as well as cell wall degrading Butyrivibrio fibrisolvens, but these products have seen limited commercial use. Our lack of knowledge of intestinal microbial ecology continues to present a challenge to the development of DFM’s that are efficacious over a wide range of ruminant production systems. Few studies have employed molecular techniques to study the interaction of DFM’s with indigenous microbial populations or the ruminant host in detail. Accelerated advancements in the genomics of microbial –host interactions could lead to the development of DFM’s with the capacity to improve production and promote health in a manner that is analogous to that presently achieved through the use of antimicrobials.
ECONOMIC EVOLUTION OF THE CONTEMPORARY DAIRY INDUSTRY

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Summary

In 2009, dairy farmers in the United States suffered their worst year financially in decades. Milk prices averaged over $5.00 below cash costs per hundredweight of milk between January and August, according to the author’s analysis based on USDA reported data. Less than two years previously, U.S. milk prices averaged about the same amount above cash costs for a somewhat shorter period in the second half of 2007, equally unprecedented over the past several decades. These extremes of economic volatility are not isolated incidents but symptoms and side effects of the rapidly-evolving structure of the industry in which U.S. farmers market the milk they produce. Accordingly, more disruptive movements of milk prices and costs of production likely lie ahead, posing further challenges to producers, their traditional milk marketing arrangements and the federal farm policies designed to provide stability in a generally more stable era, but not particularly suited to do so in the dairy industry of the future.

Introduction

Figure 1 illustrates the price-cost roller coaster on which U.S. dairy farmers have been riding since 2006. The “All-Milk Price” is the monthly U.S. average price received by dairy farmers for all milk sold to plants and dealers, which includes quality, quantity, and other premiums but excludes deductions for milk hauling and hauling subsidies. It is reported by the National Agricultural Statistics Service (NASS) of USDA. The area graph components of the cost of producing milk are reported by USDA’s Economic Research Service (ERS), based on NASS data. In addition to the important feed, hired labor and direct energy costs, these costs include veterinary, bedding, repairs, custom services, and marketing costs, plus interest on operating capital, cost of land, taxes, insurance and general farm overhead. They do not include the non-cash opportunity cost of unpaid labor and capital recovery of machinery and equipment reported by ERS. Figures shown represent a U.S. weighted-average of the 23 individual states reported monthly by ERS, which represent 89 percent of U.S. milk production during 2009.

The data shown in Figure 1 for months beyond December 2009 are forecasts based on January 11, 2010 settlement prices for the milk, dairy product and feed grain futures contracts offered by the CME Group in Chicago. As is typical, the futures tend to predict average expectation levels for future prices as opposed to the cyclical patterns that prices actually follow, particularly for milk and dairy product prices, where the biological lag time for milk supply adjustments tends to produce pricing cycles of approximately two years’ duration. In particular, milk prices for 2010 will likely be higher relative to costs that projected as of mid-December 2009. However, the financially disruptive nature of the U.S. dairy market in recent years is clear.
Increasing But More Variable Competition for the U.S. Milk and Dairy Feed Ingredient Supply

The root cause of the growing volatility of milk prices received and feed costs paid by dairy farmers in the United States is the transition of the dairy industry from a generally stable industry operating in relative isolation within the United States to one that is increasingly exposed to the more variable forces of global competition in numerous sectors.

The U.S.’s Growing Role as a Commercial Exporter

Until roughly the mid-point of the past decade, world trade in dairy products was relatively small and was transacted at prices generally well below those that prevailed in the U.S. domestic market. Commercial exports were made primarily by historically-low cost producing countries like New Zealand while dairy exports from relatively higher-cost producing countries, such as the United States and European countries required export subsidies, coupled with farm program-based import restrictions which permitted the maintenance of their domestic-world price differences. The low world market prices were the result of competition between such subsidized exports and the lower-cost producers. However, over time the “fundamental arithmetic” of the world dairy markets has been changing, as income growth in developing countries, particularly in Asia but also in Latin American and the Middle-East, has led to a predictable rise in demand for animal protein-based foods in those countries. This rising demand, including rising demand for dairy products, is generally proceeding faster than the ability of the historically-low cost producing countries to supply this demand. This is because those countries’ cost advantage stems from pasture-based production systems, which can produce additional milk supplies only by bringing more land into milk production. Coupled with reduced use, and likely elimination in the next few years, of export subsidies, world demand for milk and dairy products is simply outpacing the ability of the historically-net dairy exporting countries to supply at low prices. In classic economic fashion, world prices for dairy products are rising in the face this growing net demand.
As world dairy prices rise, they will attract additional supplies from several sources. First, historically-low costs suppliers will increase production to expand their exports. However, as discussed, this expansion comes at a cost, as ever more marginal lands are converted to milk production, as has occurred in New Zealand. This increases the cost of the additional supplies, even if no grain or supplemental concentrate feeding takes place. Furthermore, the pasture-based production systems of New Zealand and Australia have proven over the past decade to be especially vulnerable to recurring drought, while those of other dairy exporting countries such as those in the southern region of South America or the Ukraine have proven to be not especially amenable to expansion due to problems with infrastructure, lack of governmental policy support and inadequate access to capital.

A second source of increased supply to meet growing world demand for dairy products is the milk production sectors of the net dairy importing countries. For example, China, which is a major dairy importing country, now has one of the largest milk production sectors for a single country. However, expansion of the dairy industries in developing countries generally is hampered by lack of experience in milk production, underdeveloped infrastructure, climate issues, water supply problems and inadequate access to capital. As a result, the net dairy-importing countries will generally continue to expand their total dairy imports even with expansion of their domestic milk production. Currently, total imports as a percent of the total supply of milk and dairy products, domestic and imported, for major net dairy-importing countries are about 5 percent for China, 25 percent for Mexico, 30 percent for Japan, one-third for South Korea and Thailand, 55 percent for Algeria, two-thirds for Indonesia and Saudi Arabia, 90 percent for Malaysia and 95 percent for the Philippines.

As growing world dairy demand outstrips the growing export supply from the historically-low cost producing countries and the growing internal supplies in the net dairy-importing countries, the role of residual supplier inevitably falls to the historically-higher cost producing countries such as the United States, the European Union, other European countries and Canada. The United States, with the lowest production costs of this group of countries that have not historically been large commercial dairy exporters and also without a quota-type milk supply management system like most of the others, is therefore at the forefront of this group in terms of transitioning to the status of commercial exporter as world prices rise increasingly above domestic prices. As this occurs, consumers outside the United States are effectively bidding in competition with U.S. domestic consumers for the U.S. milk supply, raising the price in the process and bringing forth a greater supply to serve both groups.

Figure 2 illustrates the recent evolution of the United States into a growing commercial supplier of dairy products to world markets. It shows the total exports and imports of dairy components, measured by total milk solids (milkfat plus milk solids not fat) in all trade of dairy products and products containing dairy components, as a percent of U.S. production of those solids, between 1996 and 2009. In the second half of this period, U.S. dairy exports doubled, from about 5.5 percent to about 11 percent of total U.S. production, while U.S. dairy imports declined modestly. Some of this gain was due to a drought-induced shortfall in production in Australia and New Zealand, which was partly alleviated at about the same time that world demand underwent a temporary, but large reduction due to a combination of high retail prices and the world-wide recession of 2008-2009. These supply-demand swings were amplified for the U.S. by a combination of factors, chief among them the fact that U.S. exporters are still relative newcomers to commercial exporting and do not necessarily produce products to foreign buyers’ desired specifications nor have they had time to develop strong commitments to becoming reliable export suppliers, especially when prices drop to price support levels and products such as nonfat dry milk are then diverted from commercial exports to sales to the U.S. government. The result is larger variations in the supply-demand balance for milk in the U.S. domestic market while prices remain as sensitive as ever to relatively small variations in that balance.
Figures 3, 4 and 5 illustrate many of these evolving trends for three major categories of dairy products, nonfat dry milk, or skim milk powder, butter and cheese since mid-2005. In all three cases, the charts show the monthly domestic wholesale price of the product (the dashed lines in the upper portions), the corresponding world market price adjusted to a comparable basis in terms of net returns at the U.S. plant point of sale (the solid lines in the upper portions) and the monthly percentage of U.S. domestic production of the product that is exported (the bars in the lower portions). Among other factors, the charts show the correlations between U.S. and world prices (closest for nonfat dry milk, least so for butter), world prices leading U.S. prices upwards during times of export expansion, the drop in exports as U.S. prices fall to support levels (the dotted lines in the upper portions) during times of export contraction, the large changes in export levels during these transitions, which are generated by, and in turn generate the corresponding large changes in domestic prices.

Prices for these three products, plus dry whey, which resembles the situation for nonfat dry milk except that there is no price support for this product, are translated directly into the milk prices paid by milk buyers, and therefore into average milk prices received by U.S. dairy farmers for their milk. Thus, the working of the economic forces of an increasingly global dairy industry illustrated in Figures 3, 4 and 5, are directly indicative of the growing volatility of milk prices received by U.S. dairy farmers.
Figure 3
U.S. AND WORLD PRICES - SMP/NFDM

Figure 4
U.S. AND WORLD PRICES - Butter
Growing Competition for the U.S. Animal Feed Ingredient Supply

Increasingly volatile prices for milk sold by U.S. dairy farmers is not the only source of growing variability in their margins, or net financial returns from producing a marketing milk. Feed ingredient prices, particularly prices for corn, soybeans and soybean meal in dairy concentrate rations, have become more variable, and generally higher, partly as a result of the same global evolution that is driving U.S. export growth. Namely, as foreign demand for dairy products, and more generally for animal proteins grows, so does the supply of dairy and meat products, both in many of the countries that supply that growing demand through exports as well as in the net-importing countries. Animal numbers, and animal agriculture generally is expanding, for dairy, cattle, swine and poultry, causing an increase in the demand for, and supply of feed ingredients to support them. Therefore, global competition for U.S. dairy farmers’ feed sources, whether grown or purchased, is growing from all sectors of animal agriculture except for pasture-based animal agriculture production systems, driving up feed ingredient costs and increasing the sensitivity of those costs to changes in the supply-demand balance in those markets.

An additional, and variable source of competition for the U.S. feed ingredient supply comes from the renewable energy/biofuels sector, particularly ethanol and biodiesel production. Additional demand for feed ingredients such as corn and soybeans in the energy sector is partly driven by mandated use levels in government policies as well as government subsidies, which makes them more robust under a variety of economic situations but also ties their prices closely to energy prices in general, which continue to be volatile. For example, prices of corn, ethanol and petroleum are now closely correlated but also variable, so that the price of corn is driven increasingly by the supply-demand situation in the world-wide energy economy. This, in turn, is becoming increasingly demand-driven as – once again – incomes in developing countries, particularly China and India, continue to rise.
Concluding Comment

Detailed analysis of the evolution of the increasingly-linked global economies for energy, biofuels and animal feed ingredients is beyond the scope of this paper, but this convergence puts U.S. dairy farmers in to new global environment as far as their costs of production are concerned that is every bit as challenging as the new environment within which they must operate on the income, or milk price side of their operations. The coming years will see the continued unfolding of this evolution and will bring changes in marketing and policy arrangements that will be essential for U.S. dairy producers to cope with the negative effects of a basically positive, growth-based outlook for their industry.
Summary

Chromium functions in the trivalent form to enhance insulin sensitivity. Requirements for chromium are low, and it has generally been assumed that practical livestock diets contain sufficient chromium to meet animal requirements. However, over the past 15 years considerable research has suggested that cattle diets often may contain inadequate amounts of bioavailable chromium to maximize animal productivity. The FDA CVM issued a regulatory discretion letter in 2009 which permitted the use of chromium propionate as a source of chromium in cattle diets at a level up to 0.5 mg Cr/kg of complete feed. Addition of chromium to cattle diets has increased insulin sensitivity following intravenous administration of glucose. Supplementing high producing dairy cows with chromium during the transition period has increased feed intake and milk production during early lactation. Limited research has indicated that chromium supplementation may improve reproductive performance. A number of studies have also demonstrated that chromium supplementation can affect cell-mediated and humoral immune responses. Little is known regarding chromium concentrations in feedstuffs or bioavailability of chromium from animal feeds.

Introduction

In the late 1950’s Schwartz and Mertz (1959) reported that trivalent chromium (Cr) was an essential component of a factor in brewers yeast that corrected impaired glucose metabolism in rats fed certain diets. Subsequent studies demonstrated that Cr functioned as a potentiator of insulin action (Vincent, 2001). Considerable research has been conducted with Cr in human nutrition and an adequate intake of Cr has been established for humans by the Institute of Medicine (DRI, 2001).

Chromium requirements for cattle have been estimated by the NRC. Traditionally, practical diets fed to domestic animals were assumed to provide sufficient Cr to meet animal requirements. However, in the past 15 years a number of studies in cattle and other species have indicated that Cr supplementation of diets can affect animal metabolism and production criteria.

Although considerable research has been conducted with Cr in cattle, only recently has Cr supplementation been allowed in cattle diets. The FDA CVM issued a regulatory discretion letter in July of 2009 which permitted the use of Cr propionate as a source of Cr in cattle diets. Chromium propionate is the only Cr source currently permitted for supplementation to cattle diets in the U.S. It can be added at levels up to 0.50 mg Cr/kg of complete diet.

This paper will discuss responses that have been observed to supplementation with various forms of Cr in dairy cattle. In addition to Cr propionate (CrProp), Cr picolinate (CrPic), Cr methionine (CrMet), Cr amino acid chelate (CrAA), Cr yeast (CrY) and inorganic CrCl3 have been evaluated experimentally in cattle. It is unclear how different sources of Cr compare in regard to bioavailability.
Chromium and Insulin Action

Glucose tolerance tests have been conducted in cattle to evaluate the effects of Cr on glucose and insulin metabolism. In these studies a glucose solution has been infused intravenously (iv) and circulating concentrations of glucose and insulin measured frequently until they returned to baseline values. The addition of CrPic (Bunting et al., 1994) or CrProp (Sumner et al., 2007) to diets of growing calves has increased glucose clearance rates following glucose infusion without affecting serum insulin concentrations. Supplementing a milk replacer diet with 0.4 mg Cr/kg DM, from either CrCl\textsubscript{3} or a Cr nicotinic acid complex (CrNic) did not affect glucose clearance rate following a glucose infusion in young calves with undeveloped rumens (Kegley et al., 1997). However, insulin concentrations were lower following glucose administration in calves supplemented with CrCl\textsubscript{3}, suggesting increased insulin sensitivity in this group.

We recently examined the effect of level of supplemental Cr from CrProp on glucose metabolism in growing heifers. Chromium was supplemented at 0, 3, 6, or 9 mg Cr/head/day. These daily levels corresponded to 0, 0.47, 0.94, and 1.42 mg Cr supplemented/kg diet DM. Serum insulin concentrations and insulin:glucose ratios were much lower in all Cr-supplemented groups the first 15 minutes following glucose infusion (Figure 1). The lower release of insulin and decreased insulin:glucose ratio in Cr-supplemented heifers indicates that their tissues were more sensitive to insulin. Insulin concentrations and insulin:glucose ratios did not differ among heifers supplemented with 0.47, 0.94, and 1.42 mg Cr/kg DM. This suggests that Cr requirements of growing heifers do not exceed 0.47 mg Cr/kg DM.

There has been interest in the effect of Cr on insulin sensitivity in transition dairy cows because insulin resistance occurs in late gestation and continues during early lactation in both dairy (Sano et al., 1993) and beef cows (Sano et al., 1991). Subiyatno et al. (1996) found that supplementation of 0.5 mg Cr/kg diet, from CrAA, appeared to increase insulin sensitivity in primiparous dairy cows but not in multiparous cows at approximately 14 days prepartum. This was based on reduced insulin release and lower insulin:glucose ratios following iv glucose administration. Hayirli et al. (2001) supplemented multiparous cows with varying concentrations of CrMet from 21 days prepartum until 28 days postpartum, and conducted glucose tolerance tests at approximately 10 day prepartum and 28 day postpartum. Chromium supplementation did not affect glucose clearance or serum insulin concentrations prepartum. In postpartum cows peak glucose concentrations and serum insulin concentrations were lower following iv

![Figure 1. Effects of dietary chromium propionate on serum insulin concentrations and insulin:glucose ratios in heifers following a glucose tolerance test.](image)
glucose infusion in cows supplemented with 3.7 or 7.7 mg Cr/day compared with controls (Hayirli et al., 2001). Multiparous beef cows provided CrPic in a free choice mineral had lower insulin release following glucose infusion than control cows at approximately 30 days prepartum and 30 day postpartum (Stahlhut et al., 2006). The lower serum insulin concentrations occurred without a change in glucose clearance indicating increased insulin sensitivity.

**Feed Intake and Milk Production**

It is well documented that the transition period from 21 days prepartum to approximately 21 days postpartum is a critical period in regard to health and subsequent milk production of high producing dairy cows (Drackley, 1999). Most of the Cr supplementation studies with dairy cows have involved supplementation during the transition period. Supplementation of Cr prepartum has increased prepartum intake in some studies (Hayirli et al., 2001; Sadri et al., 2009) but not in others (Yang et al., 1996; Besong, 1996; Smith et al., 2005; McNamara and Valdez, 2005). Supplementation of 0.3, 3.9, 8.3 and 16.5 mg Cr/day from CrMet resulted in a linear increase in prepartum DM intake (Hayirli et al., 2001). Sadri et al. (2009) reported that supplementation with CrMet (approximately 10 mg Cr/day) increased prepartum DM intake when barley was used as the grain source but not when corn served as the prepartum grain source.

Supplementation of 0.5 mg Cr/kg diet from CrAA increased milk yield in primiparous dairy cows in two separate experiments (Table 1; Yang et al., 1996). Chromium was supplemented during both experiments from 6 weeks prepartum until 16 weeks postpartum.

**Table 1. Effect of chromium (Cr amino acid chelate) supplementation on feed intake and milk production of primiparous cows**

<table>
<thead>
<tr>
<th>Exp</th>
<th>Control</th>
<th>+Cr</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exp 1</td>
<td>6</td>
<td>6</td>
<td>0.06</td>
</tr>
<tr>
<td>Milk, kg/d</td>
<td>24.3</td>
<td>27.5</td>
<td></td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>16.4</td>
<td>16.8</td>
<td>0.76</td>
</tr>
<tr>
<td>Cows open</td>
<td>3/6</td>
<td>0/6</td>
<td>0.05</td>
</tr>
<tr>
<td>Exp 2</td>
<td>9</td>
<td>9</td>
<td>0.03</td>
</tr>
<tr>
<td>Milk, kg/d</td>
<td>24.1</td>
<td>25.7</td>
<td></td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>15.1</td>
<td>15.5</td>
<td>0.43</td>
</tr>
<tr>
<td>Cows open</td>
<td>2/9</td>
<td>1/9</td>
<td>0.53</td>
</tr>
</tbody>
</table>

*a* Adapted from Yang et al., (1996).

*b* Chromium was supplemented from 6 weeks prepartum until 16 weeks postpartum in both experiments. In experiment 1, chromium was supplemented at 5.5 mg Cr/cow prepartum and 10 mg Cr/cow postpartum. In experiment 2, cows were supplemented with 4.25 mg Cr/cow prepartum and 7.75 mg Cr/cow postpartum.

Besong (1996) supplemented multi and primiparous cows with 0 or 0.8 mg Cr/kg diet, as CrPic, from 30 days prepartum until 8 weeks postpartum. Performance results were not presented by parity in this study but parity was included in the statistical model. Chromium supplementation increased average milk yield from 31.1 to 33.4 kg/day. Feed intake was higher in Cr-supplemented cows during weeks 2, 3, 4, 5, and 6 of lactation.

A summary of studies evaluating the effects of Cr supplementation on milk production and DM intake in multiparous dairy cows is presented in Table 2. In most studies with multiparous cows Cr supplementation has increased or at least tended to increase DM intake and milk yield. Yang et al. (1996) observed no DM intake or milk production response to Cr supplementation with CrAA in multiparous cows. However, in these same experiments Cr supplementation improved milk yield in primiparous cows.
Estimated NE<sub>L</sub> (1.59 Mcal/kg DM) was lower in the lactation diets used by Yang <i>et al.</i> (1996) compared to the other studies (1.67 to 1.74 Mcal/kg DM) summarized in Table 2. It is unclear if feed intake and milk production responses to supplemental Cr are affected by dietary energy level. However, Cr supplementation from either CrPic (Peterson, 2000) or CrMet (Bryan <i>et al.</i>, 2004) has not affected milk production in grazing dairy cows where forage was the major source of energy.

Cows supplemented with CrMet from 21 days prepartum through early lactation had higher DM intake and milk production during the first 28 days in milk (Hayirli <i>et al.</i>, 2001; Smith <i>et al.</i>, 2005). Sadri <i>et al.</i> (2009) reported that grain source used in the pre and postpartum diets affected responses to supplemental CrMet. Chromium supplementation, at a level of approximately 10 mg/day, increased DM intake and milk production during the first 28 days in milk when barley was used as the grain source in the TMR. Feed intake and milk production were not affected by Cr addition when corn was used in the TMR.

Supplementing with Cr during the transition period may increase feed intake and milk production later in lactation even if Cr supplementation is discontinued. McNamara and Valdez (2005) supplemented dairy cows with CrProp from 21 days prepartum until 35 days postpartum. After CrProp was removed from the diet on day 35, DM intake and milk production continued to be monitored through 90 days in milk (Figure 2). Numerical increases in DM intake and milk yield were observed in Cr-supplemented cows the first 35 days of lactation. However, differences in intake and milk production between control and Cr-supplemented cows were greater from days 36-90 of lactation even though Cr was no longer being supplemented.

Studies in humans and rodents suggest that stress increases Cr requirements. Recently, Cr has been evaluated in lactating dairy cows under heat stress conditions. In Saudi Arabia, supplementation of dairy cows in mid lactation with CrY (4 mg Cr/day) increased DM intake by 1.6 kg/day and milk production by 3.3 kg/day (Al-Sarady <i>et al.</i>, 2004). Supplementation of heat-stressed dairy cows with CrPic during early lactation in China also increased DM intake and milk production (AnQiang <i>et al.</i>, 2009).

Figure 2. Effects of supplementing chromium propionate from 21 days pre until 35 days postpartum on DM intake and milk production*.  

*Adapted from McNamara and Valdez (2005).
Table 2. Summary of feed intake and milk production of multiparous dairy cows supplemented with chromium.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Cr source$^a$</th>
<th>Supplementation period</th>
<th>Cr, dose/cow/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yang et al., 1996</td>
<td>Cr AA</td>
<td>-42 to 112 d postpartum</td>
<td>Control, Level 1, Level 2, Level 3</td>
</tr>
<tr>
<td>Exp 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>11</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>22.2</td>
<td>22.5</td>
<td></td>
</tr>
<tr>
<td>Milk, kg/d</td>
<td>36.4</td>
<td>36.6</td>
<td></td>
</tr>
<tr>
<td>Exp 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>11</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>20.8</td>
<td>20.7</td>
<td></td>
</tr>
<tr>
<td>Milk, kg/d</td>
<td>36.8</td>
<td>36.3</td>
<td></td>
</tr>
<tr>
<td>Hayirli et al., 2001</td>
<td>CrMet</td>
<td>-21 to 28 d postpartum</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>13.8</td>
<td>14.9</td>
<td>17.2</td>
</tr>
<tr>
<td>Milk, kg/d</td>
<td>33.5</td>
<td>34.0</td>
<td>38.5</td>
</tr>
<tr>
<td>Quadratic P=0.01</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al-Saiady et al., 2004</td>
<td>CrY</td>
<td>120-190 d postpartum</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>80</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>19.6</td>
<td>21.2</td>
<td></td>
</tr>
<tr>
<td>Milk, kg/d</td>
<td>29.9</td>
<td>33.2</td>
<td></td>
</tr>
<tr>
<td>McNamara and Valdez, 2005</td>
<td>CrProp</td>
<td>-21 to 35 d postpartum</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>DMI, kg/d</td>
<td>17.0</td>
<td>18.7</td>
<td></td>
</tr>
<tr>
<td>Milk, kg/d</td>
<td>40.8</td>
<td>41.6</td>
<td></td>
</tr>
</tbody>
</table>

$^a$CrAA = chromium amino acid chelate, CrMet = chromium methionine, CrY = chromium yeast, CrProp = chromium propionate.
Table 2 (con’t). Summary of feed intake and milk production of multiparous dairy cows supplemented with chromium

<table>
<thead>
<tr>
<th>Reference</th>
<th>Cr source*</th>
<th>Supplementation period</th>
<th>Cr, dose/cow/day</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Smith <em>et al.</em>, 2005</td>
<td>CrMet</td>
<td>-21 to 28 d postpartum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td></td>
<td>22</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>
| DMI, kg/d          |            | 18.2                    | 18.9            | 19.7| Linear P=0.01
| Milk, kg/d         |            | 40.3                    | 40.5            | 42.8| Linear P=0.03
| Sadri *et al.*, 2009 | CrMet     | -21 to 28 d postpartum  |                 |     |
| Barley             |            | 8                      | 8  |     |
| DMI, kg/d          |            | 16.9                    | 18.4            |     | Cr x grain source, P=0.10
| Milk, kg/d         |            | 34.3                    | 37.7            |     | P=.08
| Corn               |            | 8                      | 8  |     |
| DMI, kg/d          |            | 18.3                    | 17.8            |     |
| Milk, kg/d         |            | 34.9                    | 35.2            |     |

*CrAA = chromium amino acid chelate, CrMet = chromium methionine, CrY = chromium yeast, CrProp = chromium propionate.
Reproduction

Limited research indicates that Cr supplementation may improve reproduction in cattle. Chromium supplementation reduced the number of open cows in one of two experiments with primiparous dairy cows (Table 1) but not in multiparous cows (Yang et al., 1996). Pregnancy rate tended to be higher in intensively grazed dairy cows supplemented with CrMet than in controls (Bryan et al., 2004).

Chromium has also affected reproduction in beef cows grazing pastures. Providing CrPic in a free choice mineral improved pregnancy rate in beef cows (Stahlhut et al., 2006b). The improvement in reproduction was due to increased pregnancy rate in cows 5 years of age or younger. Chromium did not affect pregnancy rate in beef cows 6 years of age or older. The improved pregnancy rate was associated with much lower plasma NEFA concentrations at approximately 21 and 79 days postpartum in Cr-supplemented cows (Stahlhut et al., 2006a). Chromium supplementation reduced postpartum body weight loss in 2 and 3-year old cows but not in older cows (Stahlhut et al., 2006b). Supplementation of CrY in a free choice mineral reduced the interval from calving to first estrus and tended to improve pregnancy rate in primiparous Zebu beef cows in Brazil (Aragon et al., 2001). Body weight gain was also greater in Cr-supplemented cows from parturition until their calves were weaned (Aragon et al., 2001). Reproductive responses to Cr may relate to its ability to increase insulin sensitivity. Insulin administration improved ovulation rate in energy-deprived heifers (Harrison and Randel, 1986).

Immunity and health

Studies in periparturient dairy cows indicate that Cr supplementation of practical diets may affect cell-mediated and humoral immune responses. Lymphocytes from cows supplemented with 0.5 mg Cr/kg diet, from CrAA, had increased blastogenic responses to Con A stimulation (Burton et al., 1993). Furthermore, Cr supplementation prevented the decrease in blastogenic response that was observed in control cows 2 weeks prepartum. Chromium supplementation also improved primary and secondary antibody response to ovalbumin administration but not antibody response to human erythrocytes (Burton et al., 1993). The primary injection of ovalbumin and human erythrocytes was given 2 weeks prepartum and the secondary injection was administered 2 week postpartum. Supplementation with 5 mg Cr/day increased antibody responses following vaccination with tetanus toxin in dairy cows (Faldyna et al., 2003). Neutrophil function has not been affected by dietary Cr (Chang et al., 1996; Faldyna et al., 2003).

Studies examining the effects of dietary Cr on health in dairy cows are limited. Supplementing 3.5 mg Cr/day (from CrPic) during the last 9 weeks of pregnancy reduced the incidence of retained placenta in dairy cows from 56 to 16% (Villalobos-F et al., 1997). Chromium supplementation (CrAA) prepartum and during the first 16 weeks of lactation did not affect mammary gland health status (Chang et al., 1996).

Chromium may affect incidence of ketosis by enhancing insulin sensitivity. Insulin is an anabolic hormone that promotes lipogenesis and inhibits lipolysis. Supplementation of dairy cows with CrMet has reduced circulating NEFA concentrations at 7 to 10 days prepartum in some studies (Bryan et al., 2004; Hayirli et al., 2001) but not in others (Smith et al., 2008). Dairy cows supplemented with CrPic had lower plasma concentrations of β-hydroxybutyrate than controls at 3 and 30 days postpartum (Besong, 1996). Liver triglyceride concentrations were also lower in Cr-supplemented cows at 30 days postpartum (Besong, 1996). Chromium supplementation has not affected clinical cases of ketosis in lactation studies that have reported health-related disorders (Chang et al., 1996; Yang et al., 1996; Smith et al., 2005).

Chromium in feedstuffs

Variation among studies in response to Cr supplementation may relate to differences in Cr content or bioavailability from feedstuffs. Little is known regarding Cr concentrations in practical feedstuffs and even less is known regarding bioavailability of Cr from common feedstuffs. In most Cr
studies with lactating dairy cows the Cr content of the control diets have not been reported. Chromium analysis of diets is challenging due to the low levels of Cr normally present and problems with Cr contamination of feed samples during collection and preparation of samples for analysis (NRC, 2005). We have found most complete diets to contain less than 1 mg Cr/kg diet DM.

References


USE OF BOVINE SOMATOTROPIN TO IMPROVE PRODUCTIVE EFFICIENCY

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Summary

Recombinant bovine somatotropin (rbST) has been marketed in the U.S. for 16 years and outside the U.S for 24 years. Despite concerns of some regarding animal and human health, there has been no evidence of health issues in animals or people associated with its commercial use. Results from post-approval monitoring and data summaries indicate that the use of Posilac raises no unique issues of concern, and the care and management of rbST-supplemented cows is the same as comparable cows not receiving supplements. These results correspond to the experiences of producers, veterinarians and dairy consultants, and to date over 30 million U.S. dairy cows have received supplements of Posilac. Producer and consumer gains from the use of rbST relate to two inter-related considerations - the efficiency of nutrient use and the environmental impact. First, rbST supplemented cows use nutrients more efficiently and this improvement is a consequence of the “dilution of maintenance”, more commonly referred to as “productive efficiency”. Second, the increase in milk yield from rbST results in ~9% reduction in the carbon footprint of producing a gallon of milk. Overall, rbST is a management tool that improves the sustainability of the dairy industry in a manner analogous to other management practices and technologies that increase the efficiency of milk production.

Introduction

Recombinant bovine somatotropin (rbST) was among the first proteins produced through the use of ‘biotechnology’. Initially, several companies actively pursued the development of rbST, but Monsanto’s injectable-formulation proved advantageous. The FDA approved the commercial use of Monsanto’s rbST in November, 1993 and commercial sales began on February 4, 1994, under the trade name “Posilac”. At that time biotechnology was a new development and its application caused concern and uneasiness in some producers and consumers. This disquiet contrasts sharply with today where 80-90% of the corn, soybeans and cotton grown in the U.S. are transgenic and recombinantly-produced proteins are used extensively in the food and biomedical industries. Examples of recombinant technology based proteins production include rennin used in production of cheeses, lactase used to produce lactose-free milk, and insulin used to control human diabetes.

There are presently 20 countries where rbST has approval for commercial use, but the human safety of dairy and meat products from rbST-supplemented cows has been confirmed by regulatory authorities in 56 countries. Even countries that don’t allow the commercial use of rbST (e.g. Canada and
European Union) allow the import of dairy products from rbST-supplemented cows with no restrictions or special labeling requirements.

There is no test to identify milk from cows supplemented with rbST, and there are no biological or nutritional differences between milks from rbST-supplemented and unsupplemented cows. Nevertheless, in addition to conventional (unlabeled) fluid milk, today’s retail dairy case may contain milk labeled as ‘rbST-free’ or ‘organic’. These specialty labeled milks represent a marketing effort for niche products labeled according to production practices. Studies comparing conventional milk with milk labeled as ‘rbST-free’ or ‘organic’ show at the retail level these milks have no important differences and are similar in nutritional quality and wholesomeness (O’Donnell et al., 2010; Vicini et al., 2008).

Posilac was marketed in the U.S. by Monsanto Dairy Business whereas Elanco distributed Posilac to countries outside the U.S. In October, 2008, Elanco purchased the Posilac business and became the world-wide distributor for rbST. In the 15 years since approval, over 30 million U.S. dairy cows have received rbST supplementation. Thus, it’s timely to update our consideration of this technology, and this is of special interest given the current economic challenges facing the U.S. dairy industry. In the following sections, we will give an overview of the biology of somatotropin that provides a historical context, discusses performance and cow health responses, and considers the implications of rbST use.

**Historical Context**

The somatotropin story began in the 1920’s and 30’s when it was discovered that a protein extract isolated from the pituitary glands affected animal performance. Russian scientists were the first to extend this to dairy cows when they administrated pituitary extract to over 2000 cows. They only gave a single injection so the increase in milk yield lasted only a day or so, but they reported the “absolute harmlessness” of the extract and that responses were “more profitable on a well-run farm than on a farm with a poor food basis or where cattle are kept under unsatisfactory conditions” (Asimov and Krouze, 1937). In the 1940’s British scientists conducted an impressive series of studies with a goal of increasing milk supply to help alleviate chronic food shortages during WWII. They were the first to identify bST as the galactopoietic factor in pituitary extract and concluded its use “would be highly profitable to the individual farmer”; however, they also found the supply of bST was too limited to significantly impact national milk supply (Young, 1947). Additional studies with lactating cows were conducted over the decades that followed (see review by Bauman, 1999), but these were constricted by two factors. First, supply of bST was limited to that isolated from the pituitary glands of slaughtered cows. Second, based on incorrect ideas on the mechanism of bST, scientists only worked with fat, low producing cows (<15 lbs/d).

In the 1970’s, Hart and co-workers in the U.K. and our group at Cornell developed new ideas on the regulation of lactation which explained the basis for improved efficiency of genetically superior cows (Bauman and Currie, 1980; Hart, 1983). Based on this, we began to work with pituitary-derived bST in high producing dairy cows and the studies that followed established the central role of bST in the regulation of nutrient use for milk synthesis in dairy cows and demonstrated its key importance in maintaining animal well-being (Bauman, 1999).

**Production Responses and Mechanisms**

Posilac is a formulation of rbST in oil that is given by subcutaneous injection at 14 day intervals commencing on the 9th to 10th week after calving and continuing until the end of lactation. Published results from controlled experiments and field trials indicate that the positive milk response has a central tendency toward 4.5 kg/d (10 lbs/d). Milk responses have been observed for all breeds and cows regardless of genetic merit. Across hundreds of experiments the variation between unsupplemented and supplemented cows is similar indicating that all cows receiving rbST are responding in a similar manner. In addition, no special diets are required and cows receiving rbST have been shown to increase their
voluntary intake to the extent needed to meet nutrient requirements for the milk response. Milk yield per cow has progressively increased over the last 60 years and this gain in productivity is due to adoption of new technologies and improvements in management practices. Data from a large field study demonstrate the annual gain in daily milk per cow over an 8 year period and illustrate the impact of rbST (Figure 1). Herds supplementing with rbST had the characteristic annual gain in daily milk per cow during the pre-approval period, but milk yield was increased by a similar additional increment each year during the post-approval period when rbST was used. When adjusted for the proportion of supplemented cows, the incremental increase due to rbST was ~ 4.5 to 5.0 kg milk per day (Figure 1). From a producer prospective the use of rbST makes all cows more like the best cows in the herd, and the importance and effectiveness of comprehensive management programs related to nutrition, reproduction, and cow health are the same for cows of comparable production regardless of whether rbST supplements are used to achieve that production (Bauman, 1992; Hartnell et al., 1991; National Research Council, 1994).

The mechanism by which rbST promotes increases in milk production involves two dimensions, one of which relates to the regulation of nutrient utilization. There are two types of controls in the regulation of nutrient utilization - homeostasis and homeorhesis (Bauman and Currie, 1980). Homeostatic controls regulate metabolic processes on an acute, minute-by-minute basis to maintain steady state conditions; the regulation of glucose utilization by insulin is an example. Homeorhesis operates on a chronic, long-term basis and can be defined as the “coordinated regulation of metabolic processes to support the needs of a physiological state” (Bauman and Currie, 1980). Homeorhetic controls are analogous to a symphony conductor who coordinates the contributions of all the various instruments that make up the orchestra to produce a harmonious symphony. Homeorhesis is regulated by the endocrine system and somatotropin is one of the major homeorhetic regulators; during lactation somatotropin regulates the partitioning of nutrients to support milk synthesis. This orchestration involves most organs and tissues in the body, and includes the metabolism of all nutrient classes – carbohydrates, lipids, proteins, and minerals. Thus, rbST treatment both increases milk synthesis by the mammary gland and orchestrates other body processes in a manner to provide the necessary nutrients to support the enhanced milk synthesis (Etherton and Bauman, 1998).

A number of the major coordinated changes that occur with rbST are summarized in Table 1. These adaptations are of special importance when rbST is first initiated because the increase in milk yield occurs immediately and the matching increase in voluntary feed intake is more gradual. Glucose provides an excellent example of the coordinated responses (Bauman, 1999; Etherton and Bauman, 1998). Glucose is utilized for milk synthesis, primarily for milk lactose, and the milk response to rbST includes increased

![Figure 1. Improvements in average daily milk yield in Northeast dairy herds. Posilac use commenced February 1994 (dashed line) and data encompass pre-approval (1990 through 1993) and post-approval (July 1994 through 1998) periods. Control herds (open diamonds) never purchased Posilac, and bST herds (closed squares) used Posilac continuously throughout the post-approval period. Data represent 340 herds with over 80,000 cows and 200,000 lactations; for comparison, daily yields are expressed relative to 1993, the year prior to commercial approval of rbST. Adapted from Bauman et al. (1999).](image-url)
mammary uptake and use of glucose. At the same time tissue responses to insulin are shifted so that liver synthesis of glucose is increased and the use of glucose by adipose and other body tissues is reduced. The net effect is that rbST-supplemented cows partition more glucose to the mammary gland for increased milk synthesis but glucose supply and use remain in balance. Thus, glucose homeostasis and the cow’s well-being are maintained.

Table 1. Effect of bovine somatotropin on specific tissues and physiological processes in lactating cows.a

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Process affected during first few days and weeks of treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mammary</td>
<td>↑ Synthesis of milk with normal composition</td>
</tr>
<tr>
<td></td>
<td>↑ Uptake of all nutrients and milk synthesis per secretory cell</td>
</tr>
<tr>
<td></td>
<td>↑ Number and maintenance of secretory cells</td>
</tr>
<tr>
<td></td>
<td>↑ Blood flow and nutrient supply consistent with increase in milk yield</td>
</tr>
<tr>
<td>Liver</td>
<td>↑ Rates of glucose production</td>
</tr>
<tr>
<td></td>
<td>↓ Ability of insulin to inhibit glucose production</td>
</tr>
<tr>
<td>Adipose</td>
<td>↓ Fat deposition if in positive energy balance</td>
</tr>
<tr>
<td></td>
<td>↑ Fat mobilization if in negative energy balance</td>
</tr>
<tr>
<td></td>
<td>↓ Ability of insulin to stimulate fat deposition</td>
</tr>
<tr>
<td></td>
<td>↑ Ability of catecholamines to stimulate use of body fat reserves</td>
</tr>
<tr>
<td>Intestine</td>
<td>↑ Absorption of Ca, P and other minerals required for milk</td>
</tr>
<tr>
<td>Whole body</td>
<td>↓ Oxidation of glucose to spare use for milk synthesis</td>
</tr>
<tr>
<td></td>
<td>↑ Fatty acid oxidation if in negative energy balance</td>
</tr>
<tr>
<td></td>
<td>ϕ Energy expenditure for maintenance</td>
</tr>
<tr>
<td></td>
<td>↑ Energy expenditure consistent with increase in milk yield (i.e. energy per unit of milk not changed)</td>
</tr>
<tr>
<td></td>
<td>↑ Cardiac output consistent with increases in milk yield</td>
</tr>
<tr>
<td></td>
<td>↑ Immune response</td>
</tr>
<tr>
<td></td>
<td>↑ Productive efficiency (milk per unit of nutrient intake)</td>
</tr>
</tbody>
</table>

Adapted from Bauman (1992) and National Research Council (1994). Changes (↑= increased, ↓ = decreased, ϕ = no change) which occur in initial period when metabolic adjustments occur to match the increased milk synthesis. With longer term treatment, voluntary intake increases to match nutrient requirements.

The second dimension of the mechanism by which rbST increases milk production involves an improvement in the persistency of milk production. Milk production typically peaks at about 60 days postpartum and then declines gradually over the remainder of lactation. The decline in lactation corresponds to a gradual loss of mammary cells referred to as cell death or apoptosis (Capuco et al., 2003). Mammary cell numbers are better maintained in first lactation heifers and in cows that have a greater lactation persistency. Supplementation with rbST also improves the maintenance of actively secreting mammary cells (Capuco et al., 2001); the net effect is that the milk yield is more persistent in rbST supplemented cows so that differences between cows receiving rbST and untreated cows tend to increase over the course of the lactation.

Cow Well-Being and Health

The success of the dairy business is in large part dependent on the health and well-being of the dairy herd. It is the absence of stress and health problems that allows dairy cows to achieve high production. However, high producing cows are also at greater risk for various production-related
metabolic disorders and health problems, and sound management programs are required to mitigate these risks so that high milk production can be achieved. If a cow is stressed or has sub-clinical or clinical problems, milk production is reduced and productive efficiency will be decreased. Thus, a comprehensive management program is essential to the dairy operation; producers, veterinarians and dairy professionals are keenly aware that the production of the dairy herd reflects the management program, and the individual cow’s performance is a clear indication of the cow’s own health and well-being.

Prior to approval for commercial use, the interest in biotechnology and rbST resulted in over 1500 scientific reports by university, government and industry animal scientists. This level of investigation on a world-wide basis was unprecedented for a new technology and results consistently demonstrated that rbST supplementation resulted in an increase in milk yield and an improvement in productive efficiency. Nevertheless, some predicted the commercial use of rbST would cause catastrophic health problems including ketosis, milk fever, catabolic stress and hypermetabolic syndrome, mastitis, heat intolerance, chronic wasting and burnout, and a high mortality rate (see references cited in Bauman, 1992).

Mastitis was of special interest and the pre-approval evaluation included a Public Hearing by The FDA Center for Veterinary Medicine (CVM), Veterinary Medicine Advisory Committee (VMAC). This Expert Panel concluded the increased risk of mastitis from rbST was similar to that observed with improvements in milk yield and miniscule compared to major risks. The risks of mastitis are mainly associated with environment and management factors, and the Expert Panel pointed out there was a much greater risk related to herd (+320%), season (+670%), parity (+440%) and stage of lactation (480%). They concluded “in view of the much larger variations in the number of mastitis cases normally observed due to herd, season, parity, and stage of lactation, the use of sometribove (rbST) would not be an important factor in considering the overall incidence of mastitis per unit of milk produced. Therefore, CVM has concluded that the use of Posilac in dairy cows will not result in an increased risk to human health due to the use of antibiotics to treat mastitis” (FDA VMAC, 1993). Interestingly, the Health Canada Canadian Veterinary Medical Association (CVMA) Expert Panel conducted a similar evaluation, but reached a different conclusion. CVMA felt more information on the nature of mastitis was needed, but agreed that use of rbST would result in a relatively small increase in the risk for mastitis. However, the CVMA Panel concluded for Canadian dairy farmers that the “current dairy health management techniques could reduce this increased risk, (but) they are not adequate to eliminate it” (Health Canada, 1998).

Research with rbST has continued in the post-approval period, although it has been focused more on basic studies of mechanisms. However, several post-approval publications relating to cow health and well-being merit mention because they represent large-scale studies conducted on commercial dairy farms. These investigations included variables such as reproductive performance (Judge et al., 1999; Santos et al., 2004), lameness (Collier et al., 2001; Wells et al., 1995) and veterinary costs (Tauer and Knoblauch, 1997). A number have examined the basis and rates for culling (Collier et al., 2001; Judge et al., 1997; Ruegg et al., 1998). Mastitis, somatic cell count (SCC) and udder health was the focus of several data summaries (Bauman et al., 1999; Judge et al., 1997; McClary et al., 1994; White et al., 1994) and post-approval studies and variables include new mammary infections, incidence of clinical mastitis and duration of mastitis. In addition, FDA CVM set up an extensive Post-Approval Monitoring Program (PAMP) to “determine if mastitis incidence and antibiotic use was manageable under actual use conditions” (FDA VMAC, 1996). PAMP involved three components: 1) a proactive system of collecting Adverse Drug Experience Reports; 2) a program of tracking milk residues by key states before and after approval, and; 3) a stringent 28-herd study involving herds of different sizes in key dairy producing states. In their follow-up evaluation of PAMP results, the VMAC concluded results “confirm that rbST is indeed safe and has no adverse effect on the milk supply” (FDA VMAC, 1996). Furthermore, post-approval studies have allowed for a marked simplification of the label for use of Posilac as many of the health concerns listed on the original label have not materialized. Importantly, rbST has also been shown to have
no adverse effects in poorly managed or sick cows, demonstrating again that rbST does not force cows to produce milk, it merely allows cows to reach their genetic potential for production in well managed herds.

Milk SCC was also of special interest because this represents a measure of milk quality, specifically a reflection of mammary health such as inflammation caused by bacterial infection during sub-clinical or clinical mastitis. The largest study examining this included 340 herds involving over 80,000 cows and 200,000 lactations over an 8 year period (Bauman et al., 1999). Results demonstrated that rbST supplements had no effect on milk SCC and that rbST did not alter the characteristic pattern for milk SCC related to stage of lactation and parity (Figure 2). Furthermore, this multi-lactation field study demonstrated that the stability and herd-life (proxies for longevity and culling) did not differ between rbST supplemented and unsupplemented herds (Bauman et al., 1999).

![Figure 2](image)

**Figure 2.** Comparisons of lactation curves of milk somatic cell counts (linear score) for control and bST herds during the pre-approval period (January 1990 to February 1994) and the post-approval period (July 1994 to March 1998). Data for primiparous cows (panels A and C) and multiparous cows (panels B and D) are presented for the pre-approval period (circles) and post-approval period (squares). Panels A and B are control herds and panels C and D are bST herds. Test-day model comparisons are expressed so that solutions sum to zero across the lactation. Adopted from Bauman et al. (1999).

The results from post-approval monitoring and data summaries established that the use of Posilac raised no unique issues of concern, and the care and management of rbST-supplemented cows was the same as comparable cows not receiving supplements. These results are consistent with producer use of rbST and over the 16 years of commercial use over 30 million cows have received Posilac supplements. Nevertheless, some have continued the claims voiced pre-approval that Posilac causes cow suffering and even death; these groups appear to have little confidence and respect in the dairy industry and rather assume dairy farmers, veterinarians and dairy consultants would continue to use a technology that adversely effects cow health, lactational performance and economic return.
Sustainability Implications

Sustainability is an important consideration in agricultural production, with emphasis on meeting human food needs while mitigating the environmental impact. The use of rbST impacts the sustainability of the dairy industry. Producer and consumer gains from the use of technologies such as rbST relate to two inter-related considerations - the efficiency of nutrient use and the environmental impact. First, rbST supplemented cows use nutrients more efficiently and this improvement is a consequence of the “dilution of maintenance”, more commonly referred to as “productive efficiency” (milk input per resource input) (Bauman et al., 1985; VandeHaar and St-Pierre, 2006). As illustrated in Figure 3, a portion of the nutrients consumed by the lactating cow is utilized for maintenance. This represents a fixed cost for the cow to live and carry out normal functions, regardless of her performance. Additional nutrients are required for synthesizing milk; a constant quantity is required for each increment of milk. This component of the nutrient requirements increases as milk output increases, but the fixed costs of maintenance are diluted as milk yield increases (Figure 3). Thus, rbST supplemented cows require more nutrients to support their increased milk output, but the proportion of total nutrient intake used for milk synthesis increases and the proportion for maintenance is reduced (Bauman, 1992; National Research Council, 1994).

The second source of producer and consumer gain from the use of technologies such as rbST relates to the environmental component of sustainability. The environmental benefits of using rbST have been enumerated in national reports (National Research Council, U.S. Congress and EPA) and a series of scientific publications (Bauman, 1992; Bosch et al., 2006; Capper et al., 2008; Dunlap et al., 2000; Johnson et al., 1992; Jonker et al., 2002). All food production has an environmental impact but the environmental impact of dairy production is reduced when milk yield per cow is increased. This is illustrated by comparing dairy production for 1944 and 2007 (Capper et al., 2009). The milk production of dairy cows in 2007 is about 4-times greater than in 1944 so the carbon footprint for the average dairy cow in 2007 is also much greater (Figure 4). However, dairy farmers are in business to produce milk, and evaluations of the environmental impact are appropriately expressed on a food output basis. When this is done, the carbon footprint for a gallon of milk in 2007 is only 37% of that in 1944 (Figure 4). Again, this relates to dilution of maintenance and gains in productive efficiency and the specific dimensions contributing to this remarkable decrease in the carbon footprint per gallon of milk include reductions in feedstuffs, water and crop land requirements, manure and animal waste outputs, and inputs of fossil fuels and electricity. The increase in milk yield from rbST has similar benefits; using a Life Cycle Approach and modeling the dairy herd revealed that rbST results in ~9% reduction in the carbon footprint of producing a gallon of milk (Capper et al., 2008). On an industry milk equivalent basis, the use of rbST for just 15% of the US dairy herd reduces the carbon footprint equal to taking ~400,000 cars from the road or planting ~30 million trees (Capper et al., 2008).
The gains in productive efficiency and environmental impact from the use of rbST also occur with other management practices and related technologies that increase the milk yield of dairy cows. A few examples include the use of artificial insemination and genetic selection, feed analysis and the formulation of balanced rations, improvements in milking systems and milking management practices, and advancements in illness treatments and the development of herd health programs. Overall, these gains benefit sustainability at the farm and industry level. Furthermore, increases in productive efficiency have been the engine fueling growth in agricultural productivity over the last 60 years (Ball and Norton, 2002).

Conclusion

There have been impressive advances in agricultural productivity over the last 60 years and this has allowed the production of safe, nutritious and affordable food. In particular, milk and dairy products are an excellent source of nutrients for the human diet. However, the U.S. and World population are growing and the sustainability of the dairy industry depends on making continued improvements in productivity. Recombinant bovine somatotropin is a valuable management tool that increases productivity. Specifically, rbST improves productive efficiency allowing milk to be produced with less resource input and reduced environmental effects.

References


STRATEGIES FOR REDUCING FEED COSTS WITH MANAGEMENT INTENSIVE GRAZING

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Summary

The economic advantage of pasture based dairy systems lie in the reduction of production costs, especially lower feed costs, better cow health and reduced labor. Purchased and home raised feed accounts for 25 to 30% of the cost of milk production for graziers, and is highest cost category for all grazing farms, regardless of production level (Kreigl, 2007). Producers that feed higher amounts of supplements to grazing cattle generally produce more milk per cow and more milk per acre than those who use little or no supplemental feed. The marginal return in milk income from using supplements is generally sufficient to improve profitability. In recent years however, milk prices have been very unstable and grain prices have dramatically increased. Many dairy producers are questioning whether supplements are still cost effective. The objectives of this paper are to evaluate the strategic use of supplements for dairy cattle, and to suggest ways to optimize profitability.

Introduction

The primary nutrient that limits milk production in pasture systems is energy. Energy intake is optimized by managing pastures to obtain adequate amounts of high quality forage, by managing cows to allow for adequate time to consume enough forage and by strategic use of supplemental forage and grain supplements to optimize the net income.

Feeding some supplement will usually increase milk yield and profit, but the milk response to supplement feeding and the marginal returns to supplement feeding vary according to many factors. The following all play a significant role in determining what kind and how much supplement should be fed:

1. The effect of the supplement on pasture intake.
2. The expected milk yield response to supplement feeding.
3. The price or value of milk relative to the cost of the supplement.
4. The effect of the supplement on fat and protein composition of milk.
5. The impact that supplement feeding may have on persistency of milk yield, herd health and reproductive performance.

Effects of Pasture Management on Responses to Supplements

The amount of forage available to the cow will impact forage intake, and affects substitution rate of pasture for supplemental forage or grain. The relationship between pasture intake and pasture availability to an animal is curvilinear (Figure 1). Poppi et al. (1987) suggests that the ascending part of the curve describes factors that limit the ability of the animal to harvest pasture and includes issues such as: pasture structure (sward height, sward density and yield) and grazing behavior of the
animal. The plateau or asymptotic section of the curve reflects the nutritional factors such as, digestibility, feed retention time, and concentrations of metabolic products that control intake.

Kolver and Muller (1998) compared intakes of high producing Holstein cows consuming pasture or a total mixed ration (TMR) fed in confinement. Dry matter intake of grazing cows was less (P<0.01) than for TMR fed cows (19.0 vs. 23.4 kg DM/d). Results indicated that Holstein cows grazing good quality pasture ad libitum without supplements are able to consume DM at 3.4% (range of 2.85 to 3.76) of live weight, which would provide sufficient energy to support 18 to 23 kg of milk per day. Muller et al. (1995) reported the range of DMI by cows consuming pasture to be 11.4 to 15 kg/d of dry matter for large cows producing 30.5 to 39.2 kg/d of milk and receiving 7.3 to 8.6 kg/d of concentrate. Studies in Europe have reported DMI by grazing cows, ranging from 17 to 20 kg/d of DM (Stakelum, 1986). In New Zealand, the DMI by cows consuming pasture has been as much as 4.5% of live weight for cows averaging 450 to 500 kg (Holmes, 1987).

Table 1 summarizes five experiments in which feed intake was measured when different herbage allowances and/or amounts of grain supplements were offered to dairy cows. These studies suggest that the substitution rate of grain for pasture is higher at high pasture allowances. Bargo et al. (2002a) found that cows grazing a pasture that offered of 27 kg DM/cow per day consumed 17.5 kg DM of pasture and produced 20.3 kg/d of 3.5% FCM. When they grazed the same pasture with a higher herbage allowance (49 kg DM/cow/d ), pasture intake and milk production increased to 20.5 kg DM and 23.3 3.5% FCM kg/cow respectively. They also found that cows grazing at a low pasture allowance consumed 10.1 kg NDF/d (1.61% of BW). For cows grazing at the high herbage allowance, NDF intake was 11.5 kg/d (1.83% of BW). When cows received grain supplements pasture intake declined with both pasture allowances, but the substitution rate was greater for cows offered 49 kg/d of pasture than 27 kg/d pasture. NDF intake was 10.2 and 10.4 kg/d (1.65% and 1.68 of BW) for the low and high allowance respectively. Wales et al. (2001) reported that cows grazing perennial ryegrass pasture at two herbage allowance levels, 19 and 37 kg DM/ha, consumed 11.2 and 15.6 kg DM/d respectively. The intake of NDF from low allowance pasture was 5.1 kg DM/d and for high allowance pasture was 6.8 kg DM/d. In both cases, the fiber intake from pasture was marginally adequate. An earlier study by Wales et al. (1999) reported that each additional t DM/ha of herbage mass resulted in an incremental increase in intake of 2.3 and 1.3 kg DM/cow per day in spring and summer respectively. They reported an increase in intake of 0.18 kg DM/kg DM increase in herbage allowance in spring, and 0.13 kg DM/kg DM in summer. From this experiment the intake and milk production for an herbage allowance of 27 kg DM/cow per day were 11.6 kg DM and 15.8 FCM kg/cow respectively, and for an herbage allowance of 48 kg DM/cow per day were 14.4 kg DM and 19.5 FCM kg/cow respectively. When cows received 5 kg DM of concentrate/day the intake was 10.3 and 12.3 kg DM/cow for the low and high allowance respectively, and milk production was 21.5 and 23.7 FCM kg/d (Table 1).
Table 1. Intake of dairy cows with different pasture allowances and levels of grain.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Allowance (kg DM/cow/d)</th>
<th>DMI (kg DM/cow/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pasture</td>
<td>Conc.</td>
</tr>
<tr>
<td>Low pasture</td>
<td>27</td>
<td>0.8</td>
</tr>
<tr>
<td>High pasture</td>
<td>49</td>
<td>0.7</td>
</tr>
<tr>
<td>Low + conc</td>
<td>27</td>
<td>8.6</td>
</tr>
<tr>
<td>High + conc</td>
<td>49</td>
<td>8.7</td>
</tr>
<tr>
<td>pasture + conc.</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>pasture + TMR</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>TMR</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>Low pasture</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>High pasture</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td>Low pasture</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>High pasture</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td>Low + conc</td>
<td>27</td>
<td>5</td>
</tr>
<tr>
<td>High + conc</td>
<td>48</td>
<td>5</td>
</tr>
<tr>
<td>Low herbage mass</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Med herbage mass</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>49</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>68</td>
<td>68</td>
</tr>
</tbody>
</table>

\(^{a,b,c,d}\) in the same column and same reference with different superscripts differ (P<0.05).

Under most commercial grazing enterprises in the United States, cows are offered between 25 and 35 kg of pasture DM per day to maximize milk output per cow. This is consistent with recommendations of Bargo et al. (2003), who suggest that pasture availability should be approximately twice the estimated pasture intake as the best compromise between maximum intake and maintenance of
pasture quality. Even at these high allowances, forage intake will not be as high as most ration balancing programs will predict because pasture intake is limited by the ability of the cow to consume forage, not the fiber level or gut filling characteristics of the pasture forage. When moderate amounts of grain supplement (5 to 7 kg) are offered, forage intakes of 11 to 14 kg DM per day per cow are typical on commercial grazing farms. Predicted intakes from ration formulation programs usually are in the range of 15 to 18 kg/d per cow (based on fiber content of the pasture). Most mid-western farms provide about 25 % of the total forage DM intake as supplemental forage (2 to 3.5 kg DM). While supplemental forage is higher in cost than pasture, the marginal return (extra milk production) exceeds the additional cost of forage.

Supplemental forages must be high in quality or substitution rates will be very high or cows will refuse to consume the supplement forage. The substitution rates for corn silage appear to be similar to those observed for high quality grass which in turn are nearly double the substitution rates for grains (Morrison and Patterson (2007). Corn silage, is an excellent forage supplement for pastures because its energy value is higher than grasses, and therefore supports a higher milk yield than grass forage supplements (Morrison and Patterson, 2007). In the Midwestern US, dairy producers typically feed 1.5 to 3 kg (DM fed basis) of corn silage to grazing dairy cows. This amount of corn silage provides supplemental fiber and is a good source of ruminally fermentable carbohydrate in addition to metabolizable energy.

Production responses to grain supplementation

Several experiments have quantified the milk response to supplemental grain for grazing cows (Arriaga-Jordan and Holmes, 1986; Hodge and Rogers, 1984; Jennings and Holmes, 1984; Kibon and Holmes, 1987; Stakelum, 1986). In general the response in milk yield to each additional kg of grain has been between 0.50 and 0.67 kg of 4% FCM per day. Each kg of grain added to the diet of grazing cows will increase total DMI by about 0.4 to 0.6 kg per day and decrease forage consumption by 0.6 to 0.4 kg per day. These are typical responses when pasture supply is not limiting. As discussed above, forage intake is less affected by grain supplements and milk production may or may not be affected by grain feeding when available pasture is less than 25 kg DM/d.

One of the most recent literature reviews on supplement feeding was published by Penn State workers (Bargo et al., 2003). They found that when averaged across 9 published studies, milk increased linearly as the amount of concentrate increased from 1.2 to 10 kg per day. Cows that were less than 180 DIM or were producing more than 28 kg milk per day (5 studies) produced 1kg more milk per kg of additional supplement over the entire range of supplement feeding. The response to grain feeding was quadratic in high producing cows in later stages of lactation (3 studies: cows producing less than 23 kg of milk and more than 160 DIM). These workers suggest that for cows with higher genetic merit, milk yield increases linearly and therefore the marginal return to supplement feeding is linear in early lactation. As milk production declines due to advancing DIM, the response to grain feeding still increases, but the marginal return becomes lower as additional increments of grain are offered.

Reis and Combs (2000b) conducted a trial to evaluate the effect of energy supplementation on milk production of cows grazing a pasture with equal proportion of grasses and legumes. With no grain supplement cows produced significantly less milk than the cows fed supplement. Cows that were offered 5 and 10 kg of concentrate produced 18.7 and 28.3% more milk respectively than the cows receiving no supplement. For each kg of supplement fed milk production increased 1.0 and 0.86 kg for 5 and 10 kg of concentrate respectively. However, milk fat percentage and yield decreased linearly with increasing supplementation. As a result no significant differences in FCM were observed among the three treatments. One must consider the effect of grain supplementation on milk composition. In most studies, moderate levels of supplementation increase fat corrected milk yield, but if pasture intake is lower than expected, fat test depression will affect cows offered moderate to high levels of grain supplement.
Effects of grain processing and source on production of lactating cows

Grain processing increases the rate and extent of starch digestion by microbes in the rumen and small intestine. Rolling, grinding, steam flaking and high moisture ensiling have been the processing techniques most extensively studied. Reis et al. (2001) evaluated the performance of dairy cows fed fresh chopped grass-legume forage supplemented with either dry shelled corn coarsely ground, high moisture ear corn coarsely ground, or high moisture ear corn finely ground. Milk production and milk composition were not affected by treatment, however, a reduction in particle size improved nitrogen utilization and reduced fecal starch excretion.

There has been almost no research conducted on frequency of grain feeding to cows grazing pasture. Pulido et al. (2009), reported that in high producing cows in early lactation (approx 60 DIM and producing 29.7 L/d of milk) feeding 6 kg DM of grain supplement increased milk yield by 4.4 kg/d. Feeding the 6 kg of supplement in equal proportions 2, 3 or 4 times per day decreased pasture consumption as grain feeding frequency increased. Milk yield and milk fat %, and milk protein % were not affected by grain feeding frequency.

So, does it pay to feed supplements?

From the above discussions it is apparent that grain feeding will increase milk yield and will depress pasture forage consumption when pasture availability is greater than 25 kg/cow per day. Bargo et al., (2003) concluded that at high pasture availability the substitution rate for temperate pastures is approximately 0.62 kg decrease in pasture intake per kg of supplemental grain fed. The literature would suggest that the increase in milk production due to grain feeding will range from 0.60 to 1.0 kg milk per kg of supplemental grain fed. Processing grains or feeding grain more than twice daily does not appear to provide any extra benefit.

Profitability of grain supplement feeding will depend on the cost of the supplement and the marginal milk production response to grain feeding, the effect of supplement on milk composition and the value of the milk. In the most conservative calculations, the input costs associated with pasture forage production will not change as supplement is offered. The efficiency of pasture forage utilization will go down as more supplement is offered, but cows will still be offered the same amount of pasture per day. The inputs costs associated with growing pasture is approximately $.06/kg of forage DM assuming a yield of 3.5 kg/ha (Kriegl, 2003). Feeding supplemental grain can be done with little additional fixed expense, so it can be treated as a variable cost in most pasture feeding systems. Income over feed costs (IOFC) can then be used to assess the economic potential for feeding grain. Based on the production responses to grain feeding cited above, we can calculate the relationship between the milk price to supplement price at which supplementation will be economically beneficial. In table 2, a positive marginal return indicates that the incremental increase in milk income is greater than the cost of the additional supplement. A negative value indicates that the incremental increase in milk income would not cover the cost of the supplement.

Table 2. Marginal return to additional grain supplemented ($/100 lb supplement)

<table>
<thead>
<tr>
<th>Supplement price ($/cwt)</th>
<th>Milk Increase: 0.6 lb / lb supplement</th>
<th>Milk Increase: 1 lb / lb supplement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk Price ($/cwt)</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>3.5</td>
<td>2.5</td>
<td>4.3</td>
</tr>
<tr>
<td>5.5</td>
<td>0.5</td>
<td>2.3</td>
</tr>
<tr>
<td>7.2</td>
<td>-1.0</td>
<td>0.8</td>
</tr>
<tr>
<td>9.0</td>
<td>-3.0</td>
<td>-1.2</td>
</tr>
<tr>
<td>10.0</td>
<td>-4.0</td>
<td>-2.2</td>
</tr>
</tbody>
</table>
If we assume that the response to grain supplementation is linear for early lactation cows with high genetic potential (Bargo et al., 2003) offered between 1.2 and 10 kg of grain supplement per day, the marginal response to grain feeding can be calculated (Table 2). The left portion of the table assumes that for each unit of supplement fed, milk yield will increase by 0.6 units. With low milk prices ($10/ cwt) the marginal return to concentrate feeding is still positive when supplement costs are less than $5.50/cwt. The breakeven is where the marginal return is equal to input cost. The tabulations in Table 2 assumes that milk composition and therefore value of milk is not affected by level of grain supplementation. The 0.6 lb response in milk per lb of supplemental grain is consistent with the fat corrected milk responses cited previously in this paper. The 1.0 lb milk/lb of milk supplement is consistent with the response cited by Bargo et al., (2003) for high producing cows in early lactation. But they found that this higher response was not observed in lower producing cows.

**What happen when prices improve?**

Decreasing supplementation and consequently production under challenging economic times can be a dangerous decision for several other reasons. First, cutting on supplementation costs may not necessarily improve the income over feed costs as discussed above. Second, most controlled feeding studies have monitored milk production responses over relatively short periods of time and have not considered long term impacts of restricted grain feeding. The long term costs may be especially high in cattle with US-based genetics. Several experiments have shown that high producing dairy cows grazing excellent quality pasture have poorer lactation persistency than cows in confinement systems (Fales et al., 1993; Hoffman et al., 1993). It is also well documented that New Zealand cattle have poorer lactation persistency than cattle with US genetics (Horan et al., 2005).

Reproductive performance has also been poorer in grazing cattle than confined cattle and the poorer reproductive performance is related to the severity and extent of negative energy balance that high producing dairy cattle experience when grazing (Muller et al., 1995). It is evident that cattle with US-based genetics undergo more severe body weight loss than cattle from New Zealand genetic lines (Horan et al., 2005).

![Figure 2. Milk income and income over feed costs at various levels of grain supplementation.](image-url)
Finally, projecting profitability only on income over feed costs does not adequately take into account that milk income will severely drop if supplement feeding is severely cut back or eliminated. Figure 2 illustrates the point that if all grain supplementation is eliminated, milk production and hence gross returns per cow will be less than one third the returns if grain were fed to sustain 22,000 lbs of milk (10,000 liters) per lactation. Even with high grain prices and low milk prices, total net receipts remain significantly higher when grain feeding is continued. In addition, the potential to recover from the devastating effects of high input costs and low milk prices is much greater if milk production per cow is sustained.

**Summary**

Feeding supplemental forage and grain to lactating dairy cattle is still profitable, even with the current situation of low milk prices and high grain costs. In difficult economic times, reducing or eliminating supplement feeding is not the first strategy to improve profitability. Focusing on management strategies that improve milk production per cow, and culling low producing cows that are unprofitable would be a better option. Dairy producers can improve milk production per cow by making sure that pastures are of high quality, and managed to maximize pasture yield. Dairy cows must be managed to assure that they can consume as much pasture forage as possible in a relatively short period of time. Finally, grain supplements should be fed to grazing dairy cattle that complement the nutrients provided by the pasture. Supplements that contain high levels of ruminally fermentable carbohydrates (NFC) and modest amounts of highly digestible fiber (NDF) are generally the best options for high producing dairy cows on pasture. Monitoring income over feed costs and the marginal return to grain supplementation can be a useful tool to reduce variable costs, but the long term implications of feeding grain on milk production, reproductive performance and the effects of grain supplements on total milk income must also be considered.

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THE ROLE OF DIRECT FED MICROBIALS IN ENHANCING PRODUCTION EFFICIENCY OF RUMINANTS

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Summary

Historically, direct-fed microbials (DFM’s) have been used in ruminants to improve rumen and gastro intestinal health and animal well being. For the most part, animal performance was a secondary benefit to improved animal well being. In recent times, consumer concern and the actions of governments and non-governmental organizations over the use of antibiotic growth promoters (AGP’s) in livestock production has increased the interest in DFM’s to positively impact livestock production and the environment. Targeting the beneficial effects of either bacterial or non-bacterial DFM’s alone or in combination, has become more scientific as a result of research enhancing the scientific communities understanding of the characteristics and modes of action of DFM’s.

Methanogenesis represents a significant loss of energy from ruminal fermentation and negatively impacts the efficiency which ruminants convert feedstuffs to milk, meat and fiber. Besides ruminal methane production contributing to a significant reduction in production efficiency, methane from ruminal fermentation is the second largest agricultural contributor to greenhouse gas elution. Refining the use of DFM’s to improve production efficiency without compromising animal well being, would enable ruminant producers to successfully adapt to the changing attitudes of consumers while improving profitability and reducing the impact on the environment.

The objectives of this paper were to demonstrate how bacterial and non-bacterial DFM’s, fed to ruminants, could improve production efficiency through modifying the rumen micro flora. Shifting ruminal fermentation in favor of propionate production or enhancing the acetogenic activity in the rumen would increase the number of favorable hydrogen sinks and consequently reduce the amount of hydrogen available for methanogenesis.

Introduction

In Metchnikoff’s (1907) book “The Prolongation of Life”, consuming lactobacilli capable of surviving the journey down the gastro-intestinal tract were reported to be desirable for human health and well being. Metchnikoff attributed the longevity of Bulgarians consuming fermented milk, to the probiotic effect of the lactobacilli in preventing disease cause by enteropathogens. The use of probiotics gained significant popularity in the 1920’s and 1930’s as a result this hypothesis. However, after the discovery of antibiotics post World War II, interest in probiotic use in human nutrition declined except for treating cases of antibiotic diarrhea. In recent times, probiotics have received a significant amount of attention due to the public outcry over health concerns about antibiotic resistance in pathogenic bacteria associated with the long term use of feeding of AGP’s to livestock. In an attempt to allay these public concerns for the long term health of both humans and animals, the European Union in January 2006 banned the use of antibiotics for non-therapeutic purposes in animal feeds. Although no similar ban has been enacted in the USA, research efforts in the use of DFM’s in both animal and human nutrition have increased significantly. These efforts have focused on the need to identify more effective bacteria, improving the stability of viable cultures, understanding their impact on the immune system, their interactions with other bacteria, their interaction with probiotics and non-bacterial DFM’s, defining their...
mode of action, designing DFM’s to target specific problems, defining use rates, and improving the consistency of response.

In North America the emphasis for using DFM’s in livestock diets has been on improving animal production, while in Europe, as a result of the banning of ionophores and antibiotics in ruminants, the focus has been more on animal health and well being. In Australasia the environmental consequences of ruminant production, especially methane formation has received a lot of attention (Wallace, 2006). Paradoxically, the objectives of the differing regions are not mutually exclusive and could be met by focusing on inhibiting methanogenic activity, thereby improving production efficiency and reducing greenhouse gas emissions.

For DFM’s to have an impact on the production efficiency of ruminants they need to be efficacious, non-pathogenic, survive the journey through the different regions of the gastro-intestinal tract, compatible with the host, genetically stable, and impart positive health and performance benefits (Holzapfel et al., 1998). Furthermore, understanding the mode of action helps target DFM’s to the regions of the gut that can optimize their use in ruminant diets. Krehbiel et al., (2003) concluded after a review of the literature that bacterial DFM’s modify the balance of intestinal microorganisms, adhere to intestinal mucosa and prevent pathogen adherence or activation, influence gut permeability, and modulate immune function. Furthermore, certain lactic acid bacteria have shown adjuvant properties by stimulating a specific antibody response after injection with pathogenic microorganisms.

It is important to note that in 1989 the FDA required manufactures to use the term DFM rather than probiotic. The FDA defines DFM’s as “a source of live (viable) naturally occurring microorganisms” and includes bacteria, fungi and yeast (Miles and Bootwalla, 1991).

Production Efficiency

Production efficiency in ruminant production systems can be defined in a number of ways depending on the input and output parameters used in the evaluation. For example, the energy and protein used to feed ruminants can be assigned a human consumable protein and energy value and then compared to the energy and protein output from ruminant production systems. Humanly edible returns from dairy operations vary based on regional production systems and the level of non-human and human consumable ingredients in the diet. Dairies in California have a greater proportion of by-products in the diet than Northeastern dairy diets resulting in a difference in the conversion to humanly consumable outputs. Oltjen and Beckett (1996) conservatively calculated that production efficiency based on the humanly edible energy and protein inputs vs. humanly edible energy and protein outputs during lactation ranged from 133 to 380% depending on the input assumptions.

Production efficiency can also be defined in terms of the total pounds of feed consumed per pound of weight gained or milk produced as feed efficiency. A more closely defined measure of production efficiency in ruminants would be gained by measuring the effects of modifying the rumen environment and determining the change in volatile fatty acid (VFA) production or microbial protein yield. Ruminal microbial shifts that change VFA or microbial protein yield will ultimately result in a change in feed efficiency and consequently the humanly edible products produced by ruminants in relation to the energy and protein inputs. For example, ionophores used in ruminant diets inhibit the growth of gram positive microbes by disrupting normal membrane physiology while enabling gram negative bacteria to grow. The shift in microbial balance in the rumen results in an increase in the molar concentration of propionate with a concomitant decline in acetate and butyrate production. This change in VFA’s is often accompanied by a decline in methane production. The net result is an improved retention of carbon and energy, which leads to improved feed efficiency as manifest by an improvement in feed: gain or feed: milk conversion (Bergen and Bates, 1984).
Methane is a by-product formed in the rumen through enteric microbial fermentation of feedstuffs, and within agriculture, considered a major source of greenhouse gas elution (Table 1). During the fermentation process hydrogen is released by the microbes and is used by the methanogenic archaea to reduce carbon dioxide to methane and water. Besides being a source of greenhouse gas, methane represents a loss of energy to the animal [between 2-3 % of GEI from high grain diets (Johnson and Johnson, 1995) and 10-12% of GEI from low quality roughage diets (Ominski et al., 2004)] and consequently reduced conversion efficiency of feedstuffs to milk, meat and or fiber (Kebreab et al., 2008).

Table 1: Relative contribution of the global production of methane (Bolle et al., 1986).

<table>
<thead>
<tr>
<th>Source of Methane</th>
<th>Relative Contribution %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-biological</td>
<td>32</td>
</tr>
<tr>
<td>Rice Paddies</td>
<td>18</td>
</tr>
<tr>
<td>Ruminants</td>
<td>18</td>
</tr>
<tr>
<td>Marshes</td>
<td>13</td>
</tr>
<tr>
<td>Other Biological</td>
<td>6</td>
</tr>
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</table>

Understanding the molecular diversity of methanogens in the rumen ecosystem and their interaction with non-methanogenic bacteria will help identify DFM’s that could be targeted toward reducing methanogenesis. Wright et al., (2007) constructed 16S rRNA gene libraries from rumen digesta of feedlot cattle and discovered a number of new taxa of methanogens. Establishing methanogenic gene libraries for ruminants increases our knowledge of the rumen community structure and increases the potential for DFM’s to reduce methane emissions and improve production efficiency. There are a number of approaches currently being explored to reduce methanogenesis:

a) Stimulating or boosting the activity of ruminal acetogens to form acetate from carbon dioxide and hydrogen (\(2\text{CO}_2 + 4\text{H}_2 = \text{CH}_3\text{-COOH} + 2\text{H}_2\text{O}\)) thereby diverting hydrogen from methanogenesis toward acetogenesis. However in the rumen environment, acetogens are less efficient in competing with methanogens for reducing equivalents and thus far attempts to boost their activity have been unsuccessful (Martin et al., 2008);

b) Isolation and culture of effective acetogens. Lopez et al., (1999) found that acetogens depressed methane production when added to rumen fluid in vitro and suggested that even if stable populations of acetogens could not be established in the rumen, it might be possible to achieve the same metabolic activity using acetogens as a daily fed feed additive. The recent isolation of new, high-hydrogen utilizing species from diverse gut environments could offer a better alternative than previously tested acetogens (Klieve and Joblin, 2007);

c) The use of capnophilic bacteria. Catnophilic bacteria use hydrogen to produce organic acids in the rumen and potentially could enhance ruminal VFA production and reduce methanogenesis, however little is known about their impact on hydrogen balance (Marin et al., 2008);

d) Use of DFM’s to shift a greater proportion of the VFA production in the rumen toward propionate. The formation of acetate and butyrate in the rumen results in hydrogen release which tends to promote \(\text{CH}_4\) production. The formation of propionate in the rumen results from a competitive pathway for hydrogen utilization with methanogens and tends to reduce \(\text{CH}_4\) production. Ruminal propionate production follows different pathways depending on the feedstock, for example, cellulolytic bacteria like \(\text{Fibrobacter succinogenes}\) produce propionate through the succinate pathway in roughage diets, while lactate is the main intermediate in the conversion of starch to propionate (Moss et al., 2000).
Identifying DFM’s that increase propionate production via multiple pathways has significant benefits besides reducing methane production, since propionate is the single most important precursor to glucose synthesis in ruminants (Nagaraja et al., 1997). For growing and lactating ruminants, propionate has been estimated to account for 61 to 67% of glucose released for energy supply to the animal. Furthermore, increasing propionate production spares glucogenic amino acids in gluconeogenesis and consequently reduces the maintenance cost of metabolizable protein and possibly lowers the heat increment (Bergen and Bates, 1984).

**Bacterial DFM’s**

The traditional concept of feeding bacterial DFM’s to ruminants has focused on mitigating some of the negative effects of stress and enhancing the post-ruminal gastro-intestinal health of the animal. In addition to the gastro-intestinal benefits, current research demonstrates a reduction in ruminal acidosis in animals supplemented with bacterial DFMs, whereas the use of non-bacterial DFMs has focused primarily on ruminal organic matter digestion, modulation of rumen pH, and rumen microbial synthesis.

In pre-ruminant calves the bacterial DFM’s commonly used in practice and research were species of *Lactobacillus*, *Bacillus*, *Streptococcus*, *Enterococcus* and *Bifidobacterium* (Krehbiel, et al., 2003). The primary focus for DFM’s in pre-ruminants has been to establish ruminal and gastro-intestinal microbial populations that limit the likelihood of enteropathogens from gaining prominence and causing diarrhea. In healthy calves the fecal lactobacilli numbers have been demonstrated to be higher and fecal coliforms lower than in calves suffering from diarrhea (Sandine, 1979). Feeding viable cultures of *Streptococcus* and *Lactobacillus* to calves resulted in a decrease in the incidence of diarrhea and improved fecal scores (Abu-Tarboush et al., 1996 and Fox, 1988). Improvements in the intestinal health of calves receiving lactobacilli have, in some cases, resulted in an improvement in body weight gains which have been attributed to less scouring (Beeman, 1985).

Beef calves sent to feed yards undergo a significant amount of stress associated with weaning, transport, handling, comingling, fasting, diet changes, vaccinations, castrating and often dehorning. As a result of the stress, the gut micro flora changes favoring pathogen proliferation and animals suffer increased morbidity, days off feed, decreased performance and mortality. Fox, (1988) reported that calves fed a combination of *L. acidophilus*, *L. plantarum*, *L. casei*, and *S. faecium* at processing or during the receiving period or both, resulted in a 13.2% increase in ADG, 2.5% increase in feed consumption and a 6.3% in FCR. Not all research on DFM’s fed to receiving cattle have been positive. Part of the reason for this could be the limited understanding of the effect of DFM dose on animal response. It is clear that dose has an effect since Orr et al. (1988) demonstrated that a significant quadratic relationship between the concentration of *L. acidophilus* fed and ADG of steer calves exists. Calves receiving $2.2 \times 10^6$ or $2.2 \times 10^8$ had greater ADG than animals fed $2.2 \times 10^8$ *L. acidophilus*.

In feedlot cattle, the potential for improving production efficiency through altering VFA production with bacterial DFM’s was demonstrated by Beauchemin et al., (2003); in which *E. faecium* significantly increased propionate and decreased butyrate concentrations and reduced the nadir of ruminal pH. Kreibel et al., (2003) summarized the research using bacterial DFM’s in feedlot cattle and reported a 2.5 to 5% increase in ADG, a 2% improvement in FCR, an inconsistent response to dry matter intake and an average increase in carcass weight of 7 kg. The summary included data from earlier studies in which lactic acid producers (LAB) like *L. acidophilus* and *E. faecium* were fed throughout the feedlot phase as well as more current data in which *Propionibacteria* were fed alone or in combination with LAB’s. Despite the positive outcome of the summary, it is clear that a lot more work needs to be done in targeting the correct combination of DFM’s and establishing the optimal dose to maximize the repeatability of the performance results.
In dairy cows, a number of different bacteria and bacterial combinations have been fed at various stages of the production cycle to improve animal performance and health with mixed results. The most common bacterial DFMs used were LABs like L. acidophilus, L. plantarum, and E. faecium, however more research is emerging on the use of Propionibacterium, a propionate producer, either alone or in combination with L. acidophilus. Until recently, the conventional wisdom was that the benefit of LAB’s in mature ruminants was in the lower GI tract, similar to young calves. However, Nociek et al., (2002) demonstrated that L. plantarum and E. faecium in combination with Saccharomyces cerevisiae (SC) helped reduce fluctuations in rumen pH. These data suggest that the LAB’s were producing lactic acid in large enough quantities to stimulate effective populations of lactic acid utilizers. Nociek et al., (2002) also demonstrated a dose response to the addition of LAB’s: increasing the levels of LAB’s caused a decrease in rumen pH.

The introduction of lactic acid utilizers to the rumen as part of LAB’s or alone could help reduce the potential diurnal fluctuations in rumen pH and potentially help the rumen gear-up to meet diet changes. Megaspheara elsdenii is a naturally occurring rumen lactate utilizer, and has been shown in both in vitro (Kung and Hession, 1995) and in vivo that acidosis can be mitigated and feed intake improved (Robinson et al., 1992) when used to supplement the rumen microflora. Commercialization of M. elsdenii as a DFM supplement has been limited due to the extreme anaerobic nature of the microgranism.

Propionibacteria offer significant potential to improve production efficiency since they are natural inhabitants of the rumen and produce propionate, a major precursor for glucose production. As with LABs, the research results are mixed when using Propionibacteria in dairy cows. Stein et al., (2006) fed two levels of Propionibacterium from 2 weeks pre-partum to 30 weeks post-partum and reported a dose response in milk fat and lactose and a 4% fat corrected milk production response over the control. Also reported was a significant increase in ruminal propionate and a decrease in the acetate: propionate ratio. However, feeding a combination of Propionibacteria and L. acidophilus to mid-lactation cows for a period of 84 days, Raeth-Knight et al., (2007) did not see any differences in dry matter intake, milk components or production.

**Non-bacterial DFM’s**

The most widely used non-bacterial DFM’s in ruminant diets include Saccharomyces cerevisiae cultures (SC) and Aspergillus oryzae extracts (AO).

Desnoyers et al., (2008) in a comprehensive meta-analysis incorporating a number of different SC products concluded that SC supplementation increased dry matter intake, milk yield, rumen pH, rumen VFA concentration and organic matter digestibility. SC has also been shown to stimulate the growth of Selenomonas ruminantium, Megasphaera elsdenii and Fibrobacter succinogenes while having no effect of Streptococcus bovis (Newbold and Olvera-Ramirez, 2006). Interestingly these same authors showed that SC may affect the survival and growth of E. coli O157:H7 and Listeria monocytogenes in vitro and in sheep by as much as 50%.

Information on the effects of SC on methane emission tends to be limited and inconsistent (Martin and Scott, 1992). Mutsvangwa et al., (1992) in an in vivo experiment, found that the addition of SC initially reduced methane emission by 10%, but this effect was not sustained. However, Chaucheyras et al., (1995) demonstrated that acetogenesis of a ruminal acetogen was enhanced in the presence of SC and was able to compete with methanogens for hydrogen, resulting in a decrease in methane production.

In Martin and Nisbet’s (1992) DFM review; the use of AO in ruminant diets increased total tract digestibility of the fiber fractions, increased L-lactate uptake, but did not alter VFA or ammonia production. Furthermore, AO increased milk production and was also reported to lower rectal
temperatures in periods of heat stress. AO’s effect on methane production, similar to that of SC is limited and the results are mixed (Martin and Scott, 1992). In vitro data from Frumholtz et al., (1989) indicated that AO reduced methane by as much as 50%, primarily due to the direct reduction (45%) in protozoal numbers. Since some methanogenic bacteria have been found to be associated with ruminal protozoa (Krumholz et al. 1983; Stumm and Zwart, 1986; Veira, 1986), some of the decrease in CH₄ reported by Frumholtz et al., (1989) may have been due to the decrease in protozoal numbers. However, Marin and Nisbet (1990) found that AO resulted in an increase in CH₄, which could not be explained. Unfortunately Martin and Nisbet (1990) did not measure protozoal numbers in their experiment.

Research in dairy cattle using a combination of SC and bacteria have shown varying degrees of response. Block et al., (2000) reported that when lactating dairy cows were fed a combination of L. acidophilus and SC or a combination of E. faecium and L. plantarum together with SC, milk yields were improved by 1.08 kg and 0.90 kg/d respectively. Nocek et al., (2003) fed a combination of SC and two strains of E. faecium to dairy cows for twenty one days prior to partum through ten weeks post-partum and reported a significant dry matter (2.6 kg/d) and milk (2.3 kg/d) production response. However, Oetzel et al., (2007) feeding the same combination of SC and E. faecium from 10 days pre-partum through to 23 days post-partum, did not observe any changes in milk yield or composition, but reported fewer antibiotic treatments for animals receiving the DFM’s. The combination of SC and Propionibacterium fed to transition cows from 2 weeks pre-partum to 30 weeks post-partum resulted in a 9% increase in milk production (Lehloenya, et al., 2007).

New Opportunities

Searching for new strains of DFMs that can help improve the production efficiency of ruminants is critical to the long term success of ruminant production systems. The advancement of the DFM pool available to producers helps expand the options for addressing future health and environmental challenges. For example, at Iowa State University a new strain of Prevotella from cows fed high concentrate diets was isolated for its ability to ferment starch to produce succinate as a precursor to propionate production. Chiquette et al., (2008) reported that feeding Prevotella bryantii 25A to dairy cows from 3 weeks pre-partum to 7 weeks post-partum resulted in improved milk fat percentage and lower rumen lactate concentrations.

Other opportunities include work by Fukuda et al., (2006) who isolated a strain of Butyrivibrio fibrisolvens that isomerizes linoleic acid to conjugated linoleic acid (CLA) without hydrogenation. The potential application for B. fibrisolvens could be in the formation of functional dairy food products with human health applications. Brashears et al., (1998) demonstrated that L. lactis could be used to control E. coli O157:H7 when sprayed onto chicken breast pieces. Implications for reducing the potential of this pathogen in livestock prior to slaughter and post slaughter are being investigated.

Research with bacteriophages offers some exciting new opportunities in modifying the gastro-intestinal ecosystem by inhibiting methanogens and enteric pathogens like salmonella and E. coli. Klive and Bouchop (1988) described a diverse number of bacteriophages in the rumen of both sheep and cattle, suggesting that phages play a role in the complex rumen ecosystem. Sheng et al., (2006) showed that phage therapy would be an effective approach to significantly reduce the number of intestinal E. coli O157:H7 in ruminants, but also highlighted the difficulties of developing effective phage intervention strategies to totally eliminate E. coli O157:H7 in the gastro-intestinal tract of ruminants. Since phages are highly specific to a particular microorganism, this specificity allows for the targeted removal of microorganisms within a mixed population without harming the rest of the microflora.
Conclusion

The successful application of DFM’s in ruminants for improving production efficiency depends on increasing the available energy yield from rumen fermentation by increasing propionate production and reducing methane emission. Coupling the improved rumen fermentation characteristics with total gastro-intestinal health establishes DFM’s as a credible approach to improving ruminant production efficiency. Greater understanding of the modes of action and interactions of bacterial and non-bacterial DFM’s will improve the specificity of use and repeatability of the response.

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MANAGING UNCERTAINTY WHEN FORMULATING RATIONS

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Summary

Diet formulation and animal feeding rely on various estimates of feed composition, anticipated milk production, and feed intake. Ration formulation needs to account for the uncertainty of these estimates of feed analysis and animal performance. Most practices simply overestimate requirements by applying “safety” margins, or adjustments above estimated requirements to compensate for the risk of underfeeding. Optimal safety margins can be calculated by balancing the increased ration cost against the potential loss in milk income from the risk of underfeeding due to uncertainty and variation. For the previous 5-yr average milk and feed prices, the optimal safety margin for diet CP was 0.95 times the standard error (SE) in predicted requirements and supply. The overall safety margin for multiple sources of uncertainty can be quantified as the sum of squared SE terms times the safety factor (e.g. 0.95) to account for uncertainty in such estimates as feed analysis, animal production, intrinsic model uncertainty, and variation among animals (assuming no covariance among factors). Possible pitfalls in use of safety margins include: failure to understand that variance of ration nutrient composition is less than the variance for individual feeds, and failure to square SE before adding. These mistakes result in overfeeding of nutrients beyond the economic optimum. Explicitly understanding the sources of uncertainty in diet formulation and feeding enables more accurate compensation for uncertainty.

Introduction

Dairy cattle feeding consultants often add safety margins to animal requirements when formulating diets. These margins decrease the risk of underfeeding nutrients due to the uncertainty of the models, feed composition, or animal requirements. The aim of this paper is to describe the factors that contribute to uncertainty, quantify the optimal safety margins for current milk and feed prices, and describe how to add together safety factors from multiple sources of uncertainty.

Uncertainty and Variation

The terms uncertainty and variation are related but not equivalent. “Uncertainty” refers to the lack of confidence one may have in a model or recommendation, whereas “variation” concerns the lack of uniformity of a feedstuff or a group of animals. Various factors contribute to uncertainty including bias associated with an analytical method, or a lack of repeatability of that method, as well as the variation of the population sampled and the number of samples. The more samples taken of a feed, the less uncertainty there will be regarding the average composition. A single sample, analyzed by a single laboratory, will leave considerable uncertainty, unless there is little variation among feeds and laboratories. Uncertainty is estimated as the standard error (SE) of a mean from several analyses, while the variation is estimated as the standard deviation (SD) determined about a mean for a population of samples. The two estimates are related as SE = SD/√n, where n is the number of samples analyzed from the population. As n approaches infinity, the SE approaches 0, but if n = 1 the SE = SD.
Uncertainty can be reduced by decreasing the variation of the sample or simply by taking more independent samples. Because it is an inverse function of the number of samples, the second sample contributes more to reducing uncertainty than any subsequent number of samples. If we are speaking of meeting the nutritional requirements for an individual cow, however, it is the cow that is doing the sampling, and she only has one mouth. We have to reduce the variation in the feed consumed, or feed above requirements, to manage the risk of underfeeding an individual cow.

**Cow Variation**

Figure 1 shows a histogram for a typical dairy herd (Dunlap, et al., 2000) with average milk production of 30 kg/d (SD = 8.4). If one diet is formulated to meet the requirements of the average cow in the herd, one-half of the cows in the herd will be overfed and one-half will be underfed. Because the value of milk is greater than the cost of feed (if the farm is profitable), it is less risky to overfeed than to underfeed. For this reason, the safety margin was introduced to increase the nutrients offered above the average requirements to reduce the chance of underfeeding. The amount of additional nutrients to offer the herd is proportional to the uncertainty (SE), which in this case \( n = 1 \) equals the SD. Thus, the safety margin equals \( \lambda \times \text{SD} \), where \( \lambda \) is the lead factor or safety factor. Note that “factor” is a value multiplied by another value. In this case, the lead factor is multiplied by the SD in the group being fed to obtain the safety “margin”, where “margin” is the total amount of a nutrient to add, above the average requirement, to optimize production relative to cost.

Stallings and McGilliard (1984) recommended a lead factor of one, indicating a group of cows should be fed to one SD above the average cow’s requirements (83rd percentile). This recommendation is similar to that described in the documentation for the Spartan ration formulation software (VandeHaar et al., 1987), which recommends feeding to the level required of the 80th percentile cow in the group. We could find no documentation where the lead factor of one was determined to be the economic optimum, but even if it had been determined, the optimal lead factor 20 yr ago may no longer be optimal considering today’s milk and feed prices.

A cow requires a certain amount of energy and protein, not a percentage of the diet. However, cows eat to their energy requirements, so cows within a diverse group would be expected to eat different amounts of feed. The 80th percentile cow would eat more feed than the average, just as she requires more protein and energy. The variation in protein and energy concentration is less than the variation in quantity required per day over the animals in the group. Estimating the requirements of the 80th percentile cow in amount per day and dividing by the average intake would greatly overestimate the concentration of protein and energy required. When using lead factors and feeding for the 80th percentile
cow, it is the variation in required concentrations that must be considered, not the variation in amount required.

**Optimal Ration Energy Content**

In order to decide whether or not to use a lead factor for a nutrient, it is important to consider the consequences of underfeeding and overfeeding individual cows within the group. In terms of ration energy content, cows that are underfed (the highest producing cows), are likely to increase their DMI and reduce their body condition. There is also a risk of reduced milk production. Cows that are overfed energy (lowest producing cows) are likely to reduce their DMI and increase their body condition. Feeding a higher energy diet to all cows is likely to increase the cost of the diet.

Previously, other scientists (Pecsok *et al.* 1992) have applied lead factors for energy content of rations, particularly for finding the optimal grouping patterns that minimize variation in energy requirements. Once this optimal group is determined, feeding above the requirement of the average animal may cause animals with lower energy requirements to become overly conditioned. If we carefully consider the NRC (1989, 2001) diet formulation models with respect to energy, the models were developed with the recommendation to expect body condition losses in early and peak lactation, and body condition gains later in lactation. Cows perform best if body condition changes are not excessive. Therefore, diets should be formulated to maintain dietary energy levels that result in desired changes in body condition, with the expectation that the highest producing cows will be losing body condition and eating more total feed DM. Although cows produce different amounts of milk and have different dietary energy requirements, the variation in a herd is minimized in terms of energy concentration in the diet that is required after considering changes in body condition. Thus, if changes in body condition and feed intake are predicted for individual animals, lead factors for energy requirements are not necessary. In essence, the same result can be achieved by feeding for an acceptable loss in body condition among highest producing cows, and gain among lowest producing cows.

It is important to consider, however, that feeding an energy content that differs from that used in the NRC models for a given level of production will result in a different DMI than predicted by the NRC. When feeding to increase body condition (higher energy), cows will likely eat less. The NRC 1989 model will predict the change in dry matter intake (DMI), but the NRC 2001 model will not. If cows eat less, the concentration of crude protein (CP) in the diet will need to increase to provide the same amount of CP per day.

**Optimal Protein Content**

The optimal lead factor for CP depends upon three variables: feed CP cost, milk value, and expected change in milk yield per unit increase in feed CP supplied. As feed CP becomes more expensive relative to the value of milk, it becomes more risky to overfeed than to underfeed. To find the optimal lead factor, a data set was generated representing 1000 cows with average milk production of 30 kg/d and SD of 8.4 as shown in Figure 1. The CP requirements for each simulated cow were determined according to NRC (2001). Assuming a corn-silage based diet supplemented with corn grain and soybean meal, and 5-yr average prices for these ingredients, the average cost of feeding each cow was determined for lead factors varying from 0 to 2. Figure 2 (top) shows the linear increase in feed cost as the lead factor increases, mainly because soybean meal was substituted for corn grain. The total milk value estimated when feeding to different lead factors was determined by subtracting the expected milk loss from cows fed below requirements for their simulated production level (Figure 2; middle). For this estimate, we assumed 0.19 g loss in milk protein for every 1 g decrease in feed protein below requirements, and 5-yr average prices of milk protein were used. Subtracting the first graph from the second yields the analysis of benefit minus cost vs. lead factor shown in Figure 2 (bottom). The optimal lead factor was 0.95 indicating diets should be formulated close to the requirements for 83rd percentile cow, as recommended more than 20 yr ago (Stallings and McGilliard, 1984).
This analysis used lower predicted losses in milk yield from underfeeding crude protein than would have been predicted from the NRC (1989 and 2001) models. The NRC (2001) estimates that when ruminally degraded protein (RDP) is limiting to microbial growth, 85% of RDP can be converted to microbial CP. This microbial CP is 64% metabolizable, and the metabolizable CP is used for lactation at 67% efficiency after accounting for maintenance, lactation, and growth. These coefficients factor together to 36%. The previous NRC (1989) calculations assumed 90% efficiency of RDP use for microbial growth, plus 15% of CP intake recycled to the rumen, 64% digestibility of bacterial CP, and 70% efficiency of use of absorbed protein for lactation. These coefficients factor together to an assumed efficiency of conversion of 47%. Both estimates from NRC models are greater than 0.19 g loss in milk protein per g of N in feed that was observed experimentally (Kalscheur et al., 2006). We chose to use the lower value observed experimentally because the losses were believed to truly represent the losses in milk when dietary protein is slightly limited. The NRC models were developed primarily to predict when losses would occur, not to predict how great those losses would be, and cows appear to buffer the underfeeding of protein in the short term (3 weeks in this study) especially when the losses are minor.

**Uncertainty of Ration Composition**

The composition of a ration is determined by taking a weighted average of the composition of each ingredient: $\Sigma X_i$, where $X_i$ is the fraction of the nutrient contributed from each feed (i), and is determined as DMI of the feed in kg/d multiplied by composition of feed in kg nutrient per kg of DM. Although these components are additive, the estimates of uncertainty or variation must be squared before adding them. Thus, the expected variation in composition of a ration is $\Sigma (X_i SD_i)^2$ where $X_i$ is the fraction from each feed (i) and SD$_i$ is the respective variation in composition of that feed, and covariance among feeds is assumed to be negligible (St-Pierre and Harvey, 1986). See Table 1 for an example. Because of the effect of adding squared terms, the SD for composition of the ration is less than it is for individual feeds. While composition of some feeds may be greater or less than anticipated, the overall composition is less variable on average, as some of the underestimates are balanced by overestimates of other feeds (St-Pierre and Harvey, 1986; Buckmaster and Muller, 1994).

Figure 2. Change in feed cost (top), milk income (middle), and milk income minus feed cost (bottom) as the crude protein percentage of a diet is increased above the average cow’s requirement as a fraction (lead factor) of the SD of the CP required.
Table 1. Coefficient of variation (CV) in ration nutrient composition is less than CV for individual feeds.

<table>
<thead>
<tr>
<th>Feed</th>
<th>Fraction ($X_j$)</th>
<th>CP%</th>
<th>$CV_j$</th>
<th>$(X_j CV_j)^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn silage</td>
<td>0.50</td>
<td>9%</td>
<td>1%</td>
<td>0.25</td>
</tr>
<tr>
<td>Corn grain</td>
<td>0.25</td>
<td>10%</td>
<td>1%</td>
<td>0.0625</td>
</tr>
<tr>
<td>SBM</td>
<td>0.25</td>
<td>49%</td>
<td>2%</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Ration $CV = SD/\text{mean} = \sqrt{\sum (X_j \sigma_j)^2} = \sqrt{(0.25 + 0.0625 + 0.25)} = \sqrt{0.5625} = 0.75\%$.

Dealing with Many Sources of Uncertainty

There are many sources of uncertainty, in addition to that caused by animal variation in a herd, which can be accounted for on a farm. One large source of uncertainty is the feed composition values used to formulate diets. Because of variation in feed on a farm, one or more samples may not precisely represent what each cow eats. Additional uncertainty may be introduced by the feed analysis procedure. Diet formulation models are developed using empirical regression models, but the animals on a given farm may differ from the ones used to develop the equations, thus introducing model uncertainty. How feeds are delivered and consumed by animals introduces additional sources of uncertainty. The following discussion will address how to add sources of uncertainty in a ration, and how to potentially reduce uncertainty from multiple sources.

Diets can be optimized to account for variation among cows in a feeding group, as has been shown above. The same lead factor can be applied to other sources of variation. However, we must first define what we mean by variation. If our model is perfectly accurate at predicting the requirement of the average cow in the average herd consuming average feeds, it still may not fit every set of conditions precisely. Accurate means it is correct on average, but precise means it is consistent. For an unbiased model (accurate), the average of residuals (predicted – observed) is 0, and the SD of residuals is an estimate of the precision. This SD can be used to adjust for the way a requirement can be met for a single set of conditions.

The optimal safety margin for crude protein was shown to be about 1 SD greater than the average cow’s requirement. In the example provided, only the variation among cows in the herd fed the same ration was considered. The actual uncertainty is greater than only that contributed by the variation among animals. Although the optimal lead factor remains the same (close to one), the dispersion estimate due to uncertainty increases. What about other sources of variation or uncertainty? Table 2 shows an arbitrary list of factors that can contribute to uncertainty and the equivalent distribution estimates as percentages of the mean CP. If five factors are considered, and the CV of residuals is 10% of the mean, the total uncertainty estimate to multiply by the lead factor is 22% (the root sum of squared terms), and not the 50% that would have been found from adding each CV individually. Again, covariance among factors was assumed to be negligible. If the average cow-feed-farm replicate was predicted to need 15% CP, the optimal concentration to feed would be 18.4% in this case to account for all sources of uncertainty.

Table 3 shows the effect of reducing animal variation by grouping cows according to feeding requirements. It may appear that increasing the number of feeding groups of cows, and feeding each group an optimal diet, can reduce the variation within feeding groups enough to increase milk by 0.5 kg/d (Pecsok et al. 1992). However, these estimates considered only variation among cows in a herd but used a deterministic model to estimate losses for each simulated cow. Actual loss in production from underfeeding the top cows will be less than was estimated when also considering variation and uncertainty in feeds and management (Dunlap et al. 1997; Dunlap, 1999). Increasing the number of feeding groups for lactating cows was estimated to decrease CP in the diet by 8% (St-Pierre and Thraen, 1999). This estimate is accurate when using the common approach of adding a safety margin of 1 times the SD of requirements within feeding groups, which only accounts for animal variation. Considering all sources of variation, the total SD of predicted requirements (relative to actual requirement), decreases
only from 5% to 4% of the mean (Table 3). The CP content can only be decreased from 18.4 to 18.0%. However, with each decrease in variation of the system, (e.g. more feed sampling and better analysis, more precise models, more accurate weighing of ingredients), the total variation decreases to a greater extent (Table 4). Improving the weakest link has far more impact on decreasing the needed safety margin than improving an element which is already well under control.

Other than to add uncertainty estimates correctly and use the correct safety factors, the only other way to reduce safety margins is to reduce the dispersion estimates about predicted requirements. The practice of doing so would be a good definition for the term “precision feeding”.

Conclusions

Feeding optimal amounts of CP requires consideration of the variation in CP requirements among cows in the feeding group, and variation and uncertainty among feeds, models used to determine requirements, and uncertainties due to how rations are mixed. The optimal safety margin (i.e. additional CP offered to compensate for uncertainty) is 0.95 times the SD of the estimate of the average cow’s requirement accounting for all sources of variation. The different sources of variation need to be added as squared SD ($SD^2 =$ variance) terms. Decreasing variation and uncertainty of predictions enables formulation for lower concentrations of crude protein without risking lost milk production. The greatest sources of variation should be the first priority for improvements in management.

Table 2. Adding sources of variation in predicting crude protein composition required for an individual cow.

<table>
<thead>
<tr>
<th>Source of Uncertainty</th>
<th>CV$_i$</th>
<th>CV$_i^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Analysis</td>
<td>10%</td>
<td>1%</td>
</tr>
<tr>
<td>Animal Estimates</td>
<td>10%</td>
<td>1%</td>
</tr>
<tr>
<td>Model Parameters</td>
<td>10%</td>
<td>1%</td>
</tr>
<tr>
<td>Animal Variation</td>
<td>10%</td>
<td>1%</td>
</tr>
<tr>
<td>Feeding Practices</td>
<td>10%</td>
<td>1%</td>
</tr>
<tr>
<td>Total</td>
<td>22%</td>
<td>5%</td>
</tr>
</tbody>
</table>

CP added for safety (%) = Lead Factor x CV = 1 x 22% = 22% of CP
Total CP % = 15% CP (100 + 22%) = 18.4 % of DM.

Table 3. Effect of decreasing animal variation by grouping animals with similar requirements on the prediction of crude protein required.

<table>
<thead>
<tr>
<th>Source of Uncertainty</th>
<th>CV$_i$</th>
<th>CV$_i^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed Analysis</td>
<td>10%</td>
<td>1%</td>
</tr>
<tr>
<td>Animal Estimates</td>
<td>10%</td>
<td>1%</td>
</tr>
<tr>
<td>Model Parameters</td>
<td>10%</td>
<td>1%</td>
</tr>
<tr>
<td>Animal Variation</td>
<td>2%</td>
<td>0.04%</td>
</tr>
<tr>
<td>Feeding Practices</td>
<td>10%</td>
<td>1%</td>
</tr>
<tr>
<td>Total</td>
<td>20%</td>
<td>4.05%</td>
</tr>
</tbody>
</table>

CP added for safety (%) = Lead Factor x CV = 1 x 20% = 20% of CP
Total CP % = 15% CP (100 + 20%) = 18.0 % of DM (Compare to result of Table 2.)
Table 4. Effect of decreasing the coefficient of variation (CV) from 10% to 2% for zero to five out of five sources of variation on crude protein feeding at 1 SD above total variation.

<table>
<thead>
<tr>
<th>Variation</th>
<th>Total CV %</th>
<th>Crude protein %</th>
<th>N Saving¹ Tonnes/yr</th>
<th>Cost Saving¹ $/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>All high</td>
<td>22.4</td>
<td>18.4</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>One low</td>
<td>20.1</td>
<td>18.0</td>
<td>0.4</td>
<td>$795</td>
</tr>
<tr>
<td>Two low</td>
<td>17.5</td>
<td>17.6</td>
<td>0.9</td>
<td>$1,692</td>
</tr>
<tr>
<td>Three low</td>
<td>14.6</td>
<td>17.2</td>
<td>1.5</td>
<td>$2,744</td>
</tr>
<tr>
<td>Four low</td>
<td>10.8</td>
<td>16.6</td>
<td>2.2</td>
<td>$4,077</td>
</tr>
<tr>
<td>All low</td>
<td>4.5</td>
<td>15.7</td>
<td>3.4</td>
<td>$6,292</td>
</tr>
</tbody>
</table>

¹Nitrogen (Tonnes) and US dollars saved per 100 cows per year.

References


FEED MANAGEMENT: NORTHEAST PERSPECTIVE ON WORKSHOPS, ARPAS CERTIFICATION AND RELATIONSHIP WITH NATIONAL FEED MANAGEMENT PROJECT AND NRCS

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Summary

Land Grant Universities in Delaware, Maryland, Pennsylvania, Virginia and West Virginia and USDA’s National Institute of Food and Agriculture, working with EPA Region III, formed a partnership to advance water quality protection and restoration efforts in the Mid-Atlantic Region by providing water quality science support, training and education. In the winter of 2006, University specialists in dairy nutrition were invited to participate in the Mid-Atlantic Regional Water Program that until then was predominately comprised of engineers and agronomists. Penn State, Virginia Tech and the University of Maryland represented the dairy nutrition component. Specialists from these three Universities decided the greatest opportunity to positively affect water quality was to implement the national initiative: Development and Integration of a National Feed Management Education Program and Assessment Tools into a Comprehensive Nutrient Management Plan, which was being lead by Washington State University. The goal of the dairy nutrition group was to cater the national program to issues affecting the Mid-Atlantic Region. Collaboration with the local Natural Resource Conservation Service (NRCS) specialists was an essential component in getting the certification process initiated.

In November 2007, the first training on how to become a certified feed management planner was held in Grantville, Pennsylvania with 105 consultants in attendance. More training followed that included both feed industry and NRCS personnel. The Mid-Atlantic group felt that for nutritionists to buy into the concept of becoming a certified feed management planner through ARPAS, off-setting the cost of the exam would be a positive incentive. As of December 2009, ARPAS listed a total of 84 certified feed management planners and 67 are in the northeast and would have attended trainings provided by the Mid-Atlantic dairy nutrition group.

Introduction

The Mid-Atlantic region is home to approximately 820,000 dairy cattle. Each state in the region has set goals for nutrient reductions in nitrogen and phosphorus. The challenge faced by the dairy industry is that the 820,000 dairy cows are found on over 10,000 individually operated dairy farms. This means the diets formulated and fed vary in forage type and quality, commodity type and quality and in feeding systems. To complicate the situation, how rations are managed and implemented on a daily basis on farm can be variable and inconsistent. Regular oversight by a certified feed management planner and routine record keeping demonstrating improvements are needed. In order to comply with the timeline for nutrient reductions set by the Mid-Atlantic region, specialists in Pennsylvania, Maryland and Virginia are working with NRCS and the American Registry of Professional Animal Scientists (ARPAS) to develop a certification process where nutritionists would be certified feed management planners to implement the NRCS Feed Management Standard 592. This process is new to the dairy industry.
On November 12, 2007, the Mid-Atlantic Regional Water Program sponsored training for dairy nutritionists on how to become certified feed management planners. One hundred and five people attended, fifty-six nutritionists took the exam and fifty passed. In the beginning of 2008, NRCS rolled out the feed management option to dairy producers along with the EQIP (Environmental Quality Incentive Program) funding. Additional training has occurred in 2008 and 2009 with 47 nutritionists and veterinarians taking the feed management exam through ARPAS. Currently Pennsylvania and Maryland are taking the lead in the northeast. Virginia NRCS has not dedicated EQIP funds for feed management at this time. They are waiting for results from Virginia Tech’s Conservation Innovation Grant. The focus locations for training have been in Pennsylvania and Maryland. As producers are being accepted for EQIP, they will require a feed management plan written. Oversight of the process will be the responsibility of the certified nutritionists. Continuing education programs and support are being provided by the Mid-Atlantic region to assist nutritionists through this initial and new process.

**Target Audience**

The concept of NRCS using technical service providers to assist in meeting certain standards is not new. For example, engineers from the private sector work with NRCS developing manure storage structures to their standards. This concept is being applied to the dairy feed industry, which is a new concept for them. The majority of nutritionists have not been involved in nutrient management or interacted with NRCS. There is an opportunity to provide continuing education and support to nutritionists to become certified feed management planners and to improve their role working with producers under EQIP.

Starting January 2008, dairy producers that applied and were accepted to receive EQIP for feed management are in need of a certified planner. Certified nutritionists are just starting to develop plans for producers requesting their services. As more producers get approved for feed management plans, feed companies will want more of their personnel trained to avoid competitors coming onto their client’s farms. Offering workshops throughout the year should provide ample opportunity for the majority of the feed industry to get certified.

Offering to pay for the exam immediately after training is a powerful incentive to attend the training and to take the exam. The offer to pay for the exam also puts the Mid Atlantic Regional Water Program in a positive light. People will be more inclined to attend educational programs about issues related to nutrient management beyond precision feeding. This has already occurred. Certified nutritionists have requested programs geared towards topics surrounding nutrients in soil and water and regulatory issues.

As more nutritionists become certified, the Mid-Atlantic Region will have a captive audience for continuing education programs. There will be issues that will arise as more people write plans. Challenges associated with precision feeding can be evaluated as more plans are written and implemented. As part of the feed management plan, manure samples have to be taken to document change. Currently there are resource tools available to estimate nitrogen and phosphorus outputs as well as total manure production. The Mid-Atlantic group will have the ability to compare actual manure values to projected values. There will be greater opportunities to address emerging issues related to nutrient management with more nutritionists involved in the process.
THE CHESAPEAKE BAY “POLLUTION DIET” AND ITS POTENTIAL IMPACTS ON DAIRY FARMS

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Summary

The Chesapeake Bay’s health, as well as that of all the streams and rivers draining into it, depends on significant reductions in nitrogen and phosphorus from agricultural runoff, sewage treatment plants, stormwater, and other sources of pollution. The U.S. Environmental Protection Agency will soon mandate significant reductions in this pollution, presenting both challenges and opportunities to regional farms.

The Chesapeake Bay and its Challenges

Formed about 12,000 years ago as glaciers melted and flooded the Susquehanna River valley, the Chesapeake Bay is North America's largest estuary, a waterbody that blends fresh and salt water. The word “Chesapeake” derives from the Native American “Tschiswapeki,” which loosely translates into “great shellfish bay.” The Bay supports 3,600 species of plant and animal life, including more than 300 fish species and 2,700 plant types. It was teeming with aquatic life when Captain John Smith described it as “a goodly Bay” during his 1608 Bay exploration. Since colonial times, the Bay has lost half of its forested shorelines, over half of its wetlands, nearly 90 percent of its underwater grasses, and more than 98 percent of its oysters.

The Chesapeake Bay is 200 miles long from the mouth of the Susquehanna River to the Atlantic Ocean, and has 11,600 miles of tidal shoreline, more than the entire U.S. west coast. However, it is very shallow, with an average depth of only 21 feet deep. Its watershed (the area of land that drains into the Bay) is 64,000 square miles with more than 100,000 small streams and rivers. It is a complex ecosystem with wetlands, forests, urban and suburban areas, and agricultural lands. Parts of six states: Delaware, Maryland, New York, Pennsylvania, Virginia, and West Virginia, as well as Washington D.C., drain into the Bay. The watershed is home to approximately 17 million people. The 2007 Census of Agriculture estimates that there are 83,775 farms on 12.8 million acres of farmland, making significant contributions to the region’s economy.
The ratio of the Bay’s watershed area to its water volume is very large, meaning that what happens on the land affects the Chesapeake Bay to a greater degree than other waterbodies. Because of this basic geographic fact, the Bay and many of its tributaries are deeply affected by pollutants running off from the land.

The leading threat to the health of the Chesapeake Bay is excess nitrogen and phosphorus pollution from agriculture, sewage treatment plants, runoff from urban and suburban areas, and air pollution from automobiles, factories, and power plants. While these nutrients are essential to the entire ecosystem, at excessive levels they fuel the growth of vast quantities of algae that throw these ecosystems out of balance. Large “blooms” of algae block sunlight from reaching underwater grasses that provide
vital habitat and food sources for fish and other wildlife. Their decomposition depletes oxygen in the water, which is essential for these same animals, and leads to “dead zones” or areas void of almost all life.

**Clean Water Act and its Ramifications**

The federal Clean Water Act passed in 1972, to ensure that all waters of the United States would be clean and healthy. It requires states to report biannually on impaired waterbodies that do not meet applicable water quality standards, and develop a Total Maximum Daily Load (TMDL), or “pollution diet,” a calculation of the maximum amount of a pollutant that the waterbody can receive daily and still meet its water quality standards. Achieving the TMDL leads to the restoration of a polluted waterbody.

The Chesapeake Bay and several tidal tributaries were listed as impaired in 1996 and 1998. In 2000, the federal government, the states, and the District of Columbia pledged to work together to ensure that the Chesapeake Bay would meet water quality standards by 2010. Now at this deadline, we are less than halfway toward meeting these pollution reduction targets.

Consequently, the Environmental Protection Agency (EPA) is developing a TMDL for the Chesapeake Bay, and asserts that this TMDL will be different from those developed elsewhere. The EPA will require states to set pollution caps for smaller geographic areas than in the past, such as counties, because much of the implementation actually occurs at the local level. Localized pollution caps will increase accountability by providing governments, citizens, watershed groups and other interested stakeholders with a goal against which they can measure local efforts. Cleaning the Bay requires pollution reductions from all the streams and rivers that feed it. So, reaching the TMDL will also help improve local streams, many of which will have their own TMDLs.

The EPA will also require state watershed implementation plans that specify, in great detail, how they will achieve pollution reductions from all sources through enforceable or otherwise binding measures. The EPA’s Chesapeake Bay Program has determined that maximum loads of 200 million pounds of nitrogen and 15 million pounds of phosphorus per year are needed for clean water and a healthy Bay. However, the current Watershed Model estimates loads of more than 258 million pounds of nitrogen and 17 million pounds of phosphorus in 2008.

The Chesapeake Bay Program’s Watershed Model (Phase 4.3) estimates the amount of nitrogen and phosphorus from each source, including agriculture, point sources (such as sewage treatment plants), and urban and suburban stormwater runoff. Updated models will be used to guide watershed implementation plans.

<table>
<thead>
<tr>
<th>Source</th>
<th>Nitrogen (lbs/year)</th>
<th>Phosphorus (lbs/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>149,380,071</td>
<td>116,295,633</td>
</tr>
<tr>
<td>Point Source</td>
<td>87,720,651</td>
<td>62,841,812</td>
</tr>
<tr>
<td>Other</td>
<td>52,306,053</td>
<td>56,985,226</td>
</tr>
<tr>
<td>All Sources</td>
<td>337,539,149</td>
<td>284,756,091</td>
</tr>
</tbody>
</table>

In President Obama’s May 9, 2009 Executive Order, he tasked the EPA with leading the effort to reduce the Chesapeake Bay’s pollution, to meet the Clean Water Act goals. The Executive Order requires the federal government to collaborate with state governments in pollution reduction, with a rigorous timetable, and very specific watershed implementation plans detailing how pollution reductions will be achieved.
These watershed implementation plans will also include two-year “milestones,” and states will be held accountable to meeting them. A sample of these milestones includes:

- 55,100 tons per year of poultry litter transported from Delaware
- 2.5 million square feet converted to green roofs each year in Washington, D.C.
- Replacement of 1.5 miles of sewer lines in Washington, D.C.
- 90,000 acres of stormwater runoff management retrofits in Maryland
- 460,000 acres per year of cover crops in Maryland
- Optimization of nutrient removal at 27 significant wastewater treatment plants in New York
- Precision feeding with 7,600 animal units in New York
- 327,599 acres covered by conservation plans in Pennsylvania
- 2,219 acres of abandoned mineland reclamation in Pennsylvania
- 47,500 acres per year of conservation tillage in Virginia
- Improvements to 806 septic systems in Virginia
- 14,000 acres with fencing to exclude livestock from streams, off-stream watering, and rotational grazing in West Virginia

The EPA has indicated its intent to invoke strict consequences (such as withholding funds available to states under the Clean Water Act) if the states fail to develop adequate watershed implementation plans or make progress in achieving the necessary pollution reductions. The possibility of these consequences is intended to drive state and local actions to reduce pollution.

*The Next Generation of Tools and Actions to Restore Water Quality in the Chesapeake Bay* outlines the EPA’s draft strategy to meet the Chesapeake restoration goals. It states: “While more than two decades of voluntary, cost-share, and regulatory efforts to reduce nutrient and sediment pollution from point and nonpoint sources to the Chesapeake Bay watershed have made some important progress, that progress has not been sufficient to restore the Bay in a reasonable period of time.” Therefore, “bold action is needed,” according to the strategy

The EPA is considering expanding the definition of Concentrated Animal Feeding Operations so that more facilities must obtain permits, and set more stringent performance standards, such as those regulating the land application of animal manure.

The EPA’s plan outlines increased coordination with the US Department of Agriculture (USDA) and targeting resources to key conservation practices in the high priority watersheds. USDA proposes an “aggressive, voluntary partnership approach” to most effectively accelerate conservation adoption by increasing incentives, simplifying program participation, and encouraging private sector investment. USDA will provide financial and technical assistance through various programs, such as the Chesapeake Bay Watershed Initiative, Environmental Quality Incentives Program, and Conservation Reserve Enhancement Program.

**Agriculture’s Role in Meeting Water Quality Goals**

A result of U.S. agriculture’s shift from diversified farms to larger, specialized operations is that nutrients are cycled less within each farm. More grains for livestock feed are now imported to the Chesapeake Bay watershed from other areas, such as the Midwest. The livestock manure remains here, resulting in a net increase in nutrients in the watershed. This constant influx of nutrients and regional imbalance must be resolved through new approaches.

The details of the Chesapeake Bay TMDL and watershed implementation plans will be available in Spring 2010, at the earliest, but it is clear now that everyone living in the Chesapeake Bay watershed
will need to reduce their nutrient pollution. The role of farms in meeting the pollution reduction goals is significant, but the exact requirements are not clear at this time. However, it is certain that there will be significant responsibilities, because agriculture is estimated to contribute 39 percent of the nitrogen and 47 percent of the phosphorus to the Chesapeake Bay.

At the very least, all farmers should be sure they are in compliance with current environmental regulations. All farms, of every size and type of production, will need to have a conservation plan ensuring that soil and nutrients are retained on the land, and not escaping to the air and water. Each farm may need a different suite of practices appropriate for the soil type, terrain and farming practices. The TMDL will require thousands of farms to establish additional conservation practices, such as cover crops and livestock exclusions from streams. Intensive manure management, along with detailed record-keeping, will be necessary. Various state and federal programs will provide financial and technical assistance for many farms to meet the TMDL goal, but all farms need to be proactive and make sure that they are adequately managing their soil and nutrients.

The current economic situation facing livestock producers will require cost-effective measures to control nutrient pollution and achieve clean water. Improved feed management is one of the best means to reduce feed costs and improve production, while resulting in manure nutrient reductions of 20-40 percent. Many strategies to reduce excess nutrients may improve farm profitability, such as:

- Eliminating phosphorus supplements if other feeds meet phosphorus requirements
- Ensuring that grains are correctly processed so more starch is fermented in the rumen
- Grouping lactating cows according to stage of lactation, so varying nutrient needs may be addressed
- Routinely testing forages and grains, and monitoring dry matter, to be sure that rations are formulated for maximum efficiency.

**Opportunities for Farmers**

**Nutrient trading** makes it possible to achieve pollution reductions efficiently and cost-effectively, and offers a new revenue source for those able to sell “nutrient credits.” Once a farm has met and exceeded state and federal environmental requirements, it may sell credits for additional pollution reduction, for example, to a municipality. Reducing pollution from agriculture is usually more cost effective than other improvements, such as upgrades to sewage treatment plants or stormwater systems. This creates opportunities for farmers to sell the nutrient credits, for significantly less than that local government would pay to reduce a pound of pollution from other sources.

A recent analysis by the World Resources Institute (WRI), an international leader in market based environmental programs, found that water quality trading could provide up to $300 million dollars per year, when pollution caps are put in place in 2010. It could provide revenue of a similar scale or greater than current annual government agriculture conservation in the Chesapeake Bay watershed.

The new **Chesapeake Bay Watershed Initiative** (CBWI), created in the 2008 Farm Bill, provides technical and financial assistance to producers to install agricultural practices to help control erosion, and to minimize excess nutrients and sediments entering the Chesapeake Bay. These measures will help retain top soil and nutrients on the land, while protecting local streams that drain into the Chesapeake Bay.

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PRODUCTION STRATEGIES AND FEEDING OPPORTUNITIES FOR PELLETS OF HIGH QUALITY

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Summary

Pellet quality produced from integrated poultry operations is often poor. Feed volume requirement and lack of data associated with economic implications of high quality pellet production and feeding may be responsible for this trend. Recent research has demonstrated economic benefits of feeding high quality pellets to broilers that were based on diet cost, feed intake, and subsequent gains in carcass weight. These benefits were associated with several feed form attributes and not changes in nutrient availability. If a poultry company were to pursue these economic benefits linked to feeding high quality pellets, then any of a number of feed manufacture strategies may be implemented. However, challenges exist in implementation of manufacture strategies that increase thermo-mechanical nutrient interactions that are favorable to pellet binding and not detrimental to nutrient availability. An appreciation of the relationship between feed manufacture strategies, pellet quality, and nutrient availability may aid in increasing overall profitability of poultry production.

Introduction

Poultry companies around the country have difficulty providing their growers pellets of high quality. The primary excuse that many companies provide for their production of poor quality pellets is the necessity for high mill through-put or need for a high volume of feed in an established amount of time. The need for high through-put may result from the poultry company increasing the number of contract growers or birds placed without a simultaneous investment in their feed milling facilities. Thus many feed mills operate above their intended capacity, which decreases pellet quality. A secondary problem that may result in the production of poor quality pellets is lack of communication concerning pellet quality among nutritionists, feed mill managers, and live production managers. For example, if a nutritionist’s primary concern is least-cost diet formulation, a mill manager’s primary concern is maximizing feed production per shift, and a live production manager’s primary concern is adequate feed volume, then high pellet quality may be impossible to achieve. Companies must take a more comprehensive view of pellet production and potential benefits of feeding high quality pellets to assess if overall profitability may be enhanced.

Feed Manufacture Strategies

For over 40 years poultry research has consistently demonstrated live production benefits associated with feeding pellets. These benefits extend to both the integrator and grower alike in providing improved feed flow through bins, improved hygienic quality of feed, decreased ingredient segregation, decreased opportunities for selective feeding, reduced feed wastage, increased intake and subsequent live weight gain, and decreased feed conversion ratio. A recent study conducted at West Virginia University explored profitability potential of feeding pellets of varying quality to modern day Cobb broilers. This study attempted to maintain consistent nutrient availability among treatments so that any performance differences could solely be attributed to feed form. Treatments were arranged in a 4x3 factorial design consisting of four variations of feed form and tested with either all males, all females or straight-run (equal male to female ratio) pens of broilers in the growing period (d21-38). All feed was manufactured at...
West Virginia University’s pilot feed mill over a two day period. High quality pellets were created by running the mill at a slow production rate and utilizing a thick die, 44.45mm x 4.83mm (1.77” x 3/16”), high steam conditioning pressure, 551.58 kpa (80 psig), and high steam conditioning temperature, 93.33 °C (200°F). In order to create variations in pellet quality, a portion of high quality pellets were ground with a roller mill to produce fine particle feed (fines) and mixed with intact pellets to create different pellet:fine ratio compositions. Treatments consisted of high pellet quality (HPQ) 90:10, medium pellet quality (MPQ) 60:40, low pellet quality (LPQ) 30:70 and Mash 0:100. Male and straight run broilers had decreased feed conversion when fed pelleted treatments (P<0.05). This effect was consistent when all birds were pooled together (P<0.05). Males fed HPQ had higher carcass weight than all other treatments (P<0.05). Female broilers fed HPQ had higher carcass weight than those fed Mash (P<0.05). Straight-run broilers fed HPQ and MPQ had higher carcass weight than those fed LPQ or Mash (P<0.05). When all birds were pooled together, carcass weight improved significantly (P<0.05) when fed HPQ in comparison to all other treatments. An economic model using all data collected and feed costs set at $300 per ton multiplied by feed intake/(carcass weight – (70% x 21d chick weight)) found a savings of $0.03 per pound of carcass weight when feeding HPQ versus Mash (Table 1). The live performance results may be attributed to several benefits associated with high quality pellets, less improvements linked with decreased ingredient segregation and increased pellet length; this being a product of the more basic research design. However, if these factors were incorporated into the treatment structure, then feeding benefits of high quality pellets would likely be more dramatic.
Table 1. Economic analysis using grower period feed intake and carcass gain.

<table>
<thead>
<tr>
<th>Feed form treatments (pellet : fine)</th>
<th>21d chick weight (kg)</th>
<th>38d carcass weight (kg)</th>
<th>21-38d feed intake/bird (kg)</th>
<th>$/kg of carcass weight</th>
<th>Relative difference between mash and pelleted treatments ($/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mash (0:100)</td>
<td>0.744</td>
<td>1.411</td>
<td>2.388</td>
<td>0.887</td>
<td>00</td>
</tr>
<tr>
<td>LPQ (30:70)</td>
<td>0.741</td>
<td>1.439</td>
<td>2.419</td>
<td>0.870</td>
<td>-0.018</td>
</tr>
<tr>
<td>MPQ (60:40)</td>
<td>0.742</td>
<td>1.465</td>
<td>2.489</td>
<td>0.871</td>
<td>-0.017</td>
</tr>
<tr>
<td>HPQ (90:10)</td>
<td>0.742</td>
<td>1.505</td>
<td>2.473</td>
<td>0.830</td>
<td>-0.057</td>
</tr>
</tbody>
</table>

$/\text{kg of carcass weight} = \frac{\$300 \times \text{feed intake}}{907 \text{ kg feed} - [\text{carcass weight} - (70\% \times 21\text{d chick weight})]^{1}}$

170\% of 21d chick weight is an estimated carcass weight of 21d chicks

Figure 1. The effect of pellet quality and bird sex on feed conversion ratio.

Results: Feed Conversion (D 21-38)

Feed Form P=0.0001 Sex P=0.0001
Figure 2. The effect of pellet quality and bird sex on carcass weight.

The aforementioned data may encourage a company to consider if an investment of time, utility cost, and labor to produce pellets of high quality would justify improvements in live production and overall profitability. More specifically, the feed mill may have to operate an additional day per week or additional shift, and electrical and gas inputs at the mill will likely increase; however, if gains are improved, and less feed and time are required for grow-out then the added investment may be well justified. The next issue for a poultry company to address is how to achieve high pellet quality within the constraints of their current production system. Many strategies to improve pellet quality have been established and new strategies are continually being developed. These strategies may be implemented alone or in combination with one another. In addition, strategies to improve pellet quality may allow for an assessment model to be created in order to estimate whether or not an investment in pellet quality is justified for a particular operation.

 возможные стратегии для создания высококачественных гранул

1. **Последовательность продукции.**
   Следующий по следующему пути позволяет для большего объема отходов в грануляционную доску, что увеличивает термо-механические взаимодействия и, следовательно, адгезию частиц. В итоге получается высококачественные гранулы (Buchanan and Moritz, 2009; Lilly et al., 2009).

2. **Уменьшение частицы кукурузы.**
   Мелкие кукурузные частицы увеличивают площадь поверхности для частицы и улучшают качество гранул (Reece et al., 1986, Wondra et al., 1995).
3. **Use a thicker pellet die.**
   Greater die thickness creates improved retention time of feed in the pellet die, thermo-mechanical nutrient interactions, feed particle adhesion and pellet quality (Buchanan and Moritz, 2009; Hott et al., 2008).

4. **Increase steam conditioning temperature.**
   Increasing moisture and heat increases feed particle adhesion and pellet quality (Cutlip et al., 2008; Lilly et al., 2009).

5. **Use a pellet binder.**
   Commercial pellet binders are available. A binding agent could be as simple as added moisture at the mixer. Additionally, recent research has demonstrated that protein pastes derived from waste products of fish processing may provide pellet binding benefits as well as nutritional benefits in the form of highly available amino acids (Fairchild and Greer, 1999; Hott et al., 2008; Buchanan and Moritz, 2009; Gehring et al., 2009).

6. **Manipulate diet formulation.**
   Least cost diet formulation often may not enhance pellet quality. Manipulating diet formulation to increase pellet quality, although potentially increasing diet cost, may decrease overall production cost, if pellet quality and subsequent live performance are significantly improved. However, caution should be exercised not to create diet formulations that increase frictional heat within the die to a degree that reduces nutrient availability (Briggs et al., 1999; Buchanan and Moritz, 2009; Gehring et al., 2009; Lilly et al., 2009).

   Most industry leaders are well aware of these somewhat intuitive strategies to improve pellet quality. The more challenging issue is assessing if investment in pellet quality is cost effective to the integrated operation. Many of the strategies can be easily implemented during short test periods at the mill. During these test periods, simple variables such as estimates of production rate and electrical energy usage can be collected. This information used in conjunction with pellet durability data (pellet durability tester ~ $250) and live performance data from past research may provide a basis to defend or refute an investment in pellet quality. If this task seems daunting, then consultation may be appropriate.

   Finally, consideration should be given to whether or not the strategies implemented to improve pellet quality may have a negative effect on nutrient availability. Many strategies to improve pellet quality involve increasing thermo-mechanical nutrient interactions and consequent feed particle adhesion. These interactions are advantageous to improving pellet quality, but caution must be exercised to prevent nutrient availability from being decreased. More specifically, conditions of high heat and moisture may also induce non-favorable reactions that lead to reduced nutrient availability (e.g., reduced protein solubility, vitamin oxidation, Maillard reaction, and exogenous enzyme degradation). If non-favorable reactions persist then benefits of pelleting could be reduced or completely negated, thus undermining the investment to improve pellet quality. Past research has illustrated that if pelleting strategies do not account for the potential to reduce nutrient availability then benefits of high quality pellets can be substantially diminished. Some specific examples include Buchanan and Moritz, 2009; Lilly et al., 2009; and Beaman et al., unpublished.

   One particular example of how a strategy used to improve pellet quality may decrease nutrient availability is reducing the amount of mixer added fat. While less fat in the diet prior to pelleting certainly aids in beneficial pelleting reactions such as starch gelatinization and protein gelation, frictional heat in the die may increase to a degree that adversely effects nutrient availability. A study was conducted to evaluate the effects of mixer-added fat (1, 2.5 or 4%) with or without exogenous enzyme addition
(carbohydrase, protease and phytase), and at different conditioning temperatures (82.2 or 85°C), on feed manufacture and finisher phase broiler performance variables. Diets were formulated using 2008 Agristat nutrient specifications, practical industry ingredients, and full matrix values of the enzymes. In order to account for potential feed form confounding effects, all pellets were ground prior to feeding. Increasing mixer-added fat significantly reduced the electrical energy usage required for pelleting, thus demonstrating increased die lubrication. Feed intake and live weight gain were significantly increased with enzyme addition. Enzyme addition, conditioning temperature and mixer-added fat interacted in their effects on feed conversion ratio. Overall, enzyme addition decreased feed conversion ratio, but the effect was greatest with 1% mixer-added fat and 82.2°C or 4% mixer-added fat and 85°C. Our thought was that a temperature induced break-point must exist for enzyme denaturation / nutrient degradation and that the break point for these particular enzymes and ingredient nutrients was within our tested range. At 85°C and 4% mixer-added fat, addition of enzyme decreased feed conversion ratio by 9 points, compared to a 3 point reduction with 2.5% mixer-added fat, and a 1 point reduction with 1% mixer-added fat. Fat pad yield was significantly reduced with increasing mixer-added fat. Mixer-added fat likely increased the protein:calorie ratio and consequently reduced adipose tissue deposition. The study suggested that mixer added fat improved broiler nutrient utilization by protecting heat sensitive nutrients, exogenous enzymes, or both from thermal degradation associated with pelleting (Gehring et al., 2009).

References


QUALITY CONTROL CONSIDERATIONS IN COMMERCIAL FEED MANUFACTURE

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Summary

Feed and feed manufacturing may comprise 60-70% of total animal production costs. It is an expensive and essential segment of production animal agriculture. In order to maximize efficiency and ensure the production of a high quality product, a comprehensive quality control program is recommended.

As defined by Rydell (2005) and Boyd (1993), quality control is a comprehensive program directed at ensuring the production of feeds that meet a predefined set of standards. Every step in the feed manufacturing process is essential to producing a healthy and marketable final product (i.e., meat, eggs, milk, etc.).

The Feed Quality Assurance Program established by the National Grain and Feed Association (NGFA) recognizes six essential segments of quality control: 1) purchasing and receiving; 2) manufacturing; 3) feed sampling and inspection; 4) shipment and delivery; 5) sanitation; and 6) product investigations/recalls.

Introduction

The feed manufacture process is costly both in capital investment and in execution. In fact, feed and the manufacturing process may comprise 60-70% of total animal production costs (Behnke, 1994). In 2008 alone, approximately 125 million tons of feed was produced in the United States (Lundeen, 2009).

An estimated 3,000 primary feed manufacturing plants and 5,500 custom-mix plants are currently in operation in the United States. In fact, the top 10 U.S. commercial feed companies have a combined production capacity of 40 million tons of feed annually, or a mere 30% of the total demand (Lundeen, 2009). Arguably, this large number of manufacturing facilities lends itself to significant variation in quality control parameters and manufacturing practices.

The objective of this proceeding is to outline some basic considerations that feed manufacturing facilities should contemplate when developing or reviewing a quality control program.

Purchasing and Receiving

Traditionally, complete feeds are composed of grains, by-products, vitamin/mineral mixes, and fats/oils. The number of available ingredients is often overwhelming and the nutrient content of these ingredients may be inconsistent. A comprehensive sampling and testing program will ensure a consistent and nutritionally-adequate finished product.
A consistent product starts with the supplier. The American Feed Industry Association (AFIA) has developed the Safe Feed / Safe Food program. A key concept in certification through this program is a list of approved and preferred suppliers. Stark and Jones (2009) have outlined the following steps to ensure the quality of incoming ingredients: 1) commit to quality, 2) decide what you want and put it in writing, 3) examine all incoming ingredients thoroughly, 4) have samples analyzed, 5) develop reporting, 6) communicate with suppliers, 7) adjust formulas to reflect changes, and 8) file every deficiency claim possible.

Many commercial facilities may use certified laboratories to analyze the nutrient content (e.g., protein, fat, fiber, etc.) of incoming ingredients. However, ingredient testing should not stop at nutrient content. There are a number of factors that directly or indirectly affect nutrient content of feed ingredients.

Under-toasting or over-toasting during processing results in a decrease in nutrient quality in soybeans (Ruiz, 2009). Therefore, testing of trypsin inhibitor or urease activity will help ensure that the supplier is providing an adequately-processed ingredient. Ruiz (2009) tested five different commercial soybean meals and found that trypsin inhibitor ranged from 2.2 to 6.0 mg TI/g (optimal levels = < 2.0 mg TI/g) and urease activity ranged from 0.02 to 0.25 pH units (optimal levels = < 0.05 pH unit).

Mycotoxins are toxic compounds found in various agricultural commodities (Cullen and Newberne, 1994). Broilers exposed to mycotoxins are subject to fertility, immune, and growth challenges (Brown et al., 1992). Unfortunately, the 2009-2010 harvest season has resulted in the prevalence of mycotoxins in various grains and grain by-products (Sellers, 2009).

Grain and grain by-products have the potential to change each season due to growing conditions, yields, and harvest conditions. It is essential to consider these changes when developing and implementing a quality control program. An annual review or audit of your quality control program should be implemented in order to stay one step ahead of potential problems involving incoming ingredients.

Table 1. Mycotoxin Prevalence in Corn Grain\(^1\) (Oct. 1, 2009 to Jan. 4, 2010)

<table>
<thead>
<tr>
<th>Mycotoxin</th>
<th>Samples</th>
<th>Positive (0.1 – 6 ppm)</th>
<th>Positive (6 - &gt;20 ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deoxynivalenol (DON)</td>
<td>880</td>
<td>77%</td>
<td>4%</td>
</tr>
<tr>
<td>Aflatoxin</td>
<td>453</td>
<td>7%</td>
<td>2%</td>
</tr>
</tbody>
</table>

\(^1\)Table adapted from Dairyland Laboratories, Inc.

Feed Manufacturing

Currently, there are no standard processing or manufacturing recommendations for commercial feed mills (Cutlip et al., 2008). Therefore, the development and implementation of a quality control program is absolutely essential in commercial feed manufacture.
Maintaining the structural integrity of pellets improves feed handling, decreases ingredient segregation, and improves feed flow (Behnke, 2004). A comprehensive quality control program should provide recommendations, standards, and testing procedures that can be used to guarantee mill personnel are producing the highest quality product possible.

In a recent survey, data on conditioning time, conditioning temperature, pellet die specifications, and pellet durability index (PDI) were collected from a series of commercial feed mills (Moritz, 2007). This survey reiterates the large variation in manufacturing technique that may directly influence the quality of the final product.

Table 2. Variation in Manufacturing Technique in Commercial Facilities¹.

<table>
<thead>
<tr>
<th>Commercial Mill</th>
<th>Conditioning Time / Temp.</th>
<th>Production Rate (ton/wk)</th>
<th>Pellet Die Length : Diameter</th>
<th>PDI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>35 seconds 195°F</td>
<td>16,400</td>
<td>7.3</td>
<td>75</td>
</tr>
<tr>
<td>B</td>
<td>20 seconds 180°F</td>
<td>1,000</td>
<td>11.2</td>
<td>70</td>
</tr>
<tr>
<td>C</td>
<td>4 seconds 155°F</td>
<td>1,000</td>
<td>13.1</td>
<td>95</td>
</tr>
</tbody>
</table>

¹Adapted from Moritz, 2007.

Maintaining high pellet quality from the feed mill to the farm is difficult. Scheideler (1995) conducted a survey of four US broiler integrators and found that feed fines present at the pellet cooler averaged 33% of the total diet. Once feed was loaded into trucks and transported to the farm, feed fines increased to 59% of the total diet. Finally, once feed was augured to the feed pan inside the broiler house, feed fines increased to 63-72% of the total diet.

A number of peer-reviewed and popular press articles have given recommendations for maximizing pellet quality. Stark and Jones (2009) suggest conditioning temperatures of 180°F in winter and 190°F in summer. Moreover, if ambient temperature and grain conditions permit, Cutlip et al. (2008) states that higher conditioning temperature, up to 200°F, will improve pellet quality and broiler performance. Buchanan et al. (2009a,b) found that utilization of a thicker die (3/16 x 1.77 vs. 3/16 x 1.50 in.) and a slower production rate will improve pellet quality and broiler performance.

Feed Sampling, Inspection, and Delivery

A finished feed's journey only starts at the feed mill. Feed sampling and sample retention are essential to the protection of a quality control program. Finished feeds should be subject to the same inspections and sampling procedures as incoming ingredients.

Samples of each feed should be taken and retained for sampling in the future. Additionally, multiple feeds should be randomly sampled and the nutrient content should be analyzed. These reports continually monitor the efficiency and accuracy of your production personnel and equipment. Continual monitoring will allow mill personnel to find problems prior to reaching the customer.

For example, loaders and drivers should be familiar with the various types of feeds that are manufactured at your facility. Drivers do not just deliver feed. They are the last inspection before the feed leaves the possession of your company. All loaders and drivers should have the opportunity to inspect the feed prior to leaving the facility and should also inspect feed while it is being unloaded at the farm.
Product Investigations and Recalls

A comprehensive quality control program will undoubtedly reduce the incidence of shipping inaccurately-manufactured feed to a farm. However, despite the best systems, mistakes can still happen. Therefore, it is essential to have a process for investigating and conducting recalls.

Proper record keeping and tracking is essential to ameliorate problems linked to an inaccurately-manufactured product. Knowing which ingredients were used in the production of that product and knowing exactly where that product was delivered are essential to an efficient investigation and, if necessary, an efficient recall. A properly trained and prepared team will be ready to face any quality challenges.

In conclusion, a commercial feed manufacturing facility must have a comprehensive program that defines policies, procedures, and process controls (Stark and Jones, 2009). Arguably, the most important aspect of any quality control program is accountability. Suppliers, employees, and management should all have a vested interest in producing the highest quality product possible.

References

Dairyland Laboratories, Inc., Arcadia, WI – Stratford, WI – St. Cloud, MN.
INCLUSION EFFECTS OF DISTILLERS DRIED GRAINS WITH SOLUBLES (DDGS) IN POULTRY PRODUCTION AND FEED MILLING

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Summary

There is little debate regarding the economic advantages of utilizing DDGS in poultry diets. Various operations have successfully used DDGS in their feed manufacturing resulting in interesting diet cost reductions. Where there seems to be some argument is with regards to management problems that arise when using DDGS after certain dietary levels, as well as some logistical management problems at the feed mill. These issues will be discussed in the enclosed proceedings.

Introduction

According to the AMRC (2010), approximately 36 million tons of DDGS will be manufactured this year as a result of the ethanol fermentation industry. That is a 3-fold increase compared to the production observed during 2004-2005. During those years the dairy and beef industry utilized the vast majority of DDGS commercially available, but now there has been an increase in the use of DDGS in poultry rations, with an estimated 1.13 million tons of DDGS destined to chicken diets in 2009. The main reason for this increase in use has to be its competitive price, which oscillates these days between 110 to 180 dollars per ton, depending on the feed mill location. This can be advantageous for the numerous commercial layer and turkey operations in the Midwest United States, because this is where most of DDGS are manufactured, but not so much for broiler integrators in the Southeast US which may endure high shipping costs. Additionally, there is some skepticism regarding the use of this ingredient in poultry diets. From a nutritional standpoint, recent research has shown high variability concerning metabolizable energy and amino acid digestibility and content between DDGS sources (Batal et al., 2006; Fatsinger et al., 2006). At Mississippi State University, several experiments have been conducted recently addressing some of these concerns.

Broiler Production

There have been various studies that discuss the effects of including DDGS at various levels in broiler rations (Waldroup et al., 1981; Parsons et al., 1983; Lumpkins et al., 2004; Min et al., 2009). In addition, at Mississippi State University we recently conducted studies evaluating the inclusion of DDGS in broiler chick diets for the 0-to-14 day feeding phase, and the 14-to-28 feeding phase (data not published). The study for the earlier feeding phase was repeated three times, and results were variable. However, they seemed to indicate that there was a drop in chick growth after DDGS were included at levels higher than 16% of the diet during this phase. These results are also in agreement with those of Min et al. (2009), who reported a depression in chick growth when DDGS were included at high levels in the diet, and particularly when high levels of canola meal were also high. In parallel with the results observed for the 0-to-14 day phase, the 14-to-28 day phase showed a tendency towards reducing the growth of broiler after 15% DDGS were included in the diet. These results are in agreement with those of Min et al. (2009), as well as those of Loar et al. (2009) who reported no negative effects in growth or carcass traits.
of broilers when DDGS were fed at 8% of the diet up to 42 days of age. More research is warranted to determine more precise inclusion levels recommended for DDGS in broiler diets, particularly during latter feeding phases.

**Broiler Processing**

As already described by Loar *et al.* (2009), there seems to be no reduction in yields of broilers when diets contain up to 8% DDGS. The influence DDGS may have on broilers may be more influential from a meat characteristics viewpoint. Corzo *et al.* (2009) fed broilers either 0 or 8% DDGS in the diet, and took samples of breast and thigh meat for analysis. Corzo *et al.* (2009) observed no effects of feeding DDGS on breast meat color (CIE*), pH, cooking loss or shear values. There were, however, some slight flavor and overall acceptability differences favoring the non DDGS-fed meat, observed when taste panelists were asked to grade the breast meat derived from those chickens fed 0 or 8% DDGS. In a follow-up study (Schilling *et al.*, 2010), this effect was not observed when panelists were asked to grade the difference in texture, flavor, aroma and appearance of breast meat derived from chickens fed either feeding up to 24% DDGS in the diet.

When chickens were fed 8% DDGS there was a tendency to observe higher levels of linoleic and polyunsaturated fatty acids in thigh meat (Corzo *et al.*, 2009). This effect was observed again in the follow-up study when broilers were fed up to 24% DDGS (Schilling *et al.*, 2010). This higher degree of unsaturated fats in thigh meat as broilers are fed higher levels of DDGS can be explained by the composition of these substrates in DDGS which is mostly an unsaturated profile. In turn, this has the potential to create a susceptibility to oxidation as observed when TBARS tests were run (Corzo *et al.*, 2009; Schilling et a., 2010).

**Layer Production**

DDGS have also been evaluated as an alternative ingredient in commercial leghorn diets (Matterson *et al.*, 1965; Lilburn and Jensen, 1984; Lumpkins *et al.*, 2005; Pineda *et al.*, 2008). Recently, Loar *et al.* (2010a) evaluated the effects of feeding various levels of DDGS to commercial leghorns. After feeding up to 32% of DDGS to second-cycle Bovans white layers, no negative effects of feeding high levels of DDGS were observed with regards to egg production, feed conversion, egg mass or feed consumption of layers (Loar *et al.*, 2010a). Inclusion of DDGS in the diet resulted in a significantly darker and redder yolk, with a tendency to increase Haugh unit values (Loar *et al.*, 2010a). Eggs from these layers were evaluated by taste panelists, and these slightly preferred the eggs that were derived from DDGS fed hens over eggs that were obtained from hens that were fed no DDGS, with regards to both the flavor acceptability and overall acceptability. Although there is some disagreement in the literature in terms of DDGS effects on layer nutrition, based on the overall results reported by Loar *et al.* (2010a), DDGS can be considered as an alternative ingredient for commercial layer diets.

**Feed Manufacturing**

The impact of DDGS in the management of commercial feed mills for the most part has been disseminated by popular belief, but has not scientifically validated. Very recently, there has been some evaluation of the impact that this ingredient has on feed mill efficiency and pellet quality (Min *et al.*, 2009; Srinivasan *et al.*, 2009; Loar *et al.*, 2010b). Min *et al.* (2009) showed how increasing levels of DDGS in chick diets resulted to higher amounts of fines. In agreement with this finding, Loar *et al.* (2010b) also reported an increase in fines as levels of DDGS increased in grower-type diets. This increase in fines was paralleled with a decrease in pellet durability index (Loar *et al.*, 2010b). A decrease in bulk density was observed with increased levels of DDGS in the diet (Loar *et al.*, 2010b). Interestingly, Loar *et al.* (2010b) reported a decrease in pellet mill relative energy usage with increasing levels of DDGS in the
diet. This decrease in energy consumption and pellet durability index was also reported by Srinivasan et al. (2009) as levels of DDGS were increased in the diet. Ultimately, from a feed mill standpoint there are pros and cons to the use of DDGS in poultry diets, and all should be considered.

Conclusions

The use of DDGS in poultry diets as an alternative feed ingredient must always be considered. Not only its price can be attractive, but also it’s nutritional profile. However, recent studies by Mississippi State University and other research institutions have shown the importance of recognizing its limitations as well as the need to be thoroughly familiar with the variation in physical and nutritional characteristics of DDGS.

References


DIET COMPOSITION AND PROCESSING ADJUSTMENTS TO COVER THE BIRD’S NEED FOR STRUCTURAL COMPONENTS

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Summary

Data has emerged during the last 10 years which indicate that the lack of structural components in most poultry diets may give rise to suboptimal performance. Structural components may be large cereal particles or it may be coarse fibrous components such as hulls. The hypothesis that poultry has a requirement for structural components is based on numerous data which indicate that when structural components are added to the diet, performance in the form of increased nutrient utilization is observed. Furthermore, this improvement has been linked to a higher secretion of digestive components, smaller size of particles entering the small intestine and a reduced incidence of feed overconsumption by individual birds. These beneficial effects have been hypothesized to be caused by a more developed gizzard when structural components are added to the diet. The use of whole cereals in the diet or the addition of hulls have been shown to be effective contributors to these beneficial effects, and it has been shown that birds given deficient diets will consume other available structural components such as litter material to compensate for lack of structural components in the diet.

Introduction

Poultry diets usually consist of cereals and other ingredients which are ground to a rather small particle size. In some cases, notably in broiler diets and in some cases layer diets, the ground cereal and other finely ground materials are moulded into pellets. During the pelleting process, where the material is forced into holes in the pellet press, the material is further ground to even smaller particles. The process of making large macro-particles in the form of pellets will therefore result in an even smaller size of the micro-particles that make up the pellet. Thus, while hammer milled wheat-based broiler diets had between 40 and 50 % particles smaller than 0.2 mm as mash before pelleting, this proportion increased to between 50 and 60 % after pelleting (Svihus et al., 2004b). Although ground wheat contained an appreciable amount of very small particles after grinding through a 3 mm sieve in a hammer mill, an even larger contributor to particles smaller than 0.2 mm in size in this experiment came from the soybean meal and other minor components which were added.

In addition to finely ground diet ingredients, fibre level is usually kept low in the diet to assure a high nutrient concentration and nutrient intake of the birds. Although fibrous ingredients such as soybean meal and wheat bran are used in the diet, these fibrous ingredients are ground to a small size and do not represent a large portion of the diet. The consequence of a low level of structural components in poultry diets due to the use of finely ground ingredients and few fibrous ingredients will be discussed in this review.

Role and Function of the Gizzard

In addition to being a compartment where feed material is sterilized and degraded under low pH with pepsin present, the gizzard functions as a specialized grinding organ which can grind whole seeds and fibrous material down to very small particles. Data from Hetland et al. (2002, 2003) and Amerah et
al. (2008) indicate that a majority of the particles entering the duodenum are smaller than 0.1 mm, even when considerable amounts of whole wheat or coarse cereal particles are added to the diet. The capacity of modern poultry strains to grind particulate matter has not been extensively studied, but Hetland et al. (2002) showed that while addition of up to 30% whole wheat did not result in more large particles entering the duodenum, addition of up to 44% whole wheat resulted in a significant reduction in duodenal concentration of particles smaller than 0.04 mm. Although feed utilization was not negatively affected even with this high inclusion level of whole wheat, inclusion of up to 60% whole wheat resulted in a considerable reduction of weight gain and a poorer feed utilization. A similar reduction in performance was found by Biggs and Parsons (2009) when whole wheat inclusion increased from 35 to 50%. This indicates that there is an upper limit to the amount of structural components poultry can handle without deleterious effects on performance. Based on the above, it may be concluded that when whole wheat is added, the level should probably be kept below 44% of the total diet to avoid exceeding the grinding capacity of the gizzard.

The main body of the gizzard comprises two thick, opposed lateral muscles and two thin anterior and posterior muscles. A thick layer of glyco-proteins that is hardened by the low pH covers the inside of the gizzard. The koilin layer is composed of a combination of rod-like and granular secretions from gizzard glands, and is continuously renewed by these glands as it is worn. The rod-like hardened glycoprotein will stand out from the remaining glyco-protein matrix and will give the surface the characteristic sand-paper like appearance (Hill, 1971). The thick muscles grind material by contractions that rub the material against the koilin layer on the inside of the gizzard, while the small muscles move material between contractions of the large muscles. Coarse feed particles need to be ground to a certain critical size before they can leave the gizzard (Clemens et al., 1975; Moore, 1999). This is because particles that have not reached a sufficiently small size will be prohibited from leaving the gizzard by folds at the duodenal orifice during contractions.

It is a well established fact that the digestive tract adapts to changes in diet composition. Studies of wild birds with large variations in their diet throughout the year for example, show that both the small intestine and the caeca fluctuate in size (Klasing, 1998). Particularly the gizzard is known to respond rapidly to diet changes, something noted amongst others by Charles Darwin during his studies of pigeons (Farner, 1960). A rapid and conspicuous enlargement in size of the gizzard is observed when structural components such as hulls, wood shavings or large cereal particles are included in the diet. This increase in size of the gizzard is a logical consequence of an increased need for particle size reduction, as the increased grinding activity of the gizzard increases the size of the two pairs of gizzard muscles. For example, Hetland et al. (2003) observed a 50% heavier gizzard when whole cereals and oat hulls were included in the diet for broiler chickens. It has also been shown that the volume of gizzard content increases when diets with whole cereals or insoluble fibre are fed (Hetland et al., 2003). Thus, structural components do not only increase the size of the gizzard, but also results in an increased holding capacity of the gizzard.

Is the Gizzard Underdeveloped in Commercial Systems?

A pertinent question which has not been adequately addressed is whether the small gizzard often observed in birds fed diets lacking structural components represents an abnormal situation, and thus may result in suboptimal performance. It is in this context worth noting that wild granivorous birds have a diet consisting of a large amount of structural components such as seeds and large fibrous materials. Also, the gizzard of these birds regularly contains grit stones which will further stimulate gizzard development and function (Gionfriddo and Best, 1996). It is therefore logical to conclude that even domesticated poultry species are evolutionary adapted to a diet with a large content of structural components.
O’Dell et al. (1959) not only found that the gizzard was underdeveloped when diets lacking structural components were fed, but also showed that lack of structural components was linked to a large incidence of proventricularitis among chicks. Proventricularitis is characterised by an enlargement of the proventriculus and a widening of the gastric isthmus, and is an abnormality which increases condemnation due to rupture of the proventriculus in the processing plant (Dormitorio et al., 2007). This early observation in fact suggests that the proventriculus/gizzard area is dependent on structural components to develop normally.

It has been shown that particle size of material entering the small intestine are smaller for a diet consisting of coarsely ground ingredients than for the same diet containing finely ground ingredients (Hetland et al., 2002, 2003). This apparently counterintuitive result may simply be caused by the fact that a well-developed gizzard will result in a very effective grinding activity which will exceed the efficiency of the grinding during feed processing. This indicates that birds that are not able to add structural components to their diet have an under-developed gizzard which may not be able to degrade particles sufficiently. This corresponds to the increased starch digestibility sometimes observed when structural components have been added (Svihus and Hetland, 2001; Svihus et al., 2004a). An increased amylase activity and bile acid concentration may also be part of the cause for improvements in nutritive value associated with structural components, as observed by Svihus et al. (2004a). The cause for this increased secretory activity remains unclear, but may be associated with a stimulation of pancreatic secretion caused by an increase in gizzard activity. Hetland et al. (2003) also found a significant increase in amylase activity and bile acid secretion when gizzard activity was stimulated by oat hulls.

Our research has led to the hypothesis that over-consumption of feeds may sometimes occur in broiler chickens fed diets lacking structural components, resulting in impaired nutrient utilization due to a too rapid feed passage through the small intestine. The first indication of this was in an experiment where it was observed that caged broiler chickens fed pelleted wheat-based diets showed improved nutrient utilization and smaller individual variation when feed intake was reduced by crushing the pellet (Svihus and Hetland, 2001). Also, plotting of feed intake for individual birds against AME frequently results in a slight inverse relationship; when feed intake increase, AME is reduced (Svihus, 2006). This has also been shown in a recent unpublished experiment at our lab (Figure 1). In this experiment, four out of ten ad libitum fed birds on a finely ground pelleted wheat diet showed signs of being feed overconsumers, characterised by a normal weight gain, a higher than average feed intake and an AME value below 10.3 MJ/kg. Furthermore, results from our lab indicate that there may be an interaction between gizzard function and overconsumption of feeds. When feeds have more structure, either through the use of whole cereals or through addition of large fibre particles (oat hulls or wood shavings) into the diet, an improvement in starch digestibility and a reduced variation between birds is commonly observed (Svihus and Hetland, 2001; Hetland et al., 2002; Rogel et al., 1987). This was also observed in the previously mentioned experiment, where variation in feed/gain, AME and starch digestibility was strongly reduced for caged Cobb broilers when whole wheat was added to the diet (Table 1). Based on the above, our hypothesis is that an active and well-developed gizzard will function as a food intake regulator that will assure that the bird does not over-consume feeds. This is due to the active retention of large particles until they are broken down, which results in a larger filling of the gizzard and thus less room for more feed to be consumed. In most animals, flow of material out from the stomach is synchronized with digestion and absorption in the small intestine, such that digestion is maximized and the capacity of the small intestine to digest and absorb nutrients is not exceeded. A fully developed gizzard where feed has a significant retention may be able to communicate better with the small intestine. The major stimuli causing an increased enzyme secretion by the pancreas are the vagus nerve and cholecystokinin (CCK). Cholecystokinin is mainly produced in the pyloric region of birds (Denbow, 2000), and acts together with the vagus nerve to stimulate pancreatic enzyme secretion (Li and Owyang, 1993). Thus, a stimulating effect of an increased gizzard activity on enzyme secretions may be mediated through increased CCK release in the pyloric region of the gizzard.
Figure 1. Correlation between feed intake and AME for 40 individually caged broiler chickens receiving a wheat-based diet.

Table 1. Broiler performance (16 to 25 days of age) and nutrient availability

<table>
<thead>
<tr>
<th></th>
<th>Ad libitum</th>
<th></th>
<th>Restricted</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ground wheat</td>
<td>Whole wheat</td>
<td>Ground wheat</td>
<td>Whole wheat</td>
</tr>
<tr>
<td>Weight gain, g:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>543</td>
<td>527</td>
<td>505</td>
<td>523</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>0.11</td>
<td>0.19</td>
<td>0.19</td>
<td>0.14</td>
</tr>
<tr>
<td>Feed intake, g:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean²</td>
<td>1022&lt;sup&gt;a&lt;/sup&gt;</td>
<td>846&lt;sup&gt;b&lt;/sup&gt;</td>
<td>890&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>795&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>0.17</td>
<td>0.19</td>
<td>0.27</td>
<td>0.15</td>
</tr>
<tr>
<td>Range</td>
<td>783 – 1347</td>
<td>636 – 1100</td>
<td>564 – 1202</td>
<td>622 – 1016</td>
</tr>
<tr>
<td>Gain/feed:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean³</td>
<td>0.54&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.62&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.58&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>0.66&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>0.16</td>
<td>0.05</td>
<td>0.10</td>
<td>0.07</td>
</tr>
<tr>
<td>Range</td>
<td>0.40 – 0.65</td>
<td>0.58 – 0.67</td>
<td>0.48 – 0.67</td>
<td>0.59 – 0.72</td>
</tr>
<tr>
<td>AMEn, MJ/kg:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean⁴</td>
<td>10.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>12.6&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>0.15</td>
<td>0.06</td>
<td>0.18</td>
<td>0.07</td>
</tr>
<tr>
<td>Range</td>
<td>8.1 – 12.3</td>
<td>10.7 – 13.5</td>
<td>8.0 – 13.1</td>
<td>10.2 – 13.2</td>
</tr>
<tr>
<td>Faecal starch digestibility:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean⁵</td>
<td>0.81&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.95&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.82&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.95&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>0.18</td>
<td>0.06</td>
<td>0.18</td>
<td>0.07</td>
</tr>
<tr>
<td>Range</td>
<td>0.59 – 0.94</td>
<td>0.81 – 0.99</td>
<td>0.56 – 0.97</td>
<td>0.75 – 0.98</td>
</tr>
</tbody>
</table>

<sup>1</sup>ANOVA main effects or interaction effects were non-significant unless mentioned.
<sup>2</sup>P-value for wheat structure and feeding system were 0.0213 and 0.1111, respectively.
<sup>3</sup>P-value for wheat structure and feeding system were <.0001 and 0.0379, respectively.
<sup>4</sup>P-value for wheat structure was 0.0003.
<sup>5</sup>P-value for wheat structure was 0.0004.
<sup>abc</sup>Means within a row not sharing a common superscript differ at P<0.05.

In addition to the factors mentioned above, other factors may also indicate that gizzard development through structural components added to the diet is necessary for an optimal digestive
function. Since an increased volume of the gizzard and thus an increased amount of feeds is found in birds fed structural components (Amerah et al., 2009; Svihus et al., 2004a,b), the resulting increased retention time may affect nutrient digestibility. It has been shown repeatedly that when structural components such as whole or coarsely ground cereals or fibre materials such as hulls or wood shavings are added, pH of the gizzard content decreases with a magnitude of between 0.2 and 1.2 units (Gabriel et al., 2003; Engberg et al., 2004; Bjerrum et al., 2005; Huang et al., 2006; Gonzales-Alvarado et al., 2008; Jimenez-Moreno et al., 2009; Senkoylu et al., 2009). The cause for this could be the increased retention time as a consequence of increased gizzard volume, which would allow for more time for hydrochloric acid secretion. Although pepsin production has not been measured directly, a common secretory pathway for hydrochloric acid and pepsinogen make an assumption of increased pepsin secretion probable. Thus, a possible explanation for improvements in digestibility with structural components could be a more complete digestion in the gizzard. Increased retention time in the gizzard may also potentially improve efficacy of exogenous enzymes added to the diet. Although this surprisingly enough appears to not have been studied, it is often postulated that an exogenous enzyme such as phytase exerts its main function in the gizzard due to the favourable pH there (Garrett et al., 2004). Thus, it is a reasonable hypothesis that a more developed gizzard as a consequence of structural components may improve efficacy of this and other exogenous enzymes. Since pH optimum for most exogenous enzymes are in the area 4 to 5 however, the reduced pH with structural components may counteract the effect of increased retention time. These important questions call for being addressed in future experiments. It has also been shown that the microflora composition in the small intestine may be altered when the diet contains structural components (Bjerrum et al., 2005). Although it is difficult to assess how changes in microflora composition affect nutrient utilization, it is possible that such changes may be linked to improvements in nutrient utilization.

**Extent of Grinding**

A major rationale for the energy- and time-consuming fine grinding appears to be improved technical properties of the feed. A fine grinding assures a homogenous diet which does not segregate easily during handling. A fine grinding has also been associated with an increased durability of the macro-particles in a situation of feed pelleting (Angulo et al., 1996; Svihus et al., 2004b), although contradictory results have been reported (Amerah et al., 2007).

Based on documented beneficial effects of fine grinding for nutrient utilization in diets for pigs and cattle, it has often been assumed that a diet based on finely ground ingredients is beneficial for a proper nutrient utilization for poultry also, but this is a view not supported by most scientific literature (e.g. Farrell et al., 1983; Reece et al., 1985; Reece et al., 1986a,b; Deaton et al., 1989; Proudfoot and Hulan, 1989; Lott et al., 1992; Nir et al., 1994a,b; Hamilton and Proudfoot, 1995; Nir et al., 1995; Hamilton and Kennie, 1997; Svihus et al., 2004b). As discussed above and extensively by Amerah et al. (2007), several reports have found that coarse particles result in an improvement in nutrient utilization for poultry.

A coarser grinding will save considerable energy and time in the grinding process. Reece et al. (1986b) stated that energy cost for hammer grinding of maize could be reduced with 27% by increasing the sieve size from 4.76 to 6.35 mm. Thus, the reduced production costs and the improvements in performance are major motivations for a coarser structure of the diet. A challenge when pelleted diets are used is that a considerable grinding takes place in the pelleting process, and that the grinding by the rolls as they force material into the die hole will have a particularly strong particle-reducing effect on large cereal particles (Svihus et al., 2004b). Results from our lab indicate that when whole cereals are added to the diet before pelleting, 50% of the kernels will be ground to mash during the pelleting process. If pelleted diets are used, a very coarse grinding of the cereals (or no grinding at all) must be undertaken if a significant increase in structural components is to be obtained.
Litter Consumption

Poultry have been shown to consume significant amounts of litter material, and the consumption has been shown to be dependent on the texture of the litter material (Malone et al., 1983). Hetland et al. (2005) confirmed these findings, but also showed that consumption of litter material increased with decreasing coarseness of the diet. This indicates that birds have a desire for structural components, and that birds will search for structural components in the environment in a situation where the diet has a low content of structural components. Litter material used as bedding in floor systems may be such an alternative source for structural components.

We have carried out two experiments to study litter consumption of broilers, presented in Tables 2 and 3. Gizzard size, gizzard content weight and fibre concentration increased for birds raised on litter, and thus it is logical to conclude that birds consumed litter. While weight gain was not significantly affected by either structural components in the diet or whether the birds were raised on wood shavings litter or not, access to litter had a significant moderating effect on feed intake, which in turn resulted in a significantly improved feed/gain for birds with access to litter in one experiment. As ileal starch digestibility was significantly improved with access to litter in one experiment, this indicates that the cause for improved feed utilization with litter was at least partly an improved nutrient digestibility. Weighing of the litter for each cage before and after the experiment indicated that birds were eating approximately one gram per bird per day. The significant trend towards a larger increase in gizzard size for diets without hulls for birds on litter in one experiment indicates that consumption of litter material interacts with access to structural components through the diet. This lends support to the hypothesis put forward earlier, that poultry eat litter material to compensate for lack of structural components in the diet (Hetland et al., 2004; Hetland et al., 2005).

Thus, these experiments indicate that litter material, when used for birds given a modern broiler diet with a low content of structural material, should be regarded not only as a bedding material, but also as a dietary ingredient. This insight has bearing for the hygienic conditions of the digestive tract, and it has bearings for the choice of litter materials, but most of all, it calls for a change in the philosophy of how diets used for poultry are optimized and processed.

Table 2. Effect of a diet with and without whole wheat given to broiler chickens raised on litter or on a rubber mat, on performance and digestive function

<table>
<thead>
<tr>
<th></th>
<th>Wheat treatment</th>
<th>No litter</th>
<th>Litter</th>
<th>P-value for litter effect</th>
<th>P-value for diet effect</th>
<th>P-value for interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight gain 11-29 days, g</td>
<td>Ground Whole</td>
<td>1175</td>
<td>1267</td>
<td>0.6836</td>
<td>0.3441</td>
<td>0.4464</td>
</tr>
<tr>
<td></td>
<td>Whole</td>
<td>1405</td>
<td>1226</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed consumption 11-29 days, g</td>
<td>Ground Whole</td>
<td>1794</td>
<td>1723</td>
<td>0.0391</td>
<td>0.1558</td>
<td>0.0960</td>
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<tr>
<td></td>
<td>Whole</td>
<td>1922</td>
<td>1713</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed/gain</td>
<td>Ground Whole</td>
<td>1.64</td>
<td>1.48</td>
<td>0.1054</td>
<td>0.7245</td>
<td>0.9812</td>
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<td></td>
<td>Whole</td>
<td>1.70</td>
<td>1.43</td>
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<tr>
<td>Ileal starch digestibility, %</td>
<td>Ground Whole</td>
<td>89</td>
<td>94</td>
<td>0.0333</td>
<td>0.1156</td>
<td>0.8946</td>
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<tr>
<td></td>
<td>Whole</td>
<td>88</td>
<td>90</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Empty gizzard, % of live weight</td>
<td>Ground Whole</td>
<td>1.4</td>
<td>1.5</td>
<td>0.0204</td>
<td>0.0004</td>
<td>0.7039</td>
</tr>
<tr>
<td></td>
<td>Whole</td>
<td>1.6</td>
<td>1.7</td>
<td></td>
<td></td>
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<tr>
<td>Gizzard content, % of live weight</td>
<td>Ground Whole</td>
<td>0.3</td>
<td>0.6</td>
<td>0.0032</td>
<td>0.0001</td>
<td>0.2858</td>
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<tr>
<td></td>
<td>Whole</td>
<td>0.7</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Fibre concentration in gizzard, %</td>
<td>Ground Whole</td>
<td>17.2</td>
<td>37.0</td>
<td>0.0001</td>
<td>0.0030</td>
<td>0.1826</td>
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<tr>
<td></td>
<td>Whole</td>
<td>34.4</td>
<td>38.7</td>
<td></td>
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</tr>
</tbody>
</table>

Based on the NDF analysis (Van Soest method).
Table 3. Effect of a diet with or without oat hulls given to broiler chickens reared on litter or on a rubber mat, on performance and digestive function

<table>
<thead>
<tr>
<th>Diet</th>
<th>No hulls</th>
<th>Litter</th>
<th>P-value for litter effect</th>
<th>P-value for diet effect</th>
<th>P-value for interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight gain 6-32 days, g</td>
<td>No hulls</td>
<td>1957</td>
<td>1919</td>
<td>0.6802</td>
<td>0.6205</td>
</tr>
<tr>
<td></td>
<td>Hulls</td>
<td>1949</td>
<td>1960</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed consumption 6-32 days, g</td>
<td>No hulls</td>
<td>3181</td>
<td>2945</td>
<td>0.0136</td>
<td>0.1623</td>
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<td></td>
<td>Hulls</td>
<td>3021</td>
<td>2931</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed/gain</td>
<td>No hulls</td>
<td>1.63</td>
<td>1.53</td>
<td>0.0006</td>
<td>0.0044</td>
</tr>
<tr>
<td></td>
<td>Hulls</td>
<td>1.55</td>
<td>1.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starch content in ileum, %</td>
<td>No hulls</td>
<td>12.2</td>
<td>9.6</td>
<td>0.1042</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>Hulls</td>
<td>1.1</td>
<td>1.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Empty gizzard weight, g on day 19</td>
<td>No hulls</td>
<td>15.5</td>
<td>21.9</td>
<td>0.0037</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>Hulls</td>
<td>25.6</td>
<td>26.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Empty gizzard weight, g on day 32</td>
<td>No hulls</td>
<td>27.6</td>
<td>31.0</td>
<td>0.5303</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>Hulls</td>
<td>44.9</td>
<td>43.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean duodenal particle µm on day 19</td>
<td>No hulls</td>
<td>160</td>
<td>120</td>
<td>0.6821</td>
<td>0.0748</td>
</tr>
<tr>
<td></td>
<td>Hulls</td>
<td>89</td>
<td>110</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean duodenal particle µm on day 32</td>
<td>No hulls</td>
<td>237</td>
<td>264</td>
<td>0.0908</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>Hulls</td>
<td>136</td>
<td>172</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

References


EFFECTS OF ENZYME SUPPLEMENTATION ON INTESTINAL ENVIRONMENT AND POULTRY PERFORMANCE

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Summary

Phytate is a water insoluble storage form of phosphorus ubiquitous to grains and oil seeds. Although phytate serves an important role in germination of the seeds, it is poorly digested in poultry diets and has been implicated not only in reduced phosphorus digestibility, but also reduction of the digestibly of other dietary nutrients. Current commercial supplementation of poultry diets with phytase results in release of phosphorus from phytate and decreases the need for supplementation of diets with inorganic phosphorus.

Supplementation of poultry diets with higher than commercial concentrations of phytase allows for more interaction between phytate and phytase (substrate and enzyme) and the opportunity to decrease the exposure of the diet and gastro-intestinal environment to phytate. These higher concentrations of phytase result in increased bird performance when fed in a corn-soybean meal diets that contain phytate. It is the objective of this paper to begin to elucidate the mechanism of enzymatic hydrolysis of phytate on the gastro-intestinal environment and poultry performance.

Introduction

Phosphorus (P) is a macro-mineral essential for life. It is involved in energy metabolism, cell signaling, acid-base balance and bone structure and function among others (Baker and Lewis, 1995). In poultry species, especially fast growing broiler strains, bone mineralization is especially important where selection for increased growth rates and breast muscle yield has placed tremendous strain on leg joints and the skeletal system (Williams et al., 2000). The daily P requirement for poultry species has historically been met by supplementation of the diet with inorganic P although corn and soybean meal, the typical grains and oilseed meals in poultry diets in the US, are rich in P. Unfortunately, P found in corn (72%) and SBM (60%) is predominantly stored in a complex called phytate (myoinositol 1, 2, 3, 4, 5, 6-hexis-phosphate; Ravindran, 1995). Although the digestibility of phytate P (PP) is affected by several factors, including dietary calcium, micro-mineral interactions, P status of the birds, and dietary ingredients, it is generally low in comparison to inorganic sources (Maddaiah et al., 1964; Vohra et al., 1965; Nelson, 1976; Nolan et al., 1987; Persson et al., 1998; Tamin and Angel, 2003). This low utilization of P in the grain and oilseed meals has resulted in the loss of valuable nutrients into a waste stream that has contributed to the buildup of P in croplands around intensive poultry production facilities (Sims, 1995).

Bird utilization of PP is low due to a lack of production of phytase, the enzyme that is responsible for the removal of P from phytate (Kerr et al., 2000). Poultry species also generally have a short retention time for feed and limited microbial fermentation to produce phytase and liberate P in areas of the gastro-intestinal tract where absorption could occur (McNab, 1973). It has long been understood that supplementation of a corn-SBM diet with exogenously produced phytase will increased the utilization of
dietary PP (Nelson et al., 1971). The increased utilization of PP with phytase supplementation will also allow for a reduction in supplementation of inorganic P and a reduction in the excretion of P in poultry species (Angel, 1999).

More recently, commercial production of phytase from microbial sources has allowed for widespread use, resulting in cost savings and reduced excretion of P as manure. Current economics allow for the utilization of between 300 and 750 FTU of phytase/kg of diet or 135 to 340 FTU of phytase/lb diet. Inclusion of phytase at these concentrations generally will allow for the release of approximately 0.07 to 0.15% of P that was previously bound as PP (Augspurger et al., 2003). In addition to the P released by phytase, it is generally believed that dietary calcium utilization is also improved by phytase supplementation (Nelson, 1968).

Limited evaluation of higher concentrations of supplemental phytase has been reported. Shirley and Edwards (2003) fed supplemental concentrations of phytase up to 12,000 FTU/kg without negatively affecting performance, although the amount of phosphorus removed from the diet (0.24% total P) might not have limited growth.

**Performance and Body Composition**

Broiler chicks were fed diets that contained 0.45% nonphytate P (nPP) in addition to 0, 500, 7,500 and 15,000 FTU/kg of supplemental phytase (Table 1). The concentration of nPP in the diets should result in maximal performance and is typical of a positive control diet when evaluating phytase enzymes. This approach was selected to highlight the response noted was not due to a simple phosphorus response. Broiler chicks fed 7,500 and 15,000 FTU/kg of supplemental phytase (regardless of source) resulted in increased weight gain in 8- to 22-day-old chicks in comparison to a typical positive control diet. The increase in weight gain was accompanied by increases in feed intake, but no change in feed efficiency.

**Table 1. Performance of broiler chicks fed diets containing 0.45% nonphytate phosphorus (nPP) and supplemented with various concentrations of phytase from 8 to 22 days.**

<table>
<thead>
<tr>
<th>nPP (%)</th>
<th>E. coli Phytase (FTU/kg)</th>
<th>Weight Gain (g)</th>
<th>Feed Intake (g)</th>
<th>FE (g/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.45</td>
<td>0</td>
<td>598c</td>
<td>778b</td>
<td>779</td>
</tr>
<tr>
<td>0.45</td>
<td>500</td>
<td>612bc</td>
<td>815a</td>
<td>751</td>
</tr>
<tr>
<td>0.45</td>
<td>7,500</td>
<td>621ab</td>
<td>819a</td>
<td>764</td>
</tr>
<tr>
<td>0.45</td>
<td>15,000</td>
<td>636a</td>
<td>824a</td>
<td>774</td>
</tr>
<tr>
<td>0.45</td>
<td>15,000</td>
<td>633ab</td>
<td>837a</td>
<td>756</td>
</tr>
</tbody>
</table>

Pooled SEM 7.9 9.6 11.3

1 Data are means of 9 groups of 8 male Ross 708 chicks from 8 to 22 d.
2 FE = Feed efficiency.
3 Phytase was a fungal phytase.

Values in a column without common superscript letters are different (P ≤ 0.05)

In a second experiment, broiler chickens were fed high concentrations of phytase, both E. coli and fungal, from hatch to 43 days of age (Figure 1). In this experiment, positive control (PC) diets were formulated to contain copious amounts of nPP (0.50, 0.40 and 0.40% nPP for the starter, grower and finisher diets, respectively). The negative control (NC) diets were similar to the PC diets with the exception of the removal of 0.20% nPP from each phase. All diets that contained phytase were based on
the NC diet formulations and phytase concentrations (from both an E. coli and fungal source) ranged from commercial (500 FTU/kg) up to approximately 292 times commercial (145,965 FTU/kg). The removal of 0.20% nPP from the PC diets to generate the NC diets resulted in a reduction in broiler performance, validating the sensitivity of the experimental diets to phytase supplementation. Addition of commercial concentrations of phytase resulted in broiler performance significantly similar to that of the PC fed birds, but numerically higher. Supplementation of phytase at 12 times commercial (5,795 FTU/kg) or higher resulted in significant ($P \leq 0.05$) increases in body weight gain, regardless of source. In contrast to the previous experiment, feed conversion ratio (FCR) was significantly improved with the higher concentration feed of phytase in this experiment. This improvement in FCR was significant despite the larger body weight of the birds that is generally thought to worsen FCR.

A. Weight Gain (kg) of 42 Day Chickens Fed Doses of Phytase

<table>
<thead>
<tr>
<th>Dose of Phytase (commercial = 500 FTU/kg)</th>
<th>PC</th>
<th>NC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.250</td>
<td>2.500</td>
<td>2.750</td>
</tr>
<tr>
<td>3.000</td>
<td>3.250</td>
<td>3.500</td>
</tr>
</tbody>
</table>

Improvement over the PC: E. coli 4.3 – 6.6%
Fungal 3.4 – 6.6%

B. Mortality Corrected Feed Conversion Ratio (FCRc) (kg/kg) at 42 days

<table>
<thead>
<tr>
<th>Dose of Phytase (commercial = 500 FTU/kg)</th>
<th>PC</th>
<th>NC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.550</td>
<td>1.600</td>
<td>1.650</td>
</tr>
<tr>
<td>1.600</td>
<td>1.650</td>
<td>1.700</td>
</tr>
<tr>
<td>1.650</td>
<td>1.700</td>
<td>1.750</td>
</tr>
</tbody>
</table>

Improvement over the PC: E. coli 1.5 – 3.0%
Fungal 0.9 – 2.1%

C. Hot Carcass Weight (kg) at 43 days

<table>
<thead>
<tr>
<th>Dose of Phytase (commercial = 500 FTU/kg)</th>
<th>PC</th>
<th>NC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.500</td>
<td>1.750</td>
<td>2.000</td>
</tr>
<tr>
<td>2.000</td>
<td>2.250</td>
<td>2.500</td>
</tr>
<tr>
<td>2.500</td>
<td>2.750</td>
<td>3.000</td>
</tr>
</tbody>
</table>

Improvement over the PC: E. coli 3.0 – 7.8%
Fungal 3.3 – 8.2%

D. Cutup Breast Weight (kg) at 43 days

<table>
<thead>
<tr>
<th>Dose of Phytase (commercial = 500 FTU/kg)</th>
<th>PC</th>
<th>NC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.650</td>
<td>0.700</td>
<td>0.750</td>
</tr>
<tr>
<td>0.700</td>
<td>0.750</td>
<td>0.800</td>
</tr>
<tr>
<td>0.800</td>
<td>0.850</td>
<td>0.900</td>
</tr>
</tbody>
</table>

Improvement over the PC: E. coli 4.2 – 8.2%
Fungal 4.5 – 9.5%

Figure 1. Effect of phytase on performance and carcass evaluation in 42 to 43 d broiler chickens. A. Weight gain (kg) at 42 days. B. Mortality corrected feed conversion ratio (FCRc) (kg/kg) at 42 days. C. Hot carcass weight (kg) at 43 days. D. Cutup breast weight (kg) at 43 days.

Body composition measurements (hot carcass weight and cutup breast weight) were measured after an 8 h fast on day 43 of the experiment (Figure 1). Both hot carcass and cutup breast weight follow the same trend as body weight gain with the NC fed birds without phytase supplementation showing reduced production in comparison to the PC fed birds. Supplementation of commercial concentrations restored hot carcass and cutup breast weight to those of the PC and higher phytase concentrations (regardless of source) resulted in significant ($P \leq 0.05$) increases in comparison to the PC fed birds. The magnitude of the body composition response are similar or even greater than those for body weight gain suggesting that the increased body weight is at least proportional resulting not only in a larger bird, but also increased salable products.
Performance and Gastro-intestinal Response

In a second 8- to 22-day broiler chick experiment, E. coli phytase was supplemented to chicks fed 0.45% nPP diets (Table 2). In this experiment all concentrations of phytase (500, 7,500 and 15,000 FTU/kg) resulted in increased weight gain in comparison to a standard PC diet. Feed intake was numerically increased in two treatments and significantly increased in the third experiment in comparison to the PC fed birds, minimizing any difference in feed efficiency of the birds ($P > 0.05$; data not reported). In this experiment intestinal samples were collected and mucin production was estimated according to Matsuo et al. (1997). No differences were noted in estimated mucin production in the duodenum, but supplementation of phytase resulted in numerical reductions in estimated mucin production in the ileum, with 15,000 FTU/kg of supplemental phytase resulting in a significant reduction in mucin production in comparison to the PC fed broilers.

Table 2. Performance and estimates of mucin production of broiler chicks fed diets containing 0.45% nonphytate phosphorus (nPP) and supplemented with various concentrations of phytase from 8-22 days.

<table>
<thead>
<tr>
<th>nPP (%)</th>
<th>E. coli Phytase (FTU/kg)</th>
<th>Weight Gain (g)</th>
<th>Feed Intake (g)</th>
<th>Duodenum (µg/mg)</th>
<th>Ileum (µg/mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.45</td>
<td>0</td>
<td>564$^b$</td>
<td>783$^b$</td>
<td>11.0</td>
<td>17.8$^a$</td>
</tr>
<tr>
<td>0.45</td>
<td>500</td>
<td>663$^a$</td>
<td>848$^b$</td>
<td>12.6</td>
<td>14.8$^a$</td>
</tr>
<tr>
<td>0.45</td>
<td>7,500</td>
<td>727$^a$</td>
<td>951$^a$</td>
<td>10.1</td>
<td>14.6$^a$</td>
</tr>
<tr>
<td>0.45</td>
<td>15,000</td>
<td>666$^a$</td>
<td>864$^b$</td>
<td>9.3</td>
<td>8.3$^b$</td>
</tr>
</tbody>
</table>

Pooled SEM 30.9 28.9 1.46 1.99

$^1$ A one cm sample of intestinal tissue was used to determine alcain blue binding as an indicator of mucin production.

$^{a,b}$ Values in a column without common superscript letters are different ($P \leq 0.05$)

In another broiler chick experiment, chicks were fed diets containing 0.45% nPP (PC); 0.30% nPP (NC) or the same NC diet with 5,000 FTU/kg of E. coli phytase from hatch until 21 days (Table 3). Although there was a numeric increase in the weight gain (a 7.8% increase) of chicks fed the 5,000 FTU/kg of phytase and the PC birds, there was no significant difference. Feed intake was not different among the treatments and feed conversion ratio was returned to the PC value, but not improved with the supplementation of 5,000 FTU/kg of phytase to the NC diet. At the conclusion of the experiment, ileal samples were collected to determine selected nutrient digestibility values (chromic oxide marker was included in all experimental diets). Nutrient digestibility was not different between the PC and NC fed broilers when phytase was not supplemented with the exception of a slight, but significant, decrease in P digestibility in the NC fed broilers. Supplementation of the NC diet with 5,000 FTU/kg of phytase resulted in significantly higher crude protein, P and Ca digestibility as well as an increase in metabolizable energy content of the diet.
Table 3. Performance and nutrient digestibility of broiler chicks fed diets containing 0.45 or 0.30% nonphytate phosphorus (nPP) and supplemented with 5,000 FTU/kg of phytase from 0-21 days.¹

<table>
<thead>
<tr>
<th>nPP</th>
<th>E. coli Phytase</th>
<th>Weight Gain</th>
<th>Feed Intake</th>
<th>FCR²</th>
<th>Crude Protein</th>
<th>Ca</th>
<th>P</th>
<th>ME³</th>
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</thead>
<tbody>
<tr>
<td>0.45</td>
<td>0</td>
<td>668&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>7.11</td>
<td>1.36&lt;sup&gt;b&lt;/sup&gt;</td>
<td>85.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>66.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>67.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3260&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.30</td>
<td>0</td>
<td>620&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.10</td>
<td>1.49&lt;sup&gt;a&lt;/sup&gt;</td>
<td>84.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>68.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>65.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3270&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>0.30</td>
<td>5,000</td>
<td>720&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.41</td>
<td>1.37&lt;sup&gt;b&lt;/sup&gt;</td>
<td>89.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>73.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>80.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3450&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

¹ Data are means of 8 groups of 6 male chicks from 0- to 21-d.
² FCR = Feed conversion ratio (kg/kg).
³ Metabolizable energy (kcal/kg).

In the same experiment, mucosal scrapings were collected from both the duodenum and the ileum at the same time as the ileal sample collections. These mucosal scrapings were immediately pressed flat and frozen in liquid nitrogen for storage before analysis for mucin mRNA abundance (Figure 2). Although alcian blue analysis indicated a general decrease in mucin in the ileum in high phytase treated diets, the relative mRNA abundance data is more complicated. The individual abundances of two mucin mRNA’s were quantified. Mucin 2 is an oligomeric gel forming mucin expressed mainly in the gastro-intestinal tract (Allen <em>et al.</em>, 1998). Under high phytase feeding conditions, mucin 2 showed no response to high concentration phytase supplementation in either the duodenum or the ileum. In contrast, high concentration phytase supplementation tended to decrease mucin 5AC abundance when fed to broiler chicks. Mucin 5AC is also an oligomeric gel forming mucin, but it is expressed in the respiratory epithelial cells in addition to the gastro-intestinal epithelial (Guyonnet Duperat <em>et al.</em>, 1995). Although these mucins have similar functions in the gastro-intestinal environment, and are mapped to 11p15.3-15.5, they are products of different gene loci (Shao <em>et al.</em>, 2003). As distinct promoters do exist, differential expression of Mucin 2 and Mucin 5AC under various dietary conditions (high or low phytase) is possible. These data indicate that the gastro-intestinal response of broiler chickens to high phytase feeding is complex as overall mucin might increase, but specific mucin mRNA abundance analysis results in a variable response.
Figure 2. Effect of phytase on intestinal (duodenum and ileum) mucin mRNA from 21-d broiler chicks.

**Summary**

In total, four experiments have been presented all showing consistent increases in bird performance with high concentration phytase supplementation. In all experiments, body weight gain is substantially increased and feed conversion or efficiency is either not affected or improved, despite the increased body weight. In the 16 comparisons made between the PC fed broilers and the broilers fed high concentrations of phytase (5,000 FTU/kg and above), all resulted in increased body weight gain ranging from 3.4 to 28.9%. Multiple sources of phytase were investigated in these experiments, including both E. coli and fungal sources. Little difference was noted between phytase source, suggesting that this effect is common to all sources of phytase and not intrinsic to a specific molecule.

Two methods were employed to demonstrate that the increased body weight was not an effect of increased phosphorus availability, including supplementation of phytase on top of a diet without any phosphorus removal and over fortification of the PC diet with available phosphorus and subsequent removal of P from the NC diet. Results from both of these types of experiments indicate that the increased growth response is not due to increased available phosphorus, but some other mechanism. As this effect is common across multiple phytase enzymes, it might suggest that the removal of phytate (a known anti-nutrient) is contributing to this increased body weight, although the proper controls are not presented in this paper to fully justify that conclusion.

Body composition data were presented that indicate the growth response to feeding of high concentrations of phytase is a general and proportional increase resulting in not only heavier birds, but increased salable product and breast weight. Nutrient digestibility of diets supplemented with high concentrations of phytase was also measured and resulted in significant increases over both the PC and NC non-supplemented diets. The increase in metabolizable energy due to supplementation of broiler...
rations with high concentrations of phytase was significant and large, resulting in a nearly 200 kcal/kg increase over the non-supplemented diets.

One proposed mechanism for the increased weight gain and performance of broilers supplemented with higher concentrations of phytase is a reduction in the negative interactions of phytate with the gastro-intestinal tract of the growing chickens. There are some preliminary data presented that might suggest that the high concentration feeding of phytase resulted in a decrease in mucin production in the intestine, although the response is complex as mRNA abundance of individual mucins are variable under the same dietary conditions. Further data are needed to fully validate the hypothesis that phytate is having a negative interaction on the gastro-intestinal tract and that the supplementation of commercial-type diets will hydrolyze the phytate resulting in increased gastro-intestinal soundness (health) resulting in more resources (nutrients) available for growth and production.

Conclusions

- Supplementation of commercial type diets with high concentrations (>5,000 FTU/kg) of phytase resulted in increased body weight gain.
- Phytase source (within and across both E. coli and fungal sources) did not appear to have an influence on the increased weight gain observed with a high concentration feeding of phytase.
- Feed conversion of these broilers was either maintained or improved despite the larger growth response.
- The increased body weight gain was proportional as hot carcass weight and cut-up breast weight responded in a similar manner to body weight gain, resulting in increased salable product and increased breast meat.
- Increased gastro-intestinal soundness (health) was proposed as the mechanism for this increased growth performance in response to higher concentrations of phytase, but data are preliminary and need further validation.

References

BROILER LIGHTING PROGRAMS, AN UNDERESTIMATED MANAGEMENT TECHNIQUE

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Summary

Manipulation of light is common in broiler production to affect bird behaviour, performance and welfare. This report discusses the impact of daylength on broiler productivity and welfare, and further examines factors that affect the use of broiler lighting programs. Research completed at the University of Saskatchewan has demonstrated that decreasing daylength reduces growth early in a broiler’s life but can produce similar or superior growth in older birds. Shorter daylength also improves feed efficiency and consistently reduces mortality. However, shorter daylengths have an important negative effect on carcass and breast meat yield that counterbalances positive effects on other traits. Therefore, selecting a lighting program from an economic standpoint must balance these effects in relationship to other economic factors such as feed prices and the nature of a broiler market. Modeling lighting programs in this way has the potential to improve profit margins in broiler production. Daylength also an important impact on broiler welfare and lighting programs should be acceptable from a welfare standpoint before economic evaluation is completed. Research has consistently shown that welfare is lower for birds given near-continuous or continuous light. Therefore, 23 or 24 h of daylength are not recommended for commercial practice. Based on welfare assessment over a range of daylengths, a maximum of 20 h daylength should be used and welfare continues to improve to daylengths of 16 to 18 h. However, the data indicate that there is little advantage from a welfare perspective for daylength much shorter than 16 to 18 h. In conclusion, the impact of daylength on broiler performance and welfare is often overlooked and underestimated. However, this relatively inexpensive and easily applied management technique should be regularly assessed to maintain broiler welfare and improve production economics.

Introduction

Light is an important management technique in broiler production and is composed of at least three aspects, light wavelength, light intensity, and photoperiod length (daylength) and distribution. The latter aspects can be considered independently but are known to have interactive effects. By far the most research on broiler lighting has been devoted to the impact of photoperiod length and distribution and it is the focus of this paper. In particular, this report will focus on extensive research collaboration between Aviagen Inc. and the University of Saskatchewan, which studied graded levels of daylength to permit prediction of the response by commercial broilers. The effect of daylength focused on production, health, meat yield, and welfare traits. This report will also discuss age at lighting program initiation, abrupt vs gradual changes in lighting programs, and intact vs. split dark periods in a lighting program.
An important rationale for research on photoperiod length and distribution is the fact that various jurisdictions in the world are either legislating requirements or setting codes of practice for broiler light management. It is therefore important to provide scientific data to provide a basis for these decisions.

**Effect of Photoperiod Length on Broiler Performance and Welfare**

A series of near-identical trials were conducted to study the effect of daylength in broilers. This report will focus on the summary of four experiments using over 16,000 broilers, which provided estimated housing densities of 24 to 30 kg/m², and where bird market age varied from 31 to 49 d. A total of just over 16,000 broilers were used in this work. Lighting treatments were 14, 17, 20 and 23 h of light per d initiated at 7 d of age with light intensity set at 8 lux. Chicks were exposed to 23 h daylength and 20 lux light intensity from placement to 7 d. Lighting was provided with incandescent bulbs. Conditions in the rooms were similar to commercial standards, with the exception that birds were housed in smaller pens (53 males or 63 females per pen). Twelve pens were located in each of 8 environmentally independent rooms with a minimum of two rooms (replications) per lighting treatment per trial. Feed was given ad libitum, with 0.5 kg starter (crumble) and 2 kg of grower (pellet) per bird placed, with the finisher 1 (pellet) fed until the end of the trial. For birds maintained to 49 d, 1.6 kg of finisher 1 was fed per bird placed, and finisher 2 (pellet) was fed until the end of the trial. All diets were based on corn and soybean meal and utilized Aviagen Inc. amino acid specifications. Water was provided to the birds ad libitum with Lubing nipple drinker systems. Two strains were tested (Ross x Ross 308 and Ross x Ross 708) in each of these trials, and sexes were housed separately. No interactions were found between genotype and lighting program, and only minor interactions were found between sex and lighting program, and therefore only main effects of daylength will be described.

**Production Results**

Daylength has an important affect on growth of broilers that is age dependent. In younger birds (31 d), growth is affected in a quadratic fashion with increases in gain from 14 h to a maximum at 20 h of daylength, followed by a decline to 23 h (Table 1). The weight of the 14 h birds was approximately 4% lower than the 23 h treatment, while the 20 h birds were 2% heavier than those given 23 h. As birds age, birds on short daylengths are able to compensate for slower earlier growth. At 38 days of age, 14 h broilers only weighed 2% less than the 23 h treatment and by 48 days the 14 h birds were equal to those given near-continuous light. Therefore, despite slower early growth, broilers given shorter daylength are able to compensate by later processing ages. An important finding is that broilers given continuous or near continuous (23 h) daylength do not grow the fastest even with virtually constant access to feed and water.

Feed intake also had a quadratic relationship with daylength that was similar to that seen for body weight (Table 1). Shorter daylength reduced feed intake, particularly early in life, but these birds appeared able to consume more feed at older ages suggesting the development of increased digestive tract capacity. The 20 h treatment resulted in the highest feed intake regardless of age and birds in the 23 h treatment did not have the highest feed intake as one might expect.

From 0 to 31 and 0 to 38 d, feed to gain ratio increased in a quadratic fashion with increasing daylength while from 0 to 48 d, the increase in feed to gain ratio with increasing daylength was linear. These data confirm the beneficial effect of darkness on feed efficiency that has been previously reported. It can be speculated that this effect is due to a darkness induced reduction in metabolism and therefore bird maintenance requirement (Apeldoorn *et al.*, 1999). Interestingly, behavioral data described later in this paper show that birds on shorter daylengths are more active when average over the entire day than birds given longer daylengths even though they are inactive at night. Increased activity suggests increased energy expenditure which would counterbalance the reduced metabolism that occurs at night. Another
explanation for improved feed efficiency may be an improvement in nutrient retention when birds are given dark exposure (Buyse et al., 1996) although this requires further study. Supporting an effect of darkness on feed utilization is research that showed an improved in nutrient retention in birds fed melatonin (Osei et al., 1989), a hormone released during periods of darkness. Our own research has also shown that feeding melatonin improved feed to gain ratio in young broilers (Clark and Classen, 1995). The above research suggests a specific physiological effect on feed efficiency. Regardless of the mechanism, shorter daylengths do improve feed efficiency, which is an even more important characteristic as feed prices increase.

**Table 1. Effect of daylength on broiler performance**

<table>
<thead>
<tr>
<th>Body weight (kg)</th>
<th>14</th>
<th>17</th>
<th>20</th>
<th>23</th>
</tr>
</thead>
<tbody>
<tr>
<td>31 d</td>
<td>1.644</td>
<td>1.677</td>
<td>1.738</td>
<td>1.703</td>
</tr>
<tr>
<td>38 d</td>
<td>2.243</td>
<td>2.309</td>
<td>2.337</td>
<td>2.291</td>
</tr>
<tr>
<td>49 d</td>
<td>3.197</td>
<td>3.268</td>
<td>3.272</td>
<td>3.170</td>
</tr>
<tr>
<td>Feed intake (kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 – 31 d</td>
<td>2.43</td>
<td>2.57</td>
<td>2.68</td>
<td>2.61</td>
</tr>
<tr>
<td>0 – 38 d</td>
<td>3.58</td>
<td>3.75</td>
<td>3.87</td>
<td>3.78</td>
</tr>
<tr>
<td>0 – 48 d</td>
<td>5.69</td>
<td>5.94</td>
<td>6.15</td>
<td>5.89</td>
</tr>
<tr>
<td>Feed to gain ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 – 31 d</td>
<td>1.507</td>
<td>1.535</td>
<td>1.557</td>
<td>1.553</td>
</tr>
<tr>
<td>0 – 38 d</td>
<td>1.618</td>
<td>1.644</td>
<td>1.672</td>
<td>1.666</td>
</tr>
<tr>
<td>0 – 48 d</td>
<td>1.787</td>
<td>1.815</td>
<td>1.844</td>
<td>1.833</td>
</tr>
<tr>
<td>Mortality (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 – 31 d</td>
<td>2.29</td>
<td>2.27</td>
<td>3.10</td>
<td>3.58</td>
</tr>
<tr>
<td>7 – 38 d</td>
<td>2.87</td>
<td>2.79</td>
<td>4.23</td>
<td>4.86</td>
</tr>
<tr>
<td>7 – 48 d</td>
<td>3.61</td>
<td>4.07</td>
<td>7.15</td>
<td>6.47</td>
</tr>
</tbody>
</table>

1 Above effects of daylength are either quadratic or linear in nature (P<0.05).

Historically, a major reason for using lighting programs was to reduce the incidence of growth associated disease such as sudden death syndrome, ascites and leg weakness. In particular, shorter daylength was used to slow early growth and thereby reduce the incidence of these disorders. The results of our current research confirm the role of darkness in improving broiler health. A clear demonstration of this effect is shown by the reduction in mortality associated with shorter daylength (Table 1). Although the major impact on health continues to relate to growth associated disease, there is evidence of an impact.
of daylength on infectious disease. It is likely that darkness and associated physiological changes are one of a number of factors that can affect immune function.

Carcass and Meat Yield Results

An important aspect of broiler production is the yield of carcass and meat with emphasis on breast portions. It has been recognized for some time that breast meat yield was negatively affected by decreasing daylength (Renden et al., 1991) but the results were not consistent (Charles et al., 1992), and a full understanding of the effect of graded daylengths was lacking. The systematic approach to lighting research in our present studies provided a more comprehensive understanding of this effect (Table 2). Longer daylengths (20 and 23 h) increased carcass yield. Breast meat was also impacted as shown by a linear increase in yield with increasing daylength. Other aspects of carcass composition decreased in proportion to the increased breast meat yield. These important economic criteria are in conflict with negative effects of long daylengths on other production traits and welfare assessment, confounding the selection of a specific optimum daylength.

Table 2. Effect of daylength on broiler carcass and meat yield (% of live weight)

<table>
<thead>
<tr>
<th>Daylength (h)</th>
<th>14</th>
<th>17</th>
<th>20</th>
<th>23</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carcass</td>
<td>67.25</td>
<td>68.04</td>
<td>68.63</td>
<td>68.63</td>
</tr>
<tr>
<td>Pectoralis major</td>
<td>14.92</td>
<td>15.51</td>
<td>15.93</td>
<td>16.19</td>
</tr>
<tr>
<td>Pectoralis minor</td>
<td>3.47</td>
<td>3.58</td>
<td>3.63</td>
<td>3.70</td>
</tr>
<tr>
<td>Total Breast</td>
<td>18.39</td>
<td>19.09</td>
<td>19.56</td>
<td>19.89</td>
</tr>
</tbody>
</table>

1 Above effects of daylength are either quadratic or linear in nature (P<0.05).

Animal Welfare Results

Increased emphasis by society on animal welfare indicates that the broiler industry must not only understand the production consequences of management practices but also their welfare implications. Considerable effort was placed on animal welfare in our research with a multi-faceted approach to measuring welfare associated with daylength.

Growth rate – Performance is often overemphasized by some as the only indicator of good welfare; i.e. if broilers are growing quickly they must have good welfare. In contrast, others disregard production characteristics as being important. Our belief is that production alone can’t establish welfare, but it is a trait that can contribute to our understanding of bird welfare. In terms of the response of growth to daylength outlined above, the lower growth rate associated with shorter daylength can readily be explained by the reduction in time available for feeding in the young bird. Hence it would not necessarily be considered a welfare concern. On the other hand, a decrease in growth for birds given 23 h of light is not easy to explain. Birds have near-continuous access to feed and water and so growth should be at its maximum. The fact that these birds do not grow as fast as other treatments such as 20 h daylength raises a flag that welfare may be negatively affected. A reason for this effect has not been scientifically established but sleep deprivation has been suggested for birds given very long daylength lighting programs.
Flock mortality – It has already been noted that mortality increases with increasing daylength and this is clearly an indicator of welfare.

Leg weakness – Leg weakness is among the most often targeted welfare aspects of the broiler industry. In the opinion of the authors, this aspect of broiler welfare has improved dramatically over the last 10 to 15 years. However, management can still affect this trait and part of the effect of daylength on leg weakness was confirmed by the level of culling which shows up in the mortality data noted above and increased with increasing daylength. The impact of daylength on leg weakness can also be determined by examining gait scores. Of particular interest are those scores which are generally considered to cause pain. In the procedure of Garner et al. (2002), scores above 2 are considered to cause pain. Our research shows that the number of birds with gait scores greater than 2 increases with daylength. Therefore, daylength does affect leg weakness and is an important management tool to improve bird welfare.

Behaviour – Behavioral observations are an important method of assessing how birds cope with their environment. In our research, infrared cameras and light sources allowed us to examine bird behaviour 24 h per d regardless of lighting conditions. It is beyond the scope of this paper to outline the details of this research but several conclusions can be drawn from data summarized over an entire d. As daylength increased, resting increased, and walking, running, preening, wing and leg stretching, feeding, foraging and dustbathing decreased. The overall summary is that mobility is decreased, and that comfort behaviours decrease and nearly disappear with increasing daylength with the effect most pronounced for the 23 h treatment. Mobility and comfort behaviours are generally considered as positive indicators of welfare and therefore the conclusion is that near-continuous light is a less desirable option from a welfare standpoint.

Eye morphology – Eyes grow in a diurnal pattern with growth occurring during the light period and stopping during the dark period. Birds given 23 h of daylength had significantly larger eyes than all other treatments. At this point, we have no evidence that this necessarily affects bird welfare but it is of concern since abnormal increased eye growth in humans can result in pressure on the optic nerve and can also lead to glaucoma.

Melatonin – As already indicated, the hormone melatonin is produced during periods of darkness in chickens. Analysis of blood samples obtained at regular intervals during a 24 h period of time from birds in all lighting treatments showed that the regular diurnal pattern of melatonin secretion was lacking for the 23 h birds. Since melatonin has important positive physiological effects on animals, the absence of such a pattern would again be an indicator of poorer welfare for this treatment.

Effect of Age of Lighting Program Initiation on Broiler Performance

The time to at which lighting programs are initiated should consider a number of factors. Brooding management is among the more important aspects of broiler management and the need to get chicks off to a good start is paramount. Therefore, most training in poultry management indicates that chicks should have long daylengths (23 or 24h) and that the light intensity should be high (>20 lux) so that they can adapt to their environment and learn to eat and drink. It is also common practice to use 7 d weights as an indicator of brooding management and hence there is a reluctance to introduce an extensive dark period before that age. But how long does light have to have a long duration and be bright? Most likely broilers that have not found food and water by 2 d post-placement are likely not going to survive.

It is generally accepted that reduced growth rate benefits bird health and further that earlier induction of reduced growth has more benefit than later in a broiler’s life (Robinson et al., 1992). Therefore, it can be hypothesized that earlier implementation of lighting programs that initially reduce growth rate will result in reduced mortality and improved bird health.
Also of interest is whether age of lighting program initiation affects carcass or breast meat yield. Research has shown that muscle development occurs both during embryogenesis and also postnatally with satellite cell differentiation providing nuclei required for protein synthesis and muscle hypertrophy (Velleman, 2007). The latter satellite cell differentiation occurs shortly after hatch and factors that affect that differentiation during that time can affect breast meat yield (Halevy et al., 2000; Mozdziak et al., 2002; Sklan et al., 2003). Very early lighting program initiation may therefore decrease breast muscle yield.

Two experiments were used to study the impact of initiating a lighting program of 18 h daylength at 1, 4, 7 and 10 d of age. Prior to initiation chicks were given 23 h daylength. Each lighting treatment was replicated twice in each experiment thereby providing a total of 4 replications.

Over the entire 39 d growth period of this research, no effect of age of light change was seen on final body weight or overall feed to gain ratio. Our hypothesis that earlier initiation of a dark period would reduce mortality was shown to be the case with the lowest mortality for birds change to 18 h light at 1 d of age (Figure 1). In addition, breast meat yield was reduced for this same group as predicted (Figure 2), likely as a result of muscle satellite cell differentiation. Although no long term effect of performance was found, growth rate decreased immediately after a change from 23 to 18 h of light regardless of age of change. In contrast to the beneficial effect of darkness on feed efficiency, it was found to be poorer immediately after the change to the shorter daylength. This effect was short in duration and its significance is unknown. However, it may indicate a disruption of the gastrointestinal tract (gut) and/or gut microbiota that in situations of disease challenge could cause clinical or sub-clinical effects.

![Figure 1. Effect of age of changing from 23 to 18 h of daylength (1, 4, 7 or 10 d) on % mortality.](image1)

![Figure 2. Effect of age of changing from 23 to 18 h of daylength (1, 4, 7 or 10 d) on % breast meat of live weight.](image2)

**Abrupt vs Gradual Changes in Lighting Programs**

In many situations changes in lighting programs are abrupt with both daylength and intensity reduced at the same time. Birds given a brooding daylength of 23 to 24 h and light intensity of 20 to 40 lux are accustomed to eating at regular intervals and will need time to adapt to a different eating pattern associated with a shorter daylength. This causes a reduction in feed intake as described above and possibly a negative effect on feed efficiency. In a recent trial, abrupt vs gradual changes in lighting programs were compared to study the effect on feed intake. A change from 23 h daylength and 20 lux intensity to 14 h daylength and 1 lux intensity caused a 31.3 and 24.8% reduction in feed intake the day after the change in males and females, respectively. Further, it took 3 to 4 d for feed intake to return to expected levels. In contrast, a similar change in daylength and intensity done gradually over 8 days did not cause a dramatic reduction in feed intake. The reduction in feed intake undoubtedly causes the reduction in growth rate noted above and may also produce a disruptive gut environment that reduces feed
efficiency. This research supports the concept that gradual changes in light accomplish the beneficial effects with reduced risk of a negative effect on gastrointestinal health.

Another way to reduce the reaction to changes in lighting programs is to use slow increases and decreases in light intensity that mimic dawn and dusk. Modern controllers make this easy to do and have beneficial effects on bird behaviour with reduced activity when lights come on and less negative chick reaction when lights go out.

**One Continuous Dark Period or Splitting the Dark Period into Shorter Segments**

Three experiments were completed to study the impact of splitting dark periods into two or more smaller segments. The experiments used 12 (12L:12D; 2(6L:6D); 12(1L:1D)), 9 (13L:9D; 13L:4.5D:2L:4.5D; 11L:3D:2L:3D:2L:3D) and 6 (18L:6D; 16L:3D:2L:3D; 14L:2D:2L:2D:2L:2D) h of darkness. In comparison to the longer period of darkness, performance of split dark periods was intermediate in performance (increased growth, decreased feed to gain ratio, increased mortality) and welfare in comparison to one dark period and near continuous light. The more times the dark period was split the closer it came to near continuous light in performance. In all trials, splitting the dark period increased mortality demonstrating that continuous dark periods are better for bird health.

**Interaction of Lighting Programs with Nutrition and Other Management Programs**

Because of the impact of daylength on feed intake, factors that increase the time required to maximize nutrient intake may have an important impact on bird performance. In a recent study, Brickett et al. (2007) studied the impact of daylength (12 vs 20 h); nutrient density (starter, grower, finisher AME (kcal/kg) for low (2800, 2850, 2900), medium (2950, 3000, 3050) and high (3100, 3150, 3200) treatments) and feed form (mash, pellet). Figure 3 demonstrates the impact of these treatments on 35 d body weight. The more restrictive 12 h daylength in combination with feeding a low nutrient density mash decreased growth by nearly 22% in comparison to birds fed a pelleted high nutrient density diet and given 20h daylength. The three treatments were additive in terms of their impact on feed intake, and other performance and health indices. Therefore factors that can affect feed intake must be considered when selecting an appropriate lighting program. Floor and feeder space, and ambient temperature are other examples of factors that need to be considered when selecting a lighting program.

**Conclusions**

Our lighting research has attempted to examine the impact of daylength on broilers in a comprehensive fashion by examining a wide range of production and welfare traits. By using graded levels of daylength, our research was also designed to allow the prediction of an “optimum” lighting program based on these traits, and the development of a model that will facilitate its selection for specific types of broiler production.

Our results have shown that many aspects of broiler production (feed efficiency, health, welfare) benefit from lighting programs that provide broilers with a period of darkness. In contrast, carcass and
meat yield are compromised by use of darkness exposure and therefore counterbalance these positive effects. It is likely that the broiler industry will need to establish a minimum amount of darkness that is required for bird welfare, and then allow economic factors to fine tune the selection of lighting programs for specific production situations. Factors such as feed prices and broiler market (whole vs further processing) will affect the economics of lighting programs and need to be considered when selecting the “optimum program”. Selection of a specific acceptable daylength on a welfare basis is not easy because of gradual changes in most welfare indices, but it is possible to eliminate lighting programs that obviously reduce welfare. Our research uniformly indicates that continuous or near-continuous light is not acceptable from a welfare standpoint and therefore a minimum dark requirement of at least four h is a good starting point in the welfare debate.

References

NONLINEAR RESPONSES OF BROILERS TO DIETARY ENERGY AND PROTEIN

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Summary

Many factors interact and many objectives compete in the optimal production of broilers. This paper summarizes the nonlinear effects of dietary balanced protein and dietary energy on feed intake, growth curves, and yield dynamics for one strain of broilers. Sex, prestarter nutrition, and subsequent dietary energy and protein levels had significant nonlinear effects on broiler feed intake, growth rates and yield dynamics. These effects have been quantified using previously available and novel nonlinear models. Feed is the largest single cost in broiler production, but predicting intake has proved challenging for the animal science community. Therefore modeling growth profiles has received much attention in recent years. In this paper, a nonlinear mixed model that describes scenario-specific growth curves, crucial for the timing of processing, is presented. Yield dynamics are explored under various nutritional scenarios aiming at the prediction of carcass value. This paper provides an integrated generalized nonlinear model that can be applied to a wide range of supply chain optimization problems. Data specific to strain, production conditions, or particular environments, will improve the value of the model in commercial applications.

Introduction

Broiler growth and development are dynamic processes. During the first week of life, development of the gastrointestinal (GI) tract is a high priority. Around 25% of the total BW gain during the first week is accounted for by the GI tract, corresponding to a 4-fold increase in GI weight during that time. Conversely, even though the breast increases 16-fold in weight during the first 7 d, it accounts for only 10% of the total BW gain of the first week. As the broiler grows to market weight, these priorities reverse dramatically (Figure 1).

As BW increases, so does the absolute value of the carcass. However, since not every portion of the carcass has the same value, and because carcass proportions change both with both age and nutrient intake, the value of the carcass changes nonlinearly as a bird develops. Nevertheless, the portion that depends on nutrient intake can be manipulated to a significant degree through diet formulation.

Different tissues have different nutrient and energy requirements, both for deposition and for maintenance. Retained energy differs for muscle tissue (4 kcal/g) and adipose tissue (9 kcal/g). The maintenance requirements of tissues relate to a large degree on the cost of protein turnover and ion transport. Gill et al. (1989) reported that in growing lambs the GI tract and liver accounted for almost two-thirds of the ion transport energy expenditure. For protein turnover, the relative contributions of various organ systems to the total energy expenditure were approximately 25% each for the GI tract, skin, muscle, and liver.
and muscle, and only 0.5% for adipose tissue. Thus, the energetic cost of gain depends on the composition of gain, and the energy cost of maintenance depends on the current body composition.

In order to optimize the process of commercial production, accurate models of feed intake, growth, and carcass yield dynamics are of crucial economic importance. To be of value to the supply chain, a model must take into consideration the natural physiological processes as well as the nutrition-induced dynamics that affect growth and development. Given that the value of a carcass can be manipulated through diet formulation, the optimization of a particular end product may be associated with specific nutrient requirements that require a different dietary formulation. The cost implications of situations that demand variable nutritional inputs are probably the most frequent challenge of optimization processes. The objective of this paper is to provide a decision making tool that takes into account the impact of diet on carcass value and enables supply chain optimization through improved nutrition-related decisions.

**Experimental Design**

A study was conducted to investigate the simultaneous interactions of dietary energy and dietary balanced protein (DBP) on performance of broilers to 56 d of age. At hatch, 3,424 Cobb x Avian 48 chicks were randomly assigned to one treatment within a 2 x 2 x 3 x 5 factorial arrangement of treatments. The experimental design consisted of 2 sexes; 2 levels of prestarter; 3 dietary ME levels; and 5 DBP levels. The prestarter was fed from 0 to 11 days of age, and the different levels of ME and DBP from 11 to 56 days. The dietary ME levels were 94, 97, and 100% of the breeder’s dietary recommendations for maximum growth rate and feed efficiency (E94, E97, and E100, respectively; Cobb Broiler Nutrition Supplement, 2004, Cobb-Vantress, Inc., Siloam Springs, AR, 72761). Target ME levels for the E94, E97 and E100 treatments, respectively, were 2,960, 3,055, and 3,150 kcal/kg in the starter phase; 3,010, 3,105, and 3,200 kcal/kg in the grower phase; and 3,055, 3,155, and 3,250 kcal/kg in the finisher phase.

The DBP levels were 85, 92.5, 100, 107.5, and 115% of the same recommendations (P85, P92.5, P100, P107.5, and P115, respectively), with Met, Met + Cys, Trp, Thr, and Arg on a total amino acid basis in constant proportions to Lys. Target %CP (%Lys) levels for the P85, P92.5, P100, P107.5, and P115 treatments, respectively, were 17.9 (1.02), 19.4 (1.11), 21.0 (1.20), 22.6 (1.29), and 24.2 (1.38) in the starter phase; 16.2 (0.94), 17.6 (1.02), 19.0 (1.10), 20.4 (1.18), and 21.9 (1.27) in the grower phase; and 14.9 (0.85), 16.2 (0.93), 17.5 (1.00), 18.8 (1.08), and 20.1 (1.15) in the finisher phase. The prestarter nutrient densities were based on breeder recommendations for maximizing growth rate and feed efficiency (HighPS), or reduced feed cost (LowPS). Sixteen pens (n=4 per treatment) were used for the prestarter phase. At 11 d of age, birds were redistributed to 60 pens (n=2 per treatment). Since after 11

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**Figure 1. Development of the broiler carcass is dynamic.** Early in life, development of supply and structural components is a priority. By 3 wk of age, priority shifts to muscle growth (meat yield). Source: Zuidhof, unpublished data.
days of age the birds on the prestarter treatments were assigned to the different ME and DBP treatments, it was possible to estimate the effect of prestarter on overall growth, but not on specific feed efficiency after 11 days of age.

Nonlinear models were developed to describe BW, feed intake, and carcass yield dynamics. A total of 1,200 broilers were individually weighed weekly, and at redistribution. These longitudinal BW data were subjected to nonlinear mixed Gompertz model analysis to estimate growth curves for each treatment (Wang and Zuidhof, 2005). The model accounted for individual variation in growth rates, and provided treatment-specific predictions of growth. A total of 1,920 broilers were dissected twice weekly from 21 to 56 d of age to evaluate the effects of sex and diet on the allometry (yield dynamics) of breast meat, legs, wings, and abdominal fatpad (Huxley, 1932). Paired F-tests were used (Motulsky and Ransnas, 1987) to test for significant differences between treatment-specific growth and yield curves. A nonlinear model based on a Cobb-Douglas form (Griffin et al. 1987) was developed using a stepwise procedure to estimate feed intake as a function of BW, ME, Lys, gain, and sex.

Results and Discussion

Feed Intake

The final form of the feed intake model incorporated significant components of BW, nutrient composition of the feed, sex, and BW gain. The feed intake model, with the final estimated coefficients was:

\[ \text{ME intake} = 0.14BW^{0.456} \left(\frac{\text{ME/Lys}}{\text{Lys}}\right)^{0.227}(1-0.013 \times \text{Sex}) + 0.67\text{ADG}^{1.44} (1-0.17 \times \text{Sex}) \]

where BW was average body weight (kg) of the broilers during the time period during which feed intake was measured, ME/Lys was the ratio of metabolizable energy content of the feed to the lysine content of the feed provided in the same period (kcal/g), sex was a dummy variable for sex of the birds (0 = female;
1 = male; 0.5 = mixed sex), and ADG was the average daily BW gain for the period. The model predicted ME intakes with reasonable accuracy. Figure 2 illustrates sex-related differences in feed intake. At higher BW, females grew at a slower rate, and thus consumed less ME per unit of BW than males. The model predicted lower intake with higher dietary ME levels, which was confirmed by analysis of variance (data not shown). Similarly, the analysis of variance indicated that ME intake was slightly higher at low BW, which the current feed intake model predicted. Analysis of variance indicated that feed intake was maximized at recommended (P100) DBP levels. The main difference was increased feed intake in P100 compared to P85 from 28 to 42 d; this effect was predicted by the current nonlinear model. These differences in feed intake are for supply chain optimization, as feed is the single largest contributor to the cost of raising broilers.

The coefficients of the ME intake model reflect underlying biological mechanisms associated with feed intake. The maintenance component of the model (intake as a function of BW) infers that the maintenance component of males was lower (1.3%) than that of females. This is somewhat surprising since males have a greater proportion of lean tissue, and thus would be expected to have lower maintenance requirements than females. Shalev and Pasternak (1998) reported a 5 to 9% higher theoretical maintenance requirements in male broilers compared to females. In contrast, Samadi and Liebert (2006) found 1.5 to 11% higher nitrogen maintenance requirements in female broiler chickens than in males. The latter finding is consistent with the inference of the current model, though it is worth noting that the 1.3% difference in maintenance requirements of males predicted by the current model is significant but relatively small.

The exponential coefficient (1.44) on average daily gain indicates that the energy cost of growth increased with increasing growth rate. This was likely due to the differences in fat deposition as broilers mature. The energy cost estimate for average daily gain was 17% lower for males than for females. This was reflected the fact that females deposited more fat than males. Comparison of a linear model analysis using the current data set and carcass composition data from the same trial inferred that the estimated energy requirement was 1.52 kcal/g for breast muscle, compared to 5.22 kcal/g for fatpad.

**Growth**

The Gompertz growth model and the coefficients estimated for all of the main treatment effects are presented in Table 1. These can be used to predict BW at any age for each treatment. Statistical comparison of Gompertz growth curves inferred that male broilers grew faster than female broilers (P<0.0001).

In males only, each decreasing dietary ME treatment resulted in an upward shift of the BW curve (P<0.05). The shape of the BW curves indicates that the differences in BW were realized after 42 d of age. There were no ME effects on female BW curves. The only significant BW curve difference due to the main effect of dietary DBP was an upward shift of the P85 treatment BW curve relative to the P115 treatment (P=0.02). Predicted BW of the P85 broilers was higher than the P115 broilers from 42 to 56 d of age.

![Figure 3](image.jpg) Higher nutrient density during the prestarter phase resulted in a persistent increase in BW.
The statistical curve comparisons demonstrated with a high level of confidence (P=0.0002) that the BW curve of broilers fed HighPS were shifted significantly higher compared to the LowPS treatment (Figure 3). The statistical analysis (confirmed with ANOVA) clearly demonstrated clearly that higher nutrient density during the first 11 d resulted in persistently higher broiler BW.

**Table 1. Coefficients for a nonlinear mixed Gompertz model\(^1\) describing the growth of male and female broilers provided diets with varied ME and dietary balanced protein (DBP) levels: main effects.**

<table>
<thead>
<tr>
<th>Effect</th>
<th>Treatment</th>
<th>(W_m)</th>
<th>B</th>
<th>(\sigma^2_u)</th>
<th>(\varepsilon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS (^2)</td>
<td>PSHigh</td>
<td>5.964</td>
<td>0.0435</td>
<td>0.512</td>
<td>0.073</td>
</tr>
<tr>
<td></td>
<td>PSLow</td>
<td>6.165</td>
<td>0.0425</td>
<td>0.564</td>
<td>0.071</td>
</tr>
<tr>
<td>Sex</td>
<td>Female</td>
<td>5.235</td>
<td>0.0439</td>
<td>0.175</td>
<td>0.060</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>6.837</td>
<td>0.0425</td>
<td>0.330</td>
<td>0.074</td>
</tr>
<tr>
<td>DBP (^3)</td>
<td>P85</td>
<td>6.116</td>
<td>0.0424</td>
<td>0.449</td>
<td>0.071</td>
</tr>
<tr>
<td></td>
<td>P92.5</td>
<td>6.025</td>
<td>0.0432</td>
<td>0.503</td>
<td>0.071</td>
</tr>
<tr>
<td></td>
<td>P100</td>
<td>6.113</td>
<td>0.0432</td>
<td>0.530</td>
<td>0.073</td>
</tr>
<tr>
<td></td>
<td>P107.5</td>
<td>6.164</td>
<td>0.0429</td>
<td>0.645</td>
<td>0.071</td>
</tr>
<tr>
<td></td>
<td>P115</td>
<td>5.892</td>
<td>0.0434</td>
<td>0.556</td>
<td>0.075</td>
</tr>
<tr>
<td>ME (^4)</td>
<td>E94</td>
<td>6.224</td>
<td>0.0423</td>
<td>0.579</td>
<td>0.071</td>
</tr>
<tr>
<td></td>
<td>E97</td>
<td>6.039</td>
<td>0.0430</td>
<td>0.576</td>
<td>0.072</td>
</tr>
<tr>
<td></td>
<td>E100</td>
<td>5.921</td>
<td>0.0437</td>
<td>0.466</td>
<td>0.073</td>
</tr>
</tbody>
</table>

\(^1\)The nonlinear mixed model was \(W_{it}=(W_m + u_i) \exp^{-\exp\left(b(t-t^*)\right)} + \varepsilon_{it}\) where \(W_{it}\) was the expected BW (kg) of individual \(i\) at age \(t\) (d); \(W_m\) was the average mature BW of all birds within a treatment; \(u_i\) was a random deviation of mature BW of the individual \(i\) from the average mature BW of its genotype \(u_i \sim N(0, \sigma^2_u)\), and independent of \(\varepsilon_{it}\); \(b\) was a maturation rate (d\(^{-1}\)); \(t^*\) was the time (d) at which growth rate was maximum \(\left[t^*=\ln\left(-\ln\left(W_0/W_m\right)/b\right)\right]\); initial chick weight, \(W_0\), was measured; and \(\varepsilon_{it}\) was the residual error of individual BW measurements.

\(^2\)Prestarter nutrient levels were based on Cobb-Vantress recommendations for maximizing growth rate and feed efficiency (PSHigh), or for reduced feed cost (PSLow).

\(^3\)Five protein treatments (P85, P92.5, P100, P107.5, and P115), balanced for 6 amino acids were provided, at 85, 92.5, 100, 107.5, and 115%, respectively, of Cobb-Vantress dietary specifications for maximum growth rate and feed efficiency.

\(^4\)Dietary ME treatments E94, E97, and E100 were 94, 97, and 100% of Cobb-Vantress dietary specifications for maximum growth rate and feed efficiency.

**Yield**

The allometric function describing yield was of the form \(y=ax^b\), where \(y\) was the weight (g) of the carcass part (i.e. breast, legs, fatpad, etc.); \(x\) was eviscerated BW (g), with head, neck, and feet removed; and \(a\) and \(b\) were coefficients. The allometric coefficient \(b\) is of particular biological interest, since \(b=1\) is a linear function, meaning the part grows at the same rate as the body as a whole. If \(b<1\), the part matures early, and if \(b>1\) the part matures later.

The breast muscle yield curve was shifted upward for females relative to males (P<0.0001). That is, at the same BW, females produced a higher proportion of breast meat. Increasing sex differences in breast muscle yield with increasing age have been observed in previous studies (Gous et al. 1999; Kidd et al., 2005; Zuidhof, 2005). The equations describing breast yield for females was \(y=0.135x^{1.112}\), and for males was \(y=0.166x^{1.081}\). The higher allometric coefficient for breast meat of females indicates that as the bird grows the rate of breast muscle growth in relation to the whole body increases at a higher rate in females than in males. Thus, at higher BW, the difference in breast muscle size between males and females is larger. In contrast, development of leg muscle (drum + thigh) was almost linear, and lower in
females than in males \((y=0.374x^{0.979}\) and \(y=0.321x^{1.002}\), respectively; \(P<0.0001\)). Wing yield was also lower in females than in males \((y=0.368x^{0.848}\) and \(y=0.292x^{0.882}\), respectively; \(P<0.0001\)). The low allometric coefficient for wings indicates that they develop early relative to the rest of the body.

The effect of DBP in relation to breast yield in male and female broilers is summarized in Figure 4. Each reduction in DBP decreased breast meat yield in males as well as in females. Increasing DBP above recommended levels did not improve breast yield of females, while in males only a moderate increase in DBP (107.5% of recommended) shifted the breast yield curve upward. A further increase, to 115% of recommended DBP, did not further improve breast yield of males.

The LowPS diet, which was formulated with lower nutrient density, resulted in a downward shift of the breast yield curve relative to the HighPS treatment \((y=0.176x^{1.075}\) and \(y=0.155x^{1.092}\), respectively; \(P=0.0378\)). Low dietary energy (E94) caused an upward shift in the breast yield curve relative to both the E97 and E100 treatments \((P<0.0001)\). This is likely due to an increase in protein intake with reduced dietary energy, as the birds in the E94 treatment increased their feed intake from 35 to 56 d of age; their ME intake did not differ during this period (data not shown).

In both sexes, fatpad weights increase exponentially with age. Fatpad yield was higher in females than in males \((y=0.008x^{1.488}\) and \(y=0.0026x^{1.269}\), respectively; \(P<0.0001)\). This is caused by differences in hormone balance related to preparation for egg production in females (Gous et al., 1999). Zuidhof (2005) assigned allometric coefficients for fatpad yield ranging from 1.23 to 2.10 in females, and 1.09 to 2.17 in males, depending on the strain, with average values of 1.59 for females, and 1.53 for males. These coefficients are in agreement with the results of the current trial in which fatpad yield was higher in females than in males \((y=0.008x^{1.488}\) and \(y=0.0026x^{1.269}\), respectively; \(P<0.0001)\).

**Figure 4. Breast yield relative to P100 males.** In males and females, each reduction in dietary balanced protein (DBP) decreased breast meat yield. In females, increasing DBP above recommended levels did not improve breast yield. In males, a moderate increase in DBP (107.5% of recommended) shifted the breast yield curve upward. A further increase to 115% of the recommended level did not further improve breast yield.

**Conclusions**

Sex, prestarter nutrition, and subsequent dietary energy and protein levels had significant nonlinear effects on broiler feed intake, growth rates and yield dynamics. To aid the process of optimizing nutritional programs, these effects have been quantified. Modeling feed intake is important because feed is the largest single cost in broiler production. Modeling growth profiles is important for the timing of processing, while models of yield predict the value of the cut up carcass. This analysis provides the most valuable insight for the specific strain that was used. Although data specific to strain, production
conditions, or particular environments will improve the value of the model in commercial applications, this paper provides an integrated generalized nonlinear model that can be applied to a wide range of supply chain optimization problems.

Acknowledgement

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References

HERITABLE DISEASES OF THE AMERICAN QUARTER HORSE AND THEIR MANAGEMENT

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The recent development of equine genome maps and the complete sequencing of the horse genome have increased the pace of genetic discovery resulting in the identification of several genetic diseases in the Quarter Horse. The first genetic disease was identified in 1992 and was a mutation in the sodium channel gene, SCN4A that is responsible for potassium-induced paralysis known as HYPP (Rudolph et al., 1992). Glycogen branching enzyme deficiency, a metabolic genetic disease that is fatal in the fetus and neonate was identified and determined to be caused by a mutation in the GBE1 Gene (Ward et al., 2004). A mutation in peptidyl-prolylisomerase B was found to be associated with hereditary equine regional dermal asthenia (HERDA), a progressive skin disease that typically develops between 6 months and 2 years of age (Tryon et al., 2007). Polysaccharide storage myopathy (PSSM), responsible for chronic exertional rhabdomyolysis, is caused by a mutation in glycogen synthase 1 (McCue et al., 2008). In addition, malignant hyperthermia has been identified in Quarter Horses and occurs in exon 46 of the skeletal muscle ryanodine receptor gene (RyR1) (Alelman et al., 2008).

Glycogen branching enzyme deficiency (GBED) is an autosomal recessive glycogen storage disorder that affects Quarter Horse or Paint Horse neonates or aborted fetuses. The mutation in the GBE1 gene markedly reduces the function of the glycogen branching enzyme. As a result, tissues such as cardiac, skeletal muscle, liver and the brain cannot store and mobilize glycogen in order to maintain normal glucose homeostasis. Carriers of GBED trace back to the sire King P234 in most cases, although King’s sire Zantanon may have also carried GBED. Currently, the carrier frequency in the Quarter Horse breed is estimated at 8.3% and 7.1% in the Paint Horse breed (Wagner et al., 2006). Affected foals may be aborted, stillborn or born alive. Those born alive appear weak and may progress to sudden death following hypo-glycemic seizures. All foals studied to date have died by 18 weeks of age due to severe muscle weakness (Valberg and Mickelson, 2006). Glycogen is a required energy source in the rapidly growing fetus and neonate. Tissues from GBED foals have no measureable GBE-enzyme activity or immuno-detectable GBE and cannot form normally branched glycogen. Aborted fetuses or foals of Quarter Horse-related breeds that die at less than 8 weeks of age should have cardiac and muscle sections obtained for periodic acid-Schiff (PAS) staining. Abnormal polysaccharide can be identified in neural tissue and is consistently found in the liver. However, the most accurate diagnosis of GBED is obtained through genetic testing by licensed laboratories such as the University of California-Davis (www.vgl.ucdavis.edu) or Vet Gen (www.vetgen.com). Mane or tail hairs with roots intact should be submitted.

Malignant hyperthermia is an autosomal dominant mutation that has been identified in Quarter Horses that developed marked hyperthermia and metabolic acidosis during inhalation anesthesia. The prevalence of the RYR1 mutation is not known and is not associated with recurrent exertional rhabdomyolysis. Classic episodes of malignant hyperthermia are diagnosed based on clinical signs of lactic acidosis and hyperthermia (> 40º C) under halothane anesthesia or following succinylcholine injection. A PCR based genetic test is now available. In a horse suspected to have malignant hyperthermia, pretreatment with oral dantrolene (4 mg/kg) 30-60 minutes prior to anesthesia would be indicated (Valverde et al., ). Other means to address hyperthermia would include external application of alcohol, fans, chilled intravenous fluids with sodium bicarbonate and mechanical ventilation, although treatment options are usually unsuccessful once the episode is underway. Genetic testing for this condition is available at the University of California-Davis (www.vgl.ucdavis.edu) and the University of Minnesota (www.vdl.umn.edu/vdl/ourservides/neuromuscular.html).
Hereditary equine regional dermal asthenia (HERDA), also known as hyperelastosis cutis, is an autosomal recessive trait affecting horses of Quarter horse lineage. The genetic defect is a G to A substitution at codon 115 in equine cyclophilin B (PPIB) (Tryon, 2007). The condition is characterized by loose, hyper-extensible and fragile skin. The gene has been estimated to occur in 3.5% of Quarter Horses in general, but in 28% of elite cutting horses (Tryon et al., 2005). Clinical signs usually do not occur until 1.5 years of age, on average, when training begins. Affected horses present with seromas, hematomas, open wounds and sloughing skin. Affected areas are primarily located along the dorsum due to saddle trauma but can occur in other parts of the body. Treatment of lesions is supportive in nature although keeping affected horses out of direct sunlight has been shown to be effective in slowing the progression of lesions. A genetic test to screen for the mutation is available through the University of California and Cornell University.

Polysaccharide Storage Myopathy (PSSM) was first identified in 1992 and is a common form of tying-up in many horse breeds including Quarter Horses, American Paint Horses, Appaloosas, Warmbloods and draft breeds. The condition is characterized by excessive and abnormal storage of sugar (polysaccharide) in muscle cells. The condition is due to an autosomal dominant point mutation in the glycogen synthase 1 gene (GYS1) which appears to cause unregulated synthesis of glycogen. When all horses screened for the condition at the University of Minnesota Neuromuscular Diagnostic Laboratory by muscle biopsy were screened for the genetic mutation, it became clear there was a subset of horses with PSSM that did not have the GYS1 Mutation. Therefore, the nomenclature for PSSM has changed; type 1 PSSM refers to horses with the GYS1 mutation and type 2 PSSM refers to horses diagnosed with abnormal glycogen storage in muscle biopsy that lack the GYS1 mutation (Valberg and Mickelson, 2007). Clinical signs of the condition include muscle pain, stiffness, sweating, exercise intolerance, weakness and reluctance to move with the hindquarters most frequently affected. A definitive diagnosis can be made by muscle biopsy for both type 1 and 2 PSSM or genetic testing for type 1 PSSM at the University of Minnesota Veterinary Diagnostic Laboratory (www.vdl.umn.edu/vdl/ourservices/neuromuscular.html). Whole blood or hair including the roots should be submitted. Treatment for an acute episode includes stall rest for no more than 48 hours, assessment of hydration status and rehydration if indicated to prevent kidney damage, sedatives, and anti-inflammatorries. Prolonged stall confinement may result in an increased incidence of PSSM and therefore, affected horses should have access to turnout as soon as possible. An appropriate exercise regimen following an episode of rhabdomyolysis would be a 2 week period of turn out while the diet is being changed and then a gradual return to exercise, with successive addition of 2 minute intervals of walk and trot beginning with only 4 minutes of exercise and working up to 30 minutes after 3 weeks. The objective of increasing the duration of exercise is to augment the capacity of the muscle to oxidize fat and glycogen as energy substrates. Dietary management should be aimed at providing adequate, but not excessive calories by decreasing the glucose load and providing fat as an alternative energy source. Decreasing the dietary starch and sugar (NSC) to <10% of daily digestible energy and increasing dietary fat up to 13% of daily digestible energy combined with a vitamin mineral supplement is recommended (Ribeiro et al., 2004). Some commercial feeds meet the recommended nutritional needs of PSSM horses in a single pelleted ration. These feeds typically contain 10 to 15% fat by weight and less than 20% starch or nonstructural carbohydrate by weight.

Hyperkalemic periodic paralysis (HYPP) is an autosomal dominant trait affecting Quarter Horses, American Paint Horses, Appaloosas and Quarter Horse crossbreds. The genetic condition traces back to the Quarter Horse sire Impressive and affects approximately 4% of the Quarter Horse breed (Finno et al., 2008). Horses affected by HYPP have been preferentially selected as breeding and show stock due to their phenotype expression of well-developed musculature and results in halter classes. In 1996 the American Quarter Horse Association (AQHA) recognized HYPP as a genetic defect and mandatory testing was instituted with the results recorded on the registration papers for all foals that are descendents of Impressive and were born after January 1, 1998. In 2007 AQHA ruled that foals born in 2007 or later...
and that tested homozygous affected for HYPP (H/H) would not be eligible for registration. Horses that tested heterozygous affected for HYPP are designated as N/H and normal unaffected horses are N/N. HYPP is due to a missense mutation (C to G substitution) resulting in a phenylalanine/leucine substitution in the alpha-subunit of the voltage-dependent skeletal muscle sodium channel alpha-subunit (SCN4A). In HYPP horses, the resting membrane potential is closer to firing than in normal horses. Sodium channels are normally briefly activated during the initial phase of the muscle-action potential. HYPP results in a failure of a subpopulation of sodium channels to inactivate when serum-potassium concentrations are increased. The result is an excessive influx of sodium and outward flux of potassium, resulting in persistent depolarization of muscles cells followed by temporary weakness. Clinical signs of HYPP affected horses vary from asymptomatic to daily muscle fasciculations and weakness resulting in recumbency and occasionally, death. Episodes of weakness or paralysis appear similar between N/H and H/H horses. Clinical signs of homozygous HYPP foals include respiratory stridor and periodic obstruction of the upper respiratory tract. Affected homozygous horses also exhibit dysphonia (a high pitched whinny) even between episodes. Foals that are heterozygous (N/H) are less severely affected and typically do not demonstrate clinical signs of disease until they are weaned. In both heterozygous and homozygous HYPP horses clinical signs begin with a brief period of twitching or delayed relaxation of muscles with some horses showing prolapose of the third eyelid. Sweating and muscle fasciculations are usually seen in the flanks, neck and shoulders. During mild attacks, horses remain standing but in more severe attacks the clinical signs may progress to staggering, dog-sitting or recumbency. Episodes last for varying periods of time, but usually last from 15 to 60 minutes. After an episode, horses appear normal. Episodes may be triggered by diets containing > 1.1% potassium in the total daily intake on a dry weight basis. Other precipitating factors include fasting, anesthesia, trailer rides and stress (Spier, 2006). Genetic identification of homozygous and heterozygous HYPP horses can be made by sending mane or tail hair to the Veterinary Genetics Laboratory at the University of California at Davis (www.vgl.ucdavis.edu).

Treatment of horses experiencing episodes includes light exercise when clinical signs are first observed. Feeding grain or corn syrup to stimulate insulin-mediated movement of potassium across cell membranes may also be beneficial. Other treatments include administration of epinephrine (3 mL of 1:1000/500kg IM) and acetazolamide (3 mg/kg every 8-12 h orally). In severe cases, administration of calcium gluconate (0.2-0.4 mL/kg of a 23% solution diluted in 1 L of 5% dextrose) will often provide immediate improvement. An increase in extracellular calcium concentration raises the muscle-membrane threshold potential which attenuates membrane excitability. To reduce serum potassium, IV dextrose (6 mL/kg of a 5% solution) alone or in combination with sodium bicarbonate (1-2 mEq/kg) can be used to enhance intracellular movement of potassium. In most cases, HYPP is a manageable disorder, although severe episodes can be fatal. Decreasing dietary potassium and increasing renal losses of potassium are the primary steps taken to prevent HYPP episodes. Regular exercise is also beneficial. Horses with HYPP can graze most pastures because the high water content of the grass makes it unlikely the horse will consume large amounts of potassium in a short period of time. Horses with HYPP should be fed a balanced ration containing between 0.6% and 1.1% total potassium concentration and meals containing < 33 g of potassium (Reynolds et al., 1998). High potassium feeds such as alfalfa hay, orchard grass hay, brome hay, soybean meal, electrolyte supplements, canola oil, kelp-based supplements, sugar molasses and beet molasses should be avoided. Ideally late cuts of Timothy or Bermuda grass hay; grains such as oats, corn, wheat and barley; and beet pulp should be fed in small meals several times a day. The potassium concentration of forages can vary widely, so it may be prudent to perform a forage analysis to determine potassium concentrations before feeding. Commercially available complete feeds with a guaranteed potassium content may be more convenient for some HYPP horses. HYPP horses should be fed several times a day and allowed frequent access to a large paddock or pasture. Several drugs have been used for prevention of clinical signs. Acetazolamide (2-4 mg/kg orally, every 8-12 hours) or hydrochlorothiazide (0.5-1 mg/kg orally, every 12 hours) have both been used with success. These agents exert their effects through different mechanisms; however, both cause increased renal potassium ATPase activity. Acetazolamide has been shown to stabilize blood glucose and potassium by stimulating insulin.
secretion. Since HYPP is a dominant trait, breeding a heterozygous affected horse (N/H) to a normal horse (N/N) results in a 50% chance of producing a foal heterozygous for HYPP, while breeding a homozygous affected horse (H/H) to a normal horse (N/N) results in a 100% chance of producing a heterozygous affected horse (N/H). Owners of affected horse should advise their veterinarian of the horse’s HYPP status before anesthesia or procedures requiring heavy sedation. Horse descended from Impressive should be tested for HYPP during any pre-purchase examination.

References


THE LATEST INFORMATION ON FEEDING MARES AND FOALS AND EFFECTS ON SKELETAL DEVELOPMENT

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Summary

The skeleton serves as the framework from which the athletic potential of the horse is built. The majority of skeletal development occurs in the 3 years following conception, and it is for this reason that nutrition and management during this period is likely to have the greatest impact on bone and cartilage health. The skeleton remains a dynamic tissue throughout life, changing due to different outside stressors as well as the inescapable effects of aging. So while the greatest impact can be had in the young growing animal, nutrition will certainly play a role in skeletal health throughout life. Because of the skeleton’s central role in the athletic ability of the horse, the optimal development and maintenance of this tissue should be a priority of those raising and maintaining horses. While genetic selection is an important tool to use in improving future generations, nutritional management is a tool that can be used each day by horse owners to not only reduce the risk of disease but also improve the quality of skeletal development. The objectives of this paper are to provide 1) a brief overview of some of the changes in nutritional requirements specific to the equine skeletal system highlighted in the 2007 NRC for horses (NRC, 2007), and 2) examine recent research on the metabolic interaction between nutrition and skeletal development, raising some questions for future research. Specific topics covered are mineral, protein, energy, and vitamin D nutrition in relation to skeletal development of the young growing horse.

Nutrition and Skeletal Development

Nutrition is associated with two components of skeletal development. First, nutrients act as a supply of building materials. Bone and cartilage are made up of a mixture of organic and inorganic molecules, the majority of which are protein and minerals. The requirement for growth for these nutrients depends on the rate of growth and the turnover of skeletal tissues. An analogy would be the steel, rivets, and plastic that are materials used for building the frame of a racecar. If there is not sufficient steel provided, either the car has to be built smaller, or the frame weakened. Second, nutrients and dietary energy act as metabolic signals for cartilage and bone cells. In this role they act as cues, signaling the skeletal tissue as to the rate it should be developing based on the current nutritional environment. Stretching the car analogy a bit, you might see the production of cars decrease at times when fuel required for powering robots on assembly line was insufficient. It is important to think about how these changes in production influence the need for materials.

Most of the current research in the area of equine skeletal development is focused on understanding the mechanisms that control the turnover of cartilage and bone. Questions that are being addressed include: How does the pattern of growth affect the quality of skeletal development? Do different dietary energy sources provide different cues to the cartilage and bone? Are there particular windows of time during development when specific feeds should be provided, and conversely are there times when some feeds or nutrients should not be fed? How do those feeding horses integrate an understanding of nutrient supply and metabolic signals to optimize skeletal development? The answer to this last question could provide ways of feeding horses that will not only reduce the risk of certain skeletal
disorders, but also potentially improve certain components of skeletal tissue quality. I will first examine
the requirements for nutrients or materials and then move on to metabolic cues for skeletal metabolism.
Again, it is important to realize that there is overlap between these, for example protein is first an
important material for collagen formation, but can also influence metabolic cues, such as insulin.

**Minerals**

Minerals can act as structural components of bone or cartilage extracellular matrix or as
functional components of enzymes that build or breakdown skeletal tissues. Minerals make up between
45 to 60% of bone matrix while also playing important roles in collagen and proteoglycan synthesis in
both cartilage and bone. Due to their important roles in the development of skeletal tissues, the
requirements of these minerals have been the focus of a significant amount of equine related research (Knight *et al.*, 1985; Hurtig *et al.*, 1993; O'Connor *et al.*, 2008).

Calcium (Ca) and phosphorus (P) both make up a considerable portion of the inorganic material
of bone. Calcium requirements for the growing horse were increased in the 2007 NRC for horses based on
endogenous losses of 36 mg Ca/kg BW, a 50% absorption rate and requirements for growth of 16 g Ca/kg
BW gain. Calcium requirements for broodmares were increased for the 7th and 8th months of gestation to
account for additional fetal development in these months. While Ca requirements for milk production
remained unchanged, the estimated milk production increased, indirectly increasing the Ca requirements
for the lactating broodmare. Changes to the P requirements were similarly increased in the 2007 NRC for
growing horses and broodmares.

Other minerals make up smaller portions of bone and cartilage, but also play important functional
roles in facilitating the dynamic nature of skeletal tissue. Examples of such minerals include magnesium
(Mg), copper (Cu), zinc (Zn), manganese (Mn), and silicon (Si). While Mg requirements remained
unchanged for growth from the 1989 NRC, requirements were increased for mares in the 7th and 8th
months of gestation, and also for lactating mares due to increased estimates of milk production. Copper
requirements have received considerable attention due to the important role this mineral plays in cartilage
and bone metabolism. The Cu requirement for growing horses and mares in the 9th, 10th and 11th months
of gestation was increased to 0.25 mg/kg BW to ensure requirements were being met. While meeting the
minimum requirement is important, the currently available research seems to indicate that over
supplementation may not further reduce the risk of problems such as osteochondrosis. Highlighting this is
research that indicates a lack of skeletal abnormalities in growing horses on pasture that was low in Cu
(Pearce *et al.*, 1998). The Zn and Mn requirements remain the same as those suggested in the 1989 NRC.
Zinc’s role is both as a component of enzymes involved in skeletal metabolism and also as an antagonist
of copper absorption or action. Manganese is required for the formation of chondroitin sulfate, and hence
critical for cartilage formation, but there is little evidence to suggest that the current requirements need to
be increased. It is worth noting that there has been limited work conducted examining Mn requirements in
growing horses. Silicon is another mineral important to both cartilage and bone development. Attention
on Si has focused on the availability of different sources for absorption (O’Connor *et al.*, 2008; Turner *et
al.*, 2008). While most horses are likely to meet their requirements for Si, there is some thought that
skeletal development may be improved at higher intakes. Future research will likely focus further on
various sources of Si and the impact of supplemental Si on measures of skeletal health.

**Protein**

Generally, interpretation of the currently available research indicates that excess dietary protein is
unlikely to negatively impact skeletal development. However, it may still be worth considering that
dietary protein has the potential to impact skeletal development in two ways: 1) as a nutrient important to
the formation of collagen and proteoglycans, 2) through amino acids’ impact on insulin secretion.
Protein makes up a considerable portion of both bone and cartilage. Both tissues have optimized levels of stiffness and flexibility to maximize strength and usability. Collagen in bone and cartilage and proteoglycans in cartilage contribute to the flexibility component. Major amino acids in skeletal tissues include glycine, proline, and hydroxyproline. Studies in rabbits have shown that intra-articular injection of these amino acids along with other nutrients may enhance cartilage healing (Park et al., 2007). This leads to the concept that a particular dietary amino acid composition may be beneficial to cartilage and bone. During periods of rapid growth it may be appropriate to fortify a diet with amino acids that are a part of the rapidly developing skeleton. A number of studies have examined fortification of the equine diet with the limiting amino acids, lysine and threonine (Breuer and Golden, 1971; Graham et al., 1994; Staniar et al., 2001). Findings from these studies indicate that fortifying with limiting amino acids may potentially affect growth rate, but specifics of skeletal development were not examined. But in these studies they were focused more on limiting and essential amino acids and less on the specific amino acids required for skeletal development. It is of interest here that folate plays an important role in glycine metabolism and therefore skeletal development in the growing horse, yet there is limited research on the folate status of young foals (Ordakowski-Burk et al., 2005). The horse is sensitive to the quality of dietary protein because it is a hindgut fermenting herbivore. This provides a nutritional opportunity to the horse owner to modify the composition of amino acids reaching the tissue. There still needs to be considerable research in this area before it is clear that modifications to the dietary amino acid composition could be beneficial to skeletal development.

Energy

Abnormalities in equine skeletal development have been associated with excess dietary energy as well as the magnitude of the glycemic response associated with the most common source of dietary energy, starch (Glade and Belling, 1984; Savage et al., 1993; Pagan et al., 2001). However, research into the physiologic mechanisms behind this association is relatively limited in the horse. A more detailed understanding of the mechanisms that link dietary energy supply with skeletal development will allow for more precise nutritional management of young growing horses, to not only reduce the risk of disease, but also actually improve skeletal tissue.

Energy is required for work. A seemingly obvious statement that is central to appreciating the importance of signals to cells as to whether energy is available or not. The chondrocytes, osteocytes, osteoblasts, and osteoclasts are cells responsible for building and maintaining the horse’s skeletal tissue; the robots on the skeletal assembly line. How do these cells know when they should build, breakdown, or not do anything at all? Availability of energy is an important factor to be considered. But cells do not consider, they respond to signals. It is generally accepted that growth is one of the first physiologic processes to be down regulated when energy is limited and conversely is up regulated when there is sufficient energy available. It is important to point out that abnormalities in skeletal development have been associated with both excess dietary energy and rapid growth. An example is a longitudinal growth study of 18 colts split into either limit or ad libitum fed groups. The results of this study indicated more rapid growth and a higher incidence of clinically assessed conformational and musculoskeletal abnormalities in the ad libitum fed group (Cymbaluk et al., 1990). Similar results associating rapid growth with osteochondrosis have been shown in more recent studies, and yet interestingly the amount fed was not found to be a contributing factor (Donabedian et al., 2006). This may be due to the fact that energy and nutrients were all increased equally in this second study.

Some of the most biologically conserved molecules are those associated with the signaling of energy availability. Examples include glucose, insulin, growth hormone and insulin-like growth factor I (IGF-I) (Stoka, 1999). All of these are also important signals regulating cartilage and bone development (Orth, 1999). It has further been suggested that abnormalities in the concentrations of these signals to skeletal issues may be associated with developmental problems (Shingleton et al., 1997; Staniar et al.,
All of this has led to many more questions than answers and a general pessimism that nutritional management of dietary energy can be used to address skeletal development. Future research should examine what, when, and how dietary energy sources are supplied to growing horses. How does modifying each of these variables influence the circulating patterns of metabolic signals? Are there patterns of metabolic signals that can be associated with developmental orthopedic disease or conversely improved skeletal development?

**Vitamin D**

Vitamin D is a nutrient that may be worth another look as it role in skeletal metabolism in the horse remains unclear. It is of particular interest that the available data indicates that the horse is significantly different from other mammalian species in regard to vitamin D metabolism (Breidenbach *et al*., 1998). The current requirements for vitamin D are based mainly on a study with a limited number of ponies (El Shorafa *et al*., 1979). This study did indicate that growing ponies kept out of sunlight and fed a vitamin D deficient diet had a decrease in the quality of skeletal development when compared to those kept outside or supplemented. Recent research in human skeletal development highlights the integrated role of vitamin D with some of the metabolic signals for growth such as growth hormone and IGF-I (Fernandez-Cancio *et al*., 2009). As our understanding of energy metabolism and mechanisms that regulate skeletal growth improve it would be helpful to have a clearer understanding of why and how vitamin D metabolism appears to be different in the horse.

**Questions for Future Research**

Recent research indicates that moderate exercise may have a positive influence on skeletal development (Rogers *et al*., 2008). *What implications might new training management scenarios have on the nutrient and energy requirements of these growing horses?* Very simply, it could be expected that nutrient and energy requirements would be increased. But which nutrients? When should they be fed so they are most efficiently utilized for skeletal development?

Rapid growth continues to be highlighted as a characteristic associated with developmental problems in young growing horses (Lepeule *et al*., 2009). This is not surprising as it has been a common theme in other species with developmental skeletal disorders. Rapid growth is generally a combination of genetic potential and a nutritional environment that allows that growth to occur. *Utilizing nutrition, how can the rapidly growing horse be fed to optimize skeletal development?* Answering this question will require more than just understanding what nutrients (building materials) are required, but also the regulatory intricacies of the skeletal growth process.

It is clear that there is a genetic component to health concerns such as osteochondrosis, and some have suggested that these traits are tied to optimal athletic performance (Kronfeld, 2003; Lampe *et al*., 2009). *If selecting horses for optimal athletic performance, can an owner significantly reduce the risk of associated skeletal problems through modified nutrition and management?* Because of the multifactorial nature of many skeletal abnormalities it is possible to remove some of the causative agents to reduce the overall occurrence of that problem. To bring back the race car production analogy a final time, not only are the materials required to build a Ferrari different from a Ford, but the way each of these assembly lines runs is also different. They run at different speeds, they require input at different times.

**Conclusions**

Research in the area of nutrition and equine skeletal development has progressed if at a slow pace in recent years. Major question in regard to macromineral and some micromineral requirements seem to be answered, but there is still need for research into manganese and silicon. There are also questions in
regard to how requirements may change in relation to short term increases or decreases in growth. Protein is a nutrient that crosses the line between a material and factor that impact metabolic regulation. There are opportunities in the areas of amino acid nutrition and dietary protein’s impact on metabolic health. Dietary energy is the driving force behind skeletal development, yet its impact on skeletal development is not simply a question of more or less. Other questions are what is the source of that energy; how often and when during development should it be provided; and how do we match energy supply with genetic potential? Finally, in humans and other species the role of vitamin D in skeletal development continues to garner significant attention, yet research in the horse indicates vitamin D metabolism is somehow different, making comparisons difficult. More work is needed in this area. Skeletal breakdown continues to occur in horses, and the skeleton is the athletic framework off of which the performance of the horse is built. The physiologic steps from nutrition to building bone and cartilage are complex, a fantastic challenge to the future of equine nutrition.

References

FEEDING THE BROODMARE: CONCEPTION, GESTATION, AND LACTATION

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Summary

The horse has evolved as a grazing animal and has the ability to adapt to changes in environmental conditions, in particular, to nutrient availability and quality. In the mare this evolution has affected when she is reproductively active. Mares are considered seasonally polyestrous, meaning they have more than one estrous cycle during a specific time of the year. This time of year occurs in spring and early summer and is associated with an increase in daylight, temperature, and availability of nutrients. If ample nutrients are not accessible to the horse either as metabolic stores (body fat) or available external nutrients (forage or concentrate) the mare may not become reproductively active. Reproduction should be considered a luxury to the horse, as it will only occur if hormonal signals within the animal trigger the brain to indicate that enough nutrients and body reserves are available to not only maintain oneself for survival, but also to sustain fetal growth and development. Understanding and manipulating this complex system of nutritional and metabolic signals occurring in the animal is critical to ensuring successful reproduction.

Conception

Nutritional management is a simple, yet cost effective tool that we can apply to ensure normal cyclical behavior, improved conception rates and pregnancy maintenance in mares to ensure overall reproductive success. Body condition scoring serves as an effective means to determine the energy balance of your mare. Using a standardized scoring system from 1 to 9, we can estimate the animal’s body energy reserves (Henneke et al., 1983). This information can be used to adjust feeding regimes to reach optimal body condition. The optimal body condition score for a mare coming into the breeding season is between 5 and 7. If a mare exhibits a body condition on the lower end of the scale (1-4 BCS) reproductive efficiency can be severely compromised. However, if a mare displays a body condition score on the upper end of the scale (8-9 BCS) there may be indirect complications due to obesity which may reduce reproductive efficiency. Obesity has been associated with longer inter-ovulatory periods in mares (Vick et al., 2006), as well as impaired oocyte quality in cattle (Adamaik et al., 2005). Body condition however, is not necessarily an accurate indicator of protein, mineral and vitamin status of the animal.

The effect of nutrition and body condition on reproduction in mares has been clearly illustrated (Belonje and Van Niekerk, 1975; Henneke et al., 1984; Hines et al., 1987). Mares coming into the breeding season with an optimal body condition score (5-7) start cycling earlier than mares with a low body condition (< 5). Thinner mares have also shown longer inter-ovulatory periods, decreased pregnancy rates, and decreased ovarian activity (Dunn and Moss, 1992; Henneke et al., 1984). The impact of energy intake and body condition on the reproductive performance of the mare has also been described where high-energy diets shortened the interval to first ovulation in thin mares transitioning from winter as compared to those on a low energy diet. This increase in dietary energy however did not benefit mares in moderate (BCS 7) or fat body condition (BCS 8 or 9) (Kubiak et al., 1987).
A mare that is very thin, either body condition score 1 or 2 at the beginning of the breeding season should be placed on a gradual increased plane of nutrition in order to restore body weight. The 2007 National Requirements for Horses suggested that it takes 16 to 20 kg (35 to 44 lbs) of gain to change a horses body condition score by 1 unit (based on a 500 kg, 1100 lb horse). Therefore a mare with a body condition score of 2 would need to gain around 60 kg (132 lbs) to increase her condition score to a 5. This would take around 6 months to achieve and would require a very energy dense feeding protocol. Care should also be taken when feeding for weight gain so as not to cause digestive disturbances with the increased feed intake. When feeding large quantities of grain in order to increase the energy density of the ration we must be careful not to feed more than 5lbs of grain in any single feeding. This is because larger meals pass more quickly than smaller meals through the digestive tract since stomach emptying is controlled by meal volume. Therefore less nutrients are absorbed and potential digestive disorders such as decreased hindgut acidity and colic can occur when these foods particularly starch overflows into the hindgut (Potter et al., 1992).

In this case it would be advisable to wait until the following year to incorporate the mare into the breeding program, this would allow her time to gain and maintain weight and resume normal reproductive cycling behavior before putting her through the stresses of trying to get her in foal. If the mare had a body condition score of 3 or 4 prior to the beginning of the breeding season it would be more feasible to increase her condition and resume cycling to be able to breed her in that year. In order to do this her caloric intake must be increased. Based on the assumptions outlined above it would take approximately 2 to 4 months of feeding the mare approximately 40% more energy per day than if she was just maintaining. Maintenance energy requirements for an average 500kg horse are approximately 16.7 Mcal/d, plus the additional 40% would equal 23.4 Mcal/d for 2-4 months to increase the mare condition score from 3-4 to 5 (NRC, 2007).

While some obese mares may continue to cycle throughout the winter there are negative repercussions for keeping mares in this condition. In humans and rodents obesity contributes to infertility, poor pregnancy and impaired fetal well-being (Pasquali et al., 2003; Widdowson, 1955). Obesity has been associated in horses and ponies with decreased insulin sensitivity (Hoffman et al., 2003), and both obesity and decreased insulin sensitivity have been associated with decreased reproductive function in mares (Vick et al., 2006). Obese mares can have longer intervals between ovulations which can be due to a persistent corpus luteum (Vick et al., 2006). This makes the obese mare more difficult to rebreed if an initial breeding is not successful increasing the cost incurred to the owner. Evidence in other species indicates that high planes of nutrition in moderately obese animals also lead to hyperinsulinaemia and impaired oocyte quality (Adamik et al., 2005).

Most mares if currently in a reproductively optimal body condition (5-7) can be sufficiently maintained on good quality pasture and hay. Horses allowed free choice grazing on quality pasture may consume as much as 3 percent of their body weight daily, which normally meets their needs for protein, energy. However, mineral requirements may not be met, particularly in mineral-deficient pastures. Therefore, a good recommendation during this time would be to provide supplemental minerals.

**Gestation**

The recently revised version of the nutrient requirements for horses has expanded the requirements for gestation from early, mid and late gestation to less than 5 months and then specific requirements for each subsequent month. For the ease of discussion this review will categorize pregnancy in early, mid and late gestation while taking into account the new feeding guidelines. Previous thoughts on fetal development placed most nutritional emphasis on the last phase of gestation. We now appreciate that critical organs are developing during early and mid gestation and specific nutrients are critical for their development an example being the heart which has begun development and a heart beat can be visualized via ultrasound by approximately day 24. Minerals such as copper and zinc and vitamins A & D are crucial for healthy development of this organ (Ashworth and Antipatis, 2001). The consequences of
specific micronutrient deficiencies can be more extreme and longer lasting than those occurring after general under-nutrition. For example, feeding rats ad libitum from mating with a zinc-deficient diet increased both the number of malformations per fetus and the number of resorptions per litter compared with animals that received a control diet (Masters et al., 1983). When developing nutritional programs for broodmares the emphasis must be placed on balanced vitamin and mineral supplementation which are in accordance with the requirements set out by the NRC, 2007.

When considering the mare’s diet and condition we must also be conscious of the affects these parameters have on fetal development. Nutrition is a major intrauterine environmental factor that alters expression of the fetal genome and may have lifelong consequences. This concept has been termed “fetal programming” and has led to the theory of “fetal origins of adult disease.” Namely alterations in fetal nutrition and endocrine status may result in developmental adaptations that permanently change the structure, physiology, and metabolism of the offspring, thereby predisposing them to metabolic, endocrine and physical disruptions later in life (Fowden and Forhead, 2004; Wu et al., 2004). Animal studies show that both maternal under-nutrition and over-nutrition reduce placental-fetal blood flows and stunt fetal growth (Wu et al., 2004).

**Feeding Through Early & Mid Gestation**

From the time of conception through foaling, the fetus is actively growing. However, fetal growth is not occurring at a steady rate. Fetal growth is quite slow during the first seven months of pregnancy and then very rapid the final trimester. During early and mid pregnancy the developing fetus is very small, less than 20% of birth weight. This represents less than 2% of the mare’s body weight. The nutrient requirements of the mare during early pregnancy are very similar to the nutrient requirements of a non-pregnant mare. A common feeding mistake is to over feed mare’s calories during early pregnancy causing them to become overweight. An all forage (hay or pasture) diet will provide most mares with adequate levels of both energy (calories) and protein, but is likely deficient in several key minerals. Critical organs including the heart, liver, kidney, brain, and lungs are being developed during the early and mid stages of gestation and while these organs may not need extra calories and protein to develop properly, several micronutrients are known to be critical (Ashworth and Antipatis, 2001). Feeding a low intake protein, vitamin and mineral supplement pellet to mares during early pregnancy ensures the developing fetus is adequately fortified with essential nutrients without causing excessive weight gain.

To satisfy the nutrient requirements of early pregnancy, a mare in good body condition will not need a large increase in total feed intake. She should be able to meet the vast majority of her nutrient needs by consuming good quality forage (hay and/or pasture) at an intake rate of 2 to 2.5% of body weight. This equates to approximately 20 to 25 lbs. of dry forage for a 1000 lb. mare. While a diet consisting of almost entirely forage usually provides plenty of protein and energy, it is likely deficient in several key minerals including copper, zinc and selenium and may not be contain proper ratios of calcium and phosphorus. The mare in good condition requires these minerals to be properly balanced in the diet, but she does not require the additional calories that would be provided by feeding large amounts of a fortified grain concentrate. In other words, this mare would become obese if fed more than a couple pounds of grain. To provide critical nutrients to a mare in early pregnancy, without providing an overabundance of calories, a low-intake protein, vitamin and mineral supplement pellet should be fed.

If the mare in early pregnancy is underweight or can’t maintain body condition on an all-forage diet, she should be fed a grain concentrate designed for pregnant mares. This will provide the essential nutrients along with the necessary calories to assist the mare in maintaining proper weight. It is important to be sure that the mare is being fed the grain concentrate according to the feeding directions on the bag or tag. If mares are fed less than recommended levels, they are likely not getting the proper levels of vitamins and minerals.
**Feeding Through Late Gestation**

During late pregnancy the fetus will gain approximately 80% of its birth weight. To support this rapid fetal growth, the mare’s requirements for energy, protein, minerals and vitamins increase. The requirements for trace minerals are especially critical since the mare will fortify the unborn foal liver with minerals such as copper, zinc and selenium. Mare’s milk is not a good source of these trace minerals therefore they must be stored in the foal’s liver prior to birth (Grace, 1999). The foal utilizes these minerals during the first two months of life to support proper skeletal growth. Without proper liver stores of trace minerals, the foal may be predisposed to growth disorders such as developmental orthopedic disease (Bridges and Harris 1988; Caure et al., 1998). Compounded with an increased requirement for nutrients, the mare in late pregnancy has a limited capacity for feed intake. Intake capacity is limited due to the size of the fetus compressing the digestive system. To meet the nutrient needs of mares in late pregnancy, hay intake is often reduced and fortified grain is fed as a concentrated source of essential nutrients. To further complicate the increased nutrient requirements, the size of the developing fetus often limits space within the abdomen and decreases the amount of feed a mare can consume. Therefore, mares in late pregnancy require feeds with increased nutrient density. In particular protein and energy requirements are higher and a 500 kg mare increases her protein requirement from 630g per day at maintenance to 893g per day in the 11th month of pregnancy. Digestible energy requirements increase from 16.7 Mcal/day to 21.4 Mcal/day for the same mare (NRC, 2007). Mares will typically consume less bulky forage and a larger amount of grain concentrate. To properly feed these mares, good quality hay should be offered free choice and a grain concentrate designed specifically for broodmares fed according to manufacturer guidelines. It may be possible in certain instances for overweight or “easy keeping” mares to be fed a low intake protein, vitamin and mineral supplement pellet rather than a grain concentrate in an effort to reduce or control weight in late pregnancy.

**Lactation**

The lactating mare has the highest nutrient requirements of any horse on the farm. To produce milk and to repair the reproductive tract in preparation for future pregnancy, the mare requires substantial amounts of energy, protein, calcium and phosphorus. To maintain both adequate milk production and body condition, lactating mares will often need to be fed substantial amounts of grain. Without adequate energy (calorie) intake, mares will lose body weight and be difficult to get pregnant. The most common feeding mistake made with lactating mares is to underfeed them.

Energy requirements will nearly double following foaling. It is usual for a 1,200-pound mare to need 12 to 15 pounds of an average energy density grain mix in addition to 10 to 12 pounds of a good quality hay to meet her energy needs. Careful management is necessary in this class of mares because individual requirements will vary greatly. A foal can quickly lower condition in the mare, and wet mares in a thin body condition may take longer to rebreed and have lower pregnancy rates than mares in a moderate to fleshy condition. Also, the mare may be moved to a new location for breeding soon after foaling, which can create a loss in condition due to stress. It is extremely difficult to increase condition in lactating mares because the amount of feed that would be necessary can lead to higher incidence of founder and colic. As such, it is important that the mare is adequately conditioned before foaling. Overconditioning however can also prove detrimental. Research has shown that obese dams are less likely to initiate lactation and are more prone to early cessation of lactation as well as a decreased prolactin response to suckling (Kubiak et al., 1991; Rasmussen, 2007).

With regard to rebreeding the lactating mare research has indicated that a body condition score of less than 5 in lactating mares means they do not have enough stored fat to support efficient reproductive performance (Henneke et al., 1984). Those mares in marginal or poor body condition (< 5) are more
likely to skip a breeding season, as their bodies use dietary nutrients primarily for milk production rather than reproduction. When mares receive inadequate nutrition the incidence of embryo loss also increases.

Just as energy and other nutrient requirements are elevated during lactation, mares have an increased need for water. Studies have shown that nursing mares increase their water intake 37-74% above maintenance needs solely to meet lactational demands (NRC, 2007). As such, mares should have unlimited access to fresh clean water. This is particularly important in the management of mares that foal early in the year when water sources may freeze or in drought conditions when water is scarce.

Conclusion

In summary, nutritional management is a simple, yet cost effective tool that can be applied to ensure normal cycling behavior, improved conception rates and increased pregnancy maintenance in mares. Mare owners should prepare mares in advance for the breeding season ensuring optimal body condition and balanced nutrition. Two common mistakes should be avoided when feeding pregnant mares. Overfeeding mares in early pregnancy should be avoided since it can lead to obesity and the potential for foaling difficulty. The second mistake to avoid is underfeeding critical nutrients in late pregnancy, when fetal growth is very rapid. Underfeeding and overfeeding essential nutrients will predispose the foal to skeletal problems. Many factors play complex roles in equine reproduction, nutritional management is one method that can be utilized to begin ensuring reproductive success. Combining visual aids such as body condition scoring with balanced nutrition can enable horse owners to be more proactive in the care and management of their broodmares.

References

FEEDING AND NUTRITIONAL SUPPORT OF THE SICK HORSE: PREVENTION AND NUTRITIONAL MANAGEMENT OF COLIC

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Summary

The gastrointestinal tract of equines has evolved on continuous grazing of forages rich in fiber (cellulose, hemicelluloses) and on reduced intake of grains rich in starch. The modern horse industry has moved far away from this evolutionary model. The change in type of work and exercise resulted in different nutrient requirements for equine athletes. While a forage-based diet is the mainstay of horse’s diet and is ideal to support gastrointestinal health, it is impossible to meet high energy and nutrient requirements of an equine athlete without addition of energy feeds (e.g. concentrates, grains, fats). Exercising horses not only have increased nutrient and energy requirements but they also have limited time to eat and graze. Therefore, it can be expected that alterations from the horse’s natural diet and feeding behavior would lead to gastrointestinal disturbances with clinical manifestation of abdominal pain - colic.

Colic, a term used to describe abdominal pain, is a common disorder of horses. Epidemiological studies report that around 5 cases of colic are expected per 100 horses each year (Archer and Proudman, 2006; Traub-Dargatz et al., 2001). The overall mortality rate for colic was 0.45 deaths per 100 horse years in thoroughbreds in the UK (Hillyer et al., 2001). Reports from Michigan and Virginia-Maryland indicate 0.5 and 0.7 deaths per 100 horse years, respectively (Kaneene et al., 1997; Tinker et al., 1997a).

There are multiple factors involved in the development of colic, including feed types and feeding practices, parasites, gender, age, breed, history of previous colic, crib-biting/windsucking behavior, exercise, stabling, transport, and dental prophylaxis. More specifically, dietary risk factors include feeding concentrates, limited access to pasture and water, poor quality forages (hay, pasture), intermittent feeding, and rapid changes of the ration.

There is only limited information on feeding management of horses recovering from the colic. In general, nutritional support should be tailored for each individual case depending on the patient’s willingness to eat, presence or absence of normal gastrointestinal motility, underlying cause of the colic and on the type of medical and surgical management. This article summarizes preventative nutritional strategies for colic as well as the author’s experience and recommendations for feeding horses recovering from colic.

Grain and concentrates with high cereal grain content

Cereal grains are a common component of a horse’s ration. They have high concentration of starch and represent high-energy feeds for horses. The most common grains fed to horses in the US are oats, corn and barley. Inclusion of starch into the horse’s ration should be done wisely to maximize its digestion by pancreatic and brush border enzymes in the small bowel and minimize their passage to the cecum and colon, the sections of the intestinal tract with high microbial concentration. Starch that escapes digestion in the small bowel is rapidly fermented in the cecum and colon, which negatively alters dynamics of microbial balance, results in growth of Streptococci and Lactobacilli, production of lactic acid and bacterial fermentation products that exacerbate abdominal pain and colonic distension.
acid and lowered intestinal pH. These changes lower population of cellulolytic bacteria leading to impaired fiber fermentation, lowered acetic acid synthesis, altered intestinal barrier, dehydration of digesta, impaired motility and distention of the bowel with excess gas. This may result in large bowel displacement, torsion and volvulus. Undigested starches and their undesirable fermentation in the large bowel are therefore one of the main dietary risk factors for development of colic.

The association between feeding grain and colic has been reported in several published studies. Tinker et al. compared cereal-fed horses with grazing horses. Horses consuming 2.5-5 kg of cereal grain a day had almost 5-times increased risk of colic, while the risk was increased further when feeding >5 kg cereal grain per day (Tinker et al., 1997b). In another study, an approximately 6-times increased risk of colic was found in horses consuming >2.7 kg oats per day (Hudson et al., 2001).

Not only the amount of grain fed daily, but also the amount fed at each feeding is an important factor in colic prevention. The feeding practice should focus on maximizing pre-cecal starch digestibility which can be accomplished by offering no more than 2 g starch/kg body weight per meal (Cuddeford, 2001). For example, if a grain concentrate is 50% starch, no more than 4g/kg bodyweight or approximately 2 kg for a 500-kg horse should be fed. I recommend lowering the amount of grain concentrate even further to 1 – 1.5 kg per meal for horses with a history of colic. Horses that don’t tolerate increased proportion of energy from starches but have high energy requirements should be supplemented with alternative energy feeds, such as sugar beet pulp, vegetable oils (e.g. soybean, canola, corn or fish oil), rice bran or with complete feeds low in sugars, starches and fructans (e.g. <20% non-structural carbohydrates; NSC) and increased concentration of fat (4 – 12% AF). The overall fat concentration of the ration should be maintained below 12% dry matter (DM) to sustain normal fermentation in the hind-gut.

**Grazing**

Maximizing access to a good quality pasture has generally been considered preventative to the occurrence of colic. One study in Texas revealed that fully stabled horses or horses that had recently reduced pasture access were at 3-times increased risk of colic (Hudson et al., 2001). However, it is important to consider some drawbacks associated with grazing, such as variable content of fructans in grasses. Accumulation of fructans in the pasture can occur at times of variable environmental temperatures and light exposure. Intake of pasture with high fructan content can cause rapid fermentation and disturbance of the hind-gut microbial flora and may predispose to colic and pasture associated laminitis.

**Type of the hay and its quality**

Intake of a poor quality mature hay with high concentration of indigestible fiber (e.g. ADF >45% DM) is often responsible for ileal and colonic impactions. Alfalfa hay with high protein and mineral content promotes increased colonic pH, which has been implicated to be a factor predisposing to enterolith and fecolith formation (Hassel et al., 2008). Oat and grass hays have been shown to reduce the risk of enterolith formation (Hassel et al., 2008). Conversely, alfalfa hay has been shown to be appropriate for prevention and treatment of gastric ulcerations due to its ability to buffer gastric acidity.

**Dietary changes**

Diet change and change of hay were reported to increase the risk of colic by 5 and 9.8-times, respectively (Cohen et al., 1999). A recent change in batch of hay (different source) but not type of hay (legume vs. grass), increased the risk of colic by 4.9-times. Furthermore, a recent change in type of concentrate (pelleted vs. textured) increased the risk of colic 2.6-times (Hudson et al., 2001). Abrupt changes in the diet alter microbial populations, which alters production of volatile fatty acids and pH of ingesta. High doses of concentrate rich in starch increase fermentation in the hind-gut, lowers pH, affects
intestinal mucosa, increases production of gas and distention of the bowel. Abrupt changes in the ration commonly occur at the beginning of the grazing season, when changing the grazing paddocks or the type/source of hay, when altering the amount of feed and feeding frequency or when changing the time of feeding. In one study, the risk of simple colon obstruction and distention increased during the first week of dietary change (forage, concentrate) and the risk was reduced but still significant between 8 - 15 days of a dietary change (Hillyer *et al.*, 2002). Increased risk of colic during the first 2-weeks after the dietary change has been confirmed in other studies. Conversely, the risk for epiploic foramen entrapment extends out to 28-days post diet change (Archer *et al.*, 2008). There are several studies reporting that a recent change in hay or forage is associated with higher risk of colic than a recent change in grain or concentrate (Hillyer *et al.*, 2002; Hudson *et al.*, 2001).

The feeding practice for prevention of colic associated with diet change is to allow adaptation of intestinal microflora by introducing the new feed gradually over 7 – 10 days.

**Access to water**

An increased risk of colic was identified in horses without access to water in outdoor enclosures (Reeves *et al.*, 1996). Conversely, horses with access to ponds have been shown to be at decreased risk of suffering colic (Cohen *et al.*, 1995) and provision of water to groups of horses from sources other than buckets, troughs or tanks was associated with decreased risk (Kaneene *et al.*, 1997). Therefore, provision of fresh palatable water is critical in prevention of colic and water sources should be regularly checked for fullness and cleanliness.

**Summary of the dietetic prevention of colic**

1. Maintain consistent type and source of the forage (e.g. hay, pasture, haylage).
2. Avoid feeding mature and poorly digestible forages with high fiber content (e.g. ADF >45% DMB; NDF >65% DMB).
3. Ensure adaptation to the diet change over at least 7-10 days by gradually increasing the new feed while decreasing the current feed (e.g. 25:75 day 1-3; 50:50 day 4-6; 75:25 day 7-10; 100:0 day 7-10+).
4. Optimize transition to the pasture. Offer hay prior to the pasture turnout and allow grazing for only few hours first day. Gradually increase the grazing time over the following 7-10 days.
5. Avoid abrupt changes in feeding frequency and in amount of feeds fed.
6. Maximize feeding frequency.
7. Minimize amount of grain and concentrates with high-starch contents to 2.5 kg per day (for horse’s body weight 500 kg) and avoid feeding more than 2 kg per meal. Divide the daily amount of concentrates between at least 2 feedings a day. If energy supplementation is needed, consider alternative energy feeds, such as beet pulp, vegetable oils, rice bran or complete feeds with a restricted-starch/sugar/fructan content (e.g. <20% NSC) and high in fat (4-12% DM).
8. Provide continual access to fresh water and regularly clean water sources.
9. Offer free-choice white salt or trace-mineralized salt.

**How to feed a horse recovering from colic?**

There are only limited information and guidelines regarding feeding horses after resolution of colic. The general recommendation consists of maintenance of hydration status of the patient, correction of electrolyte status and acid-base balance with parenteral and enteral fluids. The first feeding should be initiated at the time when normal intestinal motility has been confirmed (borborygmi, absence of gastric reflux, +/- first defecation). Providing early nutritional support to these patients is critical and this is especially important for surgical colics. Availability of nutrients promotes healing of surgical sites, improves immune function, minimizes catabolism and lean muscle mass loss, provides building blocks for albumin synthesis, decreases morbidity, mortality and perhaps, shortens time of hospitalization.
Strategies for feeding colic patients differ from clinician to clinician and vary depending on the type of colic.

Daily nutrient and energy requirements (DE; Digestible Energy) of horses after colic have not been determined. However, the energy needs during hospitalization are estimated to be approximately 70% of the Maintenance Energy Requirement (Pagan and Hintz, 1986):

Estimated daily energy requirement during hospitalization: 22-23 kcal DE/kg body weight.

Protein is essential for wound healing, tissue repair, immune function, erythropoiesis, visceral protein synthesis, maintenance of oncotic pressure and tissue anabolism. The protein requirement for colic patients is unknown. In general, critically ill patients should be fed increased amount of bioavailable protein during recovery from illness. Therefore, critically ill equine patients should be provided with protein at the elevated rate of at least 1.44 g crude protein/kg body weight/day (NRC, 2007). This increased nitrogen intake is contraindicated in horses with concurrent hepatic encephalopathy or kidney failure.

Patient is willing to eat

Horses with colic should not be fed and water should not be offered throughout colic episode. Feeding and watering in horses with simple non-surgical colic should resume as soon as possible after resolution of colic signs and once intestinal motility has been confirmed. If applicable it is necessary to correct the risk factors that could lead to the colic episode. It is advisable to avoid feeding grain and concentrates with high-starch content for 1-2 weeks after the colic episode and feed high-quality forages (i.e. hay, pasture).

Horses that are recovering from a surgical colic should be fed as soon as the intestinal motility was confirmed. Patients that underwent laparotomy without enterotomy/anastomosis can often resume feeding in 12 – 24 hrs after the surgery, while horses with enterotomy or anastomosis may need to be kept off feed for 24 – 36 hrs.

In general, there are 3 approaches to the feed selection for horses recovering from colic. These strategies are used mainly based on the clinician’s preference and experience and there are no studies available to document superiority of either approach.

1. **Example of clinical conditions:** enterotomy and anastomosis of the small and large intestine; early recovery from ileal, cecal or colonic impaction; early recovery from resection of small or large intestine; early recovery from duodenitis-proximal jejunitis; recovery after esophageal obstruction or esophageal disease.

The nutritional goals of this type of ration is to feed a highly-digestible feed with low-starch content, rich in mechanically processes fiber (>15% crude fiber DM) in the pelleted form to maintain microbial flora and healthy fermentation in the cecum and colon. With this type of ration and especially during the first 3-4 days of refeeding, it is desirable to avoid long-stem hay that increases bulk of digesta which applies mechanical pressure on the intestinal suture and irritated mucosa. The examples of such feeds are pelleted complete feeds, often formulated for senior horses, or ‘hay stretchers’ and they are often fortified with vitamins and minerals. Pelleted complete feeds or ‘hay stretchers’ can be fortified with alfalfa pellets and appropriate vitamin-mineral supplement to balance the ration. This type of ration produces low volume of digesta, decreases mechanical pressure within the gut lumen, lowers mechanical friction against the intestinal mucosa, produces decreased amount of soft manure, increases gastrointestinal transit time and provides sufficient fiber to maintain motility and microbial flora.
Aside from the colic, horses with esophageal disease (i.e. esophagitis, esophageal suture) benefit from feeding this type of ration soaked in water prior to the feeding to soften the feed, alleviate pain associated with swallowing and prevent suture dehiscence. Since the esophageal healing is a prolonged process, it is recommended to feed the ration in the form of gruel for as long as 8-10 week.

Complete pelleted feeds, hay stretcher pellets or alfalfa pellets should be fed in small and frequent meals daily and this amount should be gradually increased over 3-4 days (Table 1). Small amount of molasses can be added to improve gruel palatability.

| **Table 1. Balanced ration for a hospitalized horse, body weight 500 kg** |
| Alfalfa pellets contain on average 2.2 Mcal DE/kg, Reliance® Hay Stretcher 11P Pelleted Horse Feed (Southern States Cooperative, Inc., Richmond, VA) contain approximately 2.5 Mcal DE /kg. Daily energy requirement of a hospitalized horse with body weight of 500 kg are 11.5 Mcal DE/day (22-23 kcal DE/kg body weight), this corresponds to 2.66 kg of alfalfa pellets and 2.05 kg hay stretcher daily. EquiMin® Horse Mineral (Southern States Cooperative, Inc., Richmond, VA) granular vitamin-miner supplement should be added in amount 90 g daily. The ration can be prescribed as follows: |
| **Day 1** | **Day 2** | **Day 3+** |
| Alfalfa pellets | 150 g 6x/day | 300 g 6x/day | 450 g 6x/day |
| Reliance® Hay Stretcher 11P Pelleted Horse Feed | 120 g 6x/day | 230 g 6x/day | 350 g 6x/day |
| EquiMin® Horse Mineral, granular | 15 g 2x/day | 30 g 2x/day | 45 g 2x/day |

This ration is complete and balanced and provides 11.6 Mcal DE, 4.24 kg of dry matter, NSC 12.2% AF , NDF 25% AF, fat 2.3% AF and 720 g crude protein daily.

If the patient tolerates the feeding without complications, high-quality forage such as hay or pasture can be offered in small frequent meals in 3-4 days or later, depending on the clinical status.

2. **Example of clinical conditions:** early recovery from impaction of the colon and cecum; recovery from laparotomy without enterotomy or anastomosis; early recovery from laparotomy with enterotomy or anastomosis (variable and depends on the clinician); long-term recovery after resection of the small or large intestine.

This type of ration is based on feeding a high-quality and highly digestible hay (grass, legume, grass/legume mix) that is offered in amount of 0.25-0.5 kg every 2 to 4 hrs with gradually increasing amount over 3-4 days (Table 2). High-quality and properly cured alfalfa hay rich in leaves produces manure that is softer when compared to feeding grass hays. The assessment of the hay quality should be based on both organoleptic assessment and chemical analysis.

| **Table 2. Ration for a hospitalized horse, body weight 500 kg:** |
| Good quality grass hay contains approximately 1.8-2.2 Mcal DE/kg, alfalfa hay contains approximately 2.3 – 2.9 Mcal DE/kg. Energy requirement of a hospitalized horse with a body weight of 500 kg is approximately 11.5 Mcal DE/day (22-23 kcal DE / kg body weight), this corresponds to 5.2 - 6.4 kg grass hay* daily or 4.0 - 5.0 kg alfalfa hay* daily. * Hays should always be chemically analyzed to obtain accurate nutrient and energy profile. Hays are deficient in some vitamins and minerals and may be deficient in crude protein. Therefore it is necessary to offer an appropriate vitamin-mineral/protein supplement based on the hay analysis. |
3. **Example of clinical conditions**: simple colic; laparotomy with or without enterotomy or anastomosis (variable and depends on individual clinician’s approach); recovery from impactions.

This type of ration is based on allowing the patient to graze for 20 – 30 minutes several times a day. Access to a high-quality pasture may not be on hand for all hospitalized patients but when available, it offers highly palatable, high-moisture, highly digestible diet and supports normal feeding behavior. If the patient tolerates fresh pasture without complications, high-quality hay can be offered in small and frequent daily meals in 3-4 days, depending on the clinical status.

Feeding grains and concentrates with a high-starch content should be withdrawn for at least 14 days after the surgical colic because microbial flora may have been impaired by the course of illness, alteration in feed intake and/or medication. Feeding starches would contribute to rapid fermentation and gas formation which could worsen clinical status and predispose to laminitis. Grains and concentrates can be slowly and gradually introduced third week of recovery in amount of 0.5 – 1 kg per day divided between at least 2 meals per day. If tolerated, concentrates can be increased by 0.5 kg daily until the desired amount is reached.

**Patient is not willing to eat, is anorexic/hyporexic**

There are several criteria for introduction of assisted nutritional support:

1. Patient is consuming <75% of estimated daily energy requirement for 3 days and longer.
2. Patient presents with a poor body condition (BCS <4/9).
3. Patient has a history of weight loss of >10% regardless of the previous body condition score.
4. Patient is older than 20 years, is a lactating mare or a mare in the third trimester of pregnancy.
5. Patient is hypotriglyceridemic.

Methods for increasing palatability of the feed for horses are limited and include offering freshly cut grass, grazing or flavoring feeds with molasses or carrots. If the patient is not willing to voluntary consume the feed, has normal intestinal motility and gastric reflux and ileus is absent, it is indicated to initiate assisted enteral nutritional support. Enteral nutrition can be administered via naso-gastric feeding (NG) open-ended tube. The diet is prepared as a gruel from the soaked pelleted complete feed or pelleted hay stretcher (crude fiber >15% as-fed) with or without addition of vegetable oil (30-400 ml/day) and appropriate vitamin-mineral supplement. Pellets can be pulverized before soaking in a Willey mill or soaked and mixed in the bucket. Alternatively, there is a commercially available pulverized high-fiber product Fibervive (Oxbow Enterprises Inc.) for the NG tube feeding (Table 3). The amount of water needed to prepare the gruel varies depending on the dry pellet and NG feeding tube diameter but is on average 4 liters per 1 kg of the dry feed. The gruel is administered 4-6 times daily with a pump or with a large syringe. The amount of gruel administered daily gradually increases over 4 days. For example, a 500 kg hospitalized horse (estimated daily energy requirement 11.5 Mcal DE): 25% (2.9 Mcal) day 1; 50% (5.8 Mcal) day 2; 75% (8.6 Mcal) day 3; 100% (11.5 Mcal) day 4+ (Table 3). The NG feeding tube should be flushed with a 1 liter of water after each feeding to prevent clogging and if left in place it should be closed to prevent air suction. The maximum volume of the gruel per feeding for a 500 kg horse is approximately 7 liters and this volume includes the water used for flushing.
Table 3. Gruel for the NG tube feeding. Complete and balanced ration for a hospitalized horse, body weight 500 kg.

<table>
<thead>
<tr>
<th>Feeds and nutritional factors</th>
<th>Day 1 (25% DE)</th>
<th>Day 2 (50% DE)</th>
<th>Day 3 (75% DE)</th>
<th>Day 4+ (100% DE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibrevive (kg)</td>
<td>1.1</td>
<td>2.2</td>
<td>3.3</td>
<td>4.4</td>
</tr>
<tr>
<td>EquiMin® Horse Mineral (g)</td>
<td>23</td>
<td>45</td>
<td>68</td>
<td>90</td>
</tr>
<tr>
<td>Water (liters)</td>
<td>4.5</td>
<td>9</td>
<td>13</td>
<td>17</td>
</tr>
<tr>
<td>Digestible energy (Mcal)</td>
<td>2.9</td>
<td>5.8</td>
<td>8.6</td>
<td>11.5</td>
</tr>
<tr>
<td>Total volume (liters)/day</td>
<td>~6</td>
<td>~11</td>
<td>~17</td>
<td>~22</td>
</tr>
<tr>
<td>Crude protein (g/day)</td>
<td>184</td>
<td>368</td>
<td>551</td>
<td>735</td>
</tr>
<tr>
<td>Fat (% in the dry feed)</td>
<td>3.14</td>
<td>3.14</td>
<td>3.14</td>
<td>3.14</td>
</tr>
<tr>
<td>NDF (% in the dry feed)</td>
<td>35.7</td>
<td>35.7</td>
<td>35.7</td>
<td>35.7</td>
</tr>
<tr>
<td>Dry matter intake (kg/day)</td>
<td>1.1</td>
<td>2.1</td>
<td>3.1</td>
<td>4.1</td>
</tr>
</tbody>
</table>

* Fibervive (Oxbow Enterprises, Inc., Murdock, NE)

EquiMin® Horse Mineral (Southern States Cooperative, Inc., Richmond, VA)

* The total daily volume of the gruel should be divided between 4-6 feedings daily. 1 liter of water is needed to flush the feeding tube after each feeding. The volume per each feeding should not exceed 7 liters for a 500 kg horse and it includes the water for flushing.

Patients with ileus or gastric reflux and those with disease that is expected to prevent voluntary feed intake in 2-3 days after the surgery should be fed parenterally.

Abbreviations: DM = Dry Matter; AF = As Fed; DE = Digestible Energy; ADF = Acid Detergent Fiber; NDF = Neutral Detergent Fiber; 1 Mcal = 1000 kcal; NSC = Non-structural Carbohydrates (WSC + Starch); WSC = Water Soluble Carbohydrates.

References


HERBICIDES IN MANURE:
HOW DOES IT GET THERE AND WHY SHOULD I CARE?

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Summary

In recent years, farmers and home gardeners in many countries have experienced damage to various vegetable and flower crops following application of horse and livestock manure, compost, and hay to the soil. The symptoms exhibited on the crops are poor seed germination; death of young plants; twisted, cupped, and elongated leaves; misshapen fruit; and reduced yields. These symptoms can be caused by other factors, including diseases, insects, and herbicide drift, but another possibility for the source of this crop injury is the presence of certain persistent herbicides in the organic products applied to amend the soil. Aminopyralid, clopyralid, and picloram are the herbicides most associated with this damage. They are sometimes used in the production of hay to control broadleaf weeds. Research indicates that herbicide residue on the hay passes intact through the animal that consumes it, but is still active as an herbicide in the manure. Thus, the hay, manure, and compost made from the hay and manure still have the ability to damage or kill broadleaf plants such as tomatoes and beans.

Last year, I communicated directly with several farmers and gardeners in my area that lost crops because they used contaminated manure or compost provided free from their neighbors who owned horses, cattle, or llamas. This loss resulted in strained relationships, and in one case, the threat of a lawsuit. So, to prevent damage to future crops, livestock and horse owners who give away or sell manure for composting or crop production should be aware of whether any of these herbicides were used in the production of the hay they feed their animals. They should share that information with the end-users of the hay and manure. Farmers and gardeners should also ask about the herbicide history of any manure, compost, or hay they acquire. Many hay producers will continue to use these herbicides because they are valuable tools that help them produce high quality, weed free hay with a minimum of effort and expense. But to prevent future damage to commercial crops and gardens, information about the use of these herbicides needs to be communicated from the hay producer, to the horse and livestock owner, and on to the farmer and gardener.

Introduction

Many farmers and home gardeners have reported damage to vegetable and flower crops after applying horse or livestock manure, compost, or hay to the soil. The symptoms reported include poor seed germination; death of young plants; twisted, cupped, and elongated leaves; misshapen fruit; and reduced yields. These symptoms can be caused by other factors, including diseases, insects, and herbicide drift. Another possibility for the source of these crop injuries that should also be considered is the presence of certain herbicides in the manure, compost, or hay applied to the soil.
The Herbicides of Concern

Aminopyralid, clopyralid, fluroxypyr, picloram, and triclopyr are in a class of herbicides known as *pyridine carboxylic acids*. They are registered for application to pasture, grain crops, non-residential lawns, certain vegetables and fruits, and roadsides in many states. The herbicides containing these chemicals registered for use in North Carolina are listed in Table 1. Information on the herbicides registered for use in your state can be obtained through the Cooperative Extension office, the state department of agriculture, or your local agricultural chemical dealer. Keep in mind that hay is often transported across state lines. So, even if the herbicides are not used in your state, the hay you purchase may be affected.

These herbicides are used to control a wide variety of broadleaf weeds including several toxic plants that can sicken or kill animals that graze them or eat them in hay. Based on USDA-EPA and European Union agency evaluations, when these herbicides are applied to hay fields or pasture, the forage can be safely consumed by horses and livestock - including livestock produced for human consumption. These herbicides pass through the animal’s digestive tract and are excreted in urine and manure. They can also remain active in the manure even after it is composted. They can also remain active on hay, straw, and grass clippings taken from treated areas. The herbicides leach into the soil with rainfall, irrigation, and dew. As with many other herbicides, they can remain active in the treated soil.

The chemicals of greatest concern are picloram, clopyralid, and aminopyralid because they can remain active in hay, piles of manure, and compost for an unusually long time. These herbicides eventually break down through exposure to sunlight, soil microbes, heat, and moisture. Depending on the situation, the herbicides can be deactivated in as few as 30 days, but some field reports indicate that breakdown can take several years. Degradation is particularly slow in piles of manure and compost. When mulches, manures, or composts with herbicide activity are applied to fields or gardens to raise certain vegetables, flowers, or other broadleaf crops, potentially devastating damage can occur (Table 2).

<table>
<thead>
<tr>
<th>Pasture and hayfields</th>
<th>Commercial turf and lawns</th>
<th>Commercial vegetables and fruits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curtail (2,4-D + clopyralid)</td>
<td>Confront (triclopyr + clopyralid)</td>
<td>Clopyr AG (clopyralid)</td>
</tr>
<tr>
<td>Forefront (aminopyralid + 2,4-D)</td>
<td>Lontrel (clopyralid)</td>
<td>Stinger (clopyralid)</td>
</tr>
<tr>
<td>GrazonNext (aminopyralid + 2,4-D)</td>
<td>Millennium Ultra Plus (MSMA + 2,4-D + clopyralid + dicamba)</td>
<td></td>
</tr>
<tr>
<td>Grazon P+D (picloram + 2,4-D)</td>
<td>Millennium Ultra and Ultra 2 (2,4-D + clopyralid + dicamba)</td>
<td></td>
</tr>
<tr>
<td>Milestone (aminopyralid)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Redeem R&amp;P (triclopyr + clopyralid)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surmount (picloram + fluroxypyr)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All products listed are manufactured by Dow Agrosciences, LLC with the exceptions of the Millennium products by Nufarm Americas Inc. and Clopyr AG by United Phosphorus, Inc.
Table 2. Crops known to be sensitive to picloram, clopyralid, or aminopyralid are:

<table>
<thead>
<tr>
<th>Crops</th>
<th>Carrots</th>
<th>Compositae family</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cotton</td>
<td>Dahlias</td>
<td>Eggplant</td>
</tr>
<tr>
<td>Flowers, in general</td>
<td>Grapes</td>
<td>Legumes</td>
</tr>
<tr>
<td>Lettuce</td>
<td>Marigolds</td>
<td>Mushrooms</td>
</tr>
<tr>
<td>Peas</td>
<td>Peppers</td>
<td>Potatoes</td>
</tr>
<tr>
<td>Roses, some types</td>
<td>Spinach</td>
<td>Sugar beets</td>
</tr>
<tr>
<td>Strawberries*</td>
<td>Sunflowers</td>
<td>Tobacco</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>Umbelliferae family</td>
<td>Vegetables, in general</td>
</tr>
</tbody>
</table>

*Applies to aminopyralid and picloram only.

This information was obtained from product labels of many of the herbicides listed in Table 1, the DowAgriSciences article for cattlemen: (http://www.dowagro.com/PublishedLiterature/dh_02a6/0901b803802a69fd.pdf?filepath=/PublishToInternet/Intern etDOWAGRO/range/pdfs/noreg/010-57689, and the DowAgriSciences Manure Matters website (http://manurematters.co.uk).

How to Prevent Herbicide Damage to Non-Target Plants

The label on every herbicide product contains detailed instructions for use, including animal feeding restrictions and safe use of manure or crop residues. When used as directed on the labels, these herbicides should not cause any of the problems noted above. The manures and plant residues are safe to apply to grass pastures and grass hayfields - effectively recycling them. Most of these herbicides have a crop rotation restriction of at least 12 months before certain vegetable or forage legume crops can be planted in treated land.

The problems arise when the hay, manure, or other affected materials are sold or given to others who have no knowledge of the herbicides used or of the adverse effects their residues can have on other plants. The information about the herbicide persistence and effects on broadleaf plants does not always follow with the hay, manure, or compost. Every individual in the chain of use of products treated with these herbicides should provide detailed information on the herbicide restrictions to prevent potentially catastrophic problems for other farmers, gardeners, and for themselves (including possible liability).

Hay Producers and Dealers

If you raise hay, make sure you know if any herbicide used has the potential to remain active in the manure or urine after consumption. Communicate –verbally and in writing – that the manure is not usable as a fertilizer, soil amendment, or compost for broadleaf plants. Landowners should know and have a written record of the herbicides applied to their fields. Custom applicators must use all registered herbicides in a manner consistent with its labeling and should communicate what products are applied to customers’ fields and provide a copy of the herbicide label(s). (see footnote) The labels provide all the information on restrictions. The herbicides of concern can also remain active on the hay itself. Be cautious about selling or giving away old hay for use as mulch or for making compost. The hay can be sold for consumption by livestock and horses, but be sure the purchaser is aware that the herbicide will pass through into the manure. Advise people feeding this hay to their animals to spread the manure on grass pastures or grass hayfields, being sure to follow all safety guidelines and regulations. According to the herbicide labels, plant materials treated with these herbicides should not be considered safe to grow sensitive crops until the plant materials are completely decayed. Accelerate breakdown of plant residues by incorporating evenly into the surface soil. Breakdown of the herbicides is most rapid in sunlight under warm, moist conditions and may be enhanced with irrigation.
Livestock and Horse Owners

If you buy hay for your animals, ask the farmer or seller which herbicides, if any, were used in producing the hay. Consult a copy of the herbicide label. A simple indicator that these herbicides were likely not used in the production of hay is the presence of legumes such as lespedeza, clovers, or alfalfa. If the hay has legumes in it, it has probably not been treated with any of these herbicides. The absence of legumes in hay, however, does not mean that these herbicides are present. If you do not know the herbicide “history” of the hay, do not sell or give away the manure from animals that consumed hay for use in growing plants or to make compost as it may contain one of the herbicides of concern. Manures that contain these herbicides can be safely spread on grass pastures or grass hayfields. Contact your local Extension agent or Natural Resource Conservation Service office to develop a manure management plan. Note: It takes 4 to 7 days for most animals’ digestive tracts to clear and the manure produced to be free of any herbicide residue.

Farmers and Gardeners Wanting to Use Manure or Compost

Before acquiring or using manure - fresh, aged, or composted - ask what the animals were fed, the origin of the hay, and what, if any, herbicides were used on the hay or pasture. Some livestock owners can tell you this, but many might not know the products used or origin of the hay they purchased. They may suggest the manure is “safe” because their animals have not been affected. If you don’t know which, if any, herbicides were used, use the bioassay described below to test for the presence of these herbicides. Do not use the manure or compost to grow sensitive crops without knowing its herbicide history or testing to see that it is safe. If you find yourself with a small quantity of contaminated manure or compost, spread it on a grass pasture, grass hayfield, or non-sensitive, non-food crop area. Great care should be taken in using contaminated manure or compost to grow commercial food crops. Consult the herbicide product label to determine if the pesticide is registered for use (legally permitted to be applied) to that crop. If the product has already been applied to the soil, tilling it several times during the growing season, irrigating the area, and planting it into a non-sensitive cover crop for a year or two will help the herbicides break down. Conduct a pot or field bioassay, as described below, before planting any sensitive crops in the area.

Farmers and Gardeners Wanting to Use Hay

If you want to use hay as mulch or in your compost pile, find out what, if any, herbicides were used on the field. If you find yourself with contaminated hay, spread it on non-sensitive, non-food crop areas, arrange to have it hauled away and disposed of safely, or (least desirable) burn it. If the hay has already been applied to the field or garden, remove what you can, till the soil, sow a non-sensitive cover crop, and let it grow for a year or two to help the herbicide break down. Conduct a pot or field bioassay, as described below, before planting any sensitive crops in the area.

How to Test for the Presence of Herbicides: Pot and Field Bioassays

Some laboratories can test for the presence of these herbicides, but the tests are expensive and not as sensitive as a plant bioassay that you can perform yourself. This simple pot bioassay involves growing tomatoes, beans, or peas, which are very sensitive to the presence of these herbicides, in the aged manure or compost. First, take a number of random, representative samples (small shovelfuls) from throughout the pile of aged manure or compost, being sure to get deep inside the pile. Mix thoroughly. If there are separate sources of manure or compost, conduct individual assays for each. Prepare 3 to 6 small (4- to 5-inch) pots with a 1:1 mix of the manure or compost with a commercial potting mix with fertilizer. Fill several control pots with only the commercial potting mix. Put saucers underneath each pot, or position...
the pots far enough apart so that water running out of the bottom of the pots will not reach another pot. Plant three pea or bean seeds or a small tomato transplant in each pot, water, and let them grow for two to three weeks. There should be at least three sets of true leaves on the peas or beans. If the plants in the control pots grow normally and the ones in the pots with manure or compost do not, you can assume the manure or compost is contaminated with an herbicide that will adversely affect sensitive plants. If they all grow normally, it would be reasonable to assume that the manure or compost is fine. Keep in mind, however, that the test will only be as good as the samples you take. It would be better to err on the side of too many samples than too few (at least 20 per pile). You can create a similar test for hay by filling the pot with commercial potting mix and spreading a thick layer of the hay on top. This bioassay is explained in detail on the DowAgrisciences Manure Matters website (http://www.manurematters.co.uk/) and on the Washington State University Web site at http://www.puyallup.wsu.edu/soilmgmt/Pubs/CloBioassay.pdf (they recommend 2 parts manure or compost: 1 part potting soil).

If a field or garden site has previously been treated with one of the herbicides of concern or been contaminated through the application of treated manure, compost, or hay, a field bioassay can be conducted. Plant peas or beans in short rows scattered throughout the affected area. If herbicidal symptoms appear, do not plant sensitive plants; plant grasses. Test again the following year. If the test plants grow normally, it should be safe to grow broadleaf crops.

Please note that these tests are not fool proof. For example, if the herbicide residue is very deep in the soil and your samples do not reach to that depth, there is a possibility of injury if the crop roots reach that depth.

**Responsible Herbicide Use = Healthy Farms and Gardens**

Animal manures and composts made from them are excellent sources of nutrients and organic matter for growing food crops. Soils mulched or amended with manure and compost become dark, aromatic, fertile, and active with earthworms and beneficial microorganisms. Farmers and gardeners are encouraged to use these products, but must exercise proper caution to prevent damage.

Herbicides are important tools that many hay producers use to produce quality, weed-free hay, but not all hay producers use these particular herbicides of concern and many hayfields and pastures do not have any herbicides applied them.

Everyone should read an herbicide’s product label instructions before use. It is very important to remember that each pesticide product label states, “It is a violation of Federal law to use this product in a manner inconsistent with its labeling.” It is suggested that hay producers inform their hay buyers of herbicides they have applied to their fields and provide them with a copy of the herbicide label with the restrictions. Likewise, livestock and horse owners who give or sell manure for composting or crop production should be aware of what they are feeding their livestock and horses and share that information. All parties should communicate with the end-users of the hay and manure. Farmers and gardeners should ask about the herbicide history of manure, compost, or hay they acquire. Farmers and gardeners need to be fully informed about what they are applying to their soil because the results can be disastrous for a farm business or gardener if one of these herbicides has been applied.

Note: Grass clippings may also be a source of herbicide contamination. Be particularly careful about obtaining grass clippings from golf courses and other commercial turf fields where these herbicides are commonly used. Most homeowners do not use these herbicides because they are not labeled for use on residential lawns in most areas.
Footnote

EPA’s Office of General Counsel recently interpreted section 12(a)(2)(G) of the Federal Insecticide Fungicide and Rodenticide Act (FIFRA), “It shall be unlawful for any person to use any registered pesticide in a manner inconsistent with its labeling” as it relates to a grower hiring an applicator to apply a pesticide and whether the grower can be held liable under FIFRA if there is not compliance on the grower’s treated land with post application label requirements such as pre-harvest intervals, plant back restrictions, crop rotation restrictions, and restricted entry intervals. The Office of General Counsel believes a grower can be held responsible for any violations associated with these post application requirements.

About This Article

Most of the text in this article comes directly from an NC Cooperative Extension Service bulletin that will soon be published. I am the lead author on that bulletin with my two coauthors from NC State, Dr. Sue Ellen Johnson, Assistant Professor and Forage Specialist, and Dr. Katie Jennings, Vegetable and Small Fruit Weed Science Assistant Professor. In addition, much of the information for this article came directly from the herbicide product labels and the United Kingdom DowAgrisciences website devoted to this issue (http://manurematters.co.uk).

Resources for More Information

Washington State University Web site on clopyralid carryover includes pictures of affected vegetables, research results, and the bioassay protocol:
http://www.puyallup.wsu.edu/soilmgmt/Clopyralid.htm

Article from Minnesota Extension explaining the problem in hay and how to avoid it. The article is devoted to “ditch hay”, but the information is relevant to all hay:
http://www.extension.umn.edu/distribution/livestocksystems/M1197.html

CDMS Agro-chemical database with access to all the herbicide labels:
http://www.cdms.net/LabelsMsds/LMDefault.aspx?

Dow Agrosciences United Kingdom website with information on aminopyralid:
http://www.manurematters.co.uk/
Summary

Good nutrition is a critical part of good foal care. Malnourishment due to inadequate intake, abnormal absorption, or increased utilization results in multiple organ system dysfunction and increased morbidity and mortality. The most devastating consequence of undernutrition for the neonatal foal is decreased resistance to infection. Any feeding program for foals must address the neonate’s degree of maturity, requirements for growth, special nutritional needs created by concurrent illness, and an understanding of nutritional formulas and routes of administration available. Newborn foals nurse 5 – 7 times an hour and consume 20 – 25% of their body weight in milk daily. Broodmare nutrition during late pregnancy influences in utero fetal nutrition as well as early foal nutrition. If a foal’s own dam is not available, then alternate feeding options include a surrogate dam or the use of commercial formulas. Raising orphans requires attention not only to nutritional demands, but also to providing an environment that encourages proper socialization and behavior. The older foal’s nutrition must be balanced and caloric intake controlled to prevent energy, protein / amino acid, trace mineral and calcium / phosphorus imbalances that can contribute to developmental orthopedic diseases. Examples of these acquired bone diseases include contractural deformities, osteochondrosis, physitis and certain forms of Wobbler Disease. Growth charts and body scoring guidelines for foals are available on www.foalcare.com.

Introduction

Any feeding program for foals must address the neonate’s degree of maturity, requirements for growth, special nutritional needs created by concurrent illness, and a thorough understanding of nutritional formulas and routes of administration available. Malnourishment due to inadequate intake, abnormal absorption, or increased utilization results in multiple organ system dysfunction and increased morbidity and mortality. Malnutrition has been associated with weight loss, depressed growth rates, impaired wound healing, gastrointestinal atrophy, impaired digestion and absorption and decreased immune function. The most devastating consequence of undernutrition for the neonate is decreased resistance to infection.

Broodmare Nutrition

Although the focus of this discussion is foal nutrition, the dam’s nutrition during late pregnancy has an important impact on fetal development. The mare’s nutritional needs increase during the last 3 months of pregnancy and reach a peak during early lactation (Table 1).

Table 1. Broodmare Nutrient Requirements: Late Gestation through Early Lactation

<table>
<thead>
<tr>
<th>Stage of Gestation</th>
<th>DE (Mcal/kg)</th>
<th>CP (%)</th>
<th>Ca (%)</th>
<th>Phos (%)</th>
<th>Cu (ppm)</th>
<th>Zn (ppm)</th>
<th>Vit E (IU/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 – 10 mos</td>
<td>2.25</td>
<td>10</td>
<td>0.43</td>
<td>0.32</td>
<td>10</td>
<td>40</td>
<td>80</td>
</tr>
<tr>
<td>11 mos</td>
<td>2.4</td>
<td>10.6</td>
<td>0.45</td>
<td>0.34</td>
<td>10</td>
<td>40</td>
<td>80</td>
</tr>
<tr>
<td>0 – 3 mos</td>
<td>2.6</td>
<td>13.2</td>
<td>0.52</td>
<td>0.34</td>
<td>10</td>
<td>40</td>
<td>80</td>
</tr>
<tr>
<td>3 mos to weaning</td>
<td>2.45</td>
<td>11</td>
<td>0.36</td>
<td>0.22</td>
<td>10</td>
<td>40</td>
<td>80</td>
</tr>
</tbody>
</table>
The mare’s diet prepartum may affect milk composition. For example, mares receiving calcium deficient diets prior to delivery and during lactation raised foals that had thinner and weaker bones than foals from mares maintained on an adequate diet (Glade, 1993). Copper and zinc deficiencies have been implicated as a cause of developmental orthopedic disease (DOD). Hepatic stores are an important source of these minerals for young foals. The fetal liver accumulates minerals during late gestation. Therefore, adequate supplementation of broodmares during the last trimester may help prevent mineral deficiencies in the foal (Ullrey et al., 1974; Pearce et al., 1998).

**Normal Physiology and Nutrient Requirements**

Newborn foals nurse on average 4 to 7 times an hour during the first week of life, consume 20 to 30% of their body weight (BW) in mare’s milk daily, and gain ≥1 to 3 lbs/day (0.5 – 1.5 kg/day) during the first 30 days of life. The actual nutrient requirements of nursing foals have not been determined but estimates are based on the nutrients supplied by mare’s milk and the estimated volume of milk consumed by growing foals. When compared to cow and goat milk, mare’s milk is lower in energy, higher in water content, lower in fat and total solids and higher in lactose (Table 2). During the first few weeks post partum the concentration of total solids and protein decreases.

**Table 2. Comparison of Milk from Mare\(^a\), Cow, Goat and Selected Milk Replacers**

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Milk</th>
<th>Milk Replacer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mare</td>
<td>Cow</td>
</tr>
<tr>
<td>Total Solids DM (%)</td>
<td>10.7</td>
<td>12.5</td>
</tr>
<tr>
<td>Crude protein (%)</td>
<td>25</td>
<td>27</td>
</tr>
<tr>
<td>Crude fat (%)</td>
<td>17</td>
<td>38</td>
</tr>
<tr>
<td>Crude fiber (%)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Calcium (%)</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>Phosphorus (%)</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Zinc (ppm)</td>
<td>23</td>
<td>40</td>
</tr>
<tr>
<td>Copper (ppm)</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Selenium (ppm)</td>
<td>0.04</td>
<td>0.024</td>
</tr>
</tbody>
</table>

\(a\) During first 4 months of lactation; \(b\) Land O Lakes; \(c\) Pet-Ag Inc; \(d\) Buckeye Nutrition

Light breed mares produce approximately 3% of their body weight in milk/day during the first 3 months of lactation. The healthy, term foal consumes 20 to 30% of its BW as milk daily; 10 to 13 L of milk/day for light breed foals and 14 to 17 L of milk/day for warm blood or draft foals. Mare’s milk contains approximately 480-600 kcal/L and provides a foal with 120 to 160 kcal/kg/day, 5.0 to 7.2 gm protein/kg/day, and 4 to 5 gm fat/kg/day. By 5 weeks of age a foal’s requirements have decreased to 98 kcal/kg/day (gross energy) and 3.7 gm crude protein/kg/day (Oftedal et al., 1983)).

The vitamin and trace mineral requirements for newborn foals are based on mare’s milk composition. All trace minerals are very low in milk (higher in colostrum). The estimated daily intake of certain trace minerals from mare’s milk is as follows: iron: 10mg; copper: 7.0mg; manganese: 17mg; zinc: 40mg; selenium: 0.09mg (Rooney, 1998). Even healthy neonatal foals seem to live on the brink of copper.
(Okumura et al., 1998) zinc and iron (Brommer and van Oldruitenborgh-Oosterbaan, 2001) deficiencies during early growth. Neonatal foals have higher trace mineral requirements than adult horses.

Reliance on prenaturally acquired mineral reserves and increased efficiency of absorption are the likely mechanisms by which nursing foals avoid mineral deficiencies until the ingestion of solid food begins. Controversy continues regarding the efficacy of oral mineral supplementation in young foals to correct mineral deficiencies and prevent developmental orthopedic disease (DOD) (Knight et al., 1990). One commercially available product containing trace minerals and vitamins is Foal Aide® (Buckeye Feeds, Dayton OH). Various guidelines exist for copper and zinc supplementation. In general, foals should receive: Cu - 50 ppm of DM (dry matter) and Zn - 60 ppm of DM. In addition to its role in bone development, zinc status has also been linked to immune function. Early hallmarks of zinc deficiency include lymphopenia and thymic atrophy (Fraker et al., 2000). Selenium deficiency has been associated with myopathies, steatitis and depression of the immune system with increased susceptibility to diarrhea and respiratory disease. A foal’s selenium requirement is 0.2 mg/kg of diet DM.

Vitamin requirements are also extrapolated from the milk intake of normal foals. In other species vitamin A and E deficiencies have been associated with decreased resistance to respiratory infection. Antioxidant supplementation has been associated with improved immune function associated with increased levels of IL-2, elevated numbers of total lymphocytes and T-cells, increased killer cell activity, augmented antibody response to antigen stimulation, decreased lipid peroxidation and decreased prostaglandin synthesis (Hall, 2001). Vitamin C is present in high concentrations in white blood cells and is utilized rapidly during infection. Reduced vitamin C levels are associated with reduced immune function. Vitamin E helps maintain cell membrane integrity by limiting lipid peroxidation by reactive oxygen species. Vitamin E deficient states are associated with decreased B-cell antibody production and T-cell proliferation in response to mitogenic stimulation and an increased rate of infection. Supplementation with ascorbic acid and vitamin E has been shown to have neuroprotective effects against central nervous system (CNS) ischemia and should be considered in the treatment of foals suffering hypoxic-ischemic encephalopathy. Unfortunately there are no specific guidelines for vitamin supplementation in neonatal foals. The following doses have been used clinically: Vitamin C (Ascorbic acid): 100 mg/kg IV/PO q24 hrs; Vitamin E: 5000 U PO (68 IU/kg IV diluted in fluids) q24 hrs (Vaala, 2009).

Due to the immaturity of the large bowel, neonatal foals rely on small intestinal digestion of starch and carbohydrates and utilize milk lactose as their primary energy source. The development of brush border disaccharidase activity in the equine small intestine follows a pattern similar to other mammals and increases to adult levels by 7 months of age. Lactase is the predominant disaccharidase in the equine small intestine until 3 to 4 months of age, when maltase activity equals that of lactase.

Coprophagy is normal in young foals and occurs once every few hours during the first week of life. The rate of coprophagy is highest during the first 8 weeks (Crowell-Davis and Houpt, 1985) and gradually decreases in frequency during the next month. This behavior most likely plays a role in the bacterial inoculation of the gut and the acquisition of vital nutrients, vitamins and enzymes and does not indicate dietary deficiencies. Some studies suggest foals actively seek out the feces of their own dams which suggests a response to a maternal pheromone which signals the presence of deoxycholic acid or similar acids in the feces that the foals may be deficient in and which may be required for gut immunocompetence and myelination of the nervous system (Crowell-Davis and Houpt, 1985; Hornicke and Bjornhag, 1979). Since feces can also harbor parasite eggs, it is strongly recommended that the dam be dewormed within 24-48 hours of foaling. Other pathogens that can be transmitted via the fecal – oral route include rotavirus, Salmonella, and Clostridia sp (i.e., C. difficile and C. perfringens). As the foal ages it begins to mimic its dam as it starts to ingest solid food. Nursing frequency decreases to 1.5 to 2 times per hour during the months before weaning.
Immunoglobulins and Colostrum

The epitheliocorial equine placenta prevents in utero transfer of immunoglobulins (antibodies) from dam to fetus prepartum. Except for trace amounts of IgM, newborn foals are born agammaglobulinemic and are dependent on absorption of IgG antibody from the colostrum. Active pinocytosis of the large proteins, including antibodies, occurs at a maximal rate during the first 6 to 10 hrs postpartum and declines rapidly thereafter. Gut closure is complete by 18 to 24 hrs of age. Prematurity, cold stress, hypoxic gut damage, and ingestion of other food sources may alter immunoglobulin absorption unpredictably.

Colostrum has been recognized as a valuable “first meal” in many species including man since it contains many non-nutrient factors including hormones, growth factors, enzymes and trophic factors in addition to calories. Equine colostrum is produced by selective secretion of humoral antibodies into the mammary gland during the last month of gestation with peak secretion occurring during the last 2 weeks of pregnancy. IgG constitutes over 80% of the immunoglobulins in colostrum; the remaining 20% of immunoglobulins include IgM and IgA. Colostrum is energy dense and has higher levels of protein, calories, and vitamins A and E than mare’s milk. Colostrum contains immunoglobulins, complement and lactoferrin that aid in defense against pathogens, low MW proteins that enhance efficiency of absorption of macromolecules, and epidermal growth factor that enhances gastrointestinal mucosal growth and may help prevent gastric ulcers. Colostrum also has laxative properties. Foals that ingest and absorb sufficient amounts of colostral antibodies have a serum [IgG] > 800mg/dl by 18 - 20 hrs of age.

If equine colostrum is not available, bovine colostrum can be used, but the foal will not receive immunoglobulins against many equine-specific pathogens and the half-life of absorbed IgG will be shorter and more variable. On larger breeding operations a colostrum bank should be established. Kept frozen, colostrum can be stored for at least a year without significant loss of immunoglobulin. It should be stored in small aliquots and should not be refrozen once it has been thawed.

The Orphan Foal

Feeding the orphan foal is relatively straight forward since nutrient requirements and feeding regimes can be based on the nutrient intake and nursing behavior of healthy foals. The orphan usually represents a foal with a healthy GI tract and normal nutrient requirements. Your choices are: what formula to use, how much to feed, how often and how to administer it. Orphan foals fare best if bonded to a nurse mare. This situation ensures the most physiologic diet and nursing regimen and allows the orphan to maintain normal social and dietary behavior patterns. Bucket-raised orphans that are deprived of any four-legged role model tend to exhibit delayed ingestion of solid feeds including hay, grass and creep feed. Orphans raised in isolation do not exhibit normal coprophagy and miss the opportunity to interact with other foals. If a nurse mare is not an option, then a quiet equine chaperone should be found for the orphan. Another viable option is raising several orphans together. Orphans are more prone to gastrointestinal disturbances ranging from constipation to diarrhea. Growth spurts should be controlled to reduce the risk of developmental orthopedic disease (DOD).

Fresh mares’ milk fed straight from the udder is ideal. A nurse mare represents the perfect solution: a source for an all milk diet available on demand and a role model and protector for the foal. If a nurse mare is not available there are several protocols that can be used on non-lactating mares to encourage them to lactate and accept a foal. One treatment protocol to induce non-pregnant mares to lactate and become foster dams for orphan foals incorporates the use of domperidone. The regimen consists of a minimum 7-day course of: Domperidone (1.1 mg/kg, q 24 h, PO) + Regu-Mate™ (44 mg q 24 h, PO) + Estradiol-benzoate-in-oil (10 mg, q 24 h, IM) (Daels et al., 2002). In the author’s experience this protocol also has been used effectively to treat postpartum mares that are rejecting their foals and demonstrating varying degrees of agalactia.

If a nurse mare or goat is not available, then bucket feeding is the next best option. Popular enteral formulas include mare’s milk, goat’s milk, and artificial replacers formulated for foals. Mare’s milk is preferred. Recent studies by Ousey et al. (1997) confirmed that mare’s milk is the preferred diet for a foal in
terms of digestible energy and nutrients. Energy balance data indicate this diet provides enough excess energy to support growth as early as post partum day 2. Goat’s milk is higher in fat, total solids and gross energy than mare’s milk. (See Table 2) It is more digestible than cow’s milk due to its composition of simpler fatty acids, smaller fat globules and better buffering capacity. Foals raised on goat’s milk occasionally exhibit constipation and metabolic acidosis. Cow’s milk can be substituted for mare’s milk if additional sugar is added and some of the fat is removed. This can be accomplished using 2% skim milk and adding 20 gm dextrose/L milk (i.e. 40 ml of 50% dextrose per L of milk).

A variety of commercially available mare’s milk replacers are available. The ideal replacer should closely match the energy density of mare’s milk (approximately 0.5 kcal/ml as fed) and should contain 23% CP, 15% crude fat, 59% sugar, and less than 0.5% fiber on a DM basis. One palatable formula that is palatable and well tolerated by most foals is Mare’s Match (Land O Lakes). Many formulas when reconstituted are more concentrated than mare’s milk with nearly double the DM content and may predispose to constipation and dehydration. Free access to water reduces the risk of dehydration. Ousey’s data comparing energy balance between foals allowed to nurse from their dams, bottle fed milk replacer or maintained on total parenteral nutrition (TPN) showed that foals fed milk replacer required several days to adapt to the formula before achieving a positive energy balance and similar growth rates as the dam reared foals (Ousey et al., 1997). Dilution of the formula was required beyond the manufacturer’s recommendations due to the excessive energy density. Based on her data, Ousey advises that the final concentration of any milk replacer should be diluted until its energy density is equal to or less than that of mares’ milk (approximately 2.5 MJ/L). Use of acidified milk replacers, such as Mare’s Milk Plus (Buckeye Feed) allows milk to be left out for longer periods without the danger of it spoiling.

Routes of administration include bottle feeding or bucket feeding. Bottle feeding is not a long-term option and is the least desirable for several reasons. Bottle-fed foals often bond too closely with their human surrogates and are slow to develop normal social behaviors. Without a four-legged role model, many orphans are slow to learn to eat creep feed and to graze. They can not be left unattended outside. Bucket feeding milk replacer in a bucket is preferable to bottle feeding. Raising orphans in a group is better than rearing one by itself. If a foal has learned to nurse from the bottle it may take some time to teach it to drink from a bucket. Sometimes placing only the nipple in a shallow bowl of milk will entice the foal to use the nipple as a straw and suck milk from the bowl. Eventually the foal begins drinking without the nipple.

On demand bottle or bucket feeding is ideal but often impractical. Foals less than 7 days of age should be fed a minimum of every 2 hours. If the foal’s gut function is normal, then at least 10% of its BW in milk can be fed during a 24 hour period. If mare’s milk must be reheated a bottle warmer is preferred to the microwave to prevent over cooking, uneven heating and the destruction of normal bacteria that would be acquired naturally by the foal while nursing from the udder. When using milk replacer is it important that it is mixed the same way each time to avoid wide variations in concentration and that any unused formula is discarded. Begin offering the foal a minimum of 10% of its BW in milk daily divided into multiple feedings. A 50-kg foal would receive approximately 5L (150 oz) of milk daily divided into 416 ml (12.5 oz) feeds every 2 hours. If the foal tolerates that diet, then the milk volume can be doubled over the next few days. Make all dietary changes slowly. Allow orphans access to manure from healthy, recently dewormed adult horses so that they can engage in coprophagy like foals living with their dams.

The Sick Neonate

The highest energy need for the foal is during the first week of life. If prematurity, abnormal gastrointestinal function, and / or concurrent illness are present, then a sick neonate’s nutritional requirements become more difficult to calculate. Limited studies using indirect calorimetry to assess the nutritional requirements of sick foals confirmed a large range of individual variation (Paradis, 2001). Calcium and phosphorus requirements for sick term and preterm foals have not been established for enteral and parenteral formulas. Nursing foals ingest approximately 250 to 290 mg/kg of calcium daily. Since the calcium retention rate in foals and the intestinal absorption coefficient of calcium in mare’s milk are not known, daily oral calcium requirements can be estimated only. The calcium and phosphorus ratio should be
maintained between 1:1 and 3:1 to avoid alterations in ossification. Phosphorus excess seems to be the most common imbalance associated with DOD.

Feeding the sick foal is more challenging since there is relatively little species specific information about the unique energy and nutrient requirements associated with prematurity, sepsis, necrotizing enterocolitis and other disorders affecting neonates. Since many sick neonates experience varying degrees of gastrointestinal dysfunction, enteral feeds may need to be replaced by or supplemented with parenteral alimentation (IV nutrition).

If a foal is unable to nurse, its dam should be hand-milked at least every 2 to 3 hours. Administration of low doses of oxytocin (5 – 10U) 5 to 10 minutes before milking will facilitate milk let down. If the mare’s milk production remains poor, oral administration of Domperidone (1.1 mg/kg orally once daily) can be tried. If the foal has a productive suckle and swallow reflex, then bottle-feeding is attempted using a lamb or infant nipple. Some premature and “dummy” foals may develop a suckle reflex before an effective swallow reflex. Whenever a sick or weak neonate is allowed to nurse form the bottle or the mare for the first time, frequent auscultation over the trachea is essential to be certain there is no tracheal rattle associated with fluid aspiration. Avoid over extension of the foal’s head and neck to reduce the risk of aspiration. The foal should be encouraged to keep its nose below the level of its eyes. Normal udder bumping and teat seeking behavior can be stimulated by allowing the foal to approach the bottle from behind and under the handler’s armpit. When the foal nuzzles the armpit the bottle should be offered as a reward.

Nutrient Requirements for Sick Foals

Foals are born with relatively few energy reserves. In the absence of enteral feeding, hepatic glycogen reserves will support metabolism for only a few hours, which explains why hypoglycemia (low blood glucose) develops rapidly in newborn foals that fail to nurse soon after birth. It is estimated that energy supplied by colostrum ingestion will last less than 20 hours. Dysmature / premature foals and those neonates exposed to placental insufficiency in utero often have even more limited energy reserves at birth. Premature and growth-retarded foals have poorly defined nutrient requirements. Some foals suffering from prematurity, sepsis, and/or peripartum asphyxia may have blunted insulin responses and lower glucose concentrations at birth than full term neonates. Dysmature foals with incomplete skeletal ossification have increased calcium and phosphorus requirements that may not be met by mare’s milk alone and must be considered when feeding such foals parenterally for prolonged periods. Gram negative, bacterial sepsis, the leading cause of death in neonatal foals, disrupts intermediary metabolism, increases metabolic rate, and sequentially hinders utilization of carbohydrates, lipids, and finally protein for energy. Endotoxin release precipitates a neurohormonal cascade of events mediated by tumor necrosis factor (TNF) and increased levels of catecholamines, glucocorticoids, and glucagon.

Signs of malnourishment include weight loss, generalized weakness, lethargy, glossitis, and scaly skin with reduced elasticity. The most devastating consequence of impaired nutrition for the neonatal foal is impaired immune function and decreased resistance to disease. Malnutrition is associated with depressed bone marrow function, abnormal white blood cell function, impaired antibody production, and depressed secretory, mucosal and cell-mediated immunity.

Enteral Feeding

“If the gut works, use it!” Enteral alimentation is more physiologic and cheaper. Enteral nutrition seems to be a critical stimulus for normal intestinal function and development. Oral feeds stimulate the growth of intestinal villi and the production of crypt cells, and induce hepatic and biliary secretions and brush border disaccharidase enzyme Enterocytes rely on absorption of volatile fatty acids (VFA) such as glutamine and beta hydroxybutyrate from the gut lumen as their primary energy source. Therefore, even in foals that must be fed parenterally (intravenously), small volumes of enteral feeds are given to “feed the gut” to prevent gut atrophy. During intestinal atrophy the integrity of tight junctions is destroyed, predisposing to translocation of intestinal bacteria into the bloodstream resulting in septicemia. Oral feeds stimulate release
of enteroinsular hormones (e.g. glucagon, gastrin, secretin, and cholecystokinin) which in turn exert a tropic effect on gut maturation.

If a foal has not received any enteral meal for more than 48 hours, milk meals should be reintroduced slowly. If colostrum is available, I incorporate it into the first meals due to its proven trophic effect on gut development and local mucosal immunity. I frequently add lactase to the early meals to reduce the risk of maldigestion associated with reduced disaccharidase activity. Parenteral supplementation should be provided to all foals that are unable to consume at least 5% of their BW in milk per day for more than 48 hours.

If the foal’s swallow reflex is weak or the foal is destined to be raised as an orphan, then bucket feeding can be tried. Drinking from a shallow bowl with the head and neck flexed makes swallowing easier. Sometimes it is difficult to teach a foal accustomed to nurse from a mare or a bottle how to drink from a bucket. A shallow bowl is used initially. It may help to place a nipple in the bowl and allow the foal to drink milk through the nipple. Eventually the nipple can be removed.

If the suckling and swallow reflexes are ineffectual, then nasogastric intubation and administration of milk via gravity flow are required. A small bore (5 mm internal diameter), flexible feeding tube with a weighted tungsten end is preferred to ensure a slow, gravity flow of formula to prevent over distention of the stomach. A small diameter tube decreases nasopharyngeal irritation and allows foals to begin to nurse with the tube in place. Indwelling tubes may be sutured to the nares or taped to half a tongue depressor which is then taped to the side of the foal’s muzzle and attached to a fleece halter, positioned with the end of the tube in the distal esophagus of stomach. Tubes should be sealed between feedings to prevent aerophagia. Recumbent foals should be maintained in sternal recumbency immediately after tube feeding to reduce the risk of gastro-esophageal reflux and aspiration of milk into the lungs.

Complications Associated with Enteral Feeding

Complications associated with enteral feeding include 1) metabolic disturbances: hypoglycemia, electrolyte imbalances 2) gastrointestinal intolerance: colic, ileus, abdominal distention, gastric reflux, diarrhea, constipation, flatulence 3) nasogastric tube-related problems: misplacement of tube, tube occlusion / dislodgment, aerophagia, gastric distention, gastric irritation, rhinitis, pharyngitis, aspiration pneumonia 4) formula problems: poor palatability, spoilage. Although healthy foals consume between 20 - 25% BW in milk daily, the provision of 10% BW is a reasonable goal when initiating enteral feeding in sick foals. At this rate a 50 kg foal requires 417 ml of milk every 2 hr. Milk should fed at body temperature and should not be microwaved to avoid altering the composition and uneven heating or overcooking. Any changes in volume or composition of the enteral diet should be made slowly.

If colic, ileus (absence of gut sounds), or gastric reflux is present, an abdominal sonogram is recommended to rule out the presence of an intussusception, abnormally thickened, edematous bowel wall or other signs suggestive of necrotizing enterocolitis prior to initiating any prokinetic drug therapy. Motility modifiers should be used only after reasonable bowel integrity and luminal patency have been confirmed. Diarrhea is treated symptomatically with oral bismuth subsalicylate (Pepto Bismol™), D-smectite (BioSponge™, Platinum Performance) and/or psyllium (Metamucil™). Antibiotic diarrhea may respond to probiotic administration. Lactase therapy may correct osmotic diarrhea associated with disaccharidase deficiency.

Intestinal probiotics containing Lactobacillus sp bacteria or active culture yogurt or buttermilk are given to foals receiving antibiotics to help reestablish intestinal flora. Probiotics are defined as “living microorganisms, which upon ingestion in certain numbers exert health effects beyond inherent basic nutrition” (Fuller, 1991). Another definition describes a probiotic as a “live microbial feed supplement which beneficially affects the host animal by improving its intestinal microbial balance” (Guarner and Schaafsma, 1998). Lactobacillus acidophilus, a lactic acid producing bacteria, was later identified as a key organism in these foods (Shahani and Ayebo, 1980). There is a paucity of scientific research regarding the use of probiotics in any veterinary species during health or disease. Quality control remains an issue with the currently available commercial probiotics. Most probiotics are comprised of one or more lactic acid
producing bacteria and certain strains of yeast. In order for probiotic organisms to exert the properties mentioned the organisms must survive transit through the acidic gastric pH, resist bile digestion, be able to adhere to intestinal epithelial cells and colonize the intestinal tract, produce antimicrobial substances and stimulate the immune system. Commercial products must contain viable numbers of these organisms after processing. Many commercial yogurts may not contain adequate numbers of organisms by the time they are fed to the foal. An excellent review of these issues was presented by J Scott Weese at the 2001 AAEP convention (Weese, 2001).

Lactaid tablets containing lactase can be added to milk prior to feeding to help facilitate digestion. This may be especially helpful for foals recovering from rotavirus diarrhea or other intestinal injuries that may have altered brush border enzyme activity. It is reasonable to assume that any gastrointestinal disorder in the foal that injures or destroys the brush border of the small intestinal epithelial cells has the potential to create a lactase deficiency in that neonate leading to malabsorption of milk meals and the development of an osmotic diarrhea. Transient lactase deficiency has been documented in foals with rotavirus diarrhea and Clostridial enteritis (Weese et al., 2002). Many of these foals appear to benefit clinically from the administration of 6000 U lactase every 3 to 6 hours. If these foals are not nursing directly from the mare and are receiving their milk by bottle, bowl or tube, then lactase can be added directly to the milk before feeding.

Sick foals often lose weight during their illness followed by a period of catch-up growth during the recovery phase. Growth spurts should be controlled to reduce the risk of DOD. Keep rate of growth in mind when selecting a nurse mare for orphan foals. For example, a small orphaned Quarter Horse foal is not well suited to having a Belgian mare with excessive milk production as a foster “mom”. This scenario sets the stage for excessive growth and weight gain leading to physitis and other forms of DOD.

**Parenteral Nutrition (PN)**

Parenteral nutrition (PN) is indicated whenever feeding via the gut is inadequate or contraindicated. If a sick neonate is unable to consume at least 5% of its BW in milk per day additional parenteral nutritional using intravenous formulas containing dextrose, amino acids, lipids, vitamins and electrolytes are required.

**Growing Foals**

Foals should have free access to fresh water. Young foals can be introduced to creep feed and good quality forage (hay and/or pasture) during the first month. Most foals begin creep feeding on their own by nibbling their dam’s concentrate. The average creep feed contains 14 – 16% CP and can be adjusted based on the protein content of the available forage. There are few references that provide field-tested nutritional guidelines for the young growing foal. The NRC (1989) recommends that weanlings receive diets containing 70% as concentrates to meet their energy, protein and mineral needs with the rest provided as good quality forage. This amount of concentrate is considered too high by many nutritionists and farm managers. Recent surveys of feeding practices on QH, TB, STB, and draft horse breeding farms revealed that the majority of farms fed ≤ 40-50% of the ration as grain-based concentrates while achieving growth rates that equaled or exceeded NRC predictions (Gibbs and Cohen, 2001; Black et al., 1997; Ralston et al., 2003). Feeding increased amounts of concentrates that contain excessive levels of starch or sugar (e.g., high glycemic index feeds) has been documented to cause insulin resistance, adversely affect bone mineral content and increase the incidence of osteochondrosis (Cubitt et al., 2005; Hoffman et al., 1999; Pagan et al., 1999). The cause of DOD is multifactorial and includes genetics, exercise, and diet. Protein
excess, although often incriminated, has not been linked to DOD. The most common nutritional causes
include excess energy and imbalances of trace minerals (Cu, Zn) and calcium / phosphorus. Rapid growth
spurts have also been associated with DOD. It is best to avoid compensatory accelerated growth rates.

Concentrates should be fed at the rate of 0.25-1.0% BW (divided into 2 – 3 feeds per day) with an
emphasis on maintaining lean body condition. Owners should monitor their foal’s body condition closely and
notify their vet if the foal is experiencing rapid growth spurts and excessive weight gain, as these
conditions can predispose to acquired metabolic bone diseases that include contracted tendons, physisitis,
subchondral bone cysts and osteochondrosis as well as some forms of Wobbler disease. On the Web site,
www.FoalCare.com, you can download growth charts that help you track your foal’s growth using a weight
tape.

Detailed reviews of foal nutrition that are beyond the scope of this article are available (McKenzie

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EFFICACY OF A THERMALLY PROCESSED EXOGENOUS ENZYME COCKTAIL ON BROILER PERFORMANCE


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ABSTRACT: Feed ingredient price has influenced commercial nutritionists to attempt to maximize diet nutrient availability to non-ruminant animals through use of exogenous feed enzymes. However, non-ruminant production animals are almost exclusively fed pelleted diets. The pelleting process entails complete diets being subjected to conditions of high moisture and temperature that may denature some or all of the enzymes contained in an exogenous enzyme cocktail. Although exogenous enzyme cocktails seem a brilliant strategy to maximize diet nutrient availability, efficacy may be decreased or completely lost if enzymes are not able to survive the pelleting process. The objective of the current studies was to properly assess the efficacy of a commercially available exogenous enzyme cocktail subjected to increasing steam conditioning temperatures during pelleting. Three studies were sequentially conducted to determine the enzyme cocktail’s thermal stability of the enzyme and consequent feed efficacy for broilers. Treatments consisted of positive control (PC) and negative control (NC) diets that differed by 1% available phosphorus and 90 kcal/kg (200 kcal/lb) metabolizable energy in Study 1 and 41 kcal/kg (91 kcal/lb) in Study 2 and Study 3. A third treatment included the exogenous enzyme cocktail added to the NC diet. All dietary treatments were subjected to increasing steam conditioning temperatures (i.e. 82, 88, 93°C for Studies 1 and 2 and 71, 77, 82°C for Study 3) during pelleting. All studies used male Cobb 500 broilers obtained from the same commercial hatchery. The variables measured in each study were live weight gain (LWG), feed conversion ratio (FCR), and feed intake (FI). The experimental period was from day 3-21. Study 1 established significant differences between the PC and NC diets (P<0.05). However, the exogenous enzyme cocktail did not contribute to improved performance. Study 2 was designed to improve the opportunity for the exogenous enzyme cocktail to demonstrate a benefit. This study utilized increased mixer-added lipid addition in the diet formulation that may decrease frictional heat production in the pellet die, and a decreased metabolizable energy difference between the positive and negative control i.e. 200 kcal/kg. Again, performance differences were observed between the PC and NC control diets (P<0.05), with no beneficial effect demonstrated for the exogenous enzyme at any temperature (P>0.05). In Study 3, pelleting temperatures were decreased and an additional unconditioned mash (UCM) treatment was incorporated to potentially demonstrate enzyme efficacy. The enzyme cocktail did improve performance. Significant differences were obtained between NC diets with and without exogenous enzyme cocktail in the UCM for LWG and FCR and at 82°C for FCR (P<0.05). However, only trends were achieved between the PC and NC diets. This research demonstrates that enzyme cocktail thermostability and subsequent efficacy can be affected by several factors.
GLUCOSE HOMEOSTASIS AND THE PITUITARY-ADRENAL RESPONSE TO CORTISOL STIMULATION TESTS BEFORE AND AFTER EXERCISE TRAINING IN OLD VS. YOUNG STANDARDBRED MARES

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ABSTRACT: Age adversely affects the hypothalamic-pituitary-adrenal axis (HPAA) in horses, which may also affect glucose metabolism. These changes may be attenuated with exercise training, but mechanisms behind these phenomena are unknown. Investigators tested the hypothesis that aging and training would alter the cortisol and glucose responses to endocrine stimulation tests (STIM) of the pituitary-adrenal portion of the HPAA. Six old (O, 22 ± 1.8 yrs, mean ± SD) and six young (Y, 7.3 ± 1.5 yrs) healthy, unfit Standardbred mares were tested pre- and post-8 wks of sub-maximal exercise training (60% maximal heart rate (HR)). Graded exercise tests (GXT) and STIM were conducted pre- and post-training to measure VO\textsubscript{2}max and HR. Each mare underwent 4 STIM in a randomized crossover design: 1) control (CON), 2) adrenocorticotropin hormone (ACTH), 3) combined dexamethasone suppression/ACTH (DEX/ACTH), and 4) dexamethasone suppression (DEX). Plasma glucose concentration was measured in duplicate via an analyzer (ABL 880 Flex, Radiometer, Copenhagen). Plasma cortisol concentration was measured using commercially available RIA kits (ImmuChem™ Cortisol, MP Biomedicals, Solon, OH). Data were analyzed using a two-way ANOVA for repeated measures, with Student-Neuman-Keuls for post hoc analysis where appropriate. The null hypothesis was rejected when p ≤ 0.05. Both O and Y improved VO\textsubscript{2}max (p<0.05) from GXT #1 to GXT #2. Old and Y mares had significantly different cortisol and glucose responses to both GXTs, with O having a lower response than Y to both. There was an age difference in cortisol response for ACTH pre-training (p=0.05), where cortisol levels in O were lower than in Y, but none post-training (p>0.05). Pre-training, no difference was seen in plasma glucose between O and Y during ACTH (p>0.05), but post-training there was a difference (p<0.05) where O had lower levels than Y. For CON, there was no age difference in plasma cortisol (p>0.05) pre-training, but there was after training (p<0.05) with O lower than Y. Pre-training, there was no age difference in glucose response (p>0.05) to DEX, but post-training there was (p<0.05) with O lower than Y. Older horses appear to have decreased glucose and cortisol responses to a variety of physiological challenges, suggesting that the pituitary gland becomes impaired with age. Moderate exercise training appears to attenuate age-related changes in cortisol and glucose homeostasis.
STRATEGIES TO REDUCE PREHARVEST *SALMONELLA* IN ORGANIC BROILERS

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**ABSTRACT:** Salmonellosis is a common foodborne illness that many people suffer from each year in the United States. Consumers typically perceive poultry products to be the source of this illness. Antibiotics are popularly used to combat bacteria, but due to the concern of antibiotic resistant bacteria, organic poultry products have gained consumer interest. However, due to outdoor rearing requirements, organic poultry are exposed to a variety of species elevating concern for the products being a reservoir for *Salmonella*. Reducing the presence of *Salmonella* preharvest can aid in reducing *Salmonella* postharvest. Some strategies to combat this include the use of prebiotics, probiotics and organic acids. The objective of this USDA NIFSI funded project was to assess the effects of prebiotics and probiotics (Study 1) and acidifying water treatments (Study 2) on organic broiler performance and the presence or absence of *Salmonella* spp. Study 1: A commercially available mannan-oligosaccharide (MAN), two commercially available probiotics (PRO1 and PRO2) and a control treatment (CON) without additives were implemented on d-1. Study 2: Raw apple cider vinegar (RACV), organic acid blend (OA), hydrogen peroxide (H2O2) and a control treatment (CON) without additives were incorporated into watering systems when appropriate were implemented on d-1. For both studies, 300 1-d-old Cobb 500 male chicks were randomly assigned to treatment and pen. On d-21 birds were weighed and designated to one of 13 weight classes for each of the four treatments. Thirteen birds were allocated to each pen within each of five housing locations which included pasture access at the West Virginia University Certified Organic farm. Data collection occurred during the grower phase (d-21-49). D-21 bird weights were significantly affected by treatments for both Study 1 and 2 (P<0.05). For Study 1, PRO1 and MAN demonstrated the highest d-21 bird weight, followed by CON and then PRO2 (P<0.05). Study 1 treatments did not affect feed intake (FI), live weight gain (LWG), feed conversion ratio (FCR), ending bird weight or percent mortality (P>0.05). For Study 2, on d-21, OA birds were the largest, followed by CON, H2O2 and RACV (P<0.05). OA birds consumed more feed than H2O2 and RACV birds, but the same amount as CON. Water intake from indoor and outdoor waterers showed that OA, CON and RACV consumed the same amount of water and H2O2 consumed the least (P<0.05). On d-49, OA had higher bird weights than H2O2 and RACV, but demonstrated the same weight as CON (P<0.05). In addition, RACV d-49 bird weights were the same as CON and H2O2 had the lowest ending bird weight (P<0.05). FCR and percent mortality were not affected by treatment in Study 2 (P>0.05). PRO1, MAN and OA yielded the highest weights on d-21, but this affect did not carry over to d-49. The results observed from Study 2 indicate that the inclusion of H2O2 was too high and likely deterred intake. For both studies, on d-29 and d-50, samples were taken to determine the presence or absence of *Salmonella* spp. in treatment feed, litter and both inside and outside waterers.
THE EFFECT OF FORM OF TRACE MINERAL SUPPLEMENTS ON PERFORMANCE AND NEUTROPHIL FUNCTION IN LACTATING HOLSTEIN COWS

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ABSTRACT: Trace mineral supplementation has historically been provided as inorganic salts. Recently, organic trace mineral supplements have been formulated to increase mineral bioavailability in ruminants. The objectives of this study were to determine the effects of Cu, Mn, and Zn supplemented in either inorganic or organic forms on production, neutrophil activity, and plasma and milk mineral concentrations. 25 Holstein cows (12 primiparous and 13 multiparous) were assigned to this 12-week completely randomized design study in 2 groups. Group 1 consisted of 17 cows that averaged 77 days in milk (DIM) and group 2 began the study one month later and consisted of 8 cows that averaged 32 DIM. Diets were supplemented to 100% of NRC requirements either by inorganic trace minerals (ITM) in sulfate and oxide forms or by amino acid chelated organic trace minerals (OTM; Mintrex Cu, Mn, and Zn; Novus International Inc., St. Charles, MO). Intake and milk production were recorded daily. Milk samples were collected weekly at 2 consecutive milkings for component analysis. Additional milk samples were taken at 0 and 8 weeks for analysis of Cu, Mn, and Zn by inductively coupled plasma mass spectrometry. Blood samples were taken via jugular venipuncture at the end of weeks 0, 4, 8, and 12 for mineral and neutrophil measurements. Plasma minerals were analyzed by inductively coupled plasma optical emission spectrometry. Neutrophil phagocytosis, reactive oxygen species production, and chemotaxis were determined using in vitro assays. Statistical analysis was conducted using a mixed model with fixed effects of treatment, parity, week relative to trial start, and all interactions, and random effects of group and cow within group. As determined by wet chemistry analysis of the total mixed rations, the ITM diet provided 17, 40, and 84 ppm of Cu, Mn, and Zn, respectively, and the OTM diet provided 24, 62, and 138 ppm of Cu, Mn, and Zn, respectively. There was no effect of treatment on any of the milk parameters or on daily intake. Neutrophil function was also not affected by treatment. Plasma and milk mineral concentrations were not affected by treatment for any of the minerals. However, there was an interaction of treatment by parity on milk Cu concentration ($P = 0.05$). In primiparous cows, milk Cu concentration was 66 and 73 mg/L for the ITM and OTM treatments, respectively. In multiparous cows, milk Cu concentration was 48 and 78 mg/L for the ITM and OTM treatments, respectively. The higher Cu concentration found in the milk of multiparous cows given OTM suggests greater bioavailability of Cu provided by OTM than by CuSO$_4$. 

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JUSTIFYING PHYTOGENIC FEED ADDITIVE MATRIX VALUES IN CONJUNCTION WITH EXOGENOUS FEED ENZYMES

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ABSTRACT: Phytogenic feed additives (PFA) are purported to possess antimicrobial properties as well as nutrient sparing characteristics that may aid in alleviating high diet costs; however, in order for PFA’s to assist nutritionists in decreasing diet cost, matrix values must be determined and implemented in feed formulation. Study 1 evaluated proposed matrix values for a commercially available PFA and assessed nutrient sparing when the product was combined with commercial phytase, carbohydrase and protease. The most remarkable proposed matrix values were 14.6 kcal/lb for metabolizable energy and 0.07% for Ca and AP. The objective of Study 2 was to determine true amino acid digestibility (TAAD) and nitrogen corrected true metabolizable energy ($\text{TME}_n$). Dietary treatments for both studies included a basal, basal with phytogenic product matrix value, basal with phytogenic product matrix value and phytogenic product, and similar treatments evaluating the phytogenic product matrix with exogenous enzyme products. Decreasing the basal diet by the proposed phytogenic matrix values decreased broiler live weight gain and increased feed conversion ratio ($P \leq 0.05$). However, when the same diet included the phytogenic feed additive, live weight gain and feed conversion ratio were restored to that of the basal diet ($P > 0.05$). The proposed matrix values of the specific PFA tested were justified. However, the PFA was not additive or synergistic with exogenous enzymes. Nitrogen corrected true metabolizable energy and TAAD data did not differ when the diets varied based on the PFA per se ($P > 0.05$). However, when the PFA was incorporated using proposed matrix values and used in conjunction with exogenous enzyme matrix values, $\text{TME}_n$ and several tested TAAD values were decreased ($P \leq 0.05$).
NUTRACEUTICAL EXTRACTS AFFECT OXIDATIVE STRESS AND ANTIOXIDANT STATUS IN INTENSELY EXERCISING HORSES

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ABSTRACT: Many nutraceuticals are used as equine supplements without their efficacy having been scientifically tested. Black tea, cranberries, orange peel and ginger are a few of those nutraceuticals that warrant further study. The objective of this study was to test the effects of single doses of black tea, cranberry, orange peel and ginger extract on markers of oxidative stress and antioxidant status following exercise in horses. Study 1: Nine mature, healthy unfit Standardbred mares were administered 2 L of either placebo (water; W), orange peel extract (O; 30g extract), or decaffeinated black tea extract (T; 28g extract). Study 2: the same mares were administered 2 L of either placebo (water; W), cranberry extract (C; 30g extract), or ginger extract (G; 30g extract). In each study mares were given the extracts via nasogastric tube 1 h before performing a graded exercise test (GXT), in a randomized cross-over design with at least 7 d between GXTs. Blood samples were collected at rest, at fatigue, 1, and 24-h post-exercise and analyzed for lipid hydroperoxides (LPO), total glutathione (GSH-T), glutathione peroxidase (GPx), \( \alpha \)-tocopherol (TOC), \( \beta \)-carotene (BC), and retinol. Data was statistically analyzed using a repeated measures ANOVA. Study 1: There was no effect (P>0.05) of treatment for LPO, GSH-T, GPx, TOC or BC. Retinol was higher for both T (P=0.0006) and W (P=0.004) than for O. Study 2: There was no treatment effect (P>0.05) for LPO, GPx, GSH-T, RET, BC or TOC. These results show that a single dose of orange peel or black tea may be beneficial in increasing antioxidant status in exercising horses, however, effects on oxidative stress were not found with any of the nutraceuticals. Further investigation is needed as to whether long term supplementation would enhance these effects.
EFFECTS OF ESSENTIAL OILS ON RUMEN FERMENTATION, MILK PRODUCTION, AND FEEDING BEHAVIOR IN LACTATING DAIRY COWS

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ABSTRACT: Essential oils may manipulate rumen fermentation and they are currently being studied as an alternative to feeding antibiotics, which are commonly used to improve production in ruminants. While essential oils have been studied extensively in vitro, little is known about their effects in vivo or on feeding behavior, particularly in lactating dairy cattle. Further, essential oils at recommended doses in vitro, as well as the few studies in vivo, are reported to have little or no effect on fermentation. The objective of this study was to assess the effects of two commercially available products at recommended doses, as well as one at a high dose, on rumen fermentation, milk production, and feeding behavior. To do this, 8 ruminally cannulated lactating Holstein dairy cows were used in a Latin rectangle design. Cows were fed a total mixed ration consisting mainly of: corn silage, ground corn grain, soybean hulls, soybean meal (48%), and chopped alfalfa hay. Experimental treatments included the addition of: 0.5 g/d XT 6965 (CE Lo; 85 mg cinnamaldehyde and 140 mg eugenol), 10 g/d XT 6965 (CE Hi; 1700 mg cinnamaldehyde and 2800 mg eugenol), 0.25 g/d XT 6933 (CAP; capsicum; all oils from Pancosma S.A., France), and no oil (CON). Cows were fed ad-libitum using the Calan gate system for 21 d (14 d adaptation and 7 d sampling) during each sampling period. Total volatile fatty acids (VFA), individual VFA, acetate:propionate ratio, and ammonia production were not affected by the addition of essential oils. Mean rumen pH as well as number of bouts, total h, mean bout length (h), total area (pH*h/d), and mean bout area (pH*h/d) under pH 5.6 were not different among treatments. Total tract digestibility of OM, DM, NDF, ADF, CP, and NSC were not affected by essential oils. In situ DM disappearance was not affected by essential oils. However, OM disappearance tended to decrease compared to CON (P = 0.08; 60.3% vs. 57.6%) with CE Hi. Compared to CON, NDF disappearance (P = 0.05; 41.5% vs. 37.6%) and ADF disappearance (P = 0.04; 44.5% vs. 38.8%) decreased with the addition of CE Hi. Dry matter intake, number of meals/d, h feeding/d, mean meal length (min), rumination events/d, h ruminating/d, and mean rumination length (min) were not affected by essential oil addition. However, length of the first meal after feeding decreased with addition of CE Hi (47.2 min) and CAP (49.4 min), compared to CON (65.4 min; P = 0.01). Milk yield and % and kg/d of milkfat, lactose, and protein were not different among treatments. At the recommended dosage, CE Lo had no effect on rumen fermentation, milk production, or feeding behavior. CAP shortened the length of the first meal without changing rumen fermentation or production, making it a possible feed additive for altering feeding behavior. At a high dosage, CE Hi negatively affected rumen nutrient fermentation and altered feeding behavior, suggesting that a dosage of 10 g/d is not beneficial to lactating dairy cows. A more appropriate dosage that elicits positive effects on rumen fermentation and production needs to be established before these essential oils can be suggested as an alternative to feeding sub-therapeutic levels of antibiotics in dairy cattle.
THE EFFECTS OF STRAIN AND DIETARY PHOSPHORUS LEVEL ON LARGE TOM TURKEY PERFORMANCE

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ABSTRACT: There are several challenges associated with maintaining a competitive edge in commercial poultry production. Choosing the appropriate genetic strain of turkey can significantly impact feed conversion and carcass yield, thus profitability. In addition, environmental impacts of production agriculture (especially manure disposal) are becoming increasingly more scrutinized and consequently regulated. Dietary phosphorus levels can also significantly impact diet cost. The objective of this study was to determine differences between strain use and dietary phosphorus level in a research setting that mimics commercial production. This was a 2x2 factorial design utilizing two strains (Nicholas and Hybrid) and two levels of dietary phosphorus (high and low) in finishing diets (d-105 through d-138). All birds were reared at the newly renovated West Virginia University turkey research facility and all diets were manufactured at a commercial feed mill. Male poults (1216) were randomly placed in one of 16 pens and randomly assigned one of four treatments. Live weight gain (LWG), feed intake, feed conversion ratio (FCR), and percent mortality were recorded from d-1 through d-138. Both strains had similar finishing weights and mortality percentages (P>0.05), but the Hybrid strain had a significantly better FCR (P<0.05). An enzyme linked to protein degradation, Lysine-Ketoglutarate Reductase (LKR), had greater expression in Nicholas than Hybrid toms (d-1 through d-136), thus supporting an inferior FCR in the Nicholas strain. Changes in dietary phosphorus in finishing diets did not affect performance or litter phosphorus content, thus indicating potential to decrease feed cost but not environmental impacts.
EFFECTS OF AGING AND TRAINING ON LEPTIN AND GLUTAMINE IN STANDARDBRED MARES

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ABSTRACT: The objective of this project was to test the hypothesis that aging and training alter plasma concentrations of leptin, and amino acids glutamine and glutamate. The rationale for the general study is based on prior investigations performed at Rutgers where published reports documented that aging disrupts the immune and endocrine responses to acute exercise (Malinowski et al., 2002 and 2006 and Horohov et al. 1999). The training period for 12 standardbred mares in age groups young, middle age, and old was the duration of the summer of 2009 at the Rutgers University Equine Science Center’s Exercise Physiology Laboratory. Training was done in groups of six mares exercising on an Equisizer for 30 min, three times per week. Each mare performed a Graded Exercise test before training, after 8 weeks, and after 16 weeks of training. Muscle biopsies were taken before training and again after 16 weeks. All mares maintained body weight throughout the training period. Assuming the body weight was maintained because fat was lost and muscle was gained, the expected results are a decrease in plasma leptin concentrations over the training period and not affected by intense acute exercise. If muscle mass increases then there will be more glutamine found in plasma and skeletal muscle after 8 weeks of training (using data from a previous unpublished study). The effects of training on glutamine may diminish over an additional 8 weeks or 16 weeks training total.
VOLUNTARY INTAKE AND DIGESTIBILITY OF TEFF HAY FED TO HORSES

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ABSTRACT: Teff hay represents a novel preserved forage for horses with advantages to both horse and forage producers including low nonstructural carbohydrate content, nutrient composition comparable to other commonly fed hays, pest resistance, and flexibility of rotating crops with a perennial warm season grass. Equine metabolic syndrome, laminitis, obesity and insulin resistance are just a few examples of these health disorders associated with relatively high dietary nonstructural carbohydrate intake. Current research indicates that lowering dietary non-structural carbohydrates may help to decrease the risk of these metabolic health disorders. The objective of this study was to evaluate nutrient composition, voluntary DMI and apparent DM digestibility of teff hay cut at three different stages of maturity to evaluate its potential as a preserved forage for horses. Six mature Quarter horse mares (12 ± 2.6 yr; 553 ± 39.4 kg BW) were used in a replicated balanced Latin square design with 3 periods and 3 maturities of teff hay. Eragrostis tef ‘Tiffany teff’ was planted in May and harvested at boot, early heading or late heading stages of maturity through the summer. Horses were acclimated to a mixture of maturities of teff hay for 8 d prior to the start of the study. Following this acclimation period, each period consisted of a 9-d voluntary DMI phase followed by a 3-d DM digestibility phase. The percentages of nonstructural carbohydrates (NSC) increased from 5.4% in the boot stage to 8.4% in the late heading stage, while concentrations of CP, K, Fe and Mn decreased. The Ca:P ratio was 2.0 ± 0.3 for all maturities. Horses had a lower DMI of late heading teff hay (1.5% BW) than other maturities (1.8% BW), indicating a preference for the earlier maturities. The intake and nutrient composition of the boot and early heading maturities was sufficient to meet 90 to 97% of the horses’ average DE and most other nutrient requirements. Digestibility decreased from boot to late heading teff hay for DM, CP, ADF and NDF (3.8 – 8.6%). Digestibility increased from boot to early heading to late heading for nonfiber carbohydrates and water soluble carbohydrates (7 – 9.2%). For all maturities of teff hay the NSC intake was below 10% of the total intake. In conclusion, the low NSC and DE of teff hay grown in central Pennsylvania under the conditions in this study make it an appropriate forage source for obese horses and those at risk for laminitis or other metabolic disorders.
NUTRITION-RELATED PROBLEMS FACING ELITE LEVEL, THREE-DAY EVENT HORSES

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ABSTRACT: The main goal of feeding an elite three-day event horse is to deliver nutrients in optimal amounts that allow the horse to maximize its health and performance. However, poor nutritional management and/or physiological stressors related to intense training and competition may increase the risk of nutrition-related disorders in these horses. An understanding of the nutrition-related problems contributing to poor performance is critical to the health and welfare of the horse. The objective of this survey study was to characterize the nutrition-related problems affecting top level three-day event horses during 2008. A survey containing ten questions pertaining to participant demographics and nutrition-related problems experienced by their horses was mailed and e-mailed to 81 three and four star event riders that lived in the United States and Canada and competed during 2008. Twenty-nine of 81 riders completed the survey (35.8%). Respondents rode a total of 45 horses in top level three-day events in 2008. The top five nutrition-related problems facing horses were gastric ulcers (42.2%), joint problems (37.7%), decreased appetite (31.1%), weight loss (31.1%) and hyperexcitability (22.2%). Gastric ulcers were experienced to a similar extent both at home and competition. Joint problems, weight loss and weight gain occurred more frequently while training at home; however, hyperexcitability and decreased appetite occurred more at competition. The horses in our study competing at top levels of three-day eventing are at risk of reduced performance given the high rate of gastric ulcers, decreased appetite, and weight loss. Research as to the cause of these problems and/or feeding management changes that would reduce the incidence in these horses is needed to ensure optimal performance.
GROWTH AND BASAL GLUCOSE CONCENTRATIONS ARE CLOSELY ASSOCIATED IN THE THOROUGHBRED FOAL

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ABSTRACT: The purpose of this study was to characterize changes in basal plasma glucose concentrations during the first 18 months of life and examine associations between this pattern and various measures of equine growth. There are many factors that can affect postnatal growth including diet, weaning, and season. Blood glucose is the primary source of energy for developing tissues, and a likely signal of energy availability. Blood samples were obtained on a monthly basis along with a specific set of growth measurements from Thoroughbred foals and mares fed two different concentrates; a sugar and starch (SS) or fat and fiber (FF) based formulation. Mares and foal pairs (n=18) were maintained on mixed grass and legume pastures throughout the study period (March 2005 – August 2006). Blood samples were collect from foals and mares between 0700 and 1000 once a month prior to morning feeding. Glucose concentrations were measured in both foal and mare plasma samples with colorimetric enzymatic glucose assay and were compared to the rates of gain. Spearmen correlation coefficients for the relationship between each growth characteristic and the basal glucose concentration were calculated. There was no significant influence of diet on basal glucose concentrations (P > 0.05). Basal glucose in foals decreased from a high in the May 2005 samples (157.6 ± 23 mg/dl) to lows in January 2006 (100.4 ± 7.1 mg/dl) and July 2006 (99.1 ± 6.8 mg/dl). Strong correlations were found between glucose concentration and average daily gain measurements of weight, wither height, forearm length, cannon circumference, hip height, girth, leg length, and head length. The lowest correlation between glucose and growth measurements was 0.61 for cannon circumference gain (P<0.0115), while the highest were 0.93 for wither height gain (P<0.0001), and 0.92 for leg length gain (P< 0.0001). The strong correlation between glucose and rates of gain associated with skeletal development are supportive evidence for further research studying the impact of dietary energy sources on equine growth. Hypothetically, the change in circulating glucose concentrations is due to the shift in diet from milk to forage based. However, because of glucose’s important role as an energy source, diets that impact the setpoint in glucose homeostasis may offer an opportunity to more precisely feed horses to improve skeletal and metabolic development.