About the Plains Nutrition Council

The Plains Nutrition Council is an educational and professional organization for persons who work and serve as livestock feeding nutritionists, nutrition consultants, and educators in livestock science. The goal of the Council is to enable its members to more effectively cooperate with each other and to serve the livestock feeding industry more successfully. The Council provides a forum for study, discussion, and promulgation of current research in the fields, as well as opportunity for study and evaluation of new product applications from the industry and research sectors. Joint efforts with related organizations in chemistry, engineering, veterinary medicine, and other groups allied to the livestock industry are encouraged.

2003-2004 Officers

Spencer Swingle, President
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Ted McCollum III, Secretary/Treasurer
The origins of the Plains Nutrition Council are rooted in mutual interest expressed by the Texas A&M University Animal Scientists and feedlot industry leaders. During the fall of 1968 Texas A&M University Animal Science Chair, Dr. O. D. Butler and his Professor in Charge of Beef Cattle Research, John K. Riggs, traveled the Texas Panhandle for most of a week calling upon feedlot managers, nutritionist, scientists, and related parties. Their primary objective was to gain insight to support future planning of research and Extension programs. Texas A&M Area Livestock Extension Specialist and Assistant Professor, L. M. Schake traveled with this team as the local contact. Previously, he and other nutritionist had casually discussed the formation of a group like the PNC. Whenever appropriate this trio inquired as to the merits of forming a professional society of those serving the commercial aspects of beef cattle feedlot nutrition and management.

Responses varied. A few respondents were enthusiastic; most were ambivalent, some negative. The response of Mr. Jack Carrothers, manager of Friona Feedlot, Inc. and first Texas Cattle Feeders Association President was typical. He indicated that he already has too many meetings to attend and far too much technical information to assimilate, but if such a group would strengthen the industry — go for it! Soon Schake mailed invitations to nutritionist serving the region to hold a formative meeting leading to the establishment of PNC. An evening event was scheduled in the conference room of Farr Feeds in Hereford, Texas early in 1969. About fifteen individuals attended. Schake led a discussion on starch characteristics of processed grains. Plans were discussed to continue the activity. Subsequent meetings were held, mostly with presentations from within the local membership.

By 1970, Schake published an article in the Extension Service Review (volume 41, number 9, pages 8-9) entitled “Serving Agriculture’s Big Business”. Here he outlined the establishment of PNC and its role to effect mutual transfer of technical data and concepts between researchers and the industry. Professional consultants were now playing a major role in information transfer that was once considered the domain of the Extension Service. Attendance at PNC meetings remained relatively modest, typically in the range of 20 to 50 members. During these formative years PNC members discussed membership qualifications (independent consultants vs commercial representatives), program topics, meeting frequency and the geographic area to be served. One stabilizing factor was the office of the Area Livestock Specialist in Amarillo that continued to house the Council’s secretary-treasury.

Typically, three to six meetings per year were held in Amarillo, Hereford, Guymon, or other local sites. Soon it was discovered that breakfast meetings held in conjunction with the annual TCFA Convention increased attendance. Membership grew as the programs became more germane, now frequently presented by a national or international authority as a larger and larger trade area was being served. Some meetings were held in conjunction with the newly formed Academy of Veterinary Consultants of Amarillo, itself largely modeled after the PNC. Likewise, the recently established Southwest Nutrition Conference of Phoenix and PNC co-sponsored several conferences before SNC focused more exclusively on dairy cattle nutrition. In 1995 PNC’s present logo was developed, and its first membership directory published and distributed at an Amarillo meeting attended by over 100 members.

By this time there were 126 members representing 15 states and two foreign countries. Proceedings were published to include acknowledgement of program sponsors. Five speakers from New York to California offered an update on beef cattle protein nutrition research. Competitive graduate student posters were now added to the program. Cash awards of $750, $500 and $250 were offered for the three most outstanding posters reporting on beef cattle nutrition and management research.

Since 1998 the Spring PNC Conference has been held in San Antonio. Programs have typically included invited presentations, research reviews, competitive graduate student posters, a business meeting and social activities. The 2003 meeting was attended by over 230 members embracing PNC goals of enhancing technical information transfer between beef nutrition consultants, nutritionist and educators. As PNC approaches its 35th anniversary, it remains committed to providing its members, as well as allied interest, with an effective means of cooperating with each other while striving to improve their contributions to the world’s cattle feeding industry.

Lowell M. Schake, retired
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The following article submitted to the Plains Nutrition Council by Dr. Brown will be published in the American Scientist in the near future.

The Whys and Wherefores of Mad cow disease in North America

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Introduction

The appearance of bovine spongiform encephalopathy (BSE, or ‘mad cow disease’) in North America in 2003 fueled a predictable new interest in understanding the many still unresolved issues surrounding the group of diseases known as transmissible spongiform encephalopathies (TSEs). This article views BSE in the context of this broader perspective, including enough historical information to permit an appreciation of how BSE happened, how it managed to get to North America, and how it may play out in the future.

TSE: the disease family

The prototype TSE family member is scrapie, a naturally occurring disease of sheep and goats that was first clearly described more than 200 years ago in Europe, but may well have existed for untold centuries as an unrecognized disease entity. Figure 1 shows the various members of the family together with the dates they were first recognized, and their proven or speculative inter-relationships. It is worth emphasizing that they are all expressions of the same pathological process occurring under different circumstances in different species, and that they share far more clinical, pathological, and biological similarities than their different names would suggest.

Many mammalian species are known to be susceptible to experimental infection by TSE agents, including primates, ruminants, ungulates, felines, and laboratory rodents. Natural infections have so far been restricted to sheep and goats (scrapie), and to deer and elk (chronic wasting disease, or CWD). Sheep have transmitted scrapie in ‘unnatural infections’ to other sheep and goats via scrapie-contaminated vaccines, and very probably to mink and cattle as a result of the practice of feeding carcasses to mink, and rendered carcasses to livestock. Recycled BSE-infected carcass tissue then transmitted disease to a variety of zoo felines and exotic ungulates.

It is possible that many species other than sheep, goats, deer, and elk harbor naturally acquired infections, but if they were to occur at the same 1 per million incidence as sporadic Creutzfeldt-Jakob disease (CJD) in humans, it would require histological and immunological examination of brains from several hundred thousand members of each suspect species to determine its presence, and is unlikely ever to be carried out.
Figure 1. Known and speculative inter-relationships among the various kinds of transmissible spongiform encephalopathies. Scrapie, first recognized in UK sheep in the early 18th century, first appeared in the US in 1947. Bovine spongiform encephalopathy (BSE) first appeared in the UK in 1986, and was in subsequent years exported to other countries (including Canada and the US in 2003). CJD = Creutzfeldt-Jakob disease; TME = transmissible mink encephalopathy; CWD = chronic wasting disease of deer and elk.

Figure 2. Schematic structural transformation of the normal (left) to the misfolded (right) prion protein molecule, showing the partial conversion of α-helices (coils) to β-sheets (arrow ribbons). The structure of the normal protein has been confirmed by nuclear magnetic resonance analysis; the structure of the misfolded protein is predicted from molecular modeling.
Etiology

The disease agents that cause TSE were from the start recognized as being rather ‘special’ in that, although they behaved in many ways like a virus, they showed a very long latent period between infection and illness, a correspondingly long duration of illness, an extraordinary resistance to inactivation, and could not be linked with any identifiable morphological structure. They were for many years therefore known as ‘slow viruses’, and later as ‘unconventional viruses’. They can still be considered as ‘unconventional viruses’ if we think in terms of minimum criteria: a submicroscopic entity with the capacity both to replicate and transmit information, as in computer ‘viruses’.

However, all known biological viruses contain nucleic acid, and intensive searches during the past half century for a disease-specific nucleic acid have proved fruitless. In the interim, it was discovered that a host-encoded rather than foreign protein was inseparable from infectivity (the ‘prion’), and that mutations in its encoding gene on chromosome 20 could cause disease. Molecular biological studies showed that in the infected host, the soluble and proteinase-sensitive normal protein was converted into an insoluble and partially proteinase-resistant isoform that had the characteristics of amyloid (Figure 2).

Although we have now begun to think of TSE as a ‘misfolded protein disease’ with similarities to other amyloidoses, including Alzheimer’s disease, the unique and distinguishing feature of TSE is that it alone is transmissible. The mechanism by which a protein can appear to replicate (i.e., infectivity) and transmit specific characteristics (i.e., strain differences) continues to excite scientific interest, and there is increasing evidence that some kind of template phenomenon is occurring that constrains normal protein molecules to adapt the same abnormal conformation as the original ‘seed molecule’, and that the ‘seed molecule’ may form spontaneously as a rare random event.

Pathogenesis

Whatever the final judgment about ‘prions’ as the primary or even sole cause of TSE, there is no argument about the crucial role of the prion protein in the infectious process, or about its value as a marker of infectivity. Thus, the pathogenesis of TSE has been investigated either by detection of the protein (immunologic methods) or by measurement of infectivity (animal inoculation).

The itinerary of the infectious agent within the body depends upon how infection is initiated (Figure 3). In experimentally-induced rodent infections, when the agent is introduced by peripheral inoculation, invasion of the brain is preceded by a phase of replication within the spleen and lymph nodes, followed by transport via the splanchnic nerve to the spinal cord. When given by mouth, the agent can bypass the spleen and proceed directly from the gut to the brainstem via the vagus nerve. The optic and olfactory tracts have also been identified as potential portals of entry.
Figure 3. Neuroinvasive pathways from peripheral sites of TSE infection. The peripheral nervous system (with and without splenic involvement) has been well documented in experimental models. Hematogenous routes have been inferred to occur under some circumstances. IV = intravenous; IP = intraperitoneal; IM = intramuscular; LRT = lymphoreticular tissue; n = nerve; PNS = peripheral nervous system.

The role of circulating blood in naturally occurring disease remains uncertain. The few reported disease transmissions from the blood of patients with sporadic CJD have been questioned, and are in any case far outnumbered by transmission failures, but a highly probable case of transmission from the blood of a patient with variant CJD (vCJD) has very recently been reported from Great Britain. Blood has also been repeatedly shown to be infectious in experimental models of TSE, as well as in naturally occurring scrapie infections; however, even if neuroinvasion occurs via nerves, blood is the most plausible vehicle by which infectivity in both experimental and natural disease ultimately finds its way to the many peripheral organs in which it is present.

The origin of BSE

The origin of BSE will probably never be known with certainty, but a species-crossing infection from scrapie-affected sheep seems more plausible than the leading alternative hypothesis of a spontaneous case of BSE in cattle. Both hypotheses enlist the same mechanism of contaminated carcass recycling as the vehicle by which infection was rapidly amplified to an annual level of over 30,000 new cases within five years of its first appearance in Britain.

Any satisfactory explanation of BSE must answer two questions: why did BSE begin in the mid-1980’s, and why did it begin in Britain? Both the sheep and cattle origin hypotheses have the same answer to the question of timing, which is that changes in the system of rendering carcasses into meat and bone meal dietary supplements that took place in the 1970’s permitted infectivity to survive the process and be recycled.

At least two such changes could have contributed to the survival of infectivity: increased use of continuous rather than single batch rendering (which could have created incomplete exposure to heat), and the elimination of a final tallow extraction step consisting of exposure to hydrocarbon solvents under steam. It has since been shown experimentally that neither of these
changes had a very great effect, but if the level of infectivity entering the rendering process were near the threshold of transmissibility, small changes could have made the difference between survival and destruction. Supporting evidence comes from the fact that the prohibition of meat and bone meal dietary supplements in 1987 was followed 5 years later by the start of a downturn in BSE cases (Figure 4), and 5 years is the average incubation period between BSE infection and manifest illness.

Figure 4. Chronology of the BSE and vCJD epidemics in the UK. BSE is represented by orange bars (left-hand scale); vCJD is represented by blue bars (right-hand scale).

Whereas the timing of the epidemic is reasonably well explained by changes in the rendering process with consequent survival of infectivity in meat and bone meal dietary supplements, the origin of the contamination is open to discussion: scrapie or the chance occurrence of a de-novo case of BSE?

Accurate figures for the international prevalence of scrapie are not available, but scrapie is at least as prevalent among sheep in the UK as in most other countries of the world, and the UK has a comparatively large proportion of sheep to cattle.

Thus, a widespread potential source of infection was already in existence, whereas BSE was unknown until 1986 when the epidemic began. The argument that unrecognized ‘spontaneous’ cases of BSE could have been occurring in cattle for decades at the same one per million annual frequency as sporadic cases of CJD in humans, and that one such case was a ‘founder’ of the BSE epidemic, has a formidable obstacle: sporadic BSE cases cannot have been occurring only in the UK, yet no coincident epidemics occurred in other countries (for example, the US) in which rendering processes were changed at about the same time as in the UK. Moreover, the distribution of early BSE cases in the UK (and subsequently in other countries that unwittingly imported BSE from the UK) is more consistent with multiple initiation points than with a single point source of infection. This would favor scrapie as the source of infection, because scrapie was widespread enough to have entered rendering plants throughout the UK, whereas it would have required simultaneous cases of sporadic BSE to achieve the same effect.

On balance, the evidence favors scrapie, but it is only fair to point out that the sporadic BSE hypothesis does perhaps more easily explain two curious features of BSE: strain uniformity and human pathogenicity. Like most infectious pathogens, the scrapie agent has many
experimentally distinguishable strains. Although precedents exist for strain selection on passage to different species, a bovine origin of BSE eliminates the need for this kind of selection process. As for pathogenicity, all evidence to date indicates that scrapie is not a human pathogen, and if scrapie does not infect humans, why should scrapie passaged through cattle behave any differently? Precedents also exist for TSE in one species that is unable to transmit disease to a different species unless it has passed through an intermediate species; however, because this phenomenon is exceptional, it is not as satisfactory as the explanation implicit in the BSE hypothesis – a new strain of TSE arising in cattle could as easily as not be pathogenic for humans.

Cattle were not the only target for dietary supplements: other livestock species, such as sheep, pigs, and chickens, as well as several kinds of zoo animals, laboratory animals, and pets also received feed to which meat and bone meal had been added. Examples of disease transmission to several non-livestock species have been reported to occur in ungulates, felines, and lemurs in zoos, and pet cats. The specter of BSE-infected sheep has caused special concern because in the process of ‘back-crossing’ to sheep, the agent might carry its newly acquired ability to infect humans. Pigs are not susceptible to oral BSE infection, and chickens are resistant to infection by any route of administration. Dogs are also apparently resistant to TSE infection, as several animals inoculated intracerebrally with human strains of CJD and kuru did not become ill, and in countries with BSE no dogs have been identified with spongiform encephalopathy, despite the certainty that some dog food (like cat food) would have included bovine tissue.

The origin of variant CJD

In contrast to BSE, vCJD has a quite certain origin but still speculative vehicle of infection. The first clue to its origin came from the observation that a distinctive form of spongiform encephalopathy in adolescents and young adults was appearing in a country still recovering from a vast epidemic of spongiform encephalopathy in cattle (Figure 4). A connection between BSE and the human cases was strongly suggested, and has since been experimentally confirmed. The most plausible source of BSE infection was consumption of beef products contaminated with central nervous system tissue, but remains a hypothesis that still lacks the kind of laboratory evidence that clinched the identification of BSE-infected cattle as the source of disease. Epidemiologic study did not uncover any convincing disease clusters, or point to any regional peculiarities or vectors that might have linked BSE cattle to human disease, and investigation of ‘high risk’ contact groups such as farmers, slaughterhouse workers, or butchers did not identify any cases of vCJD (although a few cases of sporadic CJD did occur among these professions).

If physical contact with infected cattle could not be implicated, the next logical place to look was exposure to cattle products. In particular, it was important to investigate the consumption of brain by patients with vCJD because the distribution of infectivity in BSE-infected cows is largely confined to nervous system tissues, but no association was found. Moreover, because virtually the entire British population was exposed in one way or another to a huge number of bovine-derived products, there was little likelihood of incriminating one or more of these products as the cause of vCJD. Consumption of meat and dairy products, and exposure to products containing either tallow or gelatin (or their derivatives) is universal, and no correlations could be established between vCJD and exposure to any given product.

The key lay with slaughterhouse practices and meat preparation, about which the scientific
community was completely naïve (Figure 5). Before the appearance of BSE, vertebral columns were routinely included in the remains of carcasses from which as much meat as possible had been manually removed. Spinal cords were usually removed, but cord fragments and paraspinal ganglia were certain to remain. The truncated carcasses were then subjected to a process of compression to yield bone fragments (used for gelatin or meat and bone meal) and a paste of ‘mechanically recovered meat’ that was permitted to be added to a variety of packaged meat products such as hot dogs, sausages, beef patties, luncheon meats, beef stews, etc., in proportions as high as 30% (but usually in the range of 5-10%). It is now abundantly clear that central nervous system tissues were entering the human food chain through this ‘unadvertised’ vehicle, and that they were the most likely cause of human infection.

This said, two very curious questions remain unanswered by any of the hypotheses that have been advanced to explain the phenomenon of vCJD. The most puzzling question concerns the age at which disease appears – there is no satisfactory answer as to why vCJD affects such a young age group (Figure 6). Information about commercial food distribution and consumption, which might provide the best clues, is almost as unreliable as a dietary history obtained from the relative of a patient with vCJD. In consequence, although comparatively inexpensive products (including school cafeteria offerings) that contained ‘mechanically recovered meat’ have been suspected of being favored by children and adolescents, hard evidence is missing.
Figure 6. Age at onset of illness in all cases of variant CJD and sporadic CJD seen in the UK during the period 1994 through 2000.

The second question involves the relatively small number of cases (currently about 150) among a British population of 60 million that has presumably been ubiquitously exposed to potentially contaminated beef products, and only a handful of cases have appeared in other countries where BSE has been exported. Although genetic susceptibility may play a role, the most reasonable explanation is that meat product infectivity was very unevenly distributed, and only rarely achieved a transmissible level, made even more difficult by the comparative inefficiency of oral infections.

**BSE in North America**

Were it not for international trade in cattle and cattle feed, the phenomenon of BSE would very likely have remained confined to Great Britain. As it happens, both live cattle and cattle feed continued to be exported from the UK to countries all over the globe for several years after the cause of BSE had been identified (throughout the late 1980s and early 1990s, as shown in Figures 7 and 8), and thus cases of disease began to appear in many European countries – the major importers – from about the mid-1990's onward, as well as in non-European countries as far afield as Oman and Japan. Some of the later spread may have resulted from trade involving countries that had been importing feed from Britain, infecting indigenous cows that were in turn rendered for feed for both domestic and international markets.
Curiously, the appearance of BSE in the United States in December 2003 recapitulated in large measure what had occurred with scrapie nearly 60 years earlier, when Canada imported infected sheep from Great Britain, and then the US imported infected sheep from Canada. This time, the likeliest sequence of events is that BSE-infected cows, imported into Canada from the UK during the high risk 1980’s, came to slaughter and were rendered into feed that infected some ‘next-generation’ cows. Both of the identified Canadian cows (one of which was exported to the US) were born in 1997, and in principle should not have been exposed to contaminated feed because of the ruminant-to ruminant feed ban implemented in 1996. However, it is thought likely that some ‘left-over’ feed continued to be used to supplement the diets of new-born calves. When eventually slaughtered in 2003 at the age of 6 years, neither the cow remaining in Canada nor the cow exported to the United States was suspected of having BSE (they were routinely tested as part of ‘downer cow’ surveillance programs), and their carcasses were therefore sent in the usual...
fashion to rendering plants for use in recycled feed supplements (in the US, beef products were also distributed by error to the human food chain).

Canadian and US government regulatory agencies, already primed by the kinds of responses taken in the UK and continental Europe, reacted quickly to the discovery of each infected cow. Because of the likelihood that other cows born at about the same time on both affected ranches had also been exposed to contaminated feed, any still living cows that could be traced were destroyed. Other important measures prohibited all products from ‘downer cows’ from use in cattle or humans, as well as tissues from any cow shown from experimental studies to contain the infectious agent, including mechanically recovered meat. Not least important, on-site inspections of rendering plants, feed mills, and slaughterhouses were ‘beefed up’. Together with a strictly enforced ruminant-to-ruminant feed ban, these measures should be sufficient to prevent the future spread of BSE to other animals and to humans, even if the disease is eventually found to occur as a rare spontaneous event.

From the standpoint of indigenous disease, the United States remains BSE-free, and is thus a legitimate setting in which to answer this question. Moreover, at this precise point in time, we have both the motivation and resources to test the brains of enough cattle to obtain a statistically significant result. Other countries with equal motivation are disqualified by virtue of harboring cattle with food-borne disease, and motivation in the US will soon wane in parallel with public concern. Thus, we have a truly unique opportunity either to confirm or forever lay to rest the thesis that the whole BSE story resulted from the occurrence of spontaneous BSE at the one per million per year incidence of human CJD.

When BSE and its human counterpart, vCJD, pass into history, which they will, the reassessment may be that a quarter century of scientific knowledge was gained at the expense of veterinary and public health. This would be unfair, as the British were immensely fortunate in having had the services of several key investigators who correctly identified the problems and their sources with extraordinary rapidity. However, the translation of this knowledge into public policy, apart from the timely initiation of a ruminant feed ban, was generally tardy and often incomplete. Given the real damage to commercial sectors that invariably follows regulations designed to protect public health from speculative dangers, pro-active measures will always be vigorously argued, and it is not at all clear that any so-called ‘lessons’ will inform future situations for which the same kinds of risk-benefit analyses based on incomplete knowledge will continue to frustrate scientists and policymakers alike.

**Acknowledgement:** Portions of this article dealing with background information that remains accurate (including Figures 2, 6, 7, and 8) were extracted from a more extensive review of BSE published as a report by ILSI Europe in 2003. The maps shown in Figures 7 and 8 were created from data obtained by Dr. Maura Ricketts of the WHO from Dr. Robert Will at the CJD Surveillance Unit in Edinburgh, Scotland (Dr. Will also furnished the CJD data from which Figure 6 was created).
It becomes very difficult to address the current status for a very unsettled topic entitled animal by-products and rendering. As this review is being prepared the agencies of the Food and Drug Administration (FDA), United States Department of Agriculture (USDA)-Food Safety and Inspection Service (FSIS)-Animal and Plant Health Inspection Service (APHIS), Environmental Protection Agency (EPA) and many state and local counterpart departments all have mitigation initiatives, regulations and policies in various stages of development and implementation. Thus the content of this document is not intended to be a state of the art compliance guideline. But it will attempt to outline some of the challenges that are presented to the entire industries involved in meat animal production that includes rendering and animal by-products.

Certainly the challenges in this country were aroused beginning in May of 2003 with the BSE diagnosis in Canada. The arousal level amplified dramatically on December 23, 2003 with the Washington State news of BSE in the US. In retrospect the initial consumer, media and regulatory reactions were accepted with more resolve than perhaps expected. Without doubt, the reactions to the cattle market and rendered animal byproducts were much more dramatic. The markets immediately started a downward spiral at a time when everyone was filled with optimism. Despite a late December – early January stock price decline in the fast-food sector, consumer confidence about the safety of beef, the demand has been positively strong. Rutgers University has subsequently published results of a food confidence study. William Hallman, lead author of the study stated: “The isolated BSE case is not enough to dramatically disturb domestic confidence in the beef supply. Unlike consumers in many countries, Americans have a history of trust in their food regulations, and have a strong belief that the U.S. food supply is safe”. An impact currently is the loss of an export market both for beef and the animal protein and fat by-products. Thus the future economic impact is yet to be determined. However several economists have projected at least a 10 percent reduction in net farm income for 2004 compared to 2003. These estimates can be impacted by numerous factors driven significantly by the extent and duration of the major export markets.

Those that have followed the regulatory process in the US understand the progression since 1986. These have consisted primarily of import restrictions, prohibition of specified ruminant derived proteins in feed for cattle and other ruminants and the surveillance for BSE incidence in the U.S. Though many of these “firewalls” have been challenged as not being aggressive enough, the Harvard Risk Analysis” made public in November 2001 concluded that the measures provided a high degree of assurance to prevent both incidence and amplification of BSE.

A 1997 regulation and the 99.2% validated level of compliance to the regulation has been a primary component of the firewall known as 21CFR 589-2000. This rule known more commonly as the Restricted Use Protein Products (RUPP) rule is still valid in most of its original content. Basically the rule prohibits the use of protein derived from mammals in ruminant animal feed with distinct exemptions. Those exemptions included pure porcine or equine protein, blood and blood products regardless of source, gelatin, inspected meat products which have been
cooked and offered for human food, and milk products/ proteins. Additionally tallow, fats, oils, grease, amino acids and other by-products of gelatin are not included in the rule. Poultry and fish derived by-products were not included in the mammalian classification. The rule has required specific requirements and rules for handling prohibited proteins to include labeling, caution statements, records and co-mingling prevention measures.

This rule is under the auspices of FDA and it is that agency that is currently reviewing its content with anticipated interim final rules for its amendment. Proposed or inferred rule changes affect several exemptions. Plate waste is expected to become a prohibited material in animal byproduct ingredients. Though a plate waste definition has not been definitely described. It is suspected that this action is being driven by compliance rather than safety issues. Blood from all species is currently an exempt product. An initial statement would prohibit all mammalian blood from all ruminant feeds. However the current inferences are to prohibit ruminant blood from ruminant feeds or perhaps only limit its prohibited status to inclusion in milk replacers and young calf diets. Oral Transmission of BSE via bovine blood has not been definitely demonstrated. No BSE infectivity has been detected in bovine blood in either natural or experimental cases. (Bradley, 1999, 2000) (Fraser et al., 1992) (Kimberlin and Wilesmith 1994) (Middleton and Barlow, 1993) (Moon, 1996). Recent studies that reported BSE transmission by blood transfusion in sheep has precipitated abundance of precaution attitudes for perhaps placing some regulations on usage of blood as feed ingredients. (Hunter et al., 2002). There is no evidence tissue including blood from swine or poultry harbor the infective agent for BSE. Any restrictions to blood products as feed ingredients creates probable image implications and public scrutiny concerns for beef.

Tallow has not openly been referenced in any of the interim final rules directed to feed. However reference to banning material from downer cattle, dead cattle, specified risk materials (SRM) and mechanically separated beef from FDA regulated human food and cosmetics. Further statements that only edible tallow should be allowed for use in cosmetic products creates concern. Following the food uses for edible tallow, the current production level would cover very little of the oleochemical, cosmetic, fatty acid and soap demands that are currently using high grade inedible sources provided the tallow does not include an excess of 0.15% impurities. Again numerous scientific reports have concluded that tallow does not present BSE transmission risk. An international scientific review subcommittee commissioned by USDA did not reference to any actions on tallow.

Though not addressed in the current RUPP rule, poultry litter is expected to be prohibited as a protein ingredient for ruminants. The concern being poultry feed spillage that could contain prohibited material and the possible excretion of BSE infective feces by birds receiving feeds containing prohibited material. Models have been developed to illustrate the risk as measured in years of continuous consumption by a single animal to reach infective doses either from formulated into the ration or consumed from grazing litter applied to pastures. It is very probable that poultry litter will however, become a prohibited ingredient for ruminant rations.

A press release has stated FDA's intention to "require separate equipment, facilities or production lines for feed manufacturing of non-ruminant feed if they also use protein that is prohibited in ruminant feed". This is an attempt to minimize the possibility of cross
contamination of ruminant and non-ruminant animal feed. The language referred to feed manufacturing only but it is assumed to include rendering as well as feed ingredients. The language did not address receiving, grinding, cooking, conveyance or waste water treatment, nor more importantly defining dedicated as meaning a separate site, separate facilities on a common site, or separate lines in the same facility. The press release yet to be followed up with a published intention has not been made available. CRF21 589:2000 allows both feed manufacturers and renderers to utilize approved clean-out procedures to produce both prohibited and non-prohibited products. Transportation vessels should be subjected to the same clean-out scrutiny but is not included in the present rule. The probability of rule changes in production, transportation and storage of feed and ingredients is to be expected for both central and on-farm feed processing and rendering.

USDA imposed an immediate ban on non-ambulatory cattle from the human food chain following the December 23, 2003 diagnosis. This category of slaughter animals have been controversial for a long time. It was therefore an expected action. Non-ambulatory or “downer” animals must be considered as the higher risk animals for BSE infection. The definition is open for practical interpretation but not within the regulatory guidelines: “If it cannot rise and walk it is non-ambulatory”.

These actions have temporarily created concerns for proper animal disposal as well as hampering the surveillance of BSE in the U.S. cattle population. The option of disposing of non-ambulatory cattle has taken several alternatives ranging from the reliance on autolysis and carrion, unsatisfactory burial, landfill or composting to on farm slaughter and processing but in general a decreased number submitted for surveillance and rendering. Renderers and slaughter facilities generally lack adequate storage for the carcasses during the confirmatory process currently associated with BSE and all transmissible spongiform encephalopathies (TSE). Thus challenges exist in properly handling this sub-set of animals.

This is being addressed by APHIS with the recent announcement of a plan to enhance surveillance for BSE. A rather common compliant has been the perceived low number of animals examined annually for BSE in the US. During 2003 approximately 20,000 animals were examined at the National Veterinary Services Laboratory via the immunohistochemistry (IHC) method. Though this number significantly exceeds the international standard for the US cattle herd of over 35 million head, the complaints both domestic and internationally persist. Absence of evidence is not evidence of absence.

It is estimated that approximately 450,000 animals are categorized as high-risk cohorts within our cattle population. This estimate includes adult cattle condemned at slaughter for CNS signs, morbid, dead, injured, on farm deaths, lameness, nerve paralysis, broken bones, and metabolic conditions. The National Animal Health Monitoring Systems (NAHMS) estimates that approximately 1.5% of all adult cattle and 4.8% of all adult dairy cows die annually from various causes.

Thus $70 million have been allocated to test between 201,000 and 268,000 animals concentrating on the high-risk adult cattle population beginning in June 2004 and continuing thru November of 2005. The upper level would allow for the detection of BSE at a rate of 1 positive
in 10 million adult cattle with a 99% confidence level. The enhanced program extrapolates into detecting BSE even if there are only five animals in the entire country. This may not even satisfy all doubters. However, the risk, scientific knowledge of the progression of the disease and the difficulty in applying diagnostic procedures to juvenile cattle populations does not warrant testing of the entire cattle population.

Samples are to be collected at a number of locations to include farm, state and federal slaughterhouses, rendering facilities, veterinary clinics, diagnostic laboratories and livestock auctions as well as random samples of aged cattle. Currently 40 U.S. slaughter plants process some 86% of aged cattle for human consumption. All tested animals from the aged sub-set will be held and not allowed to enter the human food chain until negative BSE results are confirmed. Increased costs as a result of these plans can be expected for both renderers and meat processors. There are several operational uncertainties that are yet to be addressed. Renderers have been and will continue to be adverse to handle the on-farm deads and non-ambulatory cattle until a negative BSE confirmation is received. Without adequate cold storage facilities the risks and costs are too great in respect to recall and other associative liability. The technology and art of traceability has not perfected to a common cost effective system that is so critically needed.

Another un-resolved controversy is that of specific risk materials (SRM's) in respect to what are they, what prohibitions exist and how to accurately age cattle into the two referenced categories of under and over 30 months of age. Spinal cords have been removed as a standard processing practice for a number of years and generally are incinerated or otherwise disposed of (but not rendered). Currently the vertebral column, dorsal root ganglia, distal ileum which practically means the entire small intestinal tract, eyes, tonsils, heads (brain and trigeminal ganglia) are all considered SRM for animals over 30 months. These tissues currently can be labeled as inedible and rendered as RUPP feed ingredient. This however is subject to change as it has previously numerous times. Thus processing and rendering implications are difficult to predict. It has also been difficult to interpret infectivity data. Infectivity has been demonstrated to be present in CNS tissue in naturally infected cattle. Other referenced SRM data have been drawn from experimentally infected animals including inoculation routes other than oral. It is important that scientific scrutiny from an array of sources be used to assess risk versus abundance of precaution measures.

A recent International Subcommittee was commissioned by the Secretary of Agriculture to provide independent review of the index case of BSE in the US. This review will not allege to be a complete summary of the report but rather a synopsis and interpretation. The Committee recognized the limitations of the current cattle identification systems in place in North America. It pointed out the problems encountered with epidemiological investigations in countries which do not have an effective animal traceability system. The report surfaced numerous conflicts with the Harvard Risk Analysis. The review committee however were very supportive for the need for a rendering industry and in particular an infrastructure to handle SRM. There are further plans for the Harvard Risk and the International review Team to coordinate in further risk modeling interpretations. Of most concern, are the conclusions that the cattle in the USA are indigenously infected with BSE. Thus risk materials as per their recommendation must be considered in the development of policies for the prevention of human infection and infection of cattle through feed. The risk assessment parameters that were established with the Harvard
studies and scientifically formulated within the prohibited ruminant feed policies of 1997 were basically judged to be inadequate. In addition, the validated compliance by FDA and supported by Third Party Certification programs were assigned limited value. The recommendation that meat and bone meal from all species should be prohibited from use in all ruminant feed was made. Precautionary principles offered in the report followed closely those practiced in the European experiences. It becomes difficult to evaluate the scientific risk of preventative benefits of directives, regulations or policy that compliance cannot be documented. Certainly the compliance records of several BSE epidemic countries have proven to be substandard. Though two recent cases have been experienced, BSE has not been determined to be epidemic in North America. Table No. 1 provides data on the number of BSE cases by country since first diagnosed in the UK in 1986.

Though not documented with a reference the international report indicated new ongoing studies show that cattle can be orally infected with as little as 10 mg. on infectious brain stem tissue. The fact that no processing system exists at present to guarantee destruction of infectivity in commercial processes, it was suggested that the probable restoration of traditional uses in feed may be impossible. More radical and innovative solutions were suggested as requirements to enable the safe use of materials in the future. This should as per the report's recommendations include adding value through their use for purposes other than feed and fertilizers. All animal processed animal by-products were in effect categorized such that 10 gms. of infectious brain stem raw tissue could be extrapolated into 10 mg. of meat and bone meal, from any source, relative to BSE transmission risk. In fact, very recent work has been announced that infectivity in 1 of 15 young calves orally exposed to only 1 mg of infectious material developed BSE 72 months post exposure. Therefore the bar continues to be lowered but again separation of data on raw material from processed material should be recognized.

**Summary**

The inferences of possible new regulatory standards and abundance of precaution/precautionary principles brings serious doubt as to the future of animal by-products and rendering implications without some change. Currently approximately 54 billion pounds of animal raw tissue is generated annually by the ancillary production of livestock and poultry for meat production. There is little doubt that feed ingredient usage has commanded the primary markets for the meat and rendering industry for the past several decades. But though there are no current scientific reasons to discontinue the utilization of animal by-products as ingredients for food production, food safety interpretation extends well beyond science. There has been considerable recent interest in exploring new uses for products derived from rendering the tissues resulting from the production and processing of meat, milk, eggs and animal fibers. Thus science becomes intertwined among myths, special interests, religious beliefs, trade issues and a myriad of other influences. Very basic explorations for alternative uses usually results in less value added usage than as protein or fat ingredients. But without doubt increased emphasis on new use application research and development is indicated. Research addressing these objectives present an entirely different approach and financial commitment when compared to animal nutrition studies. Certainly as opposed to perceived risk, the monetary risk associated with success within this research arena is real. Referencing back to the International Review Committee, even usage as fertilizer was challenged. Therefore if by-products of animal production and processing cannot be utilized for value added products, the cost for disposal options, the costs to our environment,
biosecurity, ecology, and animal production will be seriously impacted. The future is uncertain!

<table>
<thead>
<tr>
<th>Table No. 1</th>
<th>BSE Cases by Country Since 1986</th>
</tr>
</thead>
<tbody>
<tr>
<td>COUNTRY</td>
<td>SIZE OF ADULT CATTLE</td>
</tr>
<tr>
<td></td>
<td>IN NATIONAL HERD (MILLIONS)</td>
</tr>
<tr>
<td></td>
<td>BSE CASES REPORTED</td>
</tr>
<tr>
<td>Great Britain and Northern Ireland</td>
<td>4.9</td>
</tr>
<tr>
<td>Ireland</td>
<td>3.2*</td>
</tr>
<tr>
<td><strong>France</strong></td>
<td><strong>11.1</strong></td>
</tr>
<tr>
<td>Portugal</td>
<td>0.8*</td>
</tr>
<tr>
<td>Switzerland</td>
<td>1.6*</td>
</tr>
<tr>
<td>Spain</td>
<td>3.4*</td>
</tr>
<tr>
<td>Germany</td>
<td>6.3*</td>
</tr>
<tr>
<td>Italy</td>
<td>3.2*</td>
</tr>
<tr>
<td>Belgium</td>
<td>-</td>
</tr>
<tr>
<td>Japan</td>
<td>0.5**</td>
</tr>
<tr>
<td>Netherlands</td>
<td>-</td>
</tr>
<tr>
<td>Denmark</td>
<td>-</td>
</tr>
<tr>
<td>Canada</td>
<td>12.9*</td>
</tr>
<tr>
<td>United States</td>
<td>35.0</td>
</tr>
</tbody>
</table>

*Cases reported in both native and imported cattle. **Cases reported in juvenile cattle.

*Source: European Consumers Association - 2004*

References


(6) Middletown, D. and Barlow, R. 1993. Failure to transmit bovine spongiform encephalopathy to mice by feeding them with entraneural tissues of affected cattle. Veterinary Record. 132:545-547.


General Virology. 83:2897-2905.

(9) Report on Measures Relating to Bovine Spongiform Encephalopathy (BSE) in the United States. The Secretary’s Foreign Animal and Poultry Disease Advisory Committee’s Subcommittee, Professor U. Kihm, Switzerland; Prof. W. Hueston, USA, Dr. D. Matthews, UK. Prof. C. MacDiarmid, New Zealand and Dr. D. Heim, Switzerland. February 2, 2004.

There are a number of pathogens that can be carried on beef products and present a human health risk. Focus of this paper will be on *E. coli* O157. Economic impact of *E. coli* O157 on the U.S. beef industry has been substantial. Kay (2003) estimated a cost of nearly $2.7 billion over the last 10 years. Over half of this cost is associated with reduced beef demand and the impact on beef product price. However, he also estimated that packing plants have spent $750 million in plant modifications and interventions to reduce the *E. coli* risk.

It is generally recognized that most of the *E. coli* interventions to date have taken place in the packing plant. Figure 1 depicts a simplified view of some steps along that process and points where interventions are imposed to reduce pathogen levels.

*Figure 1. The Slaughter/Chilling Process with Pathogen Interventions*

A variety of anti-microbial wash solutions are in use, many of which utilize some type of organic acid wash. Recently, activated lactoferrin was approved and is being used by at least one packer. Cetylpyridinium chloride (CPC) has been investigated and appears very promising but is still in the approval process.

Pathogen load is reduced as cattle/carcasses move through this process. Figure 2 shows typical reduction in microbial load that is achieved during the slaughter process. Please note that these are representative values and there can be significant variation. A key point is that current plant interventions are effective in reducing pathogen load on carcasses. Each specific intervention has a capability to reduce microbial load. If the initial load on inbound cattle is reduced, the final
outcome in terms of microbial load on chilled carcasses will also be reduced.

Figure 2. Microbial Load Reduction During Processing

![Graph showing microbial load reduction during processing.](image)

Values shown in figure 2 are total aerobic plate counts (APC) expressed as the log of colony-forming units (cfu). This is a common measurement and terminology in discussion of food safety risk associated with beef products. Workers in the area frequently talk in terms of “log reduction” in APC numbers and it is sometimes confusing to relate APC to *E. coli* O157.

A relationship between APC and *E. coli* O157 has been established (table 1). As APC numbers go up, probability of hides carrying *E. coli* O157:H7 also increases. APC is used as a proxy for *E. coli* risk because APC measurement is faster, less expensive and much more conducive to use as a routine quality control measure than measurement of *E. coli* O157.

Table 1. Relationship between APC and *E. coli* O157:H7 on Cattle Hides

<table>
<thead>
<tr>
<th>APC, log cfu</th>
<th>E. coli O157:H7, % positive</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 or less</td>
<td>44</td>
</tr>
<tr>
<td>7 – 8</td>
<td>72</td>
</tr>
<tr>
<td>8 or more</td>
<td>91</td>
</tr>
</tbody>
</table>

It is clear that hides are the primary source of carcass contamination with *E. coli* O157:H7. The link between pre-harvest and post-harvest *E. coli* risk was shown in the work of Elder et al. (2000) and Ransom et al. (2003a). Table 2 shows the relationship between fecal, hide and carcass prevalence of *E. coli* O157. This type of information has provided the impetus for research into pre-harvest interventions that could be part of overall industry efforts to reduce risk associated with *E. coli* O157.

A wide variety of pre-harvest interventions have been investigated. At least two companies have vaccines in development. There has been some research with bacteriophages, viruses that infect bacteria. Work in that area appears to be very preliminary. Antimicrobial compounds (colicin) apparently specific to *E. coli* have been isolated from plants. There has been discussion of...
research to insert genetics for a colicin into plants typically used as feedstuffs. Sodium chlorate was fed at levels up to .05% of body weight for periods of one to five days (Anderson et al., 2003). Results indicated significant reductions in *E. coli* O157 prevalence in the gut and on hides. Sodium chlorate is not approved for feeding to cattle. One or more of these approaches may prove to be the best interventions against *E. coli* O157:H7. Development and/or regulatory hurdles will probably make those potential long-term solutions but near-term use is unlikely.

Table 2. The Pre- and Post-Harvest Link for *E. coli* O157.

<table>
<thead>
<tr>
<th>Prevalence of <em>E. coli</em> O157, % positive</th>
<th>Fecal</th>
<th>Hide</th>
<th>Carcass, pre-evisceration</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 20</td>
<td>5.7</td>
<td>20</td>
<td>7.1</td>
</tr>
<tr>
<td>&gt; 20</td>
<td>12.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Loneragan, 2003

Direct-fed microbials (DFM) have probably received more research effort than any other potential pre-harvest interventions. The most well known product is sold by Nutrition Physiology Corporation. *E. coli* control is reported to be associated with *Lactobacillus acidophilus* NPC747 (also known as NP-51).

Brashears et al. (2003) reported that feeding NPC747 resulted in a 50% reduction in prevalence of *E. coli* O157 in feces and 92% reduction on hides. Younts-Dahl et al. (2003) saw 52 and 63% reduction in feces and on hides, respectively. A 38% reduction in fecal prevalence was reported by Moxley (2003). Ransom et al. (2003b) reported a 70% reduction in fecal prevalence and 44% reduction on hides. Similar results were observed in a New Mexico trial (Loneragan, 2003). Research results indicate that one can expect a 40 to 60% reduction in percentages of fecal and hide samples testing positive for *E. coli* O157 from the Nutrition Physiology product containing *L. acidophilus* strain NPC747.

Several other DFM products are in development or early stages of marketing. At this point, there does not appear to be adequate data available to evaluate those products.

The remainder of this paper will focus on research that we have conducted with cattle fed in Caprock Cattle Feeders’ facilities. At this time, we believe that research with *E. coli* interventions must be validated in production-scale facilities. Cattle behavior and environmental challenges (wind, dust) in production facilities may significantly impact response to treatment compared to small-pen facility research. In addition, epidemiology of *E. coli* O157 appears to be somewhat unusual. For example, there appears to be more variation within than between feedlots, despite higher level of variation in management systems across feedlots. Shedding patterns of individual animals within a pen also appear to be inconsistent and unpredictable. These observations tend to increase risk of extrapolating results from small-scale to production scale facilities.

Procedures for all of the *E. coli* O157 trials conducted at Caprock were generally similar. In each trial, existing pens of cattle were randomly split into new pens that were used to test interventions. The advantage of splitting pens was to make sure that cattle had similar background exposure to *E. coli* O157. However, we did not test initial prevalence levels in
manure or on hides to verify similar initial microbial loads.

Trial designs included 8-12 replications. Each replication consisted of a pair of pens, created from one common original pen, and both pens in a replication were shipped on the same day. Higher numbers of replications were used when temperatures were cooler and one would expect prevalence to be lower. In the first Tasco trial, Tasco-fed cattle were always shipped first, immediately followed by Control cattle. For all other trials, shipping order was alternated with each replication so that each treatment had equal opportunity to be first or second through both feedlot and packing plant facilities, equalizing any impact of cross-contamination. In all cases, our \textit{E. coli} research cattle were the first cattle through the plant on the first shift of the day. Trucks used to haul cattle to the plant were washed with a solution of quaternary ammonia prior to loading cattle.

All sampling was done at the packing plant. Twenty to thirty cattle per pen were randomly selected for sampling. Fecal grab samples were taken after stunning. Hide samples were taken by swabbing the hide with a sterile sponge. The top of the shoulder area was sampled in the neomycin and chlorination trials and the second Tasco trial. The ventral midline area was sampled in the chlorination trial and both Tasco trials.

Excel Beef Research personnel in Wichita, KS conducted assays for presence of \textit{E. coli} O157:H7 in the neomycin trial. Texas Tech staff from Dr. Mark Miller's laboratory conducted microbial measurements in all other trials.

The chlorination trial was conducted at the Caprock feedlot in Dalhart, Texas. Starting in April 2003, water supply was split such that roughly two-thirds of the pens received chlorinated water. Chlorination level was approximately 2 ppm. Pens were split and treatments imposed approximately 90 days prior to slaughter. Control and chlorinated test pens were located at opposite ends of the feedlot to maximize physical distance between pens. Cattle were shipped between July 22 and September 9, 2003.

Results are shown in table 3. In general, results are inconsistent in that there is no consistent relationship between total O157 and O157:H7 values. Conventional wisdom would suggest a positive correlation. After discussion with several experts, we concluded that \textit{E. coli} O157 values are most reliable results to evaluate in this trial. \textit{E. coli} O157:H7 prevalence rates were low for this time of year. This is consistent with observations from other trials at the same time and may reflect impact of relatively dry weather conditions.

Water chlorination had no real effect on prevalence of \textit{E. coli} O157. Percentage of positive tests for O157:H7 on midline hide samples was significantly higher with chlorination, but that difference was not significant for total O157. In addition, O157:H7 numbers for both treatments were extremely low. Results of this experiment indicate that addition of 2 ppm chlorine into the drinking water of feedlot cattle has no effect on prevalence of \textit{E. coli} O157.

There were some significant differences due to shipping order (table 4). One would expect higher prevalence on hide samples of cattle shipped second, due to potential contamination from the first group, passed via handling equipment. There was actually an increased prevalence of
O157:H7 in feces of cattle shipped second. That is unexpected because any cross-contamination should be external, not in the GI tract. Here again, the more reliable total O157 numbers indicate no difference due to shipping order.

Table 3. Effect of Water Chlorination on Prevalence of E. coli O157.

<table>
<thead>
<tr>
<th></th>
<th>Control, % positive</th>
<th>Chlorinated, % positive</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fecal O157</td>
<td>27.9</td>
<td>30.5</td>
<td>.699</td>
</tr>
<tr>
<td>Fecal O157:H7</td>
<td>13.1</td>
<td>16.2</td>
<td>.684</td>
</tr>
<tr>
<td>Shoulder O157</td>
<td>38.3</td>
<td>43.4</td>
<td>.455</td>
</tr>
<tr>
<td>Shoulder O157:H7</td>
<td>7.8</td>
<td>5.2</td>
<td>.305</td>
</tr>
<tr>
<td>Midline O157</td>
<td>39.2</td>
<td>48.0</td>
<td>.453</td>
</tr>
<tr>
<td>Midline O157:H7</td>
<td>.5</td>
<td>2.1</td>
<td>.003</td>
</tr>
</tbody>
</table>

There was no effect of shipping order on hide samples taken from the shoulder region. However, midline hide samples showed an increase in total O157 positives in the second group. The increase for group 2 may reflect use of a conveyor belt to move cattle through the chutes to the knock-box. The conveyor could well be the means of contamination along the midline.

Table 4. Effect of Shipping Order on Prevalence of E. coli O157.

<table>
<thead>
<tr>
<th></th>
<th>First Group, % positive</th>
<th>Second Group, % positive</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fecal O157</td>
<td>28.6</td>
<td>29.8</td>
<td>.848</td>
</tr>
<tr>
<td>Fecal O157:H7</td>
<td>9.4</td>
<td>20.0</td>
<td>.003</td>
</tr>
<tr>
<td>Shoulder O157</td>
<td>41.2</td>
<td>40.5</td>
<td>.916</td>
</tr>
<tr>
<td>Shoulder O157:H7</td>
<td>5.8</td>
<td>7.4</td>
<td>.541</td>
</tr>
<tr>
<td>Midline O157</td>
<td>33.8</td>
<td>53.8</td>
<td>.075</td>
</tr>
<tr>
<td>Midline O157:H7</td>
<td>2.9</td>
<td>1.1</td>
<td>.055</td>
</tr>
</tbody>
</table>

Tasco research was conducted at the Caprock feedlot in Lockney, TX. Our first trial with Tasco 14 was conducted in the winter of 2002-03. Approximately 30 days prior to shipping, pens were be randomly sorted two ways to create paired control and Tasco pens. Tasco was fed for 14 days prior to shipment. Results are summarized in table 5. Tasco feeding had no effect on incidence of carcasses testing positive for total E. coli 0157 or 0157:H7. Prevalence of O157 on hides was

Table 5. Effect of Tasco 14 on Prevalence of E. coli O157 – Trial 1.

<table>
<thead>
<tr>
<th></th>
<th>Control, % positive</th>
<th>Tasco, % positive</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fecal O157</td>
<td>41</td>
<td>47</td>
<td>.28</td>
</tr>
<tr>
<td>Fecal O157:H7</td>
<td>9.0</td>
<td>7.5</td>
<td>.66</td>
</tr>
<tr>
<td>Midline O157</td>
<td>72</td>
<td>89</td>
<td>.36</td>
</tr>
<tr>
<td>Midline O157:H7</td>
<td>25</td>
<td>15</td>
<td>.29</td>
</tr>
</tbody>
</table>
very high. The positive rate for O157:H7 was much lower. There was a numerical trend for fewer positives on hides of Tasco-fed cattle (15 vs 25%) but the difference did not approach statistical significance.

This trial was conducted during the winter, when prevalence of E. coli O157:H7 is seasonally low. There was a concern that relatively low prevalence would not allow for observation of differences. Therefore, a second trial was conducted during a season with generally higher E. coli numbers. In this trial, pens were split and feeding of Tasco initiated 14 days prior to shipping. Cattle were slaughtered during September of 2003.

There were no significant effects of Tasco on prevalence of E. coli (table 6). Fecal results were nearly identical with and without Tasco for total E. coli O157 and E. coli O157:H7. There was a numerical reduction in favor of Tasco for prevalence of O157 on shoulder hide samples but values were not statistically significant and there was no difference in values for O157:H7. Tasco resulted in a 47% reduction in E. coli O157:H7 prevalence on midline hide samples. This difference approached statistical significance. However, overall incidence was low (less than 10%) and there was absolutely no difference in prevalence of total E. coli O157 on midline hide samples.

As in the chlorination trial conducted last summer, the difference between prevalence of total O157 and O157:H7 was larger than one would expect, particularly on hides. Total E. coli O157 values are probably most reliable. If that is true, there was clearly no difference associated with Tasco.

Neomycin sulfate was evaluated in a trial at the Caprock feedlot in Leoti, Kansas. Research pens were established during the month of May by randomly splitting existing pens and cattle were shipped during August of 2003. Neomycin was administered in water at the rate of 13 grams per head per day on days 2 and 3 prior to slaughter. That level was based on a clearance for treatment of colibacillosis with neomycin at 10 mg per pound of body weight, assuming a 1300 final weight. Neomycin was not provided on the day prior to slaughter because the colibacillosis clearance indicates a 24-hr withdrawal period.

Table 6. Effect of Tasco 14 on Prevalence of E. coli O157 – Trial 2.

<table>
<thead>
<tr>
<th></th>
<th>Control, % positive</th>
<th>Tasco, % positive</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fecal O157</td>
<td>37.7</td>
<td>38.2</td>
<td>.944</td>
</tr>
<tr>
<td>Fecal O157:H7</td>
<td>19.4</td>
<td>18.4</td>
<td>.890</td>
</tr>
<tr>
<td>Shoulder O157</td>
<td>26.0</td>
<td>20.3</td>
<td>.386</td>
</tr>
<tr>
<td>Shoulder O157:H7</td>
<td>4.5</td>
<td>4.8</td>
<td>.830</td>
</tr>
<tr>
<td>Midline O157</td>
<td>21.8</td>
<td>21.8</td>
<td>1</td>
</tr>
<tr>
<td>Midline O157:H7</td>
<td>9.9</td>
<td>5.3</td>
<td>.147</td>
</tr>
</tbody>
</table>

Neomycin was extremely effective in reducing E. coli O157:H7 (table 7). Prevalence on hides was higher than in feces. That might be expected because it would be reasonable that feces from 1 animal could contaminate the hide of several cattle. There were significant differences
between replications. Figures 3 and 4 illustrate that the effect of neomycin was extremely consistent across replications. Note that there were some shipping dates (replications) with no *E. coli* O157 detected for any cattle.

Table 7. Effect of Neomycin Sulfate on Prevalence of *E. coli* O157:H7.

<table>
<thead>
<tr>
<th>Sampling Site</th>
<th>Control, % positive</th>
<th>Neomycin, % positive</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feces</td>
<td>15.1</td>
<td>.2</td>
<td>.002</td>
</tr>
<tr>
<td>Hide</td>
<td>50.4</td>
<td>1.5</td>
<td>.002</td>
</tr>
<tr>
<td>Feces or hide</td>
<td>56.4</td>
<td>3.2</td>
<td>.0004</td>
</tr>
</tbody>
</table>

It is somewhat surprising that oral neomycin administered 2 and 3 days prior to slaughter could have such a substantial impact on hides. Conventional wisdom would suggest that *E. coli* present on hides could survive for a long time so contamination prior to neomycin treatment would still be observed on hides at slaughter. The implication of this data is that fresh feces are the primary source of *E. coli* on hides.

Log10 APC counts averaged 5.50 for control and 5.27 for neomycin. Although the value for neomycin was slightly lower, differences were not significant. It has been suggested that APC counts are an indicator of *E. coli* O157:H7 prevalence. It would appear that activity of neomycin is relatively specific for *E. coli* or perhaps even specific strains of *E. coli* and does not have an effect on overall APC count. It is possible that pre-harvest interventions may change current thinking about relationships between APC levels and probability of *E. coli* O157.

Similar results with neomycin were reported by Ransom et al., (2003b). It appears that neomycin is the best, most cost-effective intervention discovered to date. However, current clearances for neomycin do not allow it to be used for this application. Indications for use of neomycin are for treatment and control of colibacillosis (bacterial enteritis) caused by *E. coli* susceptible to neomycin sulfate. *E. coli* O157 does not cause symptoms that would qualify feeding neomycin under this clearance. In addition to regulatory issues, there are also concerns about development of antibiotic resistance caused by routine use of neomycin.

Long-term solutions to *E. coli* O157 are likely to come from further innovations in packing plant interventions or vaccines or other new technologies. Good husbandry practice indicates that feedlots should make efforts to keep cattle and cattle water clean but that should not be expected to reduce prevalence of *E. coli* O157. Today, a direct-fed microbial product is the most viable pre-harvest intervention available. The cattle industry should make every effort to resolve regulatory and resistance issues around neomycin sulfate. Data indicates neomycin can be the most effective pre-harvest intervention in the near future.

**Acknowledgements**

Excel Beef
Dr. Mark Miller and students, Texas Tech University
Dr. Guy Loneragan, West Texas A&M University
Figure 3. Prevalence of *E. coli* O157:H7 in Feces.

![Graph showing prevalence of E. coli O157:H7 in Feces with shipping date on the x-axis and percentage positive on the y-axis.]

Figure 4. Prevalence of *E. coli* O157:H7 on Hides

![Graph showing prevalence of E. coli O157:H7 on Hides with shipping date on the x-axis and percentage positive on the y-axis.]

Literature Cited


supplementation in feed and (or) water to reduce gut concentrations of *Salmonella* and *E. coli* O157:H7 in beef cattle. Final Report to the National Cattlemen’s Beef Association. USDA, ARS, College Station, TX.


Ammonia from Livestock Operations: Measurement Technologies and Emissions


Abstract: Ammonia (NH₃) is a difficult gas to measure without disturbing its transport characteristics. It is a highly reactive, absorptive, and sticky gas requiring great care in sampling. Its chemical properties dictate the use of measuring technologies that do not interfere with the source temperature, concentration, pH, and turbulent or diffusive transport. The purpose of this report is to review available techniques for measuring trace-gas atmospheric-exchange and discuss their strengths and weaknesses.

Chamber techniques affect the microclimate of the site and should not be used for diffusive types of gases such as NH₃; however, they may be used for small-plot comparative studies for biological gases (CH₄, N₂O, CO₂, etc.) where absolute emissions are not required. Flux-gradient and dispersion-analysis techniques are preferred for both air-quality and greenhouse trace-gases; however, these techniques require large, relatively-homogenous sources for wind and concentration for vertical-profile development. Integrated horizontal flux techniques work well for small-area, homogenous source studies and mass-balance techniques work well for small-area, non-homogenous studies. Dispersions models such as Gaussian plume and puff models are usually not suitable for agricultural situations.

Comparison of measurement techniques resulted in a five-fold difference in determined NH₃ emissions between microclimate and tracer techniques. Emissions factors were presented showing differences due to measurement techniques, time-of-year, and unit-basis of comparisons. Comparison is also made between NH₃ and enteric CH₄ emissions from a beef feedlot showing the relationship between types of emissions (biological vs. diffusive), the lack of relationship between atmospheric concentration of gases and emissions, and the importance of having good technology to evaluate emissions.

Key Words: Micrometeorology, Models, Animal Feeding Operations, Feed Conversion Efficiency, Transport Technology, Trace-gas

Introduction

In general, because of low animal density, there are few if any air quality concerns with cow-calf or stocker operations with about two-thirds of operations having less than 500 cows per ranch (USDA, 1997). After the stocker phase, calves normally move to feedyards where they are fed grain-based diets until ready for harvest: normally 110 to 200 days. Before 1960, most cattle were fed in small farmer-feeder feedlots in the Corn Belt or a few large commercial operations in southern California and Arizona. Today, most of these cattle are fed in large (> 5,000 head) commercial operations in the semi-arid/arid western Great Plains, which are areas with sparse human populations. However, the high density of animals in these confined operations can lead to
air quality concerns both locally and regionally. Approximately 23 million cattle are fed in feedyards each year (Fig. 1).

Most beef cattle feeding operations differ greatly from those used in other livestock species. Although a small percentage of cattle are fed in confined or semi-confined buildings with liquid manure handling systems, most are fed in earthen surfaced pens. Some of the manure is normally scraped from the pens after each group of cattle is finished. Part of the manure may be stacked and packed in the pen to provide mounds that improve pen drainage and assure that cattle have a dry place to lie after rains. Manure removed from the pen may be immediately applied to fields near the feedlot, stockpiled for later use, or composted in windrows. Because the manure may remain in the pen or in stockpiles for several months before it is applied to the field, some of the nitrogen (N) and carbon (C) may be lost to the atmosphere in some form before the manure is collected, and each storage represents a potential emission source.

Ammonia (NH₃) is a colorless gas under standard conditions, whose pungent odor is easily discernible at concentrations above about ten ppm, and to some persons, down to almost one ppm. It is the major basic neutralizing gas in the atmosphere so it has an important role in the neutralization of atmospheric acids generated by the oxidation of sulfur dioxide (SO₂) and nitrogen oxides (NOₓ). As a result, the reaction product of NH₃, ammonium (NH₄⁺), forms an aerosol which is a major component of atmospheric aerosols and in precipitation (Asman, et al., 1998). The release of anthropogenic NH₃ into the atmosphere has increased in many regions of the world, which has led to deposition of N downwind from major sources (Asman, 1994). Areas of high deposition may show forest decline (Nihlgard, 1985) or ecological vegetation change (Todd et al., 2004) and some estimates have suggested that atmospheric deposition may contribute 35-60% of the total N loading to some coastal waters (Paerl, 1995). Although NH₃ is basic, it may still contribute toward acidification of ecosystems, as one mole of ammonium sulfate (NH₄SO₄) can result in the release of four moles of hydrogen ions (H⁺) by nitrification (Van Breemen et al., 1982). Dry deposition of NH₃ can also result in the release of one proton by nitrification. These concepts are, however, a simplification and the net acidification from atmospheric NH₃ + NH₄⁺ is complex and will vary with respect to the nutrient status of the soil. Indeed, Galloway (1995) has suggested that NH₃ emissions are, potentially, more acidifying than current emissions of SO₂ and NOₓ depositions. Other organic forms also exist, such as amines, but the concentrations of these components are generally negligible by comparison (Van der Eerden, 1982; Hutchinson et al., 1982). Most NH₃ is emitted near the earth's surface and a large proportion of these sources are of anthropogenic origin (Bouwman et al., 1997). Land-based NH₃ emissions are mainly from agricultural production. These sources are numerous, have low
source heights and are scattered both temporally and spatially. Another anthropogenic source is NH₃ emissions from motor vehicles which is usually not included in emissions inventories. Recent studies (Fraser and Cass, 1998) found that automobile emissions in the South Coast Air Basin (surrounding Los Angeles, CA) were comparable to livestock waste emissions with about 15% each of the total emissions inventory (Dickson, 1991). A comparison of vehicle emissions in North Carolina (McCulloch, 2001, personal communication) with emissions from swine production [using Harper et al. (2004a) emission factors] suggested that automobile emissions were about 28% of that from swine production.

There has been recognition of gas-phase NH₃ since the 19th century but its interest was focused largely on its effect as a fertilizer (Lawes and Gilbert, 1851). It was not until the mid 20th century that techniques were available to determine that plants emit and absorb NH₃ in relation to an NH₃ compensation point (Meyer, 1973; Farquhar et al., 1983). Because of the ability of NH₃ to react with measurement equipment, many of the early studies were somewhat inaccurate. However, non-invasive techniques were developed and used to evaluate net transport of NH₃ in cropping systems (Dennead et al., 1978; Harper et al., 1983; 1987) and using these techniques, it was found that significant amounts of NH₃ can be absorbed from the atmosphere under periods of diurnal and seasonal plant nitrogen (N) stress.

Ammonia volatilization is a complex physical and chemical process (Freney et al., 1983) and emissions are generally related to four factors: NH₄⁺ concentration of the medium, temperature of the medium, pH (hydrogen ion concentration where [H⁺] = 1 x 10⁻¹⁰ of the solution) of the medium, and turbulent transport of the NH₃ from the medium [For an in-depth treatment of the physical and chemical properties and their effect on NH₃ volatilization and transport, see Harper (2004).]. Conclusive studies on NH₃ emissions from crops and animal production systems depend on reliable experimental and analytical techniques. The purpose of this paper is to discuss field and analytical methods for measurement of NH₃ losses and present some preliminary findings made in cattle feeding operations.

**Methods for Measuring Ammonia Concentrations**

Because of its chemical properties, NH₃ concentration measurements must be evaluated appropriately in order to determine emissions. Care must be exercised in order to not destroy the emissions source and to not absorb or desorb NH₃ on or by the measurement equipment itself. If proper techniques are not observed, measurement of concentration will be erroneous. The standard technique for many years has been gas-washing techniques where the NH₃ is absorbed into an acid at a known flow-rate. From chemical analysis of the NH₄⁺ and the known flow-rate, a time-averaged concentration may be obtained (Weier et al., 1980). While this technique can be very accurate, it is very labor-intensive and is prone to sample-contamination, consequently considerable quality assurance and control is required. Additionally, gaseous amines will be absorbed but even in areas of high NH₃ emissions the levels of amines will be rather small (Hutchinson et al., 1982).

Annular denuders are similar in principal to gas-washing where air is pulled through glass tubes coated with either basic solution (such as sodium carbonate) for collection of acid gases or an acid solution (such as citric acid) to absorb basic gases (both acid and basic gases may be obtained simultaneously). Filters may be added to the denuders to obtain particulates. This
technique is also very labor intensive but the technique has been expanded for continuous system measurement (Wyers et al., 1993; Keuken et al., 1988; and Neftel et al., 1998). There are several types of instruments which measure NH$_3$ concentration electronically such as closed-path spectrometers including chemiluminescence (McCulloch et al., 2001) and tunable diode laser (Diaz, et al., 1996; Warland, et al., 2001). These instruments can be quite sensitive with proper sample handling and sequencing procedures. Open-path laser spectrometers (Bauer et al., 1999) and open-path Fourier transform infrared (OP-FTIR) spectrometers (Todd et al., 2001) provide a technique not requiring the gas sample to be transported to the laser source/detector site.

Flux Measurements

Quite often, high or low concentrations in the air are interpreted to be either large or small emissions rates. It is not possible to infer emissions from atmospheric concentrations. In general, there are two types of systems to determine emissions, those which interfere with the transport processes and those which minimize the interference of transport processes. Methods employed most frequently to measure gaseous flux include: 1). enclosure methods, in which the flux density of the gas at the surface is calculated from changes in gas concentration in an enclosure placed over the surface; 2). non-interference micrometeorological techniques, in which the vertical or horizontal flux density of the gas is measured in the free air above the soil, plant, or water surface; and 3). release of known tracer gases for ratioing the known and unknown emissions.

Enclosure methods: Enclosure or chamber methods are often used to measure gaseous flux because they are simple, suitable for pot experiments and for small field plots, and may have a lower sensitivity requirement for measuring gas concentrations. However, chambers interfere with the transport process because they disturb the sample area and the microclimate. In addition, NH$_3$ is a diffusive gas, it absorbs/desorbs on measurement equipment, and its emissions are dramatically influenced by the microclimate. These are reasons why non-interference techniques should be used (Denmead, 1983; Denmead and Raupach, 1993; Harper, 1988, 2004). Denmead and Raupach (1993) and Harper (1988, 2004) discuss in detail types of chambers and problems associated with interference techniques.

In attempts to minimize differences between enclosures and the field emissions, Vallis et al. (1982) and Lockyer (1984) developed “wind tunnel” enclosures whereby emphasis was placed on the requirement that the natural conditions of the plant community measured would be influenced as little as possible. The systems were designed so that airflow through the tunnel enclosure could be controlled within the range normally encountered in the field. This type of system requires treatments within the enclosure to increase atmospheric N above background levels or the comparison of treated with non-treated areas since the gas concentrations between entrance and exit or between treatment and control enclosures are measured. Care must be taken in the design of these enclosures to avoid countergradient flux from the tunnel opening (Vallis and Harper, 1982, unpublished data) and condensation on the inner surfaces (Vallis et al., 1982; Lockyer, 1984). Little effect was found on plant, air, or soil temperature, and soil water content when air velocity through the tunnel was matched to the ambient windspeed (Vallis et al., 1982; Ryden and Lockyer, 1985). When wind tunnels are used at fixed windspeeds, and there is an
appreciable difference between the tunnel windspeed and ambient windspeed, there is likely to be an error in the estimate of loss rates. Since large turbulent eddies convey the majority of gas transport, which cannot be replicated in a wind tunnel, true emissions are not obtained by this technique. Wind tunnels are, however, useful in comparing treatment effects where actual emissions are not required.

Generally, the surface area enclosed by chambers is relatively small, often less than one $m^2$, whereas the spatial variability of $NH_3$ and other gas emissions from soils, plants, pen surface, and water systems may be quite large (Denmead and Raupach, 1993). Soil emission rates may vary two to ten times within a few meters (Matthias et al. 1980; Galbally et al., 1985) creating highly variable results from chamber measurements. For example, Folorunso and Rolston (1984) found coefficients of variation of 282 and 379% in chamber measurements of $N_2O$ emissions and calculated that as many as 350 measurements would be necessary to estimate the true mean flux within $\pm 10\%$ on a 3 x 36m experimental plot. Based on the studies of Folorunso and Rolston, in a study of a cattle feedlot where chambers are used, it would take 550 samples per hour, 24-hours per day to obtain an approximate 10% error. Furthermore, the majority of emissions result from urine patches and samples must be taken over the urine patches immediately as Vallis et al. (1982) showed that 80% of the urea in urine will be hydrolyzed to $NH_4^+$ (and available for $NH_3$ volatilization) within two hours.

Because of the unique properties of $NH_3$, there is a pressing need for nondisturbing measurements of this trace-gas flux which integrate over larger areas and longer time scales. Micrometerorological techniques offer more promise in these respects.

**Micrometerorological Methods:** Micrometerorological methods are non-interference methods and are preferred in principle over interference methods such as chambers (Denmead, 1983; Ferguson et al., 1988; Harper, 1988) because: 1) they do not disturb the soil, plant, pen surface, water system, or environmental processes which influence $NH_3$ exchange; 2) they allow continuous measurement, facilitating the investigation of environmental effects on the production and transport of emissions; and 3) they provide average emissions over an area, minimizing the sampling problem of point-to-point variation found using enclosure techniques. However, their successful application requires relatively large experimental areas (causing problems of practical replication) and emissions are often small, requiring very sensitive equipment and careful attention to measurement protocol. Some micrometerorological techniques assume sources and sinks of energy and mass are evenly distributed and some may require a considerable amount of data processing before data analysis. A number of non-interference methods may be used to determine emissions from cropping and animal production systems; however, most techniques are not applicable to both animal and cropping systems.

Eddy covariance is based on the transport of gases by the eddying motion of the atmosphere. The instantaneous vertical flux density of a gas is the product of the vertical windspeed and its density. This technique is generally not applicable to beef feeding systems because of the roughness characteristics of the containment structures and the large fetch (upwind distance to the edge of the source area) that is needed. Meyers and Baldocchi (2004) present a discussion of the technique and underlying assumptions for its use.

Flux-gradient or aerodynamic (also called momentum balance) techniques are based on the
analogy between turbulent transport and molecular diffusion, assuming both processes transport a

gas along its mean concentration gradient. Application of these methods are limited to
measurements above crops or other systems where there is adequate profile (vertical point
measurements) development of windspeed, temperature, and gas concentrations. An additional
assumption is that horizontal concentration gradients are negligible in relation to vertical
gradients. If these requirements are met, the vertical flux density of the gas in question will be
constant with height in the air layers close to the measurement surface and a one-dimensional
(vertical) analysis can be made (Denmead and Raupach, 1993). This method has been widely
used and measurement of gas transport between soils, plants, water systems, and the atmosphere
have been reported by a number of researchers (Harper, 2004). The flux-gradient technique has
been recently used in large cattle feedlot conditions (R. Todd and A. Cole, personal
communication) where the fetch is very large in relation to the roughness elements of the animal
detail including estimation of the transport coefficient from wind profile data and approaches to
correct for atmospheric stability.

Another flux-gradient method is the energy balance technique where all radiative and
turbulent energy components are measured. The technique assumes equality of transport
coefficients for heat, water vapor, and NH\textsubscript{3}, so that measurements of each at two heights is
sufficient to determine the fluxes of all three. A disadvantage of the energy balance method is
that in early morning, late evening, and nighttime, incoming and outgoing radiation become small
or approach the same value and the error may get large. Also at night, condensation on the
instrumentation can cause erroneous measurements. Since many of the measurements are
common to both techniques, both the momentum and energy balance methods should be used in
conjunction giving a comparison in diffusivity coefficients during periods when the energy balance
technique may be used. Harper (1988, 2004) discusses the use of this technique.

Mass balance methods: The eddy covariance and gradient methods require extensive and
uniform surface areas for sufficient profile development. Mass balance techniques, commonly
called integrated horizontal flux (IHF) methods, overcome this limitation. Flux densities are
determined from the differences in the quantity of gas carried by the wind across the upwind and
downwind boundaries of an experimental area of uniform flux (Denmead et al., 1974; Denmead,
1983). Instrumentation is relatively simple, requiring only windspeed and gas concentration
profiles and wind direction. The concept is relatively simple and physically correct with no
requirement for stability corrections [for a discussion of the technique see Denmead (1983) or
Harper (2004)].

A modification of this technique [micrometeorological mass difference (MMD), Fig. 2] has
been used successfully for measuring enteric CH\textsubscript{4} emissions from grazing and feedlot animals
(Harper et al., 1999; Denmead et al., 1998), N\textsubscript{2}O emissions from grazed pastures (Leuning et al.,
1998; Denmead et al., 2000b), and CH\textsubscript{4} and N\textsubscript{2}O from landfills (Denmead et al., 1998a). This
technique may not be used for reactive gases such as NH\textsubscript{3} emissions because of the problem of
absorption/desorption of the gases on the sampling tubing; however, with the advent of multiple-
sensor, open-path laser spectrometers for NH$_3$, this technique may become useful to measure source emissions which are horizontally, vertically, and temporally variable. Harper$^1$ developed a modified mass balance technique of the same principle as the MMD technique to be used with vertically-arrayed open-path lasers (Fig. 3). This technique, is useful for variable sources (spatially and vertically) and has minimal interference and/or stress on crops or animals. Since only upwind and downwind measurements are made, this technique must be used in a general cross-wind direction (Desjardins et al., 2004).

**Dispersion Analysis Techniques:** Flux-gradient techniques have been used extensively to describe NH$_3$ transfer between the atmosphere and crop surfaces, but theoretical difficulties limit the use of flux-gradient techniques within plant canopies, particularly where there are vertically distributed sources and sinks. The Lagrangian dispersion theory developed by Raupach (1989) enables a prediction of the gas concentration profile from knowledge of the source strength and has been used by Raupach et al. (1992) and Denmead et al. (2000) to deduce source and sink strengths for water vapor, heat, and CO$_2$ exchange in crop canopies. Harper et al. (2000a) extended the analysis to identify sources and sinks of NH$_3$ in a canopy following sprinkler application of dairy effluent. The technique allowed an examination of the processes of loss within the canopy showing small but not insignificant NH$_3$ losses from the soil, while showing unexpectedly large losses occurring from the foliage in the top half of the canopy.

The backward Lagrangian stochastic analysis (bLS) defines a forward “source-receptor relationship” from a source field, and on the basis of some assumptions about the turbulent flow, it gives expression for a resultant mean concentration field (Wilson et al., 2001). In this technique, the gas concentration is measured at a single point and the variables defining the state of the surface layer (at least minimally a single windspeed and wind direction) are required. For improved accuracy, atmospheric stability is needed.). The model is applied by generating an ensemble of $n$ trajectories, such as NH$_3$, from a point backward in space and time (Fig. 4) and where any trajectory touches the ground, the point is recorded and the particle’s touchdown position and vertical velocity is inferred from those

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touchdowns. Studies by Flesch et al. (2004) considered the bLS method as applied to an ideal case: estimating emissions from a synthetic source (a square grid of gas emissions of known rate) located in an open landscape where the Monin-Obukhov similarity theory (MOST) [a framework for describing surface layer winds] is likely to be upheld. They found the diagnosed emission rates were satisfactory when MOST gave a good description of the surface-layer, but poor during periods of extreme atmospheric stability and transition periods in stratification. With such periods eliminated, the average flux density spanning over six days over-predicted the true flux density by only 2%.

However, individual 15-min predictions exhibited sizeable variability. In the best case for the individual 15-min predictions where MOST gave a good description, the variability in the bLS flux density was approximately 20% of true flux density.

While the bLS model used by Flesch et al. (2004) has been thought to be valid only for ideal conditions (i.e. a homogeneous landscape), the studies of Wilson et al. (2001) and Flesch et al. (2005) indicate a robustness in flux-density determinations in non-ideal settings. Wilson et al. (2001) used a wind-flow-model to simulate winds around a hypothetical lagoon that was aerodynamically smoother, and either warmer (night) or colder (day) than the surrounding ground. This situation creates a disturbed wind environment (which can cause dramatic wind complexity) that invalidates the assumptions used in the bLS model. Despite this complexity, the emissions diagnosed from the bLS model, using observations over the lagoon, were within 15% of the true emissions except in the most extreme case. The study of Flesch et al. (2005) considered a different type of complexity. They constructed an emission source surrounded by a windbreak fence (an analog of a real farm setting). Despite the wind complexity caused by this fence there was surprising accuracy in emissions determined by the bLS when observations were taken far downwind of the fence (beyond five fence heights). Taken together, these two studies suggest that a simple bLS technique can be used in non-ideal cases if care is taken to avoid locations immediately downwind of dramatic changes in surface conditions and obstacles which disturb the ambient wind.

Other dispersion models are the Gaussian plume and puff models which have become a standard for modelling atmospheric dispersion for two reasons: simplicity and flexibility. They are attractive because of the large degree of flexibility in handling arbitrary source characteristics (continuous line source, moving source, etc.), effluent characteristics (buoyancy, stack downwash, etc.), and varying meteorological conditions. They are promoted as having a modelling range of tens of meters to thousands of kilometers. Despite their apparent sophistication, the Gaussian framework is rather primitive. While the derivation of these models starts with the rigorous mass-conservation equation, often a host of unrealistic assumptions are then employed: homogeneous wind field (conditions of steady, uniform wind-flow, spatially-independent turbulence), a gradient-diffusion hypothesis of turbulent transport, and mass
diffusivities independent of position (Arya, 1999). The result is a deceptively simple relationship for the concentration field downwind of an emission source. But, because the underlying Gaussian model assumptions are not generally realistic, these models are essentially empirical. In many agricultural and environmental applications, accurate models of dispersion near the ground (height < 100 m) and over short ranges (horizontal distance < 1000 m) are required. These conditions are where Gaussian models are most unreliable. Near the ground, the average wind and turbulence levels change dramatically with height, invalidating the foundation of Gaussian models (T.K. Flesch, 2001, personal communication). In most agricultural situations, Gaussian models should be not used, or should be used with a great deal of caution.

**Tracer-gases:** A ratioing technique is often used for comparing known tracer-gas emission rates with unknown gas emissions rates (ex. Eklund and LaCosse, 1995; Todd et al., 2001). The limitations and assumptions inherent in this measurement approach must be recognized when using this technique. They include the following: 1) The tracer gas must adequately simulate the emission source [Note: a potential error is introduced due to the assumption that the point or area release of the tracer gas, which may be lighter or heavier than air, mimics the area NH$_3$ emissions, which is itself lighter than air (McCulloch, 1999)], 2) the vertical distribution of the tracer gas emissions must not be different from that of the unknown emission plume from the measurement area (Eklund and LaCosse, 1995), and 3) the horizontal distribution of the tracer is not different from that of the unknown emission plume. This technique does not use plume dispersion models nor other meteorological measurements such as stability corrections. Other uses of tracer techniques have been to release and evaluate known amounts of the gas to be determined prior to the measurements themselves. Denmead et al. (1998a) found that using CH$_4$ as a tracer released to simulate emissions from a point source (such as from a cow) that under windspeeds of less than one to 1.5 m sec$^{-1}$, much of the released CH$_4$ was lost to the atmosphere above the measurement height. This problem had the effect of biasing the rates low. For commonly-used tracer gases such as sulfur hexafluoride (SF$_6$) and carbon tetrafluoride (CF$_4$), which are heavier than air, if the tracer gas plume tended to remain closer to the ground than the source plume, the measured tracer gas concentrations would be relatively lower and the calculated source emission rates would be biased high (Eklund and LaCosse, 1995). Results using these tracers have tended to be higher than comparable measurements or reasonable results.

**Other techniques:** Isotopes have been used to estimate NH$_3$ emissions; however, N is so much a part of plant and microbial activity that non-interference techniques must be used concurrently to evaluate isotope substitution and fractionation. For discussions on the use of isotopes see Harper and Sharpe (1998) and Harper (2004) for further information.

**Emissions from Animal Feeding Operations**

**Emissions factors:** Emission factors have been used to calculate NH$_3$ emissions from livestock production in Europe (Asman, 1992) and the U.S. (Battye, et al., 1994). Table 1 presents a list of U.S. and European emission factors for swine based on a “per animal per year” basis. The factors are quite variable because there are not clear-cut links between countries and their studies (Battye
Table 1. U.S. and Europe swine production emission factors (after Harper, 2004).

<table>
<thead>
<tr>
<th>Source</th>
<th>Emission Factor (kg NH₃-N animal⁻¹ yr⁻¹)</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asman (1992)</td>
<td>4.4</td>
<td>Europe</td>
</tr>
<tr>
<td>Buijsman et al. (1987)</td>
<td>1.9</td>
<td>Europe</td>
</tr>
<tr>
<td>Cass et al. (1982)</td>
<td>3.7</td>
<td>Europe</td>
</tr>
<tr>
<td>Jarvis and Pain (1990)</td>
<td>3.6</td>
<td>Europe</td>
</tr>
<tr>
<td>Krause et al. (1989)</td>
<td>2.9</td>
<td>Europe</td>
</tr>
<tr>
<td>van der Hoek and Couling (1995)</td>
<td>#0.7</td>
<td>Europe (composite)</td>
</tr>
<tr>
<td>Farrow to Finish</td>
<td>#1.8</td>
<td>Europe (composite)</td>
</tr>
<tr>
<td>Farrow to Wean</td>
<td>5.3</td>
<td>Europe (composite)</td>
</tr>
<tr>
<td>Farrow to Finish</td>
<td>13.5</td>
<td>Europe (composite)</td>
</tr>
<tr>
<td>Battye et al. (1994)</td>
<td>9.2</td>
<td>U.S. (NC10-chambers)</td>
</tr>
<tr>
<td>Eklund and LaCosse (1995)</td>
<td>517.6</td>
<td>U.S. (TX-tracer studies)</td>
</tr>
<tr>
<td>Harper et al. (2000b)</td>
<td>#1.3</td>
<td>U.S. (Georgia)</td>
</tr>
<tr>
<td>Farrow to Finish</td>
<td>#2.1</td>
<td>U.S. (Georgia)</td>
</tr>
<tr>
<td>(Primary lagoon)</td>
<td></td>
<td>Netherlands</td>
</tr>
<tr>
<td>(Four-stage lagoons)</td>
<td></td>
<td>U.S.</td>
</tr>
<tr>
<td>Voorburg and Monteny (1991)</td>
<td>#3.0</td>
<td></td>
</tr>
<tr>
<td>Warn et al. (1990)</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>Harper et al. (2004a)</td>
<td>#1.1</td>
<td></td>
</tr>
<tr>
<td>Farrow to Finish</td>
<td>#1.7</td>
<td></td>
</tr>
<tr>
<td>Harper et al. (2004b)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sow farms (lagoons)</td>
<td>#2.6</td>
<td></td>
</tr>
<tr>
<td>Nursery farms (lagoons)</td>
<td>#0.3</td>
<td></td>
</tr>
<tr>
<td>Finisher farms (lagoons)</td>
<td>#1.8</td>
<td></td>
</tr>
</tbody>
</table>

# storage only
& per fattening place
et al., 1994), between measurement technologies, components included (housing, storage, application), and animal categories. Consequently, emission factors must be used with caution because of variability induced by geography and meteorology, methodology for measurement (Denmead and Raupach, 1993; Harper, 1988), type and weight of animals (Harper et al., 1998), N content of feedstuffs, housing and management, and other factors. Asman (1992) developed a composite swine emission factor for Europe of 4.4 kg NH₃-N animal⁻¹ year⁻¹. Later evaluations by van der Hoek and Couling (1995) separated animals into classes and gave slightly higher emissions for farrow-to-finishing (FF) animals of 5.3, and considerably higher factor of 13.5 for farrow-to-wean (FW) animals. Battye et al. (1994), using emissions from Europe and USDA Agricultural Statistics Service animal classifications, developed a similar composite factor to that of Asman (1992) for the U.S. of 9.2 kg NH₃-N animal⁻¹ year⁻¹ which is considerably higher than the European factors or the earlier NAPAP factors (Warn et al., 1990) [There is some question that the Northern European emission factors (Asman, 1992) were used improperly and the U.S. factors developed may be too large by about a factor of two (Asman and Harper, 2000. Personal communication). Comparison of lagoon emission factors for FF management systems were similar for van der Hoek and Couling (1995) in Europe, for Harper et al. (2000b) in Georgia (the primary lagoon only), for Harper et al. (2001) in North Carolina, and Harper et al. (2004b) in Utah.

Even emission factors determined from the same lagoon using different technologies have shown considerable variation (Table 2). On a highly-studied farm in the Coastal Plains of North Carolina (designated NC10), several studies of NH₃ emissions were compared. Aneja et al.

Table 2. Comparison of lagoon emissions determined by different techniques on a swine production farm in North Carolina (after Harper, 2004).

<table>
<thead>
<tr>
<th>Method</th>
<th>Season</th>
<th>Lagoon Emissions (kg NH₃-N/ha/day)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chambers</td>
<td>Summer</td>
<td>57.8</td>
<td>Aneja et al. (1999)</td>
</tr>
<tr>
<td>Flux-gradient</td>
<td>Summer</td>
<td>18.7</td>
<td>Harper et al. (2001)</td>
</tr>
<tr>
<td>Gaussian model</td>
<td>Summer</td>
<td>42.3</td>
<td>McCulloch (1999)</td>
</tr>
<tr>
<td>Tracers</td>
<td>Summer</td>
<td>96</td>
<td>Todd et al. (2001)</td>
</tr>
<tr>
<td>Chambers</td>
<td>Winter</td>
<td>12.2</td>
<td>Aneja et al. (1999)</td>
</tr>
<tr>
<td>Flux-gradient</td>
<td>Winter</td>
<td>7.6</td>
<td>Harper et al. (2001)</td>
</tr>
<tr>
<td>Gaussian model</td>
<td>Winter</td>
<td>19.4</td>
<td>McCulloch (1999)</td>
</tr>
<tr>
<td>Tracers</td>
<td>Winter</td>
<td>27.5</td>
<td>Todd et al. (2001)</td>
</tr>
</tbody>
</table>

(1999), using floating chambers obtained an estimate of lagoon annual emissions 2.7 times larger than those of Harper et al. (2001) using non-interference, micrometeorological techniques for the same lagoon. McCulloch (1999), using a non-interference Gaussian model, determined annual emissions 2.3 times higher than Harper et al. (2001) whereas Todd et al. (2001), using tracer
techniques (non-interference technique), obtained annual emissions 4.7 times that of Harper et al. (2001). For that farm, a total N balance of individually-measured components (Fig. 4) accounted for about 95% of the input N as feed (Harper et al., 2004a). Use of lagoon emissions measured by the other techniques on this lagoon would suggest more N was emitted from this farm than entered the farm as feed N input.

**Emissions:** Since NH$_3$ is a diffusive gas, emissions result from an interaction of physical and chemical factors. Figure 5 relates NH$_3$ emissions from a swine lagoon to microclimate variables during a period of large weather variation (Harper et al., 2000b). Increases in lagoon water temperature resulted in average NH$_3$ emissions approximately three times larger on day of year (DOY) 46 compared to DOY 43. Windspeeds between days were not significantly different but the water temperature increased by about 10 °C during the period causing an average daily increase in emissions. The effect of short-term changes in windspeed on flux density can also be seen, superimposed on the effect of the water temperature increase. Figure 6 gives an example of the effect of windspeed on flux density when water temperature is constant (Harper et al., 2000b). In long-term studies, the effect of windspeed on NH$_3$ emissions had the largest effect accounting for about

![Fig. 4. Mass-balance of individually-measured nitrogen components in a North Carolina (NC 10) swine farm (after Harper et al., 2004a).](image)

![Fig. 5. Lagoon ammonia emissions in relation to windspeed (at 1.6-m above the water surface), water temperature (at 0.05-m below the water surface), and to sludge temperature (located within the sludge layer usually around 3.0-m deep), Georgia Coastal Plains, winter, 1996 [after Harper et al. (2000b)].](image)
70% of the variability; however, when water temperatures decreased to about 3 °C, emissions ceased [Harper (2004), unpublished data]. The effect of NH₄⁺, temperature, and pH on emissions influences the dissociation and partial pressure of NH₃ in the water (De Visscher et al., 2002). The higher the partial pressure of NH₃ in the water, the greater potential for diffusion in the water and escape from the air-water interface.

On an annual basis, chemical and physical factors similarly influence NH₃ emissions. Figure 7 gives a typical example of annual cycling of these factors in relation to emissions. Monthly average emissions varied on an annual cycle with higher emissions during the summer and autumn; however, the autumn emissions were higher in 2001 than 2000 due to much higher windspeeds in the autumn of 2001.

Emission rates from lagoons are difficult to measure, requiring specialized equipment and appropriate atmospheric transport technology to obtain realistic emissions in relation to variable climatic and management conditions where animal production occurs. Because of the cost of measuring emissions from lagoons, a statistical model (Harper et al., 2004a) based on lagoon NH₄⁺ content, temperature, pH, and wind speed explained 78% of the variability in emissions. This model was geographically limited to the Humid East since the ranges upon
which the statistical model were developed were limited to this geographical area, so a process model (DeVisscher et al., 2002), based also on the same above physical and chemical factors, was developed which is much more transferable to other regions. The process model predicted daily emissions, as measured by micrometeorological techniques, with an accuracy explaining 70% of the variability of the data using average daily input values ($R^2$ of 0.85). The process model more reliably measured emissions than a statistical model, which generally underestimated emissions.

While current estimates of emissions from swine production by the USEPA of 70% of feed input N (USEPA, 2004) (Note: Approximately 30% of feed input in swine leaves as animal protein N [Hall et al. (1988), Jongbloed (1991), and Jongbloed and Lenis (1992).]) and current estimates by the state of North Carolina of 36% (Doorne et al., 2002) do not provide error limits on their published emissions, Harper et al. (2004b) reported emissions (as % of input feed N) from swine lagoons in Utah ranging between 11 and 16% for all (sow, nursery, and finisher) production types. When the difference in amounts of feed input to the production types was accounted for, the composite emissions for lagoons on the entire farm was 9.8% of feed input with an estimated variability of about 4%.

There are few published studies on NH$_3$ emissions from beef feeding operations. Hutchinson et al. (1982) measured daytime emissions over a short period during summer using microclimate techniques. These emissions, although measured only during daytime, have been used extensively for developing an emission factor for beef feeding operations (USEPA, 2004). Recent studies by Harper, Todd, and Cole (2004, unpublished data) in a beef feeding operation in the Semi-arid West used non-interference techniques to evaluate NH$_3$ and other trace-gas emissions during summer and winter periods. Flux-gradient and bLS

![In-Feedlot NH3 Emissions](image)

![In-Feedlot NH3 Concentrations and Stability](image)

![In-Feedlot NH3 Wind Conditions](image)

Fig. 8. Preliminary results of NH$_3$ emissions determination, in relation to microclimate conditions, from a beef feedlot (after Harper and cooperators, 2004, unpublished data).
techniques were used simultaneously to determine NH₃ emissions. Figure 8 shows daily variation of emissions estimates and exemplifying why 24-hour measurements must be used in developing emissions factors. During this winter study, daytime emissions estimates were often 15 times larger than nighttime emissions estimates. Whereas minimum nighttime emissions remain relatively constant for several hours, daytime maximum emissions last only briefly, exemplifying why daytime emissions cannot be used as a valid indicator of average daily emissions. Average daily emissions for four days of complete data gave wintertime average NH₃-N emission of 38% of feed intake. These emissions compare well with the 40-60% range using mass balance techniques by Erikson and Klopfenstein (2001).

Figure 9 gives two days of summertime NH₃ and CH₄ (enteric plus some anaerobic)

Fig. 9. Preliminary results of summertime NH₃ and CH₄ emissions and concentrations comparisons, in relation to microclimate conditions, from a beef feedlot (after Harper and cooperators, 2004, unpublished data).

relative concentrations measurements and emissions determinations (likewise using the bLS
technique) over the same feedlot\(^2\). Comparison of diurnal cycling suggested that wintertime variation increased from nighttime emissions to daytime emissions of about a 10-fold increase whereas summertime variations was about half the increase from nighttime to daytime. From DOY 197.5 to 198, the wind direction showed that concentrations measured resulted from both the feedlot and a nearby retention pond—resulting in higher apparent emissions. From DOY 198 to 199.5 the wind direction was such that emissions were only from the feedlot. The relationship between \(\text{NH}_3\) concentration and emissions show that while the emissions increase about 5-fold, the concentration does not significantly or appreciably increase. The concentration remains relatively constant due to the interrelationship between windspeed and atmospheric stability. During daytime, even though emissions are considerably higher, turbulence is also higher; while at night, even though emissions are much smaller, atmospheric stability and reduced turbulence holds the gases closer to the ground thus maintaining concentration even though the emissions are smaller. The opposite effect is seen with enteric (plus some \(\text{CH}_4\) from manure) emissions. From DOY 198 to 199.5 the \(\text{CH}_4\) emissions are relatively constant but during stable, nighttime periods the concentrations increase—providing an opposite effect of the \(\text{NH}_3\) emissions. Observation of the interrelationship of \(\text{NH}_3\) and \(\text{CH}_4\) emissions and concentrations exemplifies why the measurement of concentrations do not correspond to actual emissions.

**Summary**

Because of its chemical properties, \(\text{NH}_3\) is a difficult gas to measure without disturbing its transport characteristics. Ammonia is a highly reactive, absorptive, and sticky gas requiring great care in sampling. Its chemical properties dictate the use of measurement equipment and transport technologies that do not interfere with the source temperature, concentration, pH, and turbulent or diffusive transport. Its chemical measurement necessitates precautions since it may adsorb and desorb with most surfaces and with the sensors themselves. The purpose of this report has been to review available atmospheric-exchange and transport technology and discuss strengths and weaknesses of the methodologies.

Chamber techniques affect the microclimate of the site and should not be used for diffusive types of gases such as \(\text{NH}_3\); however, they may be used for small-plot comparative studies for biological gases (\(\text{CH}_4\), \(\text{N}_2\text{O}\), \(\text{CO}_2\), etc.) where absolute emissions are not required. Flux-gradient and dispersion-analysis techniques are preferred for measuring air-quality and greenhouse gas emissions; however, these techniques require large, relatively-homogenous sources for wind and concentration vertical-profile development. Integrated horizontal flux techniques work well for small-area, homogenous source studies and mass-balance techniques work well for small-area, non-homogenous studies. Some microclimate and tracer techniques are not suitable for agricultural situations.

A number of examples have been presented comparing measurement techniques. Emissions factors were presented showing differences due to measurement techniques, time-period when data were taken, and basis of comparisons. Comparison was made between \(\text{NH}_3\) and enteric \(\text{CH}_4\) emissions from a beef feedlot showing the relationship between types of emissions (biological vs. diffusive), the lack of relationship between atmospheric concentration of gases and emissions, and the importance of having good technology to evaluate emissions.

\(^2\)Absolute emissions are not presented in this preliminary data.
References:


Eklund, B. and J. LaCosse. 1995. Field measurements of greenhouse gas emissions from the


0.93) concentrations among different treatments. The N:P ratio, however, was different ($P = 0.038$). The N:P ratio was 3.87, 3.45, and 3.56 in manure obtained from pens fed the 10% CP, 11.5% CP, and 13% CP diets, respectively. Carcass characteristics of steers did not differ ($P > 0.1$). Data indicate that under the condition of this study CP levels can be reduced during the final stages of finishing without effects on feedlot performance.

Exit Velocity as a Measure of Temperament to Predict Performance of Growing Cattle

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Texas Agricultural Experiment Station, $^1$College Station and $^3$Overton, Mississippi Agricultural Experiment Station, Raymond

Two studies were conducted to examine the relationships between exit velocity (EV) and temperament and to determine the value of using EV to predict performance, efficiency and carcass composition of growing calves. In experiment 1, Bonsmara bulls ($n = 62$) were individually fed a roughage based diet (1.7 Mcal ME/kg DM) using Calan gate feeders. Weekly BW and dry matter intake (DMI) were measured for 70 d and residual feed intake (RFI) calculated as the difference between actual DMI and DMI predicted from linear regression of DMI on mid-test BW$^{75}$ and ADG. In Experiment 2, crossbred steers ($n = 44$) were assigned to one of three tall fescue varieties or ryegrass with two pasture replicates per forage treatment. Steers were grazed for 168 d and BW measured at 28-d intervals. On d 0 of each study, pen temperament scores (PS, 1 = non-aggressive to 5 = aggressive) were assigned, and EV measured as the time cattle took to transverse a distance of 1.83 m upon release from a squeeze chute using infrared sensors. Ultrasound measurements of backfat (BF), longissimus muscle area (REA) and intramuscular fat (IM) were obtained on d 70 and 168 of each study, respectively. PS were positively correlated with EV in bulls ($r = .46; P < .001$) and steers ($r = .47; P < .001$). EV was negatively correlated with ADG in bulls ($r = -.25; P < .05$) and steers ($r = -.11; P = .07$). Final BW were negatively correlated ($P < .01$) with EV in bulls and steers. In bulls, EV was negatively correlated ($P < .01$) with DMI, but not with FCR or RFI. Fast EV bulls ($> 0.5$ SD above the mean EV) ate $12\%$ less feed than slow EV bulls ($< 0.5$ SD below the mean EV), but had similar FCR and RFI compared to slow EV bulls. Bulls and steers identified as having fast EV had lower ($P < .05$) final BW compared to slow EV bulls and steers. EY was negatively correlated ($P < .01$) with REA in bulls ($r = -.32$) and steers ($r = -.18$), and BF ($r = -.25; P < .001$) and IM fat ($r = -.12; P < .06$) in steers only. Fast EV bulls had smaller ($P < .05$) REA (58.0 vs 63.3 ± 1.8 cm$^2$) and less ($P < .05$) BF (5.3 vs 5.71 ± .15 mm) than slow EV bulls, but there were no differences in REA and BF between fast and slow EV steers. Calves identified as having fast EV at the beginning of the studies were significantly lighter at the end of the studies then slow EV calves. Moreover, bulls with fast EV at the start of the study ate less feed, and had smaller REA and less BF at the end of the study than slow EV bulls, suggesting that EV may be a useful management tool to sort calves into productive outcome groups. More research is warranted to determine if temperament classification of calves upon feedlot entry affects performance or carcass quality responses to standard feedlot management practices (e.g., implants, feed additives, mass medication).
Rate and extent of in situ DM disappearance of feedstuffs in cows fed different strains of yeast

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An in situ experiment was conducted to determine rate and extent of DM disappearance (DMD) of corn grain (CG), sorghum grain (SG), alfalfa hay (AH) and brown mid-rib forage sorghum silage (SS) in the presence of different strains of yeast. Four mature rumen cannulated non-lactating cows were fed a control diet (C), or C diet plus 20 g/d P7, 20 g/d SC47 or 40 g/d DV-XP strains of yeast in a 4X4 Latin square design. A 13% high concentrate diet (9.5 kg/d) consisting of 80% of steam flaked corn, 10% soybean hulls and 10% protein/vitamin mineral supplement was fed to each cow twice a day (60% at 0800 h and 40% at 1600 h). Yeast strains were top dressed on the respective diet at the morning feeding and mixed by hand. Cows were fed their respective diet in each period of the Latin square for 14 d. On d 12 of each period, duplicate in situ digestion bags (10 X 20 cm) containing substrate (12.5 mg/cm² of bag surface area) were incubated for 72, 48, 24, 12, 6, 3, 1.5, 0.5 and 0 h. Immediately after submersion of the 0 h bags of substrate into the ruminal fluid, all bags were removed and rinsed with tap water. After an initial rinse, all bags were placed into an automatic clothes washing machine and rinsed using 4 to 6 gentle cycles of agitation until rinse water was clear. Bags were then dried at 60 C for 48 h and weighed to determine DMD. The rate of DMD for CG, SG, AH and SS was 2.7, 2.1, 1.88 and 0.94 %/h, respectively. P7 and SC47 increased (P = 0.0075) rate of DMD of CG over that of C and DV-XP (3.28 and 3.43 vs 1.96 and 2.52 %/h, respectively). Yeast strains did not change the rate of DMD of SG, AH or SS (p > 0.10). The extent of DMD was similar across all treatments for CG (95.4%), SG (89.3%) and AH (74.54%). The extent of DMD of SS was decreased (P = 0.04) when DV-XP was fed compared C, P7 and SC47 (56.0% vs 76.9, 74.0 and 69.5, respectively). These data indicate that various yeast strains affect rate or extent of DMD of CG and SS in this study.

Effects of phase feeding of protein on performance, blood urea nitrogen, manure N:P ratio, and carcass characteristics of feedlot cattle

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One hundred eighty four steers (BW = 406 kg) were used in a randomized block design to determine the effects of phase feeding of protein on performance, blood urea N (BUN), manure N:P ratio, and USDA carcass characteristics of feedlot steers. Steers were fed ad libitum a finishing diet containing 10% roughage (DM basis) formulated to contain 13% CP (DM basis). When steers reached 477 kg the diets were either maintained at 13% CP or reduced to 11.5% CP or no supplemental CP (approximately 10% CP). Reducing the CP to 11.5% or no supplemental CP did not affect (P = 0.21) ADG of steers (1.62, 1.71 and 1.53 kg/d for 13%, 11.5% or no supplemental CP, respectively) from day of diet change to day of harvest. The ADG of steers was similar (P = 0.09) throughout the finishing period regardless of level of CP treatment (1.69, 1.86, and 1.74 for approximately 10% CP, 11.5% CP and 13% CP, respectively). Similarly, dry matter intake and feed efficiency did not differ (P > 0.05) among treatments. BUN concentrations were determined (mg/dL) on d 1, day of the diet change, and immediately before harvest. Differences (P < .0001) in BUN were observed only immediately before the harvest. Animals fed the 13% CP diet had greater (P < .0001) BUN concentration (13.85 mg/dL) than animals fed the 11.5 % and no supplemental CP (12.08 and 10.04 mg/dL, respectively). Manure from the pen surface was collected and analyzed for N and P. No differences (P > 0.05) were observed in N (P = 0.60) and P (P =
grade, dressing percent, percentage of cattle grading USDA Choice, marbling score, backfat thickness, or longissimus muscle area. Incidence of liver abscess did not differ (P = 0.30) among the three treatments; however, the 33% treatment had a numerically higher rate (12.25%) than the 67% (8.26%) and the 100% (7.50%) treatments. Results indicate that when feeding a finishing diet based on steam-flaked corn that contains 25% (DM basis) Sweet Bran® WCGF, providing supplemental CP with a ratio of at least 67% urea:33% cottonseed meal improves ADG and feed efficiency compared with 33% urea:67% cottonseed meal.

**Effects of Corn Bran and Steep Inclusion in Finishing Diets on Performance, Nitrogen Balance, and Diet Digestibility in Feedlot Cattle**

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Two finishing trials using calves fed 167 d from November to April (WINTER) and yearlings fed 126 d from May to September (SUMMER) were fed to evaluate the effects of decreasing digestibility of a finishing diet by replacing dry rolled corn (DRC) with corn bran and steep, on performance and nitrogen (N) balance in open feedlots. Cattle were stratified by weight and assigned randomly to one of four treatments. A metabolism trial was also conducted to evaluate the effect of corn bran and steep inclusion in finishing diets on diet digestibility. Dietary treatments for all trials included Control (CON), 30% Corn Bran (30/0), 30% Corn Bran/15% Steep (30/15), and 45% Corn Bran/15% Steep (45/15) with byproducts replacing DRC in the diet (DM basis). Pens were cleaned four times in WINTER and three times during SUMMER, across all treatments. WINTER cattle on CON tended to eat less than cattle on byproduct diets (23.1 lb/d vs. 24.5 lb/d, P = 0.06), however no differences in final weight (1322 lb) or feed efficiency (0.157) were detected (P > 0.05). SUMMER cattle were also not different in final weight (1330 lb, P > 0.05) however, CON yearlings had lower DMI then those on the byproduct diets (24.0 lb/d vs. 25.6 lb/d, P < 0.01) and cattle on 30/0 were less efficient than other treatments (0.135 vs. 0.144, P = 0.05). WINTER percent N losses from the pen floor surface were 63.9%, 50.7%, 51.9%, and 35.8% for CON, 30/0, 30/15, and 45/15, respectively, (P = 0.01). SUMMER percent N loss of total N excreted was not different (P > 0.05) across treatments (averaging 60.1%) however, more N was removed in the manure from byproduct pens than CON pens (29.3 lb N/hd vs. 22.2 lb N/hd, P = 0.01). A 4 X 4 latin square design was used to evaluate diet digestibility. An in-situ trial was also conducted on DRC and Bran, during the final period with incubation time points of 0, 12, 24, 48, and 96 h. Dry rolled corn (DRC) and bran were evaluated for DM disappearance rates, and corn bran was calculated for NDF disappearance rate in each of the four diets. Byproduct diets had higher rumen pH (5.96) than CON (5.75) across all time points (P < 0.01), DMI average was 25.1 lb/d and was not different among diets, but was numerically higher in byproduct diets. Total tract DM digestibility was higher in CON vs byproduct diets (79% vs 73.0%, P < 0.01), as was OM digestibility (80.2% vs. 74.6%, P < 0.01). DM disappearance (%/h) of DRC was lower in CON diet (2.45) vs byproduct diets (2.93, P < 0.01). NDF disappearance rates (%/h) were dramatically lower in CON (0.82) diets than in byproduct diets, suggesting that the microbial population is being shifted towards more cellulolytic bacteria (P < 0.01). Steep did not help to improve diet digestibility, however it was beneficial in maintaining cattle performance. Byproducts help to improve disappearance of DRC and Bran, however, cattle need to be adapted to byproduct diets in order to take full advantage of the improved rumen environment. Byproduct diets may prove valuable as a management tool for increasing N removed in manure and lowering percent N lost from the pen floor surface.
gain. Hay-fed steers were fed to similar final weight. Carcasses adjusted fat thickness (ATF), marbling score, postmortem plasma, muscle, subcutaneous, and intramuscular adipose tissues were collected. Data were analyzed as a complete block design. Plasma glucose (µmol/mL) was numerically greater (P=0.06) in corn-fed (3.77±0.06) vs. hay-fed (2.88±0.05) steers. Glucose (µmol/g) in muscle was greater (P=0.04) in hay-fed steers (4.68 ± 0.07 vs. 3.07 ± 0.08). Muscle glucose-6-phosphate (G6P), and fructose-6-phosphate (F6P; µmol/g) were similar (P=0.10) between diets. Glucose (P=0.13), G6P (P=0.34), and F6P (P=0.22) concentrations in subcutaneous tissue were also similar. Glucose and F6P concentrations in intramuscular tissue were 2-fold and 10-fold higher, respectively, than observed in subcutaneous depots, but were similar (P>0.6) among treatments. G6P was numerically greater in hay-fed (0.186 ± 0.008) vs. corn-fed steers (0.084 ± 0.009; P=0.08). Mean carcass ATF was similar (0.47 cm) from both diets. Mean marbling score in corn-fed steers (710 ± 78) was numerically greater than in hay-fed steers (564 ± 72) although statistical separation was not achieved (P=0.4). Plasma glucose indicates greater glucose pool size in corn-fed steers; greater concentrations of glucose and intermediaries in muscle of hay-fed steers may reflect decreased pathway flux. Correlations between marbling score and intramuscular tissue glucose concentration were -0.6 (P=0.18) for corn-fed steers and 0.7 (P=0.04) for hay-fed steers, supporting the concept that corn-based diets promoted provision and utilization of glucose for accretion of intramuscular fat relative to hay-based diets. Manipulation of glucose disposal rate in finishing steers may improve carcass quality grade.

Effects of the Proportion of Supplemental Dietary Crude Protein Supplied by Urea on Performance and Carcass Characteristics of Finishing Beef Cattle fed Steam-Flaked Corn-Based Diets with Sweet Bran® Wet Corn Gluten Feed

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An experiment was conducted to examine the effects of urea level in steam-flaked corn-based diets containing 25% (DM basis) Sweet Bran® wet corn gluten feed (WCGF) on performance and carcass characteristics of beef steers. British x Continental steers were blocked by BW (average initial BW = 402.76 kg ± 10.75; n = 240) and assigned to one of three dietary treatments, which consisted of three different ratios (N basis) of urea:cottonseed meal provided in the supplemental CP: 1) 33%urea:67% cottonseed meal (33%); 2) 67% urea:33% cottonseed meal (67%); and 3) 100% urea:0% cottonseed meal (100%). Eight pens per treatment were arranged in a randomized complete block design. Performance and carcass data were analyzed using mixed model procedures of SAS (SAS Institute, Cary, NC), with pen designated as the experimental unit and block as the random effect. There was a quadratic (P = 0.06) effect of the proportion of urea in supplemental CP on ADG from d 0 to 56, as steers fed the 33% diet gained less than cattle fed either the 67 or 100% treatment. From d 0 to 112, ADG increased linearly (P = 0.09) with increasing proportion of urea provided in the supplement. For the overall feeding period, but especially early in the feeding period, ADG was numerically greatest in the steers fed the diet with 67% urea:33% cottonseed meal. Average daily DM intake (DMI) was affected linearly (P = 0.001), by urea level, as cattle fed the 33% treatment consumed less than those fed the 67 or 100% treatments from d 0 to 28. For the entire feeding period, DMI tended (P = 0.14) to increase linearly with increasing proportion of urea. There was a quadratic effect on gain:feed ratio from d 0 to end; steers fed the diet containing 67% urea:33% cottonseed meal gained more efficiently (P = 0.09) than those fed the 33% diet, whereas gain:feed by steers fed the 100% treatment did not differ from that of steers in the other two treatments. Furthermore, there was a tendency for a quadratic effect (P = 0.14) of urea level relative to hot carcass weight (HCW). Average HCW was 393.0 kg for the 67% treatment, whereas the 33% treatment averaged 384.3 kg, with an intermediate value of 390.5 kg for the 100% treatment. Percentage of internal fat was least (P = 0.10, linear effect of urea level) for the 33% diet. There were no treatment effects for yield.
collected at the initiation, intermediate (186.7 ± 1.1 d) and completion of the experiment. Intermediate (281.0 vs. 238.2 ng/ml) and final (322.2 vs. 267.5 ng/ml) serum ROL values were greater (P < 0.05) in steers fed HVA. Vitamin A status and carcass quality were not correlated (P > 0.05). Dietary intakes of vitamin A at three times NRC recommendations increased circulating levels of serum retinol, but did not affect carcass quality parameters in Angus x Simmental feedlot cattle.

The Effect of Castration on Animal Health, Growth Performance, and Carcass Characteristics in Intact Males Entering the Feedlot

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Two thousand three hundred and sixty-four high-risk calves were procured through sale barns by three order buyers in Arkansas, Mississippi, and Texas for participation in a 240-day metaphylactic antimicrobial research trial. Of the 2,364 head, 1716 were heifers (mean arrival weight = 512 lb), 299 were steers (mean arrival weight = 523 lb), and 889 were intact males (mean arrival weight = 508 lb). In addition to evaluating treatment effects of the various antimicrobials, one additional objective of this study was to characterize and quantify the impact of castration on animal health, growth performance, and carcass characteristics in growing-finishing cattle. Individual data were collected on each calf including standard animal health parameters, growth performance, and carcass characteristics. Each intact male calf was non-surgically castrated by administering an elastrator band at processing, which occurred within 24 hours of arrival. The morbidity of the intact males (49%) was higher (P<0.01) than the individuals that were castrated prior to arrival (35%). The relative risk of undergoing one morbid episode was 1.42, or 42% greater for intact males than for the steers. Furthermore, 24% of the population’s morbidity can be attributed to being castrated on arrival. The mortality (4.91%) and study rejection (4.91%) of the steers were lower than the mortality (7.1%) and study rejection (8.01%) of intact males, yielding a cumulative rate of loss of 9.82% of steers versus 15.11% of intact males that did not reach a desirable harvest weight. The risk of mortality was 1.42 times greater in the intact male population relative to the steer population. Similarly to the impact on mortality, the intact male population had a relative risk of removal of 1.63, indicating an excess study rejection of 63% compared to the steers. Morbidity was negatively associated with average daily gain, yield grade, hot carcass weight, and quality grade in this study. Intact males had a lower average daily gain at the time of reimplant and at harvest relative to the steers, while the steers had a 33 lb heavier hot carcass weight. The impact of individuals identified to have a pneumonia lung lesion at harvest revealed a reduction in overall average daily gain (.14 lb), yield grade (.13), and hot carcass weight (23 lb) compared with those with no lesions. Lung lesions were identified in 42% of the animals harvested, however 57.4% of them were never been pulled for treatment, thus illustrating the difficulty and lack of accuracy in detecting respiratory disease in commercial feedyards. Castration at arrival in to the feedlot had substantial negative impacts on morbidity rates, mortality rates, removal rates, average daily gain, yield grade, quality grade, and hot carcass weight.

Glycolytic Intermediates in Muscle and Adipose Tissue of Cattle Fed Different Sources and Amounts of Energy

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Seven Angus and eight Wagyu steers (BW= 208 and 172 kg) were used to evaluate energy source effects on glycolytic intermediates within muscle and adipose tissue. Steers were blocked by breed and fed a corn-based diet for 244 d or a hay diet for 362 d. Corn-based diet was adjusted to target a 1.3 kg/d
Factors Contributing to Carcass Value and Profitability in Early-Weaned Simmental steers

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Early-weaned Simmental steers (n = 192) of known genetics were individually fed in a four-year study to determine genetic, performance and carcass factors explaining variation in carcass value and profitability. Steers were weaned at 88.0 ± 1.1 d and fed a high-concentrate diet ($108.99/T) for 84.5 ± 0.4 d prior to allotment. Calves were implanted with Synovex® C at weaning and successively with Synovex® Sand Revalor® S. Steers consumed a 90% concentrate diet ($98.93/T), consisting primarily of whole shelled corn and corn silage, for 249.7 ± 0.7 d and harvested at 423.3 ± 1.4 d of age. Five-year price data were collected for feedstuffs, dressed beef, and grid premiums and discounts. Average dressed beef price was $110.67/45.4 kg. Premiums ($/45.4 kg) were given for Prime ($5.62), premium Choice ($1.50), yield grades (YG) 1 ($2.46), 2A ($1.31) and 2B ($1.11). Discounts ($/45.4 kg) were given for Standard (-$17.72), Select (-$8.90), YG 3A (-$0.12), 3B (-$0.19), 4 (-$14.16) and 5 (-$19.56), and hot carcass weight (HCW) extremes (409-431 kg, -$0.64; 432-454 kg, -$11.39; > 454 kg, -$19.71). Input costs included annual cow costs ($327.77), veterinary/medical and labor ($35/hd), yardage ($0.25/hd., d.) and interest (10%). Dependent variables were carcass value and profit per steer. Independent variables were yearling weight EPD, marbling EPD, daily DMI, ADG, HCW, calculated YG and marbling score (MS). Carcass value was correlated (P < 0.05) with yearling weight and marbling EPD, daily DMI, ADG, HCW, calculated YG and marbling score (MS). Carcass value was correlated (P < 0.05) with yearling weight and marbling EPD, daily DMI, ADG, feed efficiency, HCW and MS. Carcass weight, MS and YG accounted for over 79% of the variation in carcass value among steers; explaining 57, 12 and 10%, respectively. Profit was correlated (P < 0.05) with DMI, ADG, feed efficiency, HCW and MS. Marbling score, HCW, YG and DMI accounted for nearly 77% of the variation in profit among steers; explaining 32, 30, 10 and 5%, respectively. Carcass weight was the most critical factor contributing to carcass value while carcass quality and weight were leading factors affecting steer profitability.

Effect of Vitamin A on Carcass Quality and Serum Status in Angus X Simmental Cattle

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Vitamin A derivatives play a role in cell growth and differentiation and have been negatively correlated with beef marbling. Three feedlot experiments were conducted to examine the effect of dietary vitamin A level on carcass quality and serum retinol (ROL) status in cattle. All animals were fed similar finishing diets, consisting primarily of whole shelled corn and corn silage. Dietary supplements were calculated to contain either 8250 (LVA) or 33000 IU vitamin A/kg (HVA). Vitamin A content in LVA met NRC requirements while HVA was three times recommended levels. Cattle were harvested at 1.0 cm 12th rib fat thickness. In Exp. 1, 48 early-weaned Angus x Simmental heifers (309.3 ± 7.0 kg) were randomly allotted to 12 pens and fed dietary treatments for 163.3 ± 4.1 d. Serum samples were collected at the initiation, intermediate (d 79) and completion of the experiment. No treatment differences (P > 0.05) existed for carcass quality, however intermediate (320.9 vs. 228.0 ng/ml) and final (277.7 vs. 189.5 ng/ml) serum ROL was greater in heifers fed HVA. Vitamin A status and marbling score (MS) were not correlated (P > 0.05). In Exp. 2, 42 Angus x Simmental yearling steers (371.8 ± 0.8 kg) were randomly allotted to six pens and fed treatment diets ad libitum for 105 d. Serum samples were collected at the initiation and completion of the experiment. No treatment differences (P > 0.05) existed for carcass quality or serum parameters. In Exp. 3, 144 early-weaned Angus x Simmental steers (184.8 ± 1.6 kg) were randomly allotted to 18 pens and fed dietary treatments for 280.1 ± 3.5 d. Serum samples were
calculated from performance data. The NEg value of Sweet Bran was approximately 80.4% of the NEg value of steam-flaked corn. Cost of gains were lower for the Sweet Bran diets than for the Std3 diets ($43.48 vs $44.38/cwt) and the average profit for the steers fed the SB2, SB3 and SB4 diets was $12.53 greater than steers fed the Std3 diet. Hot carcass weight (HCW) was the only characteristic that differed statistically among treatments. Differences in HCW reflected differences in ADG, such that HCW for the SB3 (P = 0.09), SB4 (P < 0.01), and the average of the SB2, SB3 and SB4 diets (P < 0.01) were greater than for the Std3 diet. Increases in DMI were favorable and resulted in greater ADG, more saleable carcass weight, and overall greater profitability by steers fed Sweet Bran.

Intervention Strategies to Reduce the Prevalence of *Escherichia coli* O157:H7 Associated with Market Ready Cattle

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Clinical trials were conducted to test the effect of vaccinating feedlot cattle against Type III secretory proteins of enterohemorrhagic *Escherichia coli* (Exp. 1) and feeding a *Lactobacillus acidophilus* direct-fed microbial (DFM; Exp. 2) product on the proportion of feedlot steers shedding *E. coli* O157:H7 in feces. In Exp 1., 480 steers were assigned randomly to 60 pens (8 hd/pen) and to one of four vaccination treatments (2 hd/trt) within pen. Treatments included: 1) no vaccination; 2) vaccinated once at re-implant (d-42); 3) vaccinated upon arrival (d-0) and again at re-implant (d-42); and 4) vaccinated on arrival (d-0), at d-21, and again at re-implant (d-42). An additional 128 steers were assigned to 12 pens within the same feedyard to serve as unvaccinated controls. In Exp 2., 448 steers were assigned randomly to pen (n=48; 8 hd/pen in 40 pens; 16 hd/pen in 8 pens) and then assigned randomly to DFM or no DFM. The DFM product was mixed with water and applied to the feed in a mixing box of a separate feed truck (to eliminate the chance of cross contamination) at the rate of 1x10^9 colony forming units (CFU’s)/steer/day. Fecal samples were collected (n=2,944) from each animal every three weeks during the summer months of 2002 and 2003 by rectal palpation. In both trials fecal samples were collected from each animal in the study every three weeks and O157 was isolated using selective enrichment, immunomagnetic separation, and PCR confirmation. Additionally for both trials, the odds for a treated animal to shed O157 were compared to its appropriate control, accounting for repeated measures, block, pen, and year. In Exp 1., pre-treatment prevalence of O157 in the 60 treatment pens averaged 45% and did not differ (P>0.10) between treatment groups. Initial mean prevalence of the external control pens (30.5%) was lower (P<0.05) than vaccinated pens (45%). Vaccine efficacy of receiving 1, 2, or 3 doses of vaccine was 52, 58, and 68% respectively (P<0.01), compared with cattle in pens not receiving vaccine. Unvaccinated cattle in treated pens were 50% less likely to shed O157 than cattle in pens not receiving vaccine (P=0.02; herd-immunity). In Exp 2., prevalence varied significantly between 2002 and 2003. In 2002 the probability for a DFM-treated steer to shed O157 over the test periods was 13% compared to 21% among untreated cattle. In 2003 the average probability of shedding was 21% among DFM-treated steers compared to 28% for controls. Over the two years DFM treated cattle were 35% less likely to shed O157 than cattle in untreated pens (P=0.002). Feeding the DFM product did not affect (P>0.10) overall ADG, DMI, or ADG:DMI. Although not significant (P=0.13; 24 pens/trt) ADG:DMI was improved 2% by including the DFM product in the ration. We concluded that vaccination effectively reduced the proportion of feedlot cattle shedding O157 in the feces, that the effect was dose-responsive, and that vaccination within a pen conferred protection to unvaccinated pen-mates (herd-immunity). Because there was a reduction in O157 shedding in Exp 2., we concluded that DFM supplementation is also a reliable intervention strategy when trying to reduce the proportion of feedlot cattle shedding *E. coli* O157:H7 in the feces.
Effects of Limit Feeding on Net Nutrient Flux and Oxygen Consumption by the Portal-Drained Viscera

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Ten steers (average initial BW = 430 ± 42 kg) were used in a randomized complete block design over two observation periods. Steers were blocked by previous treatment (high or low BW gain while grazing winter wheat pasture) and allotted to two treatment groups in a switch-back design. The purpose of the experiment was to determine the effects of ad libitum feeding versus limit feeding on diet digestibility, visceral organ mass, blood flow, blood gas measurements, oxygen consumption, and net flux of metabolites across the portal-drained viscera (PDV) of finishing beef steers fed a high-concentrate diet. Treatments were ad libitum feeding of the diet (CON) or feeding at 90% of ad libitum (LF). Limit-fed steers consumed 86.5% and 87.8% of the actual DMI of CON steers during period 1 and 2, respectively. Limit-feeding increased DM (P < 0.05) and OM (P < 0.05) digestibility of the diet by 3.9% and 3.8%, respectively compared with CON steers, whereas N digestibility did not differ (P = 0.21) among treatments. The increase in digestibility resulted in similar (5.53 vs 5.22 ± 0.48 kg/d; P = 0.46) digestible OM intake among treatments. Net flux of a-amino N and urea N were not different among treatments. Concentrations of glucose in arterial and portal blood tended (P = 0.06) to be greater for CON steers; however, net portal removal of glucose tended (P = 0.07) to be greater in CON steers suggesting greater glucose utilization by the PDV. No significant differences were observed in blood gas measurements, and oxygen consumption by the PDV did not differ among treatments (-475 vs -437 mmol/h for CON and LF, respectively). After 34 d of limit-feeding, visceral organ mass did not differ among treatment groups. The increase in OM digestibility by LF steers suggests nutrient availability was similar among treatments. Combined with lower utilization of glucose and similar oxygen consumption by the PDV, our data suggests more efficient utilization of nutrients by limit-fed steers.

Effects of Sweet Bran® and added fat level on performance and carcass quality responses by finishing beef steers

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The feeding value of diets containing 25% Sweet Bran compared to a standard steam-flaked corn based finishing diet and the effects of added fat level (0, 2, 3, or 4% DM basis) in finishing diets containing 25% Sweet Bran were evaluated. Angus and Angus x Charolais steers (n = 360, 12 steers/pen, six pens/treatment) were blocked by BW (initial BW = 350 ± 1.1 kg) and were fed one of five diets: 1) 0% Sweet Bran/3% added fat (Std3), 2) 25% Sweet Bran/0% added fat (SB0), 3) 25% Sweet Bran/2% added fat (SB2), 4) 25% Sweet Bran/3% added fat (SB3), 5) 25% Sweet Bran/4% added fat (SB4). During the first 3 wk of the experiment, steers were stepped up weekly from 71 to 81% concentrate, then to the final 91% concentrate diet. Diets were fed to minimize refusals which were weighed and analyzed for DM content. Percentage DM of treatment diets were determined weekly and were used to compute average DM intake by the steers in each pen. Cattle were weighed individually on d 0, 49, and the final day of the experiment. When the majority of steers in a block had approximately 1.3 cm of backfat, they were individually weighed and shipped to IBP, Amarillo, TX for slaughter, where individual carcass data were collected (weighted days on trial = 121). Dry matter intake was greater (P < 0.05) in steers fed Sweet Bran and fat (all levels) than those fed Std3 and SB0. Compared to steers fed the Std3 diet, steers fed the SB4 diet had increased (P < 0.01) gains of 7.1%. Addition of fat to the Sweet Bran diets increased (P < 0.05) ADG and DMI relative to the SB0 treatment. Dietary NEm and NEg concentrations were


Twenty years ago, Ricks and co-workers (1984) reported that clenbuterol, a compound with structural similarity to endogenous catecholamines, modulated beef cattle growth. In particular, clenbuterol increased muscle deposition at the expense of adipose tissue accretion in steers. The authors coined the term “repartitioning activity” to describe the dramatic changes in carcass composition observed after oral clenbuterol administration to growing beef cattle.

Since then, numerous studies have evaluated other compounds (Figure 1) that had repartitioning activity and could modulate lean tissue deposition in a variety of species, including beef cattle. Like, clenbuterol, these other compounds (cimaterol, L-644,969, ractopamine, and zilpaterol) have similar structural and pharmacological properties with the endogenous catecholamines, norepinephrine (NEPI) and epinephrine (EPI). Additionally, these repartitioning agents are often referred to as β-adrenergic agonists (βAA) due to the relative high affinity for

Figure 1. Structures of selected β-adrenergic agonist that have been evaluated in beef cattle. Preferential receptor subtype (β_1 or β_2) is shown after each compound.

the β-adrenergic receptor (BAR). As of March 2004, only one of these compounds, ractopamine (Optaflexx™) is approved and being marketed for use in beef cattle in the United States. Zilpaterol (Zilmax™) is approved for use in beef cattle in South Africa and Mexico, but has yet to be approved in the United States.

β-Adrenergic Receptors

A biological response to any extracellular signaling pathway is dependent on the presence of a specific receptor on cells of a target tissue. β-adrenergic agonists bind to βARs to produce a biological effect. Early research indicated that the presence of different receptor subtypes may
exist due to differences in potency and efficacy of selected NEPI and EPI analogs. Two major types of adrenergic receptors were discovered and classified, \( \alpha \) - or \( \beta \) - AR. Further investigation revealed three \( \beta \)AR subtypes, \( \beta_1 \)-AR, \( \beta_2 \)-AR, \( \beta_3 \)-AR. Most mammalian cells contain the \( \beta \)AR but the distribution and number of each subtype varies between different tissue of the same species, thus suggesting explanation for differences in magnitude of biological effects across tissues of the same animal. Additionally, the \( \beta \)AR subtype distribution can vary within a given target tissue between species. The same tissues from across species may have different distribution of \( \beta \)AR subtypes which in part explains differences in biological responses of the same compound administered to two different species. Finally, many tissues express various proportions of \( \beta_1 \)-AR and \( \beta_2 \)-AR which further complicates our understanding of the mode of action of the \( \beta \)-AA.

The \( \beta \)AR are members of a family of receptors that function by binding \( G \), proteins. A common feature of these receptors is that they contain seven membrane-spanning domains which form loops, both on the extracellular and intracellular portions. Ligand binding occurs on the extracellular side which causes conformational change of the membrane-bound receptor. The \( \beta \)AR is coupled to \( G \), protein (GTP-binding protein) that activates adenylate cyclase to synthesize cAMP. Cyclic AMP in turn regulates activity of protein kinase A. Protein kinase A is responsible for the phosphorylation of key enzymes involved in various biological effects. Phosphorylation can cause activation or inactivation of numerous enzymes. Additionally, transcription factors which bind to DNA and regulate transcription of DNA to mRNA are also targets of protein kinase A. One specific example is cAMP response element binding protein (CREB), which can be phosphorylated by protein kinase A. Phosphorylated CREB has enhanced transcriptional activity which in turn can play a role in regulating transcription of numerous \( \beta \)-AR responsive genes in a cell (Mersmann, 1998).

Finally, the intracellular domains of the \( \beta \)-AR are phosphorylation targets of protein kinase A and a specific, \( \beta \)AR-associated protein kinase (\( \beta \)ARK). Phosphorylation causes an uncoupling of the \( \beta \)AR from \( G \), protein which ultimately inactivates the receptor, this phenomenon is often referred to as acute \( \beta \)AR desensitization (Mills and Mersmann, 1995). Often acute desensitization can be over come by increased dose of the \( \beta \)AA. However, chronic exposure to higher doses of the \( \beta \)AA often results in internalization of the \( \beta \)AR receptor and down-regulation of \( \beta \)AR mRNA abundance. Increased understanding of both acute and chronic desensitization processes could be important to achieve maximal biological response to \( \beta \)AA administered to cattle.

**Efficacy of \( \beta \)-Adrenergic Agonists in Beef Cattle**

The \( \beta \)AA have been shown to have biological effects *in vivo* when administered orally to beef cattle. It is presumed that a significant dose of the orally-delivered \( \beta \)AA leaves the rumen intact, progresses through the lower parts of the gastrointestinal tract where it is absorbed. Once absorbed the \( \beta \)AA enters the bloodstream and circulates through the liver where there is further opportunity for degradation of the compound. The \( \beta \)AA would then be delivered to target tissue at an acceptable dose, where if the receptor is available and functional, would bind the \( \beta \)AA and potentially elicit a biological response.

Ricks and co-workers (1984) first reported that the \( \beta_2 \)-AA, clenbuterol, when orally-administered to cattle, significantly increased muscle mass and decreased adipose tissue mass. A summary of the report as well as subsequent reports of other \( \beta \)AA fed to steers and heifers is
summarized in Table 1 and 2. The effects of βAA on live weight gain or ADG appeared to be quite inconsistent in both steers and heifers (Table 1 and 2). The range in response in steers was between -9% to greater than 30% improvement in ADG during the experimental periods. Where there was opportunity to compare studies with the identical βAA, it appeared that the shorter duration studies often led to the positive improvements in live weight gain as compared to controls. This would imply that longer exposure to a constant dose of βAA may result in desensitization, and potential loss of detectable advantages in ADG. This will be discussed in more detail in a later section. Voluntary feed intake (ADFI) appeared to be unaffected with βAA administration in steers and heifers (Table 1 and 2). When differences were noted, often intake was lowered in the βAA treated cattle compared to controls. Many of the authors speculated this may have been due palatability issues with the top-dress applied in these experimental studies. This data suggests that βAA would have minimal effects on dry matter intake in beef cattle. While live weight gain or growth rate (ADG) may or may not be increased with βAA in cattle, feed efficiency was generally improved 10 to as much as 30% in steers and heifers (Table 1 and 2). These improvements in feed efficiency are primarily the result of dramatic changes in the composition of gain (> protein, < fat).

Although the effects of βAA on growth rate of beef cattle may be inconsistent, their effects on carcass weight gain, dressing percentage, and carcass composition are unequivocal. In most, if not all, cases carcass lean was increased and carcass fat was reduced in both steers and heifers (Table 1 and 2). Due to numerical advantages in dressing percentage, it appeared that carcass tissues (e.g. skeletal muscle and adipose tissue) were the primary targets for βAA action. Non-carcass tissues (e.g. gastrointestinal tract) were unaffected by the βAA. This would not be the case with other growth promotants used in growing cattle, such as somatotropins. Somatotropins have been reported to increase nitrogen retention and whole body protein accretion in growing ruminants, but in many instances there appeared to be a disparate response between carcass and non-carcass components favoring growth of the latter (Early et al., 1990, Dalke et al., 1992). Consequently, dressing percentage was often negatively influenced with somatotropin administration in growing beef cattle (Early et al., 1990).

β-Adrenergic Agonists and Skeletal Muscle Growth

Rapid increases in skeletal muscle protein mass is one of the most consistent biological effects observed when βAA are administered to beef cattle. Muscle hypertrophy can be defined as the increase in size (diameter and length) of existing muscle fibers. Often a practical approach to estimate muscle hypertrophy is to assess differences in size (area) and weight of individual muscles. Much of the data presented in Tables 1 and 2, in regard to changes in muscle mass, is observed differences in area of longissimus muscle or weight of selected muscles, such as the longissimus or semitendinosus. Although administration of βAA to cattle results in rapid, preferential increases in muscle mass, the mechanism of action by which βAA causes this preferential effect of growth on skeletal muscle is still elusive. These proposed mechanisms include direct effects of βAA, through its receptor, on muscle growth, potential secondary or indirect effects of other cell types secreting factors important for muscle growth or the combination of both direct and indirect effects. The objective of this section is to discuss our current level of understanding of the potential direct mechanisms by which βAA affects skeletal muscle growth in cattle.
**Muscle Hypertrophy and Fiber Types.** Clenbuterol administration to steers at 10 and 500 mg·hd$^{-1}$·d$^{-1}$ increased longissimus muscle area at the 12th rib, 11 and 16%, respectively, compared to untreated controls (Ricks et al., 1984). Furthermore, these advantages in longissimus muscle area were maintained when adjusted for differences in carcass weight. Similarly, Schiavetta and co-workers (1990) reported 28% greater longissimus muscle area in carcasses from steers fed clenbuterol at 7 mg·hd$^{-1}$·d$^{-1}$ for 50 d compared to carcasses from control steers. Additionally, the weight of the longissimus obtained from the 9-10-11th rib section was 25% greater in carcasses from clenbuterol-fed steers compared to control. To further increase the understanding of the effects of clenbuterol on muscle hypertrophy in beef cattle, Miller and colleagues (1988) reported an increase in diameter of type II muscle fibers and a numerical decrease in diameter of type I fibers in heifers fed 10 mg·hd$^{-1}$·d$^{-1}$ clenbuterol compared to untreated controls. Similarly, Smith et al., (1995) observed that mean diameters of SDH-positive (type II A) muscle fibers were greater in clenbuterol-fed steers compared to controls. Taken together these data suggested, βAA caused individual muscle fiber hypertrophy. Specifically, type II A fibers were the most responsive to βAA administration.

**Muscle Satellite Cells.** Satellite cells are mononucleated cells that lie between the sarcolemma and basal lamina of the muscle fiber (Mauro, 1961). Moss and Leblond (1970) observed that nuclei within the multinucleated muscle fiber were no longer able to synthesize DNA. In subsequent work, Moss and Leblond (1971) found that satellite cells were able to proliferate, and ultimately, a proportion of these daughter cells fused into the existing multinucleated muscle fiber. This established satellite cells as a source of nuclei for hypertrophic muscles. Since this early work, satellite cells have been shown to be critically important in supporting postnatal muscle growth in numerous species (Campion, 1984). Since fiber number is fixed at birth in most mammals and nuclei within the muscle fiber have lost their mitotic potential, satellite cells provide the important DNA necessary to support increased muscle hypertrophy during postnatal growth. It has been estimated that approximately 60 to 90% of the DNA in a mature muscle fiber originated from satellite cells. Thus, satellite cell proliferation and subsequent fusion into existing muscle fibers to provide DNA required for fiber hypertrophy maybe a critical, rate-limiting step for muscle growth. Increasing either the rate of satellite cell proliferation or the number of proliferating satellite cells could enhance the extent and efficiency of muscle growth. Due to the dramatic increase in muscle hypertrophy following βAA administration to beef cattle, one would expect satellite cell proliferation and subsequent fusion of the satellite cell, to provide a source of DNA, to be involved in this process. However, the total DNA content of muscles from animals treated with βAA is unchanged, and the DNA concentration of individual muscles is often decreased due to the dramatic increases in mass of these muscles and no change in DNA content (O’Connor et al., 1991). These data suggested that stimulation of satellite cell proliferation and subsequent fusion into existing muscle fibers was not a rate-limiting step of muscle hypertrophy. Research has been conducted to evaluate the direct effects of βAA on cultured muscle cell proliferation and differentiation. Ractopamine was shown to increase the number myotube nuclei in primary cultures of chicken satellite cells at the end of the culture period, suggesting rate of proliferation of the satellite was enhanced (Grant et al., 1990). However, the dose required to elicit this response in muscle satellite cell proliferation would be considered greater than normal physiological levels expected after feeding ractopamine. Likewise, pharmacological doses of ractopamine (10 μM) stimulated rate of C2C12 myoblast proliferation approximately 30% (Shappell et al., 2000). These equivocal cell culture
results coupled with the lack of significant increased DNA content in muscles from βAA-treated animals, suggest muscle satellite proliferation and subsequent fusion may not be important for βAA-induced muscle hypertrophy. Thus, other contributing factors that lead to muscle hypertrophy may be altered with βAA administration. For example, an increase in muscle protein synthesis, a reduction in muscle protein degradation, or a combination of both could be responsible for the βAA-induced increase in muscle mass.

**Muscle Protein Synthesis.** Ractopamine has been shown to increase fractional protein synthesis rate in pigs (Bergen et al., 1989). This research was further supported by muscle cell culture work, in which ractopamine increased both total and myosin heavy-chain protein synthesis rate in L₆ cells (Anderson et al., 1990). These data confirmed that the ractopamine-induced increase in muscle cell protein accretion was due in part, to the increased total and myofibrillar protein synthesis rate. Interestingly, ractopamine, a β₁-AA, did not alter protein degradation rates in cultured L₆ muscle cells (Anderson et al., 1990). Thus, the authors concluded that ractopamine-enhanced muscle protein accretion was due to increased protein synthesis rates with no detectable effect on protein degradation rates. Additionally, ractopamine increased myosin light-chain mRNA abundance in the longissimus muscle of beef cattle approximately fivefold as compared to untreated cattle (Smith et al., 1989). Likewise, clenbuterol increased myosin light-chain mRNA levels after 50 d of treatment as compared to control steers (Smith et al., 1995). These increased myofibrillar protein mRNA species could be a result of βAA-induced gene transcription and/or increased stability of the mRNA. Regardless of the mechanism, increased mRNA abundance of muscle-specific proteins was related to the marked increase in muscle hypertrophy, potentially through alterations in protein synthesis. These conclusions are further supported with muscle cell culture results in which clenbuterol stimulated both fractional and absolute rates of protein synthesis in primary cultures of neonatal rat muscle cells (McMillan et al., 1992).

**Muscle Protein Degradation.** Rate of protein degradation can also impact net protein accretion in skeletal muscle. Often, protein degradation rate is calculated by differences between measured protein accretion and fractional synthesis rates (Beermann, 2002). Alternatively, activities of muscle proteases (calcium-dependent and lysosomal) and their inhibitors have been determined following βAA administration. Generally, results of various studies suggest that muscle protein degradation may be reduced or not affected by βAA administration. In cattle, the majority of work in the area of protein degradation has been conducted with the βAA, L-644,969. This β₂-AA caused a 27% reduction in fractional protein degradation rate in steers compared to untreated controls (Wheeler and Koohmaraie, 1992). Additionally, the activity of a specific inhibitor to the calpains, calpastatin, was elevated in bovine muscle samples obtained from steers fed L-644,969 (Wheeler and Koohmaraie, 1992; Killefer and Koohmaraie, 1994).

Often, these reductions in protein degradation are the basis for observed decreases in meat tenderness from animals treated with βAA. Specifically, the muscle proteases and inhibitor activities that are affected in vivo often follow parallel responses in the postmortem meat. Obviously, concerns arise with decreases in the tenderness of meat, specifically beef, and the potential negative effect this could have on demand. Ractopamine fed to steers and heifers at the 200 mg·hd⁻¹·d⁻¹ level had no effect on tenderness (Schroeder et al., 2003). However, as dose increased to 300 mg·hd⁻¹·d⁻¹, shear-force values also increased compared to controls (Schroeder et al., 2003). This reduction in tenderness with ractopamine at 300 mg·hd⁻¹·d⁻¹ is somewhat
surprising due to the preponderance of data suggesting ractopamine had no effect on rate of protein degradation in skeletal muscle (as previously discussed). However, it may indicate that at higher doses ractopamine, a β₁-AA, can bind to β₂-ARs.

β-Adrenergic Agonist and Adipose Tissue Growth

In addition to the rapid increase in skeletal muscle mass following βAA administration, the other obvious effect of βAA is significant reductions in carcass fat mass (Mersmann, 1998). Most scientists agree, that these βAA-induced reductions in adipose tissue accumulation, are caused directly by βAA binding to its receptor on adipose tissue. Specifically, βAA stimulated triglyceride hydrolysis (lipolysis) and concomitantly reduced fatty acid synthesis (lipogenesis). Enzymes responsible for both lipolysis and lipogenesis are targets of βAA-induced phosphorylation by protein kinase A.

Since the original report by Ricks and co-workers (1984) that clenbuterol reduced 12th rib fat, approximately 40% in steers, researchers have focused on the potential mode of action of βAA on adipose tissue growth and cellularity. Indeed, in cattle, clenbuterol administration resulted in a decrease in adipocyte size (hypertrophy) with no apparent effect on number of adipocytes (hyperplasia) compared to control cattle (Miller et al., 1988; Schiavetta et al., 1990). This lack of an effect of βAA on adipocyte hyperplasia may become very important in addressing βAA-induced alterations in intramuscular fat (marbling).

Practical Considerations

Ractopamine-HCl was approved (June, 2003) for cattle and is marketed under the trade name, Optaflexx™ in the United States. Many questions will arise as to the appropriate application of this product to optimize the efficiency of beef production.

Dose and Duration. The dose (acute) and duration of that sustained dose (chronic) of βAA has been shown to affect the maximal response. It has been well documented that the βAR-mediated increase in cAMP is transient. Continuous, receptor activation by the βAA ligand is necessary to maintain the cAMP levels and to potentiate the response. Exposure of a constant dose of βAA to the receptor will eventually cause acute desensitization or inactivation of receptor-mediated signaling. This phenomenon occurs due to phosphorylation of the βAR by both protein kinase A and βARKs (Hausdorff et al., 1990). Acute desensitization can be circumvented to some degree by increasing the dose and potentiating the signal. Long-term exposure (chronic) at elevated doses of βAA leads to internalization or loss of the receptor from the cell surface and down-regulation in βAR mRNA abundance (Hausdorff et al., 1990). These alterations appear to be irreversible at least in the short-term.

Another practical issue in regards to duration of feeding of βAA is skeletal muscle’s ability to sustain the muscle hypertrophy without the concomitant increase in DNA to aid in maintaining the extra protein mass. Anabolic steroid (TBA+E2) administration to beef cattle has been shown to stimulate muscle satellite cell proliferation (Johnson et al., 1998). Proper timing of implant administration prior to βAA exposure may be crucial to stimulate muscle satellite cell proliferation and subsequent fusion into the existing fiber. The added DNA to the fiber will become beneficial during the rapid muscle hypertrophy phase caused by βAA administration. This could allow the fiber to maintain the additional size for a longer period of time.
**Comparative Efficacy of Steroid Implants and βAA.** With the recent (June, 2003) approval of ractopamine-HCl (Optaflexx™) for beef cattle in the United States, producers will now be able to administer two distinct types of growth promotants to beef cattle during the finishing phase: steroid implants and βAA. Naturally, questions will arise as to the comparative efficacy of these two classes of growth promotants used together in beef cattle production. In theory, steroid implants and βAA should be nearly additive at stimulating muscle growth in beef cattle due to presumably different mechanisms of action. Earlier research evaluating the effects of bovine somatotropin (bST) and steroids revealed additive effects of these two growth promotants on weight gain and protein deposition in beef cattle (Preston et al., 1995). The conclusion that each had distinct mechanisms of action in stimulating growth was surprising since E2 had been shown to increase circulating ST levels. In fact research suggests that E2 and bST were not additive in the effects on circulating ST. Taken together these data suggested that growth-promoting effects of estrogens were not fully mediated by the increase in ST secretion (Enright et al., 1990).

Steroid implants stimulate skeletal muscle growth through both increases in muscle hypertrophy as well as activation of muscle satellite cells to provide the critical DNA to sustain muscle hypertrophy (Johnson et al., 1996; 1998). It appears locally-produced IGF-I can mediate many of these effects in skeletal muscle (Dunn et al., 2003; Pampusch et al., 2003; White et al., 2003). As stated earlier, βAA had no effect at increasing DNA content of skeletal muscle. Therefore administration of a steroid implant 60 to 90 days prior to feeding βAA should have additive effects on lean tissue deposition in beef cattle due to different mechanisms of action. However, recent research has shown that clenbuterol (β2-AA) increased local expression of IGF-I in skeletal muscle of rats (Awede et al., 2002). If this is the same in beef cattle, there may some overlap in potential mechanism of action in which the two classes of compounds would not be completely additive. Additionally, recent research suggests that anabolic steroids may be working through non-genomic mechanisms in peripheral tissues, like skeletal muscle (Sissom and Johnson, 2004). These non-genomic effects of steroids often work through a different class of receptor, which involve activation of second messenger systems. One proposed second messenger system that has been shown to mediate non-genomic steroid effects is an increase in intracellular cAMP levels. This could also be a point of overlap between the two classes of growth promotants, which could attenuate the degree of additivity. Finally, from a practical standpoint, it may be difficult to ascertain the degree of additivity of steroid implants and βAA, since they will not be administered at the same time. Much research is needed to clearly delineate the interaction between steroid implants and βAA.

**Other.** Many other issues will certainly arise with use of βAA in beef cattle. For example, animal type (holsteins vs. beef-type) and maturity (cull cows vs. young cattle) may impact biological response of βAA in cattle. Certainly, the impact of βAA on nutrient requirements will be addressed in future research studies.
### Table 1. Comparative responses of steers to various β-adrenergic agonists.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Dose</th>
<th>Days</th>
<th>ADG</th>
<th>F/G</th>
<th>ADFI</th>
<th>Dressing %</th>
<th>Muscle</th>
<th>Fat</th>
<th>Reference</th>
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<tr>
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<td>130</td>
<td>70</td>
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<td>108</td>
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<td>91</td>
<td>101</td>
<td>93</td>
<td>101</td>
<td>111</td>
<td>65</td>
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</tr>
<tr>
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<td>50</td>
<td>134</td>
<td>67</td>
<td>101</td>
<td>101</td>
<td>128</td>
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<td>Schiavetta et al., 1990</td>
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<tr>
<td>L-644,969</td>
<td>7.5</td>
<td>84</td>
<td>117</td>
<td>80</td>
<td>94</td>
<td>107</td>
<td>113</td>
<td>71</td>
<td>Moloney et al., 1990</td>
</tr>
<tr>
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<td>42</td>
<td>111</td>
<td>90</td>
<td>100</td>
<td>101</td>
<td>102</td>
<td>98</td>
<td>Carroll et al., 1990</td>
</tr>
<tr>
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<td>120</td>
<td>84</td>
<td>100</td>
<td>101</td>
<td>104</td>
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</tr>
<tr>
<td>Zilpaterol</td>
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<td>52</td>
<td>113</td>
<td>85</td>
<td>98</td>
<td>104</td>
<td>112</td>
<td>82</td>
<td>Zilmax Tech. Broch., 1996</td>
</tr>
</tbody>
</table>

*mg·hd⁻¹·d⁻¹*

### Table 2. Comparative responses of heifers to various β-adrenergic agonists.

<table>
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<tr>
<th>Compound</th>
<th>Dose</th>
<th>Days</th>
<th>ADG</th>
<th>F/G</th>
<th>ADFI</th>
<th>Dressing %</th>
<th>Muscle</th>
<th>Fat</th>
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<tr>
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<td>118</td>
<td>118</td>
<td>60</td>
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<tr>
<td>Ractopamine</td>
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<td>28-42</td>
<td>118</td>
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<td>101</td>
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<tr>
<td>Zilpaterol</td>
<td>53</td>
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<td>88</td>
<td>100</td>
<td>104</td>
<td>-</td>
<td>-</td>
<td>Zilmax Tech. Broch., 1996</td>
</tr>
</tbody>
</table>

*mg·hd⁻¹·d⁻¹*

b cull cows
Literature Cited


FEEDLOT MANAGEMENT CHALLENGES AND OPPORTUNITIES WITH $\beta$-AGONIST USE

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New technology helps to keep a food commodity competitive in the consumer’s food basket. The feedlot segment of the beef industry now has another technological development that will improve the efficiency of beef production and provide the packer, purveyor and consumer with a leaner product. As with any new technology, however, there are new challenges.

This new technology comes in the form of $\beta$-agonists, which to me sounds terrible. This terminology relates to their site of action via the $\beta$-adrenergic (catecholamine) cell membrane receptors. They are also known as phenethanolamines, which relates to their chemical structure. I prefer calling these compounds **repartitioning agents** because this is what they do, repartition dietary protein and energy towards greater lean meat growth with less fat.

There are several reviews on this class of compounds, their action and their repartitioning effects in many animals (Anderson, et al, 1991; Moloney, et al, 1991, Steel, et al, 1994; Beerman, 1994; McKeith et al, 1994 and Moody et al, 2000). Presently, there are three repartitioning compounds of interest:

- clenbuterol (infamous)
- zilpaterol (approved in Mexico and South Africa)
- ractopamine (approved in the U.S.)

I have classified clenbuterol as “infamous” because, while it was the first repartitioning agent to show promise as a lean meat enhancer in animals, there were tenderness problems probably more related to dose or time of application than to the compound itself, and because it has been used illegally in show cattle in the U.S. and illegally in meat animal production in many parts of the world. This reputation may taint opinions about repartitioning agents in general.

Zilpaterol fed during the last 42 days of the feeding period improved weight gain (27%), gain efficiency (28%) on the same feed intake, increased dressing percentage and rib eye area, with no change in fat thickness or marbling score. Percent of closely trimmed primal cuts and retail cuts were also increased (Plascencia, et al., 1999). These authors conclude that 55% of the net economic value of zilpaterol supplementation benefits the cattle feeder while increased carcass cutability accounts for 45% of the net value, which benefits the meat packer and retailer.

This presentation will focus on ractopamine since this is the repartitioning agent approved in the U.S. at the present time. Ractopamine is approved for swine and is sold under the logical trade name, Paylean. Ractopamine is approved for feedlot cattle and is sold under the trade name, Optaflexx. When I first heard this word, I thought it was a geriatric exercise that might be of value to me.
Information on Optaflexx is available in the Freedom of Information (FOI) statement available from the U.S. Food and Drug Administration (FDA, 2003). The approved claim reads: “For increased rate of weight gain, improved feed efficiency, and increased carcass leanness in cattle fed in confinement for slaughter during the last 28 to 42 days on feed.” Data supporting this claim from the ten pivotal trials are presented in the FOI. At the recommended dose (200 mg/hd/d), rate of weight gain is increased 17%, gain efficiency is improved 17% with no change in feed intake, and carcass protein (leanness) increased 2%. These improvements were similar in steers and heifers. Carcass lean gain per day was improved 69%! Other observations were as follows: slaughter weight, increased; carcass weight, increased; dressing percentage, trended up, especially in steers; fat thickness, no change; rib eye area, increased, in relation to carcass weight; yield grade, small improvement; marbling, no trend; carcass fat, decreased; Warner-Bratzler shear value, no trend through 200 mg/hd/d, increased 12% at 300 mg/hd/d; taste panel tenderness, no trend through 200 mg/hd/d, decreased 6% at 300 mg/hd/d; flavor and juiciness, no trend. All shear force values were in the “tender” range and all taste panel evaluations were very acceptable. Statistical probabilities for these changes are given in the FOI.

Other information that can be found in the FOI include investigators/locations for the trials, breed types included, diets and diet composition, target animal and human safety, residue depletion, withdrawal determination, analytical methods, and comparative metabolism studies. I did not find product stability data but the product label provides expiration times.

Thus the “opportunities” provided by Optaflexx are clearly stated in the approved claim. These have been summarized (Schroeder et al, 2004a and 2004b) and several product information publications also graphically present the above results (Schroeder, et al., 2003).

Earlier trials with ractopamine in finishing cattle have been conducted and published (Anderson, et al, 1989; Carroll, et al, 1990; Parrott, et al; Preston, et al, 1990a; and Schluter, et al, 1990). These trials are in general agreement with those reported in the FOI. In our own research (Preston, et al, 1990b), weight gain and gain efficiency were improved 25% in steers when ractopamine was fed during the last 46 days of the feeding period. Carcass protein, however, was not altered perhaps because these steers were leaner at slaughter (16.2% protein in control steers) compared to the control steers (14.8%) in the pivotal trials reported in the FOI. Sensory panel evaluation revealed no difference in tenderness, juiciness or flavor intensity of steaks from steers fed ractopamine although Warner-Bratzler shear force value was increased (6.6 vs 7.7 lb) but still within the “tender zone” (Dietzel, et al., 1990). During storage, lean color and appearance was better maintained in steaks from ractopamine fed steers compared to controls (Thompson, et al. 1990).

It should be pointed out that even though the feedlot response to Optaflexx is great, the response time is short (28 to 42 d) which limits the total response. The expected total live weight response will be 16 to 17 lbs, which will be worth, depending on the price of cattle, from $10 to $17 per head. This is not insignificant. However, net return will obviously depend on the cost of Optaflexx supplementation. Additionally, if cattle are sold on the grid or grade and yield, there should be some additional financial benefit from the increase in dressing percentage and yield grade.
What will be some of the challenges in introducing this new technology? I think that almost all new technology introduced in the beef industry in my experience has met with packer resistance in the form of reasons to “ding” the price paid for cattle. I predict that packer buyers will ask if Optaflexx has been fed and if so, will say that because dressing percent and grade will be lower, they won’t offer as much for the cattle even though dressing percent will be somewhat greater, marbling and therefore quality grade will be unchanged and yield grade will be better when Optaflexx is fed. The old dogma was that carcass fat increased dressing percent. However, increased carcass weight in the form of lean meat also increases dressing percent. I think that dressing percent has been a great deterrent to the acceptance of new technology in the beef industry. Packer buyers will probably also say that repartitioning agents negatively affect tenderness because of the reports when clenbuterol was fed.

Another challenge that is more real will be the number of diets required at the feedlot. Since the diet containing Optaflexx is fed during the last 28 to 42 days of the finishing period, when the cattle are already on the final diet, an extra bin or an altered mixing program will be required. If there is inadequate bin space, an additional bin will be required or if proper mixing can be achieved in the feed truck or delivery wagon, then the Optaflexx supplement could be added after the diet is prepared and placed in the truck or wagon. In this case, adequate mixing should be determined by taking several samples of a mix for Optaflexx assay.

Will diet specifications require changes while Optaflexx is fed? Probably not. One can theorize that because lean meat growth is enhanced, dietary protein requirements might increase. If the protein levels fed at the feedlots used for the pivotal trials (13.0 to 15.2%, DM basis) are typical of the industry for this stage of the feeding period, then it is my opinion that protein was grossly overfed (contributing to excess nitrogen excretion). Also, one might conclude that more protein is required in Colorado since the two feedlots there fed the most protein (14.6 and 15.2%). Perhaps these protein levels were required to meet the rumen degradable protein requirement. However, I believe that 10 to 12% CP is certainly adequate at this stage of the feeding period and some may recall ancient history when I proposed removing all supplemental protein towards the end of the feeding period.

One point that needs quantification is the additive response between Optaflexx and implants that are currently used by the beef industry. It is my understanding that the responses are additive but data are limited that quantify this. In the pivotal trials, when Optaflexx feeding was initiated, a “short acting estrogenic implant” (Synovex) had been administered 98 to 176 days previously. I think everyone would agree that there would be little implant effect by this time. In the case of the zilpaterol experiment cited above, the steers were implanted with Revalor 30d before zilpaterol feeding was initiated, or 72d before slaughter. A response to zilpaterol was observed. In another study using a 2x2 design (Casey, et al, 1997), carcass weight was additively increased by zilpaterol plus Revalor over either treatment alone. Dressing percent was increased by zilpaterol and marbling score was decreased (0.4) by both treatments. Probably, experiments need to be conducted using “aggressive” and “less aggressive” implant strategies that are still active when Optaflexx is fed.

Probably the biggest challenge in using Optaflexx will be predicting when cattle are 28 days away from slaughter. Perhaps feedlot managers and consultants are more confident than I
am in their computer models or "eye-ball" appraisal to make this prediction. Then there will be situations where cattle may require marketing before or after the 28-day date because of sorting, packer calls, weather, futures packages and other unforeseen circumstances. In our own experiment cited above, the protocol called for the steers to be slaughtered at 46 d after initiating ractopamine feeding with 60% of the steers to grade Choice. These steers were primarily of Angus breeding and the first replicates averaged near 1,100 lb at slaughter, however, they graded only 50% Choice, as I recall. As mentioned above, these steers were leaner than average that made our prediction unreliable 46 days before slaughter. With Optaflexx, there is an approved 14 d window (28 to 42 d) for harvesting the cattle. This gives some flexibility for marketing cattle fed Optaflexx. If cattle are marketed before this window, there will be no problems other than the overall response to Optaflexx will be proportionately reduced. The maximum response to Optaflexx occurs at about 35 d, after which the response declines. Optaflexx should not be fed beyond the approved 42 d. If cattle are kept on feed beyond this point, Optaflexx should be removed from the diet, which will result in a decline in response, negating some or all of the return on the investment in Optaflexx.

These and other challenges have been presented and recommendations provided in the manufacturer’s marketing literature (Elanco Animal Health, 2003b).

Summary

The introduction of repartitioning agents into the beef production industry will improve the efficiency of beef production and provide the packer, purveyor and consumer a leaner product with unchanged eating quality. With new technology, there are new challenges for the cattle feeder and packer. Application of this technology will require altered feedlot management considerations related to market (harvest) timing that will give additional focus to the carcass side of the industry.

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Logistic and operational issues in a large cattle yard

M. Dror
The University of Arizona & Massachusetts Institute of Technology

ABSTRACT: This paper examines in detail a number of operational issues inherent in the daily running of a very large cattle yard. We describe in simple terms mathematical models which capture the operational interdependencies, discuss their complexity, and propose appropriate solution procedures. We demonstrate that coupling the “right” mathematical problem description with an intelligent solution procedure can increase the operational efficiency and noticeably reduce the cost of feed distribution, cattle lot management, and a number of other cattle yard operational problems.

Key Words: Feed Distribution, Cattle Yard Operations Research

Introduction

The cattle yard in Arizona described in this paper produces cattle for the general meat market. Cattlemen do not set the price for their product, which fluctuates depending on supply, demand, and the psychology of the cattle market at the time of sale. Therefore, reducing operational costs is a major concern of a cattle yard, whose main operation is the daily delivery of feed to all the livestock.

We describe the operation of a single cattle yard which houses over 100,000 head of cattle, on average, in about 600 cattle pens dispersed over an area that measures roughly 10 miles by 5 miles. In addition to pens for keeping livestock, this yard contains a large mixing plant which produces the daily feed rations, storage facilities (both for feed ingredients and finished feed), and loading/unloading facilities including a rail depot for receiving feed ingredients and shipping/receiving cattle. With over 100,000 head of cattle, there is almost a daily movement of new (young) incoming cattle and the shipping out of mature cattle. We note that at the cattle yard in Arizona, at the initial time of the study, five different feed types/feed rations were produced and distributed by dedicated trucks. Later, the cattle yard moved to an operation mode with three feed types only. Feed types are specially formulated for various types of breeds of cattle; as the cattle mature, their diet requirements also change. Therefore, the feed type, volume of feed, and the feeding time for each pen may vary from day to day.

The operational activities in the cattle yard are intuitive and simple and are organized around the feeding needs and plans for the cattle. We distinguish between three major kinds of daily planned activities in the yard: (1) The operation of the large mixing plant that produces the daily feed rations, (2) The feed distribution. That is, planning the assignment and the routes for each one of the feed distribution trucks (five trucks in our case), (3) The management of the cattle in the pens. That is, splitting cattle lots and moving cattle groups from one pen to another or to vaccination and hormonal treatment confinement “service” areas.

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The operations management problem for activities (1) and (2) can be viewed as a hierarchical production mix and distribution problem. The daily feeding demands placed by the cattle form the input for the feed distribution system—the construction of the delivery routes. The feed delivery routing solution in turn forms the input for the truck assignment and scheduling problem which assigns the delivery routes to the available trucks. The output from the routes assignment problem then drives the production scheduling problem for the feed mixing plant. Since a typical head of cattle spends on average 200 to 250 days in the yard, the cattle yard system can be characterized, using industrial engineering jargon, as that of high value of “work in process” inventory. In this system of maintaining a high value of work in process inventory, it is operationally important to ask how significant is a 20% or 30% cost reduction in the feed distribution operation? Is a 20% reduction of the average number of in-yard moves per head of cattle a significant improvement? How would the planning of the production mix be effected by close coordination of feed production with feed distribution? It is perhaps more important to control cost parameters such as the cost of feed ingredients and profit parameters such as the price at the slaughter house. However, these parameters are exogenous (that is, necessarily controllable) and the operational cost parameters are endogenous, and to almost entirely are controllable.

The outline of this paper is as follows: The next section (Section 2) will describe in detail the feed distribution problem. That is, the mathematical model for the feed distribution problem is outlined with some graph theory related background. The model inputs, the decision variables, and the solution output for the feed distribution problem are discussed and a number of solution methodologies are briefly examined. Section 3 focuses on the feedmill operation: Production of the feed rations and synchronization of production and distribution. In Section 4, the problem of managing the in-yard cattle movement and the related problem of assigning cattle lots to pens is presented. Section 5 summarizes our findings.

The Feed Distribution Operation

In this section, we first focus on the problem of delivering the right feed to the cattle at the right time, assuming that the appropriate feed can be produced and will be ready for delivery as needed.

To abstract the mathematical model, consider the cattle yard’s physical layout as a graph. (See the cattle yard map below.) That is, we have points we call nodes, with some pairs of nodes connected by a segment of a road we refer to as an arc, from the first node to the second node in that pair. Say, one node would be a feed storage hopper under which a truck can be loaded with feed, and the other node would be the first road corner of the closest cattle pen. The road segment connecting the two is an arc in our graph. For instance, another arc would be the road segment in front of a feeding trough of a pen, say the closest pen, and the arc would be pointed in direction of discharging the feed (to the left of the drivers side). Thus, a road segment in front of each pen’s trough in the feed discharging direction would constitute an arc in the graph. Road segments linking different groups of pens or other road segments in the yard would also be denoted as arcs (one arc in each direction of the road segment). The nodes in the graph are of two kinds: (1) nodes which are feed loading nodes and nodes representing intersections of roads (any service or connecting roads), (2) nodes which correspond to the boundary between the feeding troughs of two adjacent pens. In principle, we do not distinguish between arcs corresponding to
the road segments in front of troughs and arcs for the other road segments. The graph thus constructed is denoted by $G=(V,A)$, where $V$ is the set of nodes and $A$ is the set of arcs. Some of these arcs correspond to the feeding troughs. Since at least three different feed rations are produced daily, we can view each feed ration with its appropriate pens designation as “marking” a subset of troughs. Say $A(1)$ is the subset of arcs (troughs) which require the delivery of feed type 1. Similarly $A(2), A(3), ..., A(K)$, when $K$ is the number of the different feed rations produced in the cattle yard. The feed delivery trucks which deliver feed type 1 have to traverse the arcs in $A(1)$, each starting its feed delivery trip at the pickup node (the appropriate feed storage hopper) and ending its trip either at the original starting node or another node (a different feed storage hopper) when switching to a different feed type. There are a number of requirements for each feed delivery trip: (1) The “right” feed type has to be delivered to each of the pens. (2) Since each pen has its specified feeding time window, the feed delivery to its trough has to respect the time window. (3) The feed delivery capacity of each truck cannot be exceeded. (4) Partial deliveries to a pen are allowed (by more than one truck trip – usually the same truck – may deliver feed to one pen). Under these restrictions the operational objective is to design a feed delivery plan which minimizes the total distance traveled by the trucks. In a large cattle yard, this task of planning feed deliveries is quite complex.

In graph theory (a subfield of mathematics) the problem described above falls under the broad category of ‘arc routing problems’ which dates back to the 18th century. (Node routing problems focus on constructing routes “covering” the nodes of a graph whereas arc routing problems focus on routes through the arcs of the corresponding graph.)

Since, in a sense, one has to plan the feed delivery routes for each feed type separately, the more specific single feed type delivery problem, is classified as a Capacitated Rural Postman Problem with time windows and split deliveries. Despite the fact that this problem is solved routinely in the daily operation of a cattle yard, there is very little in the general mathematical literature or the operations research (a subfield of applied mathematics) literature about solving this problem or similar problems. In fact, most of the published papers on this or related topics are listed in the reference list of this paper and in the book, edited by M. Dror (2000).
Considering that literature, there is bad news about solving this problem, but also some good news. The bad news is that it is a very difficult problem to solve optimally – to find the best (shortest distance) solution. In fact, in the mathematical classification of this type of problems (discrete optimization problems), “our” feed distribution problem belongs to a set of problems which are NP-hard in the strong sense (see Garey and Johnson, 1979). This means that nobody knows how to find the shortest distance solutions with a reasonable computational effort.

Now the good news: Even though we have to give up on the attempt to solve the feed distribution problem optimally, we can solve it heuristically in reasonable time with very good results for the real-life setting (for instance, the cattle yard in Arizona).

The mathematical formulations of the cattle yard feed distribution problem are presented in Dror and Leung (1998), Dror and Mullaseril (1999), and in Dror et al. (2000). These mathematical formulations can be considered only of academic value, because they are not solved directly. The exact (in equations format) mathematical formulations are not discussed any further here.

The heuristic solution procedures for the cattle yard feed distribution problem are described in Mullaseril et al. (1997), in Dror and Mullaseril (1999), and Dror et al. (2000). We assume implicitly an infinite number of identical capacity delivery trucks and minimize the total distance traveled by the fleet of trucks. The solution generates delivery trips which are then assigned to the actual fleet of trucks. (See the next section.) The main thrust of these heuristic solution procedures is stated below.

**Solution Procedures for Feed Distribution**

Having modeled the feed distribution problem as a number of capacitated Rural Postman problems with time windows and split deliveries (the number of the different problems is as many as there are feed types), we tested computationally a solution strategy adapted from the heuristic procedures for split-delivery node routing problems described in Dror and Trudeau (1990).

Our heuristic approach consists of two phases:

1. **Route Generation** -- a set of trips are generated which satisfy all the demand requirements with their corresponding time window requirements and truck capacity constraints, but no demand is split between the different truck trips.

2. **Split Delivery Introduction and Improvement** -- heuristics are applied which generate split deliveries that reduce the total distance traveled without violating time windows.

A full description of the route generation and route improvement procedures is stated in Mullaseril et al., (1997). Here we just summarize the heuristic principles and the corresponding routing results.

To generate the initial capacitated arc-routing solutions in phase 1, two heuristic procedures were used:

(i) **A Path Scanning procedure** --- which constructs a route adding the path segment to one demand arc at a time until the truck capacity is reached (introduced by Golden et al., 1983) and,

(ii) **An Augment and Merge heuristic** --- introduced by Golden and Wong (1981) which is based on a savings principle similar to Clark and Wright (1964) for node routing.

Both procedures were modified for routing with arc time-windows (Mullaseril et al., 1997).
In phase 2, the heuristics applied are k-split generation and k-route addition subroutines. Both subroutines were adapted from the heuristics developed by Dror and Trudeau (1990) for split delivery node routing. In Dror and Trudeau (1990) a k-Split procedure for node routing was introduced which tests if delivery to a node can be split across k other candidate routes in such a way that the highest savings is obtained. Another concept introduced in Dror and Trudeau (1990) for split delivery was that of route addition. This procedure searches over nodes whose demand is split among several routes and considers consolidating them into a new route which will realize net savings in distance traveled. We do not describe the full algorithmic details of the adapted solution procedures here and the interested reader is referred to Mullaseril et al. (1997).

In our computational experiments on data obtained from the cattle yard in Arizona, the heuristics sketched above were able to lower the total distance traveled by the trucks substantially, when compared to existing practices. For all five different feed types used at the time at the Arizona cattle yard, the heuristic procedures we proposed outperformed the current solutions by at least 25%, and as much as 50% on the denser subgraph – corresponding to the most dominant feed ration.

Note that the routes generated by the above procedures respect all the feed delivery time windows. This is usually not the case in practice where solutions are generated based on managerial experience and subsequently some time window violations are commonly observed. The reason is that the complexity of the corresponding routing problem is too great for the manager to fully incorporate all the variables into a solution using only intuition and experience.

Next, we describe the problem of assigning the delivery trucks to perform the feed distribution routes generated by the algorithm.

Assignment of Routes to Trucks: The Scheduling Problem

Given a solution to the feed distribution problem in the form of detailed delivery routes (truck trips) described in the previous section, we are still required to address the problem of assigning the trips to the delivery trucks in the cattle yard and scheduling their timely execution.

A solution to the feed distribution results in a set of trips which start and end at the feed storage hoppers (located essentially at the same node on the graph). The total number of such trips is expected to exceed the number of trucks in the yard and each truck is expected to make a number of feed delivery trips during a work day. Given the set of trips, the truck scheduling (dispatching) problem consists of the assignment of starting times and specific trucks for each trip, so that trips do not overlap in time for each truck, and "right" feed is delivered to each trough within its feeding time window on the corresponding trip. In the case of a different size trucks we assume the feed with the highest usage has the exclusive use of the largest truck, etc. In the case of the cattle yard in Arizona, there was only one larger truck and four identical trucks. In our computational testing, the trips generated by the procedures described above for the different feed types were generated according to an identical truck capacities adjusted for feed type. We summarize the procedure next.

First, for the jth trip (denoted by T(j)), compute its duration t(j) by adding the travel time at the idle speed (when not discharging feed) for each arc in the trip to the incremental time of feed-discharge for each of the arcs corresponding to feeding troughs serviced by this trip. (This incremental time is feed and pen/arc dependent.)
To compute the latest completion time of a trip, we assume that it is started as late as possible so that it finishes serving its first required arc at the end of its allowed time window. Next, we examine the start and completion times for feed delivery to the pens along the driving sequence of the trip and check that the feeding times are feasible in relation to the trip's travel time. If a time window for a subsequent feeding trough is violated, the entire trip is shifted to begin earlier so that the time window constraint is just met. The completion time of this trip is the latest completion time of the trip. We can compute the earliest start time for the trip by assuming that the trip is started so that it arrives at the first pen at the beginning of its feeding time window and adjust for the traversal of the remainder of the trip in a similar manner.

Given that the trucks are all of the same capacity, the problem of assigning start-times and trucks to these trips is equivalent to finding a feasible solution to the scheduling problem with parallel machines (corresponding to the trucks) and jobs (corresponding to trips) with release times and deadlines where no preemption is allowed. This problem (known as *Sequencing Within Intervals*) is hard to solve (NP-hard) even for one truck/machine (see Garey and Johnson, 1979, Dempster, Lenstra, and Rinnooy Kan, 1982). However, if preemption is allowed, then a solution to the problem is readily obtainable (see Horn, 1974).

We do not present a mathematical formulation of the problem. (For the mathematical formulation see Dror and Leung, 1998.) We note that the split delivery policy used in construction of the feed delivery trips does not affect the subsequent scheduling problem. In our application, preemption is not allowed. That is, trucks obviously cannot stop delivery in the middle of a trip (with the truck somewhere in the cattle yard) and immediately start another trip from the depot or continue delivery of a different trip.

**Heuristic for Generating a Feasible Trip Covering Solution - List Algorithm**

Given that there exists a feasible solution to the trip scheduling problem as above, we describe a simple list processing algorithm for assigning trips to the trucks and their starting times.

As we mentioned earlier, we can view the trucks as parallel identical processors and list the trips according to a nondecreasing earliest start time. Then we apply a list processing algorithm which assigns the trips in order to the first available truck, breaking ties according to the lower truck index. For the large truck which delivers only one feed type in the Arizona cattle yard, its dispatch schedule is easily found. It simply executes its trips in order, according to a nondecreasing earliest start time. We consider the two algorithms: Algorithm 1 (*backward algorithm*) and Algorithm 2 (*forward algorithm*). Both algorithms produce feasible solutions not necessarily identical for trips of equal duration and are described in more detail in Dror and Leung (1998).

In the preliminary computational testing when checking for feasibility with respect to time windows, the route generation heuristics assumed a deadheading speed of 15 miles per hour and a feed discharging speed of 1 mile per hour. For the data we tested, a feasible assignment of the trips to five trucks is possible using Algorithm 1. As mentioned above, because of the complexity of the problem, in principle, neither Algorithms 1 nor 2 guarantee to construct feasible solutions even if they exist. The trucks' speed turns out to be a critical factor for determining whether feasible assignments are found; this was shown by the results of a computational 'sensitivity' study reported in Dror and Leung (1998). In particular, the feed discharging speed is very important; when it is below 0.4 mph, no feasible schedule is found for
our test data unless the feed discharging speed is substantially increased – for example, when it is above 0.6 mph – feasible schedules are found.

The Feedmill Operation - Synchronizing Production with Distribution

A solution to the feed distribution problem presented in previous sections generates a feasible feeding schedule for the different cattle pens by specifying the time, the truck, and the trip which delivers the “right” feed ration to a cattle pen. To execute such a schedule, the feedmill has to produce the appropriate amounts of the different feeds in coordination with the distribution schedule. (5 feed types were used in our test data since at the time of the study the Arizona cattle yard used 5 different feed rations.) We assume that quality considerations require that fresh feed rations are produced daily. Since the distribution plan is driven by the cattle’s needs, the feed production schedule has to maintain the inventory levels of the different feed categories, while also focusing on the important aspect of feed quality in its feed mixing process. The quality of feed mixing objective can be expressed in terms of the length of a production run of a feed type. The longer the production run, the greater the control over the feed-mix specifications. Thus, minimizing the number of total production startups for all feed types, while satisfying the demand of feed-requirements as prescribed by the distribution plan, serves as an appropriate surrogate objective for optimizing quality. A similar problem exists in a paper mill operation when changing from one grade of paper to another where paper is wasted until a machine can be fully adjusted. This is referred to as a changeover penalty. The problem of constructing a short-term production schedule for a facility that processes one product at a time and incurs a changeover penalty when changing from one product to another has actually received considerable attention in the literature. For instance, see Magnanti and Vachani, (1990) for determining the start times and run length of the production run, in our case, for the different feed types which enable the subsequent execution of the feed distribution solution. Similarly stated problems and an overview discussion can be found in Maes and Van Wassenhove (1988) and Salomon et al. (1991), where the problem is called a Discrete Lotsizing and Scheduling Problem. One important difference between our problem and that described in Magnanti and Vachani (1990), is the fact that the storage facilities for the different feed types (in finished product) are of finite capacity and each storage facility can store only one feed type at a time.

In our modeling of the feedmill operation we make a number of assumptions:
1. The changeover time is zero, that is, the changeover preparations can be done off-line before the changeover has to take place. Machine setup can be maintained even if a machine is idle for a particular period.
2. The changeover costs are not sequence dependent, but only depend on the product for which the facility is to be setup.
3. The production level at any period is either set to the required, feed specific, production rate, or is zero (i.e., discrete production policy).

The mathematical problem with the above assumptions is stated as that of minimizing the total number of feed-mixing setups while satisfying the feed rations requirement set by the feed delivery trip generation and scheduling procedures. This mathematical model is presented in
more detail in Dror and Leung (1998) and is not restated here. Again, in general it is not easy to solve this problem quickly to optimality because of its inherent complexity.

Discussion of Solution Approaches

Many authors have investigated problems similar to the one presented in this section. Some of the latest literature on this topic include Cattrysse et al. (1993) and van Hoesel et al. (1994). Most of the other related important references are mentioned in these two papers.

In Cattrysse et al. (1993), the authors discuss an uncapacitated version of the Discrete Lot-sizing and Scheduling Problem and formulate the problem as a Set Partitioning Problem. In their formulation, they also include inventory holding costs and production costs which are omitted from our formulation of the problem, but they did not address storage capacity limitations in their formulation. We are optimistic that the solution methodology (known as dual ascent and column generation) which they have developed for their Set Partitioning Problem formulation would be a promising approach for our problem. Cattrysse et al. (1993) report computational results on 420 test problems where 82% of the test problems were solved to optimality and the problems which were not solved to optimality had a (duality) gap – guaranteed difference from the optimal solution -- of at most 1.5%. They compare their computational results to the ones obtained by a heuristic described in Fleischmann (1990). The speed of Fleischmann’s heuristic was found to be superior but the resulting solution somewhat worst than that of Cattrysse et al. (1993).

In van Hoesel et al. (1994), the Discrete Lot-sizing and Scheduling Problem is examined and two solution procedures are described in some detail. The first procedure is based on a "reformulation of the Discrete Lot-sizing and Scheduling Problem as a linear programming assignment problem, with additional restriction to reflect the specific (setup) cost structure. The second procedure is based on dynamic programming". The authors do not report computational results for the two procedures.

We have not conducted any significant computational experimentation to solve this problem in the cattle yard setting, but we plan to examine an adaptation of the solution methodology of Cattrysse et al. (1993) in future research.

In-yard Management of Cattle Lot Movements

In this section we describe the problem of modeling the assignment and movement of cattle lots among the pens in the yard. On the average, each head of cattle spends about 200 to 250 days in the cattle yard before being sent to a slaughter house. During that period, each head of cattle has to be assigned an initial pen, followed by reassignments to different pens as the cattle matures, until it is shipped out. On the average, each head of cattle experiences about 3-4 moves during its stay in the cattle yard (based on the Arizona cattle yard experience). With 100,000 head of cattle in the yard and an estimated cost of 6 to 10 dollars per head per move (computed from the cost of a move and the corresponding weight loss), such costs quickly add up to a significant amount. For proper feeding, the maximum number of cattle allowed in a pen is proportional to the length of the feeding trough and this ratio is dependent on the age of the cattle. Thus, the capacity of a pen is different for cattle of different ages and breeds. As the cattle matures, it may outgrow the capacity of the pens they are housed in, and the lot or a subset of the lot needs to be moved to a different pen. The perception of the management is that the decision
In this section we present a draft of a mathematical formulation for this cattle assignment and movement problem. We do not propose here a solution methodology for the resulting very large integer-programming problem. We also do not know of any other study regarding problems of this type, size, and structure. We only view this formulation (Dror and Leung, 1998) as an initial attempt to model the problem and provide a starting point for future research.

In this formulation we initially assume that the information regarding the number, time period, and the exact age of the young calves entering the yard is known in advance and the number, age, and time period of the cattle leaving the yard is also known. That is, we model this problem as a deterministic problem although, in reality, there are stochastic variations in the shipment dates, etc. Depending on the number of time periods included in the model, we can repeatedly solve this problem using a rolling time horizon. We also assume that every movement occurs at the beginning of the time period and has no significant duration.

Clearly, the time units are the different days and, in principle we need to determine how many heads of cattle of a certain category (determined by age and breed) indexed by c(k) should be moved from given pen, denoted as p(i) to another pen p(j) on every day indexed by d(t). We of course have to know if on d(t) there is cattle of category c(k) in pen p(i). We have to know how many heads of cattle of different categories c(k), k=1,..., N(c) – total number of different categories, are entering the cattle yard on day d(t), t=1,..., T, where T is the planning horizon. How many heads of cattle of each category are shipped out on day d(t), t=1,...,T, Capacities of each pen in terms of cattle categories have to be specified. We have to keep track (through flow equations) of empty pens and the specific pens for the arriving cattle, etc. The cattle growth (maturity) has also to be monitored daily. That is, changes in cattle categories are monitored by flow equations also accounting for average mortality factors. We also have to estimate the cost of moving one head of cattle of specific category from pen p(i) to pen p(j) for all pens in the yard. Thus, the objective is to minimize the cost of in-yard cattle movements over the time horizon for the model in response to the natural growth and maturity of the cattle in relation to the capacity of the pens.

Incorporating requirements like certain pens are only suited to certain category of cattle is natural in this model. Clearly, the model captures requirements like only one category of cattle can reside in a single pen. There are the “conservation of flow” requirements stating that the cattle leaving different pens is equal to the cattle entering the different pens accounting for incoming cattle and the cattle being shipped out.

In the problem we studied, there are over 600 pens and about 40 different age groups for the cattle. With 52 weeks in the planning period, the initial model is an integer program (cattle numbers are positive integers) where the number of integer variables is on the order of 100 million. Clearly, solving a problem of such complexity directly to optimality is not very realistic. In our future research, we plan to examine heuristic methods for this problem, with the goal of providing the cattle yard manager a tool that would be used to generate cattle movement plans a few times each month, for example, when new shipments of cattle are identified or new significant information becomes available. The real life problem is more stochastic in nature in terms of stock availability and demand, and cattle yard data is periodically updated.
Conclusions

In this paper, we have described several problems encountered in the operations of a cattle yard. Many of these problems can be formulated as large combinatorial optimization problems. We have developed some algorithms for feed distribution planning which appear to be effective. On the other hand, the model for some other operational problems (e.g. cattle movement) are of a size that would challenge the state of the art in integer programming methodologies.

In addition to problem modeling for cattle yard operations we have developed a visual computer-based graphic interactive management tool for feed distribution at a cattle yard (see Tarcey and Dror, 1997). The computer-based tool is constructed to graphically present the feed distribution solution and to facilitate the management of cattle feed related inputs and update operations. We chose to implement the decision support system for cattle feed distribution using PC Arc/Info. This software best met our criteria without imposing any obvious limitations and provides the functionality required for our application.

In the present daily cattle yard operations, to our knowledge none of the problems described above is solved using the mathematical representation and solution methodology described in this paper. In addition, the feed distribution problem is treated as a prerequisite of solving of the truck scheduling, and next in the sequence of problems which have to be solved is the feedmill production scheduling problem. Another challenging problem to consider is that of the interdependence when modeling these problems separately and the possibility of getting better answers by optimizing a combined objective of the three problems together. This indicates that much research is needed to investigate problems of this nature so that effective optimization-based decision-support tools can be offered to cattle yard manager.

Literature Cited


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Beef cattle Research at the University of Arizona: Effects of nutrition and management on health, performance and carcass characteristics of beef cattle.

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Introduction

Our research program in beef cattle at the University of Arizona encompasses several aspects ranging from range cattle production to Holstein steers fed for beef in the feedlot. In addition, we offer a unique opportunity to study the effects of environmental stress (both heat and solar) on metabolism at the cellular level with our new state of the art Agricultural Research Center. The newly constructed center has two environmental chamber with one chamber containing a solar unit. Therefore, our long-term goals are to maximize performance under the semi-arid regions of the United States.

Effects of early-weaning on metabolic profiles of first-calf heifer and mature cows, and effects of diet for early-weaned steers

The arid southwest region of the U.S. has reoccurring periods of drought in which forage availability declines. Consequently, producers must continually analyze not only forage resources, but also animal production parameters to decide if reducing animal units will decrease grazing pressure. Therefore, developing proper management techniques for both first-calf heifers and mature cows during periods of nutritional distress requires knowledge of factors and interactions that affect metabolic conditions. Nutritional programs can be more effectively developed and evaluated if research continues to integrate production decisions with metabolic and cellular responses. In addition, proper nutrition of the early-weaned calf deserves consideration. Producers may be able to background their calves on the ranch using available feed sources prior to marketing. However, steers backgrounded on a non-supplemented, low-quality forage may become increasingly susceptible to immune challenges such as infectious bovine rhinotracheitis. In addition, it is not known if calves backgrounded on a low-protein forage diet require supplemental CP to elicit an effective immune response during the feedlot receiving period. Two studies were conducted to evaluate 1) effects of early-weaning on metabolic profiles of first calf heifers and mature cows, and 2) effects of diet for early-weaned calves on febrile response to a bovine herpes-I virus.

The first study investigated effects of early weaning calves in first-calf heifers and mature cows on performance and metabolic profiles. Treatments were arranged in a 2 x 2 factorial and included 14 crossbred first-calf heifers and 14 crossbred mature cows assigned randomly to one of two treatment regimens: early-weaned (EW, calves weaned at an average age of 114 d) or normal-weaned (NW, calves weaned at an average age of 197 d). Blood samples were collected from heifers and cows on d 114, 141, 197, and 205 postpartum via coccygeal venipuncture. Heifers with calves EW experienced 2.34% increase in BW over heifers with calves NW, but no change in BW due to weaning was observed for mature cows. Early weaning increased body condition ($P < 0.05$) and change in body condition (BC) of dams when compared with NW. There were no parity x weaning or parity x weaning x day interaction effects observed for IGF-1,
NEFA, or serum urea nitrogen (SUN). A parity x day interaction for serum IGF-1 (P < 0.01) and SUN (P < 0.05) and parity x day interaction for serum NEFA (P < 0.10) were observed, but no differences were detected between first-calf heifers and mature cows within sampling day. Early weaning tended to decrease (P < 0.10) SUN when compared with NW status. These results suggest that EW can increase BW and BC in first-calf heifers and decrease SUN concentrations in both first-calf heifers and mature cows. However, no other differences in performance or serum chemistry were detected between first-calf heifers and mature cows with either weaning regimen applied, in open rangeland conditions of the arid southwestern United States during drought conditions. Liver biopsy samples were collected and are currently being analyzed for mRNA concentrations for IGF-1.

In the second experiment, early-weaned crossbred steers (n = 33; initial BW = 106 ± 7.59 kg; average age at weaning = 132 d) were used to evaluate effects of protein supplementation of forage diets vs. a 70% concentrate diet fed during a backgrounding phase (d 0 to 84) on performance, metabolic profiles, and febrile response to an infectious bovine herpesvirus-1 (BHV-1) challenge during a receiving phase (d 84 to 112). The four treatments during backgrounding included a bermudagrass hay diet (CTRL); bermudagrass hay plus soybean meal (SBM) fed at 0.175% of BW; bermudagrass hay plus SBM at 0.35% of BW; or a 70% concentrate (CONC) diet. During the receiving phase, all steers were fed CONC and intranasally challenged on d 85 with BHV-1. No differences (P = 0.69) were observed among treatments for G:F during the receiving phase. Treatment x day interactions (P < 0.01) were observed for serum concentrations of NEFA, total protein, urea nitrogen, glucose, immunoglobulin G (IgG), and insulin, and for rectal temperature. On d 88 (P < 0.05) and 91 (P = 0.07), serum IgG was greater for steers fed forage diets vs. CONC, and NEFA and glucose were greater (P < 0.02) for CONC vs. forage diets. On d 88 and 89 (3 and 4 d after the BHV-1 challenge), rectal temperature was greater (P < 0.01) for protein supplemented steers vs. CTRL steers. We conclude that a higher quality diet fed during a backgrounding phase enhances performance of early-weaned steers and may increase febrile response to an infectious BHV-1 respiratory challenge.

**Effects of castration method and flunixin meglumine on performance and behavior of newly received beef calves**

Although castration has been a common practice in beef production for a long time, relatively few refereed publications are available evaluating the different castration methods on performance of beef cattle. Flunixin meglumine is an anti-inflammatory analgesic, which suppresses endogenous production of prostaglandins. Flunixin meglumine was recently approved for use in feedlot cattle in November 2001. Use of flunixin meglumine in castrated animals may improve their well being by one of two methods. The analgesic mode of action in flunixin meglumine may decrease both the pain and discomfort associated with the various castration methods. In addition the anti-inflammatory nature of the compound may decrease the swelling normally observed in the scrotal area with the two castration methods. Behavior in calves associated with castration is an area in need of further research. The objective of this study was to determine the effects of flunixin meglumine and castration method, on performance and behavioral characteristics of newly received beef calves.

One hundred eighteen beef calves (British x Continental x Brahman) were purchased from an order buyer in Fort Worth, Texas, and shipped 924 miles to the University of Arizona.
Feedlot. Ninety-four bulls and 24 steers were preconditioned for 7 days prior to castration. During preconditioning, cattle were metaphylactically treated with tilmicosin phosphate @ 1.1 mg/kg BW and observed twice daily for signs of respiratory disease. The intact males were randomly assigned to one of four treatments; steers were used as controls. Treatment groups were arranged in a 3 x 2 factorial and are as follows. 1) steers (control group), 2) steers + flunixin meglumine @ 1.1 mg/kg of BW on day 0 and 3, 3) surgical castration, 4) surgical castration + flunixin meglumine @ 1.1 mg/kg of BW on day 0 and 3, 5) banding, 6) banding + flunixin meglumine @ 1.1 mg/kg on day 0 and 3. Animals were individually weighed on d 0, 1, 3, 7, 14, 28 after castration. Feed bunks for each pen were swept and unconsumed feed weighed on days 1, 3, 7, 14 and 28 and its DM calculated. Behavioral data was collected continuously for 24 h after castration and for 1 h at 36 and 48 h after castration. Observations included standing, walking, lying, kicking, tail twitching, licking, eating, ruminating, drinking, and vocalizing.

A castration method x flunixin meglumine interaction was observed for ADG during d 3 to 7; however, no other interactions were observed for performance data. Flunixin meglumine did not influence (P > 0.10) ADG or DMI throughout the duration of the 28 d trial. Dry matter intake and ADG were higher for steers compared to castrated animals for the entire 28 d receiving period. No differences in ADG and DMI were noted between the different castration methods. No castration method x flunixin meglumine, castration method x time, flunixin meglumine x time, or castration method x flunixin meglumine x time interactions (P > 0.10) were observed for any of the behavioral data. However behavioral differences were noted between castration methods. Knife castrated calves stood an average of 34 sec longer (P < 0.01) than banded group. Banded groups lied down an average of 35 seconds longer than the knife groups (P < 0.01). Banded groups also kicked at their belly more (P < 0.01) often than the knife castrated groups. No differences were observed for vocalizing, licking and eating patterns. Castrated cattle twitched their tails more vs. steers and knife castrated cattle displayed greater (P < 0.01) tail twitching behavior vs. banded cattle. Banded groups ruminated an average of 15 seconds longer (P < 0.05) than the knife castrated animals; whereas knife castrated animals spent more time (P < 0.05) drinking than banded cattle. No two or three way interactions were observed in the blood serum data. Blood serum haptoglobin concentrations were higher (P < 0.01) in the knife and band castration groups vs. steers. Although flunixin meglumine showed no significant effect for the majority of the receiving period, we believe it plays an important role in the 3 to 7 day time period after castration to alleviate pain and discomfort in not only for banded animals but more-so the knife castrated animals.

**Effects of dietary urea concentration on acid-base balance of feedlot steers**

Urea is commonly used in feedlot diets to supply ruminally degradable protein. Additionally, it has a transient buffering effect in the rumen and recent speculation has suggested urea could possibly combat systemic acidosis. Thus, this experiment was conducted to determine the effects of dietary urea concentration on acid-base balance in feedlot steers. A 4 x 4 Latin square was used to determine the effects of isonitrogenous steam-flaked corn based diets containing 0, 0.5, 1.0 or 1.5% urea (DM basis). Steers (306 ± 11 kg) were allowed a 21-d adjustment period to each diet followed by a 1 d sampling period. Immediately prior to, and 1, 2, 4, and 8 h after feeding, arterial (auricular) and jugular blood as well as urine samples were collected from each steer. Arterial blood samples were immediately analyzed for pH, pCO₂, and pO₂ and urine samples were immediately analyzed for pH. Serum was harvested from venous
blood and stored (-20° C) for later serum urea nitrogen (SUN) concentration (mg/dL) evaluation. A treatment x time interaction \((P < 0.001)\) was observed for urine pH, however, the biological significance of this interaction is doubtful; no other treatment x time interactions \((P > 0.26)\) were observed. No treatment effects were observed for arterial pH \((P > 0.52; 7.51, 7.53, 7.51, \text{ and } 7.55 \text{ for } 0, 0.5, 1.0, \text{ and } 1.5\% \text{ urea, respectively})\), SUN \((P > 0.40; 14.67, 12.42, 12.08, \text{ and } 12.66 \text{ mg/dL for } 0, 0.5, 1.0, \text{ and } 1.5\% \text{ urea, respectively})\), pCO\(_2\) \((P > 0.62)\), pO\(_2\) \((P > 0.32)\), or urine pH \((P > 0.89)\). These results indicate that increasing urea concentrations in high concentrate feedlot diets has no effect on arterial pH, blood gas profile, SUN, or urine pH. Therefore, dietary urea is unlikely to combat systemic acidosis.

**Effects of implant programs for long-fed Holstein steers**

In recent years Holstein feeder steers have become of great importance in the beef production feed yards, particularly in the southwestern U.S. Their uniformity, live performance, and carcass value outweigh their potential deficits in carcass characteristics and increased maintenance costs. In Arizona alone approximately 225,000 Holstein steers are raised in beef production facilities. This represents approximately 75% of the cattle fed for beef in Arizona with their value exceeding $200 million. It is well recognized that implant programs improve average daily gain, feed efficiency and protein deposition. However, limited research has evaluated the effects of implant programs on lipid metabolism.

Twenty Holstein steer calves (average initial body weight approximately 400 lb) were purchased from an Arizona feedlot producer. Steers were raised in a manner consistent with approved protocols at the University of Arizona Feedlot. Treatments included implant regimens used during raising the animals from a calf to harvest. Treatments were 1) no implant (Control), 2) an implant with zeranol (Ralgro; estrogen-based; Schering-Plough Animal Health, Union, NJ) on d 0 followed by a Synovex-S (estrogen-based; Ft. Dodge Animal Health, Ft. Dodge, IA) implant on d 84 and 168, 3) an implant with zeranol on d 0 followed by an implant on d 84 with Synovex-S followed Synovex Plus (estrogen plus trenbolone-acetate-based; Ft. Dodge Animal Health) implants on d 168, and 4) an implant with zeranol on d 0 followed by an implant with Synovex-Plus on d 84 and 168. Implant programs are typical programs used by commercial feedyards and encompass non-aggressive implant program (trt 2), more aggressive implant program (trt 3), and an aggressive implant program (trt 4). Steers were individually fed a diet typical of commercial feedyards and contained (DM basis) 67.54% steam-flaked corn, 14% sorghum sudangrass hay, 6.25% soybean meal, 5% molasses, 4% tallow, 0.75% urea, and 2.5% of a finishing supplement containing vitamins, minerals, Rumensin and Tylan. Steers were housed in (2.5 x 6 m) outdoor pens with soil surface; each pen contained an individual water source.

Adipose tissue biopsies were performed at d 0, 84, and 170 of the experiment. A biopsy sample was collected from the subcutaneous adipose depot of the hip region. Steers were tranquilized with xylazine (30 to 40 mg) 15 min. prior to the procedure. The hip region was shaved and aseptically prepared for surgery. A 2% lidocaine HCl (20 mL, s.c.) was administered in a circular pattern 5 min prior to biopsy. A lateral incision (approximately ~5 cm) was made through the skin and subcutaneous adipose tissue at an area perpendicular to the long axis of the hip, immediately cranial to the pin bone. Subcutaneous adipose tissue (approximately 1 to 2 g) was dissected from the skin and muscle fascia and then cut out with scissors. The incision was
then be cleaned with sterile saline and closed with absorbable sutures. Adipose tissue biopsies were immediately frozen in liquid nitrogen and stored at -80°C until analysis.

Upon completion of the feeding period, all animals were humanely slaughtered at the University of Arizona Meats Laboratory. Carcasses were evaluated for USDA quality grades (% Prime, % Choice, % Select, % Standard), ribeye area, fat thickness, and marbling score. Fat samples from the tail head region were collected at harvest and processed as described previously. Two steaks 2.5-cm thick were removed from the posterior end of each longissimus muscle section, vacuum-packaged, and frozen for Warner-Bratzler shear force determination.

Adipose RNA is currently being isolated for quantification of gene expression of adipose tissues as influenced by implant regimen. In particular, we will be measuring acetyl CoA carboxylase, stearoyl-CoA desaturase, uncoupling proteins, uncoupling protein 2, leptin, fatty acid transferases, fatty acid binding protein and adiponectin.

Steaks used for tenderness were weighed, and broiled over an open-hearth electric grill to an internal temperature of 70°C. Steaks were weighed after cooking and percent shrinkage calculated for each steak. After cooling to room temperature, six 1.27-cm cores were removed from each steak parallel to the direction of the muscle fibers. Each core was individually sheared using a Warner-Bratzler shear apparatus.

As expected, implanted steers had greater ADG (P < 0.01), increased DMI (P < 0.01), but no differences in F:G (P = 0.40). As a result, implanted steers had heavier final BW (P < 0.01), heavier HCW (P < 0.01), and larger LM area (P < 0.01). In addition, implanted steers had a slightly darker coloration (P < 0.08) vs. control steers. No differences among treatments were observed in dressing percentage (P > 0.52), kidney pelvic and heart fat (P > 0.20), back fat (P > 0.54), yield grade (P > 0.46), marbling score (P > 0.35), texture (P > 0.27), firmness (P > 0.34), or Warner-Bratzler shear force values (P > 0.32). Averaged across sampling d, serum concentrations of glucose (P > 0.23) and NEFA (P > 0.13) did not differ among treatments. Overall, the implant programs evaluated enhanced performance, carcass weight and LM area, did not affect adipose deposition, and thus, did not adversely affect carcass characteristics in long-fed Holstein steers. No responses in serum concentrations of glucose or NEFA were detected.

We conclude that long-fed Holstein steers can be aggressively implanted without adversely affecting carcass characteristics. However, we acknowledge the limited number of animals on this study and are concentrating our efforts on metabolic profiles to elucidate the mechanism of action.

Effects of CLA for improving carcass characteristics of naturally-fed Holstein steers

Consumer interest in “natural beef” continues to increase and thus developing “natural” methods of maximizing efficiency and improving meat quality are vital to the industry. Unfortunately, opportunities to naturally manipulate nutrient partitioning and metabolism without sacrificing production parameters are limited. However, recent rodent and pig research utilizing dietary CLA (a naturally occurring fatty acid) offers exciting possibilities to improve body composition parameters. The optimum CLA dose in beef cattle is currently not known. We are suggesting utilizing subcutaneous fat thickness and abdominal (kidney) fat depot weight as measures of selecting appropriate CLA dose. In addition, we are basing our hypothesis on the following abstracts presented at the 2004 national ASAS meeting.
Effects of CLA on tissue response to homeostatic signals and plasma lipid metabolism variables in growing beef steers

The ability of CLA to modify beef body composition and the mechanism by which it alters lipid metabolism are poorly understood. Objectives of this study were to evaluate basal energetic and temporal metabolite patterns in response to epinephrine, insulin, and glucose challenges in cattle fed rumen protected (RP) CLA. Twenty British x Continental beef steers (280 ± 29 kg BW) were fed isoenergetic steam-flaked corn based diets containing equal amounts of FA (5.74 vs 6.25% EnerGlI®; a RP palm oil and RP CLA, respectively) for 45 d. The CLA supplement contained 71.4% FA of which 40.0% were CLA isomers (5.4% t-8, c-10; 6.3% c-9, t-11; 7.9% t-10, c-12; and 8.2% c-11, t-13 CLA). Controls were pair-fed with CLA steers in order to minimize caloric intake variability. All steers were fitted with indwelling jugular catheters on d 14, 28, and 42. Epinephrine (1.4 μg/kg BW), insulin (3.0 μg/kg BW), and glucose (0.3 g/kg BW) challenges were conducted and blood samples collected on d 15, 30 & 43; 16, 31 & 44; and 17, 32 & 45, respectively. Subcutaneous adipose tissue was collected from the tailhead region in 10 randomly selected steers (n = 5/trt) on d 45. Production variables (ADG, G:F, BW, DMI and DMI as %BW) did not differ (P > 0.15) between treatment groups. Dietary CLA did not alter basal circulating plasma NEFA or glucose concentrations. In addition, there were no CLA effects on metabolic responses to the aforementioned homeostatic signals. On d 45, adipose tissue of CLA-fed steers had increased (P < 0.03) concentrations of c-9, t-11 CLA (0.78 vs 0.52%), t-10, c-12 CLA (0.21 vs 0.08%), total CLA (2.85 vs 0.97%), and total t-18:1 FA (8.92 vs 5.70%). There were no effects on the Δ9-desaturase index (43.3) or the total saturated and unsaturated levels (45.7 and 54.3%, respectively). These data indicate that short term CLA supplementation did not alter basal or stimulated NEFA or glucose parameters, but has the ability to dramatically increase CLA content in bovine adipose tissue.

Effects of conjugated linoleic acid (CLA) and trans-C18:1 fatty acids (TFA) on energetic metabolites and subcutaneous adipose tissue fatty acid composition.

Finishing beef cattle (n = 30, 359 ± 60 kg BW), which were studied in an immune trial, were also utilized in this experiment. Cattle were fed isoenergetic diets (steam-flaked sorghum based) supplemented (top dressed) with rumen protected (RP) palm oil (559 g/d; EnerGlI®[EII]; control), RP TFA (594 g/d) or RP CLA (609 g/d) for 35d. Each treatment provided 475 g lipid/d and RP TFA consisted of 17.2% trans-6-8, 8.7% trans-9, 8.8% trans-10, 5.8% trans-11 and 7.3% trans-12 C18:1 and the RP CLA contained 6.5% cis-9, trans-11, 5.4% c/t-8, c/t-10, 8.25% c/t-11, c/t-13 and 7.9% trans-10, cis-12 CLA. All bull calves were weighed and blood collected on d 0, 7, 13, 21, 28 and 35. Subcutaneous adipose biopsies were taken from the tail head on d 35. Overall, CLA supplementation decreased DMI (P = 0.04; 7.6, 7.4 and 6.1 kg/d for EII, TFA and CLA, respectively) and did not effect G:F or ADG. CLA supplementation tended (P = 0.10) to increase NEFA concentrations (196a, 213ab and 258b μmole/L, for EII, TFA and CLA, respectively) and this was not dependent upon time. Supplementing CLA reduced (P=0.04) plasma glucose levels (5.4%) compared to EII and there was no trt x time interaction. Compared to EII cattle fed TFA had increased (P<0.01) concentrations of trans-6-8 (120%), trans-9 (113%), trans-11 (30%) and trans-12 (62%) C18:1 fatty acids, but did not change trans-10 C18:1 (64 mg/g fat) and also increased cis-9, trans-11 CLA (10%). Irrespective of treatment the content of trans-10 was 3.8 fold more than trans-11 C18:1. CLA supplementation did not alter the trans-
C18:1 profile but increased *cis*-9, *trans*-11 and *trans*-10, *cis*-12 CLA content by 8 and 50% respectively. There was no treatment effect on total unsaturated fatty acid content (54%) or on the Δ⁹-desaturase index (42.5) nor any of the specific Δ⁹-desaturase ratios. These data indicate the Δ⁹-desaturase system contributes to the *cis*-9, *trans*-11 CLA content in beef adipose tissue.

We will be using 108 Holstein steers that will be housed at the University of Arizona and grouped into 18 pens (6 animals/pen). Approximately 170 days prior to anticipated harvesting date, animals will be transported to the U of A feedlot. At 150 days prior to calving treatment will be initiated. Six pens will be utilized as controls, six pens will receive 200 g CLA/hd/d (Bioproducts Inc. Fairlawn OH) and six pens will receive 400 g CLA/hd/d. All animals will be weighed and backfat thickness measured (ultrasound) every 28 d until harvested. After 150 d on trial, all animals will be harvested at Sun Land Beef Co. Two days post slaughter carcass measurements will be obtained and adipose tissues collected.
Kansas State University Growing and Finishing Cattle Research Update


Introduction

Research with growing and finishing cattle at Kansas State University covers a broad spectrum of activities, including experiments to evaluate grain processing, co-product utilization, pre-harvest food safety, lipid metabolism, immune function, and the influence of nutrition on quality, composition and sensory attributes of beef. Graduate students in our program are directly responsible for one or more specific research areas, but also become intimately involved in a wide range of projects performed by their student peers. Individual trials range from small scale, relatively basic "discovery" experiments utilizing a few animals to larger production studies involving 300 to 700 animals, and ultimately the commercial-scale experiments involving 2,000 to 20,000 head. Some of our more current research projects are discussed in the paragraphs that follow.

Grain Processing

We have conducted several experiments in order to gain a more thorough understanding of the importance of moisture during the steam flaking process. These studies are based on the assumption that moisture is required to gelatinize starch, and that greater gelatinization will lead to more extensive ruminal digestion of starch. In our initial experiment we compared performance of finishing cattle fed steam flaked grains that contained approximately 18% or 38% moisture. Starch availability, as measured by susceptibility to enzymatic hydrolysis, was dramatically increased with higher moisture levels, thus confirming the role of moisture in the gelatinization of starch. The flaked corn with 38% moisture resulted in substantially lower dry matter intake and gain, but efficiencies were comparable to those of cattle fed grains with the lower moisture level. Cattle fed the high-moisture flakes also tended to accumulate more body fat, suggesting the grain sources may be metabolized somewhat differently. In a follow-up factorial experiment we have evaluated interactions between degree of processing (flaked density) and moisture content of flaked grains in individually fed cattle. This study has suggested that moisture levels and degree of processing may interact with respect to their impact on feed efficiency in finishing cattle. Higher moisture grains (30%) flaked to 28-lb flake weights yielded performance similar to that obtained with grain containing 18% moisture flaked to a density of 24-lb/bushel. However, the high moisture corn flaked to 24 lb/bushel yielded much poor performance. Collectively, we believe these data suggest that it is possible to over process grains by adding moisture to promote gelatinization of starch.

We have investigated different grain hybrids using individual animal feeding models to determine possible impact of corn endosperm type (soft, intermediate, and hard) on flaking characteristics, gelatinization of starch, and animal performance. Corn hybrids representing soft, moderate, and hard endosperm types appear to yield more-or-less comparable animal performance, but have substantially different processing characteristics, suggesting that some hybrids may be more suited to flaking than others. More recently we have initiated experiments to evaluate over 70 varieties of wheat in terms of their suitability as animal feeds. The selection of these wheat varieties will be irrespective of traits deemed essential for bread flour production,
potentially allowing for development of higher yielding varieties that could replace corn in geographical regions in which irrigation is either costly or unavailable.

Co-Product Utilization
Co-products derived from fuel ethanol production, corn sweetener production, sugar refining, and other processing industries frequently constitute economical alternatives to grains in cattle finishing diets. Rapid expansion of several of these industries had lead to more widespread availability of co-products throughout a broad geographical area, including the Central and Southern Plains. These areas are predominated by feedlots that process grains via steam flaking. The majority of research with grain co-products has been performed in the Midwest and Northern Plains areas where dry-rolled and high-moisture ensiling constitute the predominant feed grains. Recognizing that flaking dramatically improves energy value of grains, and that it also alters ruminal availability of protein, replacement value of co-products cannot be presumed to be similar for flaked and dry-rolled or high-moisture grain diets.

We recently completed an experiment with short-fed yearling heifers in which we replaced steam-flaked corn in finishing diets by incorporating wet sorghum distiller's grains (WDG) at 0, 8, 16, 24, 32, or 40% of the diet dry matter. Addition of WDG yielded a quadratic effect on dry matter intake, gain, and feed efficiency. Intake was optimized at 8% WDG, and efficiency was optimized with 16% WDG. Levels of WDG of 24% or less yielded efficiencies comparable to or superior to that of the traditional flaked grain diet. Increasing WDG significantly increased overall carcass fatness in a linear fashion (P<0.05). In a separate experiment with dry corn distiller's grains (DDG) fed to heifers at 0, 15, 30, 45, 60, or 75% of dry matter, efficiency was optimized with 15 to 30% addition of DDG. Carcasses again appeared to become fatter as the level of DDG was increased. Though not an objective of our experiments, a major consideration in feeding higher levels of co-products is the impact on nutrient waste management, most notably phosphorus.

Concentrated separator byproduct (CSB, or desugared molasses) is a liquid derived from the chromatographic separation of sucrose from beet molasses. This byproduct contains some residual sugars, most notably raffinose, but its carbohydrate content is relatively low in comparison to molasses. Consequently, the energy value of CSB is presumed to be quite low in comparison to beet or cane molasses. When CSB and Cane Molasses were compared as additions to diets for finishing heifers, we determined that performance and carcass value were essentially equal for cattle fed the two products, if anything favoring the CSB. Several years ago we conducted a series of experiments with methyl donors such as choline and betaine, and determined that these compounds could be useful when added to finishing cattle diets in the appropriate form. CSB contains substantial quantities of betaine, so the response to CSB may not have been attributable solely to its role as a source of energy.

Lipid Sources
The evaluation of lipid sources has become a substantial component of our research program in the past several years. We have evaluated several lipid sources with respect to their impact on growth performance, health, carcass quality, meat composition, and meat sensory attributes. Flax as a source of lipid. Flax is an oilseed characterized by high concentrations of alpha-linolenic acid, an 18-carbon omega-3 fatty acid. While our initial studies pertained primarily to the anti-inflammatory effects of flaxseed, our more recent experiments with flax have focused on animal performance and carcass attributes. We have conducted about a dozen experiments to
date, and found that flax consistently increases the proportion of omega-3 fatty acids deposited into edible tissues. Levels of omega-3 fatty acids are increased as much as 10-12 fold compared to levels associated with feeding more traditional lipid sources such as tallow. We also have observed that meat containing higher levels of alpha linolenic acid is predisposed to oxidation, but addition of vitamin E to the diet can completely ameliorate this effect. Currently, research efforts are underway to further increase the proportion of omega-3 fats incorporated into beef tissue in order to support the commercialization of a branded beef product.

Feeding flax has yielded variable effects on quality grade of beef cattle. In some cases, the improvement in grade has been dramatic, and in others it has been a modest effect, and in at least one study we have observed no change in quality. The reasons for this variability are not, however, readily apparent. Often we have observed a tendency for cattle fed flax to consume more feed than their contemporaries fed other fats or no supplemental fat. This typically has been accompanied by increases in gain, but most frequently has not influenced feed efficiency. We currently have approximately 16,000 to 18,000 head of cattle involved in commercial feedlot experiments at several locations to evaluate impact of the timing of flax supplementation. Early indications are that grade is indeed influenced by feeding flax. On average, we believe that feeding flax will yield modest improvements in carcass value amounting to $10-25 per head. These improvements may manifest as increases in quality grade, decreases in yield grade, or both.

We also have evaluated full-fat corn germ as an alternative source of fat for finishing cattle. The dried corn germ is a dry, flowable product containing about 46% fat and 12-15% protein (dry basis), and is conveniently handled in trucks and auger systems. Corn germ yields performance responses in finishing cattle that are comparable to more traditional sources of fat such as tallow. Interestingly, in studies involving 350 to 900 head, we have observed a significant reduction in the incidence of liver abscess when germ is incorporated into finishing diets at 5-10% of the ration dry matter. In an attempt to explain this phenomenon, we have conducted a metabolism study and evaluated the impact of different lipid sources (tallow, germ, corn oil, linseed oil) on populations of *Fusobacterium necrophorum* in the rumen. Counter to our expectations, all sources of fat tended to support greater populations of Fusobacterium than the diet with no added fat. Also of interest is that corn germ (and tallow) appears to alter the distribution of fat accretion, favoring greater deposition in less desirable fat depots (subcutaneous, seam, and internal fat) and less as intramuscular fat. Germ thus provides for favorable improvements when cattle are marketed live, but the benefits are less when cattle are marketed using a formula or grid-based system of marketing. There are suggestions that this same effect may occur when feeding distiller’s grains, which obviously contain the germ fraction of corn.

Yet another component of our lipid research has evaluated sunflowers as a source of fat. Sunflowers make an interesting research model because it is possible to obtain varieties with widely varied concentrations of linoleic and oleic acids. In the single experiment completed to date, we found that high oleic sunflowers increased feed intake rather dramatically compared to tallow, high-linoleic, or mid-oleic varieties. Moreover, high oleic sunflowers yielded distinct flavors in meat that were readily and consistently detected by sensory panelists. Follow-up studies are currently underway to determine if these observations can be repeated.

**MGA as a Prophylactic**

A couple of years ago we initiated experiments to evaluate MGA as a prophylactic for high-risk weaned heifers. Our hypothesis was based on observations from human studies in
which synthetic progestins were used to facilitate recovery of patients afflicted with septicemia. We compared health and performance of lightweight (470 lb), prepubertal heifers fed diets with and without MGA during the first 35 days after arrival in the feedlot. Feeding 0.5 mg/head daily during the receiving period yielded significant greater gains throughout the receiving and finishing period. No significant effects were noted for incidence of respiratory disease. However, chronicity rates tended to be lower for cattle fed MGA in the receiving period. In a follow-up challenge experiment in which cattle were administered intravenous injections of bacterial lipopolysaccharide (LPS), the inflammatory response was moderated by MGA administration, as evidenced by less dramatic temperature shifts and less pronounced changes in circulating white blood cells. We are attempting to further corroborate these observations using a bacterial challenge model in which *Mannheimia haemolytica* was instilled into the lungs to induce respiratory disease. The disease was monitored over a period of 1 week, after which animals were euthanized. Gross pathology of lungs and pancreas were performed, along with histopathology of these tissues, and examination of a wide spectrum of blood constituents are currently being performed.
Muscle Glycogen Response to Stressors. (J. McCarthick) We are using a needle biopsy technique to allow repeated measures of muscle glycogen status. The stressors include implants, heat, and transit. To achieve implant stress we administered Synovex Plus to 14 of 28 steers 70 d prior to slaughter. Prior to shipping, implanted steers had elevated (P<0.01) serum estradiol (9 vs. 19 pg/ml; P<0.01) and lower (P<0.01) NEFA (0.15 vs. 0.12 mEq/l). Insulin/glucagon ratio and muscle glycogen were unaffected. Transit caused elevated NEFA (0.13 vs. 0.22 mEq/l; P<0.01), but no change in muscle glycogen (94 vs. 93 μmol/g). Post-transit NEFA and glycogen were not affected by implants but post-transit insulin/glucagon ratio tended (P<0.15) to be higher in non-implanted steers. No dark cutters were present at grading. Insulin/glucagon ratio and muscle glycogen were highly variable among steers and differed (P<0.05) between the longissimus dorsi (100 μmol/g) and the semi-membranosus (83 μmol/g) muscles.

Banded Bulls. (K. Bruns) Bull calves (n=164; age=1 to 2 mo) were alternately selected in May to be surgically castrated at selection (SC) or left intact to be banded at 850 lb (BB). Steers received a Synovex C at castration and Synovex S in October during backgrounding. There were no differences in BW at Oct weaning (494 vs. 489 lb; SC vs. BB) or after backgrounding (827 vs. 827 lb). Bulls were then banded, and steers and banded bulls remained on the backgrounding diet for 29 d. During this period, ADG was substantially reduced (2.4 vs. 1.3 lb; P<0.01) and F/G increased (8.2 vs. 15.7; P<0.01). There was a slight decrease in DMI (18.8 vs. 18.2 lb; P<0.05) by BB. Five BB steers (6%) developed complications associated with banding (performance data reported exclude realizers). Following the 29 d observation period, all steers were implanted (Revalor S) and stepped up to a finishing diet. The cumulative performance during the finishing phase was similar across treatment. Differences (P<0.05) in final live weight (1298 vs. 1273 lb) and hot carcass weight (791 vs. 774 lb) reflected differences (P<0.05) in BW at the end of the 29 d post-banding period. Carcass quality traits (including shear force) were not affected by treatment.

Limit Feeding During Cold Stress. (S. Holt) Steer calves (n=96; BW=657) were limit fed a high moisture ear corn diet to allow an ADG of 3.1 lb for a 56 d grower period. Steers were fed once daily at either 0900 (AM) or 1300 (PM). Despite fixed DMI, PM steers had higher ADG (3.13 vs. 3.43 lb; P<0.05) and lower F/G (5.19 vs. 4.74; P<0.05). Mean ambient temperature during the study was 22° F. The day before a predicted cold spell, tympanic temperature loggers were applied to 3 hd/treatment for a 6 d period. Diurnal patterns and overall mean tympanic temperature (TT) were not affected by treatment. However, TT patterns were consistently higher in AM steers with a trend (P<0.10) for increased daily maximum TT and an elevated (P<0.05) daily minimum TT. The TT response suggests an elevated metabolic rate which would contribute to the reduced efficiency observed for the AM treatment.

Lifetime Implant Strategies. (R. Pritchard) Most implant research has been restricted to a specific production segment. Most of the studies that have spanned production segments were factorialized treatments, often with limited observations in the most reduced comparisons. This
study was designed to evaluate whether intuitive perceptions of lifetime implant strategy potencies would culminate in dose responsive outcomes of production rates and efficiencies. Four strategies perceived to reflect increasing potencies applied to 310 steer calves were:

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<thead>
<tr>
<th>Component TS</th>
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<tbody>
<tr>
<td>Finishing</td>
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Finishing phase performance (ADG, F/G), final live weight, carcass weight and REA increased (P < 0.05) in a dose responsive manner. Lean and bone maturities increased due to implants, but the increase was similar for strategies 2, 3, and 4. The proportion of premium Choice carcasses declined (P < 0.05) at higher strategy potency. There were no implant strategy effects on shear force. This study demonstrated that cumulative potency of implant strategies can be anticipated; the responses will persist throughout the various production segments; and that prudent use of aggressive strategies will increase production efficiencies without increasing the production of unacceptable carcasses.

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Yearlings

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Wet and dry products
Inclusive rates
Storage – Stabilizers

**Calcium Depletion/Repletion:** T. Walsh
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Performance and carcass characteristics of finishing beef cattle as affected by shedding of *Escherichia coli* 0157

C. S. Abney, J. D. Rivera, M. M. Brashears, and M. L. Galyean
Texas Tech University, Lubbock

Individual animal data from four studies (n = 835) were pooled and analyzed to determine whether shedding of *Escherichia coli* 0157 affected average daily gain and carcass characteristics of finishing beef steers. Three of these studies examined the effects of direct-fed microbials, and the fourth examined the effects of whole cottonseed on performance, carcass characteristics, and incidence of *Escherichia coli* 0157 shedding of beef cattle. Fecal samples were obtained at various times (seven times for Study 1, three times for Study 2, seven times for Study 3, and three times for Study 4) throughout the finishing period and analyzed for the presence of *Escherichia coli* 0157 by immuno-magnetic separation techniques. Performance data were modeled accounting for the effects of shedding from 0 to 28 d, 0 to 56 d, or incidence of shedding at any time during the finishing period, study, and treatment nested within study, whereas carcass data were modeled accounting only for incidence of shedding at any time during the finishing period, study, and treatment nested within study. All data except quality grade were analyzed using the Mixed procedure of SAS (SAS Inst., Inc., Cary, NC), with block nested within study and treatment x block nested within study as random effects. Quality grade data were analyzed using the Genmod procedure of SAS, with the model including incidence of shedding, study, treatment nested within study, block nested within study, and treatment x block nested within study. Shedding of *Escherichia coli* 0157 had no effect (P > 0.10) on 28 d, 56 d, or overall average daily gain (1.587 vs. 1.590 kg/d for non-shedding vs. shedding). Likewise, carcass measurements and quality grade did not differ (P > 0.10) between animals shedding *Escherichia coli* 0157 at any time and animals not shedding (e.g., hot carcass weight = 366.7 vs. 365.0 kg; P > 0.35 and yield grade = 2.80 vs. 2.89; P ≤ 0.30 for shedders and non-shedders, respectively). There was a tendency for a larger longissimus muscle area (89.62 vs. 88.59 cm²; P ≤ 0.14) in steers that shed *Escherichia coli* 0157 at some point during the feeding period than in non-shedders. Results suggest that infection with *Escherichia coli* 0157 has little effect on performance and carcass characteristics of finishing beef cattle.

Effects of corn processing method and length of ensiling on cattle performance and dry matter and protein digestibility of corn

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University of Nebraska, Lincoln

Two studies were conducted to evaluate corn processing method and length of ensiling of corn on finishing cattle performance and DM and protein digestibility. Corn processing consisted of early-harvest corn at 24 or 30% moisture (24HMC or 30HMC), reconstituted field-dried corn at 28 or 35% moisture (28REC or 35REC) and field-dried corn (DRC), all the same hybrid. In the first study, four hundred eighty steers (BW = 743 lb) were used to compare the feeding value of the five corns. Cattle performance and degradable intake protein (DIP) balance were evaluated. Steers were stratified by weight, allotted to one of 60 pens and fed one of 15 finishing diets. The treatment design was a 5x3 factorial with factors being corn type (24HMC, 30HMC, 28REC, 35REC, or DRC) and DIP balance (negative, zero, or positive). Addition of urea was required at 0, 0.45 or 0.90% of the diet (DM basis). The finishing diets contained 65% of the test corn, 18% corn bran, 5% grass hay, 4% DRC, 3% tallow, and 5% dry supplement (DM basis). No interaction occurred between corn type and DIP balance. Steers fed diets containing 30HMC or 35REC gained 6.9% faster and were 10.4% more efficient than steers fed DRC diets (P < 0.05). Steers fed diets containing 24HMC and 28REC had intermediate performance. Within DIP balance, steers fed diets supplemented with urea were 7.0% more efficient (quadratic response, P <
0.02) and gained 6.7% faster (quadratic response, \( P = 0.06 \)) than steers fed diets with no supplemental urea. In the second study, three cannulated steers were used to evaluate the five corns. All corn (except DRC) was ensiled for at least 298 d, and sampled every 28 d. Corn samples were incubated in situ for 0, 22, 30, and 72 h and DM digestibility (ISDMD) and DIP (% of CP) were calculated. Values (22 h) were regressed over ensiling days. The intercept represents changes in ISDMD or DIP of the first 28 d of ensiling where the greatest changes occurred, with the greatest increase for 35REC followed by 30HMC and then 28REC (\( P < 0.10 \)). The slope represents changes in ISDMD or DIP over time of ensiling after 28 d. When moisture increased for HMC (24 to 30%) and REC (28 to 35%), total ISDMD and DIP increased (\( P < 0.10 \)), and both HMC and REC had increased ISDMD and DIP compared to DRC. Results suggest that increasing moisture of either HMC or REC enhanced the feeding value in a finishing diet. When moisture and length of ensiling are increased, ISDMD and DIP are increased.

**Key Words:** Feedlot Cattle, Grain Processing, Protein Digestion

### Performance and morbidity responses of steers fed three protein levels during the receiving period

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*Clayton Livestock Research Center, New Mexico State University, Las Cruces, NM*

Effects of three levels of protein on calf performance and morbidity were evaluated during 28-d receiving periods for three groups of cattle. Mixed breed steers (\( n = 120, 120, \) and 117 in groups 1, 2, and 3, respectively) were randomly assigned to pen (eight steers/pen, five pens/treatment in group 1; 10 steers/pen, four pens/treatment in group 2; 13 or 14 steers/pen, 3 pens/treatment in group 3) and were fed diets containing either 12, 14, or 16% CP (DM basis). Diets were fed to minimize refusals which were weighed weekly. Animal weights were recorded on d 14 and 28. Dry matter intake (DMI), average daily gain (ADG), and gain to feed (G:F) were evaluated. Furthermore, evaluations of respiratory disease were recorded daily (0700) and sick steers were pulled for treatment. Results from group 1 are described as Exp. 1 and results from groups 2 and 3 were pooled and are presented as Exp. 2. During the initial 14 d of both experiments, DMI, ADG, and G:F did not differ (\( P > 0.25 \)) among treatments. From d 15 to 28 of both experiments, DMI and G:F did not differ (\( P > 0.30 \)) among treatments. However, ADG during the second 14 d of Exp. 1 (but not Exp. 2) tended to increase with increasing dietary protein level (0.82, 0.95, and 1.08 \pm 0.09 kg/d in steers fed 12, 14, and 16% CP, respectively; linear, \( P = 0.08 \)). When the entire 28-d receiving period was evaluated, no performance differences were detected (\( P > 0.50 \)) among treatments in either experiment. The percentage of steers treated a single or multiple times for respiratory disease in Exp. 1 did not differ (\( P > 0.60 \)) among dietary CP levels. Likewise, the percentage of animals treated a single time during Exp. 2 was similar (\( P > 0.77 \)) among dietary treatments. However, the percentages of steers treated more than once in Exp. 2 were 21.2, 8.7, and 21.5 in those receiving 12, 14, and 16% dietary CP, respectively (quadratic, \( P = 0.02 \)). Results indicate that performance responses were unaffected by increasing dietary protein above 12% of diet DM but the decrease in morbidity with 14% CP was significant.

**Table 1:** ISDMD and DIP (% of CP) of different corns over time

<table>
<thead>
<tr>
<th>Corn</th>
<th>ISDMD Day 0</th>
<th>ISDMD Intercept</th>
<th>ISDMD Slope</th>
<th>DIP Day 0</th>
<th>DIP Intercept</th>
<th>DIP Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>24HMC</td>
<td>38.0</td>
<td>37.7 (1.2)</td>
<td>0.44 (0.06)</td>
<td>45.1</td>
<td>41.6 (0.9)</td>
<td>0.51 (0.05)</td>
</tr>
<tr>
<td>30HMC</td>
<td>45.4</td>
<td>61.3 (1.0)</td>
<td>0.38 (0.06)</td>
<td>48.8</td>
<td>68.1 (0.8)</td>
<td>0.40 (0.05)</td>
</tr>
<tr>
<td>28REC</td>
<td>29.0</td>
<td>46.3 (1.0)</td>
<td>1.21 (0.05)</td>
<td>34.3</td>
<td>47.1 (0.7)</td>
<td>1.38 (0.04)</td>
</tr>
<tr>
<td>35REC</td>
<td>29.0</td>
<td>68.8 (1.0)</td>
<td>0.70 (0.06)</td>
<td>34.3</td>
<td>64.9 (0.7)</td>
<td>0.95 (0.05)</td>
</tr>
<tr>
<td>DRC</td>
<td>29.0</td>
<td>--</td>
<td>--</td>
<td>34.3</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

*Values in parenthesis are standard errors

\( ^a \)Predicted ISDMD or DIP = Intercept + Slope (10 days of ensiling)

\( ^b \)Slopes within a column with different superscripts differ (\( P < 0.10 \))
dietary CP in Exp. 2 warrants further consideration.

Effects of Feeding a Polyclonal Antibody Preparation against *Streptococcus Bovis* or *Fusobacterium Necrophorum* on Performance and Carcass Characteristics of Feedlot Steers


*University of Minnesota, St. Paul*

Steer calves (n = 226; 272 kg), stratified by weight and housed in 16 pens, were used to evaluate effects of feeding a polyclonal antibody preparation (Ab; sprayed onto soy hull pellets) against *Streptococcus bovis* (AbSb) or *Fusobacterium necrophorum* (AbFn) on performance and carcass characteristics. Pens were randomly assigned to one of four dietary treatments resulting from a 2 X 2 factorial arrangement that included AbSb or AbFn. Diets (1.39 Mcal NEg/kg DM, 12.5% CP, .7% Ca, and .35% P) were formulated with high-moisture corn and dry ground corn (50:50 mix, as-fed), corn silage, and supplement. Interaction terms for final and carcass-adjusted final weight, gain and carcass-adjusted gain were significant (P < 0.05). Steers receiving AbSb or AbFn had heavier (P < 0.05) final BW resulting from faster (P < 0.05) daily gains. Adjusted-final weights of steers fed AbSb were heavier (P < 0.05) than those fed both or no Ab. Only AbSb was effective (P = 0.08) at enhancing carcass-adjusted daily gain. Interestingly, steers receiving both Ab gained similarly (P > 0.05) as steers fed no Ab. Interaction terms were significant (P < 0.05) for feed efficiency (analyzed as gain-to-feed), and tended (P = 0.08) to be significant for carcass-adjusted feed efficiency. Steers receiving AbSb were more efficient (P < 0.05) than those receiving both or no Ab. Steers receiving AbSb were more efficient (carcass-adjusted; P < 0.09) than those receiving both or no Ab. Steers supplemented with AbSb had heavier carcasses (P < 0.05), which accounted for greater (P < 0.05) subcutaneous fat, and greater (P < 0.05) yield grades than those of steers fed both or no Ab. These results demonstrate that feeding a polyclonal antibody preparation against *Streptococcus bovis* or *Fusobacterium necrophorum* influences performance and carcass characteristics of feedlot cattle fed high-grain diets.

Growth Performance and Carcass Characteristics of Finishing Beef Steers Implanted with Component TE-S or Component TE-S with Tylan


*Kansas State University, Manhattan; ‡Cattlemen’s Consulting; †Vetlife*

Component TE-S and Component TE-S with Tylan growth promoting implants were compared in an experiment conducted at a commercial feedlot operation in central Kansas to determine differences in growth performance and carcass characteristics. Crossbred steers (n=1843, initial BW = 827 lb) were implanted with either Component TE-S or Component TE-S with Tylan and were fed a finishing ration based on steam-flaked corn for an average of 116 days before slaughter. Cattle were assigned randomly to the implant treatments at processing and allotted to 12 pens containing an average of 154 head each. No differences were detected in dry matter intake (P=0.18), average daily gain (P=0.41), or feed efficiency (P=0.59) of cattle administered the two different implants. Component TE-S with Tylan did, however, produce fewer (P<0.05) buller steers. Cattle implanted with Component TE-S with Tylan in general were more heavily conditioned than cattle implanted with Component TE-S. Cattle implanted with the Tylan-containing implant had a higher percentage of USDA Choice or Prime carcasses (P=0.11) and a higher percentage of USDA Yield Grade 4 carcasses (P=0.03). Component TE-S with Tylan also tended to produce fewer (P=0.12) USDA Yield Grade 1 carcasses as compared to cattle implanted with Component TE-S. Total carcass value was also higher for the Component TE-S w/Tylan cattle using...
both a muscle-based and quality-based marketing grid. Inclusion of a pellet of the antibiotic, Tylan, appears to result in modest changes in carcass fattening, as well as significant reductions in the incidence of buller activity among feedlot steers.

Effect of commingling ranch cattle with cattle from multiple sources on receiving health and performance

Oklahoma State University

The objective of this experiment was to determine health and performance of ranch calves on different pre-conditioning strategies during a 42-d receiving period when commingled with calves from multiple sources. A total of 509 steers were received during November and December 2002. Steers were separated by source of origin and blocked by initial BW. Steers from a single source ranch were weaned and shipped to the Willard Sparks Beef Research Center (WEAN, initial wt = 247 ± 29 kg), weaned, vaccinated with modified live vaccine, and held on the ranch for 45 d before shipping (WVAC, initial wt = 274 ± 21 kg), or weaned on the ranch for 45 d before shipping, but did not receive any vaccinations (WNVAC, initial wt = 231 ± 26 kg). In addition multiple-source steers were purchased through auction markets (SALE, initial wt = 238 ± 13 kg), and upon receiving, a portion of steers from each weaning group were commingled with a portion of SALE cattle (COMM). Those calves that were not commingled were designated as RANCH or SALE calves, depending on origin, resulting in a 3 x 2 +1 factorial arrangement with SALE calves as the control. Multiple-source and WNVAC steers were vaccinated on arrival. Average daily gains were not affected \( P = 0.65 \) by weaning, however RANCH calves had greater \( P = 0.03 \) ADG than calves that were commingled (COMM) or purchased through auctions (SALE). Weaning strategy had an effect on DMI \( P < 0.01 \) as calves in the WVAC treatment consumed more feed than calves in the other treatments \( P < 0.04 \). However, WVAC calves converted feed to gain less efficiently \( P = 0.09 \) than calves in the WEAN or WNVAC treatments. This is most likely due to the heavier body weights \( P = 0.02 \) of the WVAC calves when compared to calves in the other treatments at the initiation of the trial. Both weaning and commingling had an effect on morbidity. Calves in the RANCH treatment were less likely to be treated \( P = 0.06 \) than calves in either the COMM or SALE treatments. Calves that were retained on the ranch after weaning (WVAC, WNVAC) were also less likely to be pulled \( P = 0.08 \) than SALE or WEAN calves. As expected, differences in morbidity related to differences in health costs and cost of gain. Calves in the WVAC and WNVAC weaning treatments had lower health costs \( P < 0.01 \) than calves in the SALE and WEAN treatments. Calves in the WNVAC treatment exhibited the lowest cost of gain \( P = 0.03 \) of all weaning treatment groups. Based on this study, it is concluded that cattle from a single source that are retained on the ranch for a short time after weaning will exhibit fewer health problems and more economic gains during the receiving period than when cattle are commingled or shipped to the feedyard immediately after weaning.

Key Words: Commingling, Shipping Fever, Stress
Impact of Daily Feeding 2,500, 50,000 or 100,000 IU Vitamin D$_3$ on Feedlot Performance, Metabolite Concentrations, and Beef Tenderness

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One hundred eighty yearling steers (initial BW 357 ± 28 kg) were used in a randomized complete block design to determine the effects of supplementing vitamin D$_3$ throughout the finishing phase on feedlot performance, metabolite concentrations, and beef tenderness. Previous research has reported high levels (5 to 8 million IU-animal$^{-1}$-d$^{-1}$) of vitamin D$_3$ fed for short periods of time (5 to 10 d) before slaughter improved Warner-Bratzler Shear Force of specific cooked beef cuts. However, decreased DMI, live BW, and hot carcass weight (HCW), as well as toxic tissue levels of vitamin D$_3$ metabolites are common when supplementation occurs at extremely high levels. Therefore, in the present experiment, vitamin D$_3$ was supplemented at 2,500 (control), 50,000 or 100,000 IU-steer$^{-1}$-day$^{-1}$ over the entire 175-d (avg) finishing phase. Dry matter intake did not differ among treatments (9.15, 8.86, and 9.49 ± 0.20 kg/d, respectively); actual vitamin D$_3$ intakes were 3,607, 27,506 and 70,075 IU-steer$^{-1}$-day$^{-1}$ for 2,500, 50,000 and 100,000 IU-steer$^{-1}$-day$^{-1}$, respectively) and ADG (1.55, 1.51, and 1.60 ± 0.02 kg/d) did not differ among treatments. Vitamin D$_3$ supplementation did not affect HCW, carcass characteristics or lean and skeletal maturity. Plasma D$_3$ (5.3, 17.3, 30.9 ± 0.8 ng/mL) and 25-hydroxyvitamin D$_3$ (68.1, 97.0, and 117.0 ± 3.5 ng/mL) concentrations increased (P < 0.0001) as level of supplementation increased, whereas plasma 1,25-dihydroxyvitamin D$_3$ level numerically (P = 0.13) increased. Liver and muscle levels of vitamin D$_3$ and metabolites did not differ among treatments. Slice shear values recorded on longissimus steaks collected from each animal showed no treatment x age interaction. Slice shear values decreased (P < 0.0001) with ageing but did not differ (P = 0.27) among treatments. Slice shear values were 18.8, 19.2, and 18.4 ± 0.55 kg, respectively for 2,500, 50,000 and 100,000 IU of vitamin D$_3$. As 100,000 (70,000 actual) IU of vitamin D$_3$ numerically improved tenderness, more data are needed to determine at what level, if any, vitamin D$_3$ can have a positive effect on beef tenderness when fed over the entire finishing period.

Effects of stocker supplementation on feedlot performance, feed efficiency, and carcass traits in Simmental cross-bred calves

J. T. Fox$^1$, G. E. Carstens$^1$, F. M. Rouquette, Jr.$^2$, D. P. Hutcheson$^3$

Texas Agricultural Experiment Station, $^1$College Station, and $^2$Overton, $^3$Animal-Agriculture Consulting, Inc.

At weaning, Simmental-sired calves (n = 132) from two consecutive calving seasons were assigned to one of three stocker treatments (ST); no supplement (NS), low-intake (LP), or high-intake (HP) protein supplement. Calves grazed replicated bermudagrass pastures stocked at similar rates for 168 d. Upon feedlot entry, calves were adapted to an 80% steam-flaked corn diet and trained to eat from Pinpointer feeders for 28 d. From 28 d until harvest, individual feed intakes were measured daily and BW measured at 28-d intervals. Calves were harvested at two or three days on feed (DOF) at a back fat endpoint of 1.0 cm. Residual feed intake (RFI) was calculated as the difference between actual DMI and expected DMI from linear regression of DMI on ADG and mid-test BW$^{0.75}$ with year, sex, DOF and significant interaction terms included in the model. Feed-to-gain ratio (F:G) was calculated as DMI/ADG. Data were analyzed with a Proc GLM model that included initial stocker BW as a covariate,
and ST, DOF, year, sex, and significant interaction terms. Partial correlations were obtained using the MANOVA option in the GLM procedure. Stocker ADG for NS, LP, and HP calves were 0.44, 0.56 and 0.70 ± 0.03 kg/d (P < .01), respectively. Initial 28-d feedlot BW were 7.5 and 4.9% higher (P < .01) for steers and heifers consuming HP vs NS during year 1, but not year 2. ST did not affect (P > .20) DMI (8.30 ± 0.25 kg/d) or ADG (1.12 ± 0.05 kg/d), but NS calves tended (P = .12) to have lower F:G than HP calves (7.19 vs 7.77 ± 0.31). RFI was not affected by stocker treatment. Hot carcass weight (HCW), ribeye area (REA), KPH and quality grade (QG) were not affected by ST. Back fat (BF) thickness and yield grade (YG) were greater (P < .01) for heifers consuming LP supplement vs heifers receiving NS and HP supplement, however, ST did not affect BF or YG in steers. F:G was correlated with feedlot ADG (r = -0.78; P < .01), final BW (r = -0.46; P < .01), HCW (r = -0.26; P < .01), and tended to be correlated with REA (r = -0.18; P < .10). RFI was not correlated with (P > .30) ADG, BW, REA, KPH, YG or QG. However, RFI tended to be correlated (P < .10) with HCW (r = 0.16) and BF (r = 0.18). Age of calves upon feedlot entry were correlated (P < .05) with F:G (r = 0.22), ADG (r = -0.21), BF (r = 0.22), and tended to be correlated (P = 0.11) with RFI (r = 0.16). Calves with low RFI (< 0.5 SD from mean RFI) consumed 22% less DM and had 21% lower F:G than high RFI calves (> 0.5 SD from mean RFI) even though ADG were similar for both groups. Stocker supplement had minimal effects on feedlot performance, feed efficiency, and carcass traits. However, results suggest that stocker supplementation had less influence on RFI than F:G.

Growth Response of Wheat Pasture Stocker Cattle to Alternate Day Feeding of a Monensin-Containing Energy Supplement

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Oklahoma State University, Stillwater

This experiment was conducted during the winter of 2002-03 to evaluate the feeding of a monensin-containing energy supplement on alternate days on growth of steers grazing winter wheat pasture. Seventy-eight Angus-crossbred steers (initial BW = 240 ± 24 kg) were grazed 120 days (Nov. 13 to Mar. 13) on six different pastures in a randomized complete block design. Pastures were blocked by location, while steers were stratified by initial weight and randomly allocated to treatments. Average stocking rate was 1.46 steers/hectare. Dietary treatments were either a mineral mixture (offered free-choice) or a monensin-containing energy supplement. The energy supplement was formulated to contain 352 mg of monensin per kg of supplement (as-fed). Supplement was offered every other day at a rate of 0.91 kg/steer, to achieve a target daily monensin intake of 160 mg/steer. Daily supplement intake across all supplemented pastures averaged 0.41 ± 0.09 kg/steer, resulting in a daily monensin intake of 143 mg. Daily supplement intakes for individual pastures ranged from 0.39 ± 0.10 to 0.43 ± 0.06 kg/steer. Despite these minimal differences, the consumption pattern of supplements was highly variable between and within pastures. Daily mineral consumption averaged 0.13 kg/steer. Daily gains and overall gains were increased (P < 0.03) by feeding the monensin-containing supplement. Daily gains of supplemented steers were 0.11 kg greater than those of steers receiving mineral alone, 1.45 vs. 1.34 kg. Overall gains were increased 15 kg by supplementation (167 vs. 152 kg). Supplement conversion, expressed as kg of supplement consumed per kg of additional gain compared to control steers, averaged 4.40. Despite supplement intakes slightly less than targeted, these data indicate that a daily dose of monensin capable of eliciting a positive gain response can be provided to cattle in an energy supplement fed every other day at the rate of 0.91 kg/steer.
Phosphorus Requirement of Finishing Heifers, and the Effects on Route and Amount of Phosphorus Excreted

B.G. Geisert, G.E. Erickson, T.J. Klopfenstein, C.N. Macken, and M.K. Luebbe

University of Nebraska, Lincoln

It is important to determine the P requirement for finishing cattle because not supplying adequate P in the diet may hinder performance, however overfeeding P potentially leads to environmental problems associated with excess P in surface waters. Determining the effects of diet P on the amount and the route of phosphorus (P) excretion is equally important due to the increasing pressure to manage P in animal waste. We conducted 2 experiments to address these P concerns. Experiment 1 was designed to determine the P requirement for finishing heifers and experiment 2 evaluated the effects of different dietary P levels on the amount and the route of P excreted in finishing cattle. Experiment 1 used 60 (initial BW = 613 lbs) large framed, crossbred heifers. Treatments consisted of 5 levels of dietary P (0.10, 0.17, 0.24, 0.31 and 0.38 % P of DM) achieved by feeding one base diet (0.10 % P DM basis) of 50 % course brewers grits (i.e., corn starch), 15 % high moisture corn, 15% corn bran, 10 % sorghum silage, 5 % tallow and 5 % supplement. Monosodium phosphate was top-dressed to obtain the other 4 levels. ADG and DMI responded quadratically (P<0.01) across diet P treatments, with heifers fed 0.10% P gaining and eating less. Breakpoint analysis for ADG suggested the requirement was 0.115 (0.104 to 0.127 % P; 95% confidence interval). Plasma P was collected every 28 d and was not different on day 0. Heifers fed 0.10% P had significantly lower plasma P throughout the feeding period and appeared to be deficient, averaging 4.6 mg/dL for d 28 through slaughter. Plasma and performance data were supported by bone ash weights with heifers fed 0.10% P having lower bone mineral content. In experiment 2, 5 diets were evaluated in a latin square digestion trail with total urine collection. 3 diets were similar to the requirement study (LOWP, MEDP HIGHP containing 0.12, 0.27, 0.42% P DM basis, respectively), with 2 additional diets, one consisting of DRC (CORN, 0.30% P) and one with dry distillers grains (DDGS, 0.36% P). Steers were adapted to diets for 16 days with a 5-day collection period. Chromic oxide was dosed at 10 grams per day for the last 8 days of each period. Total urine was collected and analyzed for P concentration. There were no differences in DMI (P>0.05). P intakes were 10.5, 26.7, 37.9, 29.5, 34.6 g/d for LOWP, MEDP, HIGHP, CORN, DDGS, respectively. P excretion was related to P intake and was lower (P<0.05) for LOWP. Route of excretion whether feces or urine, was also affected by dietary P intake. Steers fed LOWP excreted very little P in urine (0.50 g/d). However, if diet P was > 0.20%, more P was excreted in urine (2.1 g/d), but was not different across diets and was variable among animals. P retention was lower for LOWP than other diets, suggesting that cattle fed 0.12% P were deficient and excreting 85.3 % of the P fed. Based on experiment 1, we suggest that the P requirement for finishing heifers between 0.104 and 0.127 % P of diet DM. These results indicate that corn-based finishing rations supply adequate P levels to finishing cattle without additional supplementation, because corn based diets will normally be greater than 0.28% P.

Impact of Feeding Distillers’ Grains to Dairy-Beef Steers on Beef Color, Tenderness, and Sensory Traits

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The study presented herein was designed to evaluate effects of feeding distillers’ grains (DG) on color, tenderness, and sensory traits of dairy-breed steers. This study complements studies conducted at the University of Illinois (Exp. 1) and Iowa State University (Exp. 2) to evaluate effects of feeding wet (WDG) or dry (DDG) DG on feedlot performance. From Exp. 1 dietary treatments evaluated consisted of feeding a whole corn:corn silage diet with soybean meal (Control), 12.5% DDG plus urea, and 25% or
50% DDG or WDG (DM basis). From Exp. 2 dietary treatments consisted of feeding cracked corn:corn silage:hay diets with soybean meal (SBM Control) or urea (Urea Control), 10%, 20% or 40% DDG or WDG (DM basis). Within study, strip loins from each of four steers (representing 45.7% and 66.6% of steers in Exp. 1 and 2, respectively) in each of all four replicate pens per treatment were aged for 13 d at 21°C for subsequent color, tenderness, and palatability evaluation. Color of steaks was measured objectively by using a HunterLab Miniscan XE spectrophotometer and was subjectively measured by a trained panel. Tenderness was measured using the Warner-Bratzler shear force instrument on steaks cooked to 70°C. For sensory evaluation, 95 consumers were recruited to evaluate tenderness, flavor, and juiciness in cooked steaks. Each panelist evaluated 14 steak samples using a nine-point, end-anchored hedonic scale, where 1 = dislike extremely and 9 = like extremely. In Exp.1, steaks from steers fed 25% WDG had higher a* values (P < 0.05) after 138 h than all other treatments except for those from steers fed 12.5% DDG. In Exp. 2, greater (P < 0.05) percentages of steaks from steers fed 40% DDG and 40% WDG were considered 'moderately unacceptable'. No differences (P > 0.05) were observed in tenderness, flavor, and juiciness in Exp. 1, and 6.2 ± 2.1, 6.2 ± 1.8, and 5.8 ± 2.0 for juiciness in Exp. 2). Feeding distillers’ grains at up to 50% of the diet DM did not affect tenderness or sensory traits.

Timing of flax supplementation for finishing cattle


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An experiment was conducted with finishing beef heifers (n=80; 803 lb initial BW) to determine the optimal time and duration for supplementation of ground flaxseed (0 or 5% of DM). Treatment periods included: 0% flax fed for 109 d (AllControl), 5% flax fed for 109 d (AllFlax), 5% flax fed for 60 d followed by 0% flax fed for 49 d (FlaxEarly), and 0% flax fed for 60 d followed by 5% flax fed for 49 d (FlaxLate). At the end of the finishing period, hot carcass weight, USDA yield and quality grades, marbling score, subcutaneous fat thickness, longissimus muscle area, and percentage of kidney, pelvic and heart fat (KPH), were determined for each animal. Retail display life, 2-thiobarbituric acid reactive substances (TBARS), fatty acid composition, tissue vitamin E concentration, and sensory attributes of longissimus steaks also were evaluated. FlaxEarly increased ADG (P< 0.05) compared with AllFlax or FlaxLate, but neither DMI nor gain:feed were affected. Feeding FlaxEarly increased fat over the 12th rib (P<0.05), but there were no differences in KPH, USDA quality grade, or TBARS among any of the treatments. A trained sensory panel evaluated myofibrillar tenderness, juiciness, flavor intensity, connective tissue amount, overall tenderness and off-flavor intensity of steaks, but detected no differences among treatments. Moreover, there were no differences among treatments with respect to Warner-Bratzler shear force, retail display life, or tissue vitamin E concentrations of longissimus steaks. Feeding flax increased (P<0.05) levels of α-linolenic acid in the longissimus dorsi both pre-and post cooking, as well as in plasma. The α-linolenic acid content of plasma from cattle fed FlaxEarly returned to levels similar to those of AllControl cattle in response to removal of flax from the diet after 60 d. Feeding ground flaxseed resulted in no negative effects on meat quality, and may be most beneficial during the early finishing phase.
Comparison of Rectoanal Mucosal Swabs (RAMS) and Fecal Culture for Determining Prevalence of *Escherichia coli* 0157 in Feedlot Cattle

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The lymphoid tissue in the rectoanal junction (RAJ) of the gastrointestinal tract has been suggested as the principal site of colonization of *E. coli* 0157 in cattle. Samples collected by swabbing the rectoanal mucosa have been shown to be superior to fecal grab samples for detection of *E. coli* 0157 in a study involving experimentally inoculated cattle and in a small number of dairy heifers. Our objective was to compare the utility of the two sampling techniques for determining prevalence of *E. coli* 0157 in feedlot cattle (n = 747) fed high-grain diets. Isolation procedures included enrichment of RAMS or fecal samples in Gram negative broth with cefixime, cefsulodin, and vancomycin, followed by immunomagnetic bead separation and plating on sorbitol MacConkey agar with cefixime and potassium tellurite. Sorbitol-negative colonies were identified as *E. coli* 0157 based on indole production, positive latex agglutination for O157 antigen and API 20E test strip results.

<table>
<thead>
<tr>
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<th>Number of positive samples (% in parenthesis)</th>
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<tbody>
<tr>
<td>RAMS</td>
<td>Fecal</td>
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<tr>
<td>Cattle (n=747)</td>
<td></td>
</tr>
<tr>
<td>71 (9.5)</td>
<td>35 (4.7)</td>
</tr>
<tr>
<td>RAMS or Fecal</td>
<td>82 (11)</td>
</tr>
<tr>
<td>RAMS and Fecal</td>
<td>24 (3.2)</td>
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(Chi Square test for RAMS vs. Fecal culture P < 0.01).

Of the 82 animals that tested positive for *E. coli* O157, 87% were detected by the RAMS method, but only 45% by the fecal culture method. Genomic fingerprints of isolates were analyzed by pulse-field electrophoresis (PFGE) to compare clonal identity between RAMS and fecal isolates from the same animal. Of the 24 pairs of isolates evaluated, 20 had 100% similarity and 4 had >95% similarity in PFGE banding patterns, suggesting that strains colonizing the RAJ are the same as those isolated from feces. RAMS culture appears to be more sensitive than the traditional fecal culture method for determining prevalence of *E. coli* O157 in feedlot cattle.

Effects of Ground Flaxseed or Tallow on Finishing Performance and Carcass Characteristics of Crossbred Heifers

Kansas State University, Manhattan

Six hundred eighty-one crossbred beef heifers (728 ± 7 lb initial BW) were fed for 105 days to compare ground flaxseed and beef tallow as supplemental energy sources. Heifers were randomly sorted into feedlot pens and pens were allotted randomly to dietary treatments. The tallow diet consisted of (dry basis) 78% steamed flaked corn, 6% alfalfa hay, 7% steep liquor, 4.4% supplement, 2.5% soybean meal, and 2% tallow. The ground flaxseed diet consisted of 77% steam flaked corn, 6% alfalfa hay, 5% ground flaxseed, 7% steep liquor, and 5% supplement. Supplements were formulated to provide 300 mg monensin, 90 mg tylosin and 0.5 mg MGA per head daily. Diets were fed ad libitum once daily. A pen weight was taken prior to shipping heifers to a commercial slaughter facility. Using muscle- and marbling-based beef pricing grids, carcass values were determined. Data were analyzed as a completely randomized design with the GLM procedure of SAS. Dry matter intake was greater for cattle fed ground flaxseed than for cattle fed tallow (P = 0.03; 16.5 vs. 16.0 lb, respectively) and there was a tendency (P = 0.07) for flaxseed to improve daily gain, but efficiency was not affected by diet (P = 0.79). Hot carcass
weight was not different between treatments ($P = 0.39$). Diet did not affect the marbling score ($P = 0.73$); when the profile of cattle within each USDA Quality Grade was calculated, there was a tendency ($P = 0.09$) for more carcasses grading average Choice or greater (6.1 vs 2.9%) and fewer USDA Standard carcasses (5.9 vs 9.9%) for heifers fed ground flaxseed compared with those fed tallow, respectively. Source of fat did not affect carcass value. Ground flaxseed can be used as a replacement for tallow in finishing diets, potentially yielding improvements in carcass quality with no detrimental effects on performance.

**Use of corn gluten feed and distillers grains combinations in finishing diets and interactions of corn processing and alfalfa levels in diets containing wet corn gluten feed**

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Two experiments were performed with the objective of evaluating the performance of beef steers fed diets formulated using two corn processing methods, different levels of corn milling by-products (BP -50% Sweet Bran ®, 50% wet distillers grains; DM basis-) and alfalfa hay levels. In exp.1, 60 yearling steers (876 lbs BW) were stratified by initial BW and assigned randomly to one of the four treatments in a 2 x 2 factorial design and individually fed for 101 d. Factors included corn processing as dry rolled (DRC) or reconstituted high-moisture corn (HMC), and ALF level of 0 or 7% of diet DM. In exp. 2, 280 yearling steers (814 kg BW) were blocked (3 blocks) by weight, stratified within block and assigned to 35 pens (8 steers/pen). Pens were assigned randomly to one of seven treatments (5 pens total/treatment) in a 3 x 2 plus 1 experimental design. Treatments consisted of a control diet (0%BP, 7.5% alfalfa) and three BP levels at 25%, 50% and 75% diet DM, in combination with two levels of alfalfa. Alfalfa level was kept constant at 7.5% of DM or formulated for equal eNDF of control, i.e., 7.5, 5.0, 2.5, and 0% alfalfa for the 0, 25, 50, and 75% BP, respectively. Steers were fed for an average of 113 d and harvested at a commercial abattoir. In exp 1, no corn processing by ALF level interactions were observed, thus only main effects are discussed. Steers fed HMC had lower ($P<0.01$) DMI, lower ($P<0.01$) ADG, but similar gain efficiency (ADG:DMI) as steers fed DRC. Alfalfa level did not affect ADG. A trend ($P=0.14$) for an interaction between corn processing and alfalfa level was observed for ADG:DMI. The addition of ALF tended ($P=0.16$) to decrease conversion in the DRC diets. However, although a numerical difference (6.71 vs. 6.45 for 0% and 7.5% ALF respectively) was observed, addition of alfalfa did not significantly affect feed conversion in HMC diets. In exp 2, interactions were only observed between BP and Alfalfa level (P<0.05) for marbling and YG. Quadratic responses (P<0.05) to the BP level (0, 25, 50, and 75%BP, respectively) were observed for DMI (24.35, 26.44, 25.83 and 23.3 lbs DM/d), ADG (3.99, 4.63, 4.56 and 3.90 lb/d), and G:F (0.162, 0.177, 0.176, and 0.167). Improved conversions and ADG were observed at the 25 and 50% BP levels, without significant (P<0.05) differences between 25 and 50% BP inclusion. The results of exp. 1 suggest that in finishing diets containing wet corn gluten feed, the value of inclusion of forage such as alfalfa, may depend on corn processing method. Based in exp. 2, the use of a 50:50 blend of Sweet Bran ® and wet distillers grains enhanced ADG and feed conversion. However, the use of diets containing 75% of the BP blend resulted in same ADG and conversion that the control (0% BP) diet.
Influence of corn hybrid characteristics on digestibility and the relationship to efficiency of feedlot cattle

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Seven commercially available hybrids representing a range within and among kernel characteristics were used in one performance and one digestion trial to evaluate the relationship between corn kernel characteristics and subsequent performance. The seven hybrids consisted of H-8562, 1; H-9533, 2; H-9164, 3; H-9235, 4; 33P67, 5; 33B51, 6; and H-9230, 7. Each hybrid was represented equally in two fields until harvest where they were sampled and transported to storage. For laboratory analysis the samples were allowed to equilibrate in mesh bags to allow moisture to equilibrate. Corn hybrids were evaluated for a variety of chemical and physical characteristics that included: test weight, 1,000-grain weight, kernel size, percentage starch, CP, amylose, Stenvert hardness tests, 12-hour in vitro starch disappearance, and rate and extent of in-situ dry matter disappearance. Differences among hybrids existed for all characteristics measured with the exception of 12-hour in vitro starch disappearance. Two hundred twenty-four steer calves (609 lb) were stratified by weight and assigned randomly to 1 of 28 pens (8 steers/pen). Pens were randomly assigned to one of seven hybrids. All diets among the seven treatment groups were the same except for the hybrid fed as dry-rolled corn. The diet consisted of 66.0% dry-rolled corn, 20.0% wet corn gluten feed, 10% corn silage and 4.0% supplement (DM basis). Results from the 167-day feeding trial indicate that there were no differences in DMI, ADG or carcass characteristics among treatment groups (P>0.10). However, there was a difference in feed efficiency (DMI/ADG) among hybrids (P<0.01), with a maximum difference of 9.5% from hybrid 1 to hybrid 7. Hybrid 1 was also 5.7% more efficient than cattle fed 3 other intermediate hybrids (6, 5, 4). The kernel characteristics that correlated with feed efficiency were 1,000-grain weight (r = -0.81), Stenvert grinding time (r = -0.83), and the proportion of Stenvert soft to coarse particle height (r = 0.83). In situ DM disappearance for 16 hour (r = 0.72), and 24 hour (r = 0.71), were also correlated to efficiency in the performance trial. Seven ruminally cannulated steers were used in a 7 x 7 Latin square design to evaluate the digestibility of the same hybrids used in the performance study. There were no differences in rumen pH (P>0.10), or intake patterns (P>0.10), among hybrids. Average pH, pH change, and area below 5.6 were 5.3, 1.18, 880, respectively. Intake observations showed animals consuming 7.2 meals, and spent 10 hours eating/day with an average meal size of 3.4 lbs DM. Total tract digestibility and VFA concentrations were also measured. Cattle fed hybrids with heavier 1,000 grain weights and higher proportions of soft endosperm gain more efficiently than cattle receiving corn hybrids with a lower 1,000 grain weight and a harder endosperm in a dry-rolled corn based diet.

The Effect of Processing Flax in Beef Feedlot Rations on Performance, Carcass Characteristics, and Trained Sensory Panel Ratings

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A randomized complete block design was used to evaluate the effects of processing flax in beef feedlot diets. One-hundred twenty eight beef heifers (360.3 ± 0.4 kg initial BW) were stratified by weight and assigned randomly to 16 pens (8 heifers/pen). Pens were then assigned to one of four diets. Heifers were fed a growing diet for the first 56 days after which they were stepped up to a finishing ration. The
control growing diet consisted of corn, corn silage, alfalfa, barley malt pellets and linseed meal, and the finishing diet consisted of corn, corn silage, alfalfa, and linseed meal. Flax diets added whole, rolled, or ground flax to rations at 8% of DM, replacing linseed meal and partially replacing corn. Supplements were formulated to provide 0.5 mg MGA, 2000 IU vitamin E, and 232 mg monensin daily. Heifers were harvested by block on days 96, 97, and 124 (two blocks) with carcass data and m. longissimus lumborum samples for shear force and sensory panel analysis collected. Dry matter intake (11.5 ± 0.2 kg/d) was not affected (P = 0.79) by treatment. Flax addition increased (P ≤ 0.01) ADG (kg/d), gain efficiency (gain:feed; G:F), and hot carcass weight (kg; HCW), and increased KPH fat %, and calculated yield grade. Processing (grinding or rolling) increased (P ≤ 0.001) ADG, G:F, and HCW. No treatment effects (P ≥ 0.23) were noted for dressing percent, external fat, or ribeye area. Marbling score tended to increase with flax addition (P = 0.14). Steaks from cattle fed flax were less juicy (P = 0.06) than those from control diets, and steaks from cattle fed rolled flax were more juicy (P = 0.09) than those fed ground flax. Treatment did not affect (P ≥ 0.16) sensory tenderness or flavor ratings. Warner-Bratzler shear force tenderness was affected (P = 0.06) by treatment, with steaks from cattle fed flax rated more tender (P = 0.04) than the control cattle, and steaks from cattle fed processed flax were more tender (P = 0.05) than steaks from cattle fed whole flax. These data indicate including flax at 8% of diet DM improves growth and efficiency of feedlot heifers, but may increase internal fat deposition and negatively affect yield grade. Additionally, processing flax is necessary in order to optimize these effects. Feeding flax reduced sensory panel ratings of beef juiciness, however flax did increase mechanical measurements of tenderness in the resultant beef.

Effects of roughage source and particle size on feedlot performance, carcass merit, and chewing behavior by finishing cattle.


Oklahoma State University, Stillwater

Two experiments were conducted to evaluate differences in feedlot performance, carcass characteristics and chewing behavior due to roughage source and particle size. In Exp. 1, 100 crossbred yearling heifers (initial BW = 364 ± 10 kg) were used to evaluate differences in feedlot performance and carcass merit. Diets consisted of (DM basis) 80% dry rolled corn, 3% fat, a pelleted supplement, and one of four roughage treatments. Dietary treatments consisted of either 12% alfalfa hay (32% NDF; DM basis) or 4.5% cottonseed hulls (86% NDF; DM basis) as the roughage source, and diets were formulated to provide an equal concentration of NDF from roughage. Geometric mean diameter (d_{gw}) of roughage treatments was determined by dry sieving, and particles retained on a 1.18-mm screen or greater were considered physically effective. Alfalfa hay was fed either coarsely chopped (AC; d_{gw} = 4.73 mm) by a Rotomix bale processor, or finely ground (AF) through a hammer mill equipped with a 1.3 cm screen (d_{gw} = 1.13 mm). Cottonseed hulls were fed as either unprocessed (CSH; d_{gw} = 4.78 mm) or pelleted (PCSH; d_{gw} = 8.76 mm). The percent of roughage retained in the physically effective fraction was 99.8, 96.0, 77.2 and 34.0% for PCSH, CSH, AC and AF, respectively. Physically effective NDF from roughage was estimated to be 10.9% for AF, 24.6% for AC, 82.6% for CSH and 85.9% for PCSH. Total dietary NDF concentrations (DM basis) were 19.8, 17.2, 18.0 and 19.6% for AC, AF, CSH and PCSH, respectively. No treatment differences were observed for ADG (P = 0.78) or DMI (P = 0.44). In the initial 28-d period, heifers fed AF had greater (P < 0.05) ADG:DMI compared with the other treatments. However no differences were observed for feed efficiency in the subsequent periods and overall efficiency did not differ (P = 0.84) among treatments. Additionally no treatment differences were observed for any carcass characteristics. In Exp. 2, four ruminally and duodenally-cannulated steers were used in a 4 x 4 Latin square design to determine the effects of roughage source and particle size on rumination response and ruminal pH. Steers were fed the same treatments described in Exp. 1. Each feeding period included a 21-
d adaptation period and a 7-d collection period. Chewing response was determined by observing steers every 5 min over a 24-h period and recording activity (eating, ruminating, resting) at each observation. Ruminal pH was measured at 0 h, immediately before feeding, and every subsequent 3 h for a 24-h period. No differences were observed among treatments for chewing response. A significant ($P = 0.05$) treatment x time interaction was observed for ruminal pH. Steers fed cottonseed hulls had a greater decrease in ruminal pH over time than steers fed alfalfa. We conclude that roughage source (alfalfa vs CSH) or physical form does not affect performance or carcass characteristics of heifers fed high-grain diets balanced for NDF from roughage. In support, chewing response was not affected by roughage source or physical form.

Observations on The Nutritional Value of Forage Sorghums for Silage

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Texas A&M University Agricultural Research and Extension Center, Amarillo

Data from four years of variety trials were combined to evaluate agronomic and nutritional characteristics of specific types and varieties of forage sorghums. This data has not been subjected to statistical analyses and all statements are simply observations drawn from data plots and simple regression. All observations are across years and among varieties rather than within varieties. Sorghum types include conventional (Non-BMR), brown midrib (BMR), photoperiod sensitive (PS), and traditional grain producing varieties. For comparison, corn was planted for silage adjacent to the sorghum plots. Sorghum plants were harvested when grain was in the soft dough stage to insure similar maturity between varieties. Headless varieties were harvested when the final group of grain-producing varieties reached the soft dough stage. Whole plant sub-samples were collected from the yield sample immediately after harvest, chopped, and frozen for pre-ensiled nutrient analysis. Grain samples were collected and thrashed to obtain yield data. Among non-BMR varieties, in vitro true digestibility (IVTD) appeared to increase linearly from low to high grain yield varieties; the correlation between grain yield and IVTD was $R^2 = 0.3$. For the BMR group the correlation was $R^2 = 0.18$ but the BMRs were more digestible than the non-BMR varieties at any given grain content. The improved forage digestibility of BMR types may counterbalance the higher digestibility of grain in non-BMR types. BMR varieties do not deposit as much lignin as their non-BMR cohorts. Consequently, similar ADF values may not result in similar digestibilities. When comparing ADF concentrations and IVTD, BMR varieties were more digestible than the non-BMR varieties within the range of ADF values. The PS varieties yielded more but were less digestible. Averaged across varieties, BMR yields were lower than non-BMR varieties. Higher yielding BMR varieties maintained a higher quality with higher-yielding non-BMR varieties. Corn silage required the greater amount of irrigation per ton of both total and digestible DM produced. The PS types appeared to be most efficient while both Non-BMR and BMR varieties were intermediate. The forage sorghums to provide viable alternatives to corn silage production and can conserve groundwater. It is important to consider individual characteristics of specific varieties when choosing a forage sorghum variety to plant or feed. A great deal of overlap exists between nutritional quality and yield of specific varieties within broad categories of forage sorghums.