Challenges Along the Trail to the 21st Century
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### Challenges Along the Trail to the 21st Century

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Ultrasound Technology for Precision Marketing of Cattle
Plains Nutrition Council
Amarillo, Texas, September 5, 1997

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The cattle industry is rapidly evolving toward marketing on carcass merit. This seems to be a reaction against the old way of marketing on averages with little concern about consumer satisfaction. The change has evoked immense interest in technology that evaluates live animals, predicts future carcass quality, and sorts cattle into outcome groups. The emerging technologies enable producers to build quality into production systems as espoused by Total Quality Management principles.

Cattle feeding has been a batch process in which all animals in a pen are marketed on the same date. That results in half being over fed and the other half underfed. More importantly, about 30% of the animals are more than 25 days away from their optimal marketing date and some cattle are fed as much as 50 days too long and others are marketed 50 days early. There is at least $1 per head per day lost profit for each day that the optimal marketing day is missed. Overfed cattle represent feed wasted in adding excessive fat, which is often penalized in formula pricing scenarios. Underfed cattle include animals with additional gain potential, undesirable quality grades, and low dressing percent. Outliers on both sides may incur carcass weight penalties. Often, the date to market a pen is arbitrarily chosen. Clustering cattle into outcome groups based on days-on-feed and focused on carcass merit seems an obvious way to improve both production efficiency and product quality.

Ultrasound technology has advanced so that it provides the capability to evaluate cattle upstream and predict future carcass merit. That enables incorporating the technology into an application that enables objective estimates of the optimal number of days that each individual animal should be fed to maximize profit. That has resulted in building what is called an ultrasonic cattle sorting machine which has now been used on well over 250,000 cattle in a region between Illinois and Colorado and from Texas to Alberta.

With ultrasound, carcass attributes (backfat thickness and marbling) are measured at processing time and future carcass merit as a function of days on feed is estimated. Intensive research has provided models that objectively plots those changes and enables upstream evaluations with ultrasound. Recent advances exploit computer artificial intelligence to process the ultrasound image and automatically pipe that information into an economic decision model. Projected carcass quality and yield grades, along with carcass weight, are plotted and stochastically matched to a matrix of packer formula prices. The feedlot model includes economic constraints relating to production costs and projected carcass gain performance. The software determines the optimal day to market each individual animal to obtain
maximum profit through a proprietary decision process. Because it is not logistically reasonable to sell market-ready cattle on a day-to-day basis, the software includes algorithms to automatically assign cattle to outcome groups. Sorting into 3 or 4 groups captures most of the benefit from this procedure.

The ultrasound sorting machine focuses on carcass merit and the interfaced feedlot model is dynamic. A setup procedure provides rapid entry of changing schedules of premiums and discounts as well as cattle price-production cost relationships. In some situations, the largest component of the extra profit from sorting is generated by identifying candidates for retained feeding and recovering more gain from a pen of cattle. This is done simultaneously with avoiding over-fat and over-weight carcasses.

Sorting procedures will appeal more to feeders who market on a grade and yield (formula) pricing system. The apparent benefit in the traditional close-out report that focuses on gain and feed efficiency will be small. That is because the system is built for carcass gain performance, not live weight gain, and retained cattle may indicate low incremental live gains. However, end stage carcass gain is probably 80% of live weight gain and often exceeds two pounds per head per day.

Present premiums for Yield Grade #1 and #2 carcasses often do not offset the profit advantage from holding cattle for additional gain when the margin between gain costs and selling price is substantially positive. However, animal performance drops precipitously after backfat reaches .5 inch because that is the point when animals switch from a growing to a fattening mode. That and the huge discount for Yield Grade #4 carcasses causes the program to avoid over-fat cattle. If the proposed splitting of YG#3 carcasses into YG#3A and YG#3B (with a pronounced discount for the latter cutability grade) should become effective, ultrasound would be a powerful tool to focus into the narrower windows of acceptability.

The sorting procedures will not increase quality grade substantially because the increase in marbling progresses at a dismally slow rate. Marbling appears to be controlled much more by genetics than management. Perhaps seedstock producers should concentrate on quality attributes rather than leanness because the latter can be manipulated by management strategies. Several of our experiences in sorting have resulted in the first marketing group having the best quality grade and the poorest yield grade along with the opposite observed in the delayed group.

Present procedures rely on only a backfat measurement to project future yield grade. Backfat thickness can be measured accurately with ultrasound, especially with computerized, automated measurement procedures. The increase in backfat as a function of days on feed can be plotted with usable accuracy. In the USDA Yield grade equation, about 70% of carcass variation is attributable to backfat thickness and it is the best single predictor of lean proportion in both cattle and swine. Graders subjected to chain speeds of several hundred carcasses per hour say that backfat thickness accounts for over 80% of their yield grade decision.
The feedlot model includes features that account for errors in projections and it acknowledges that estimates of future carcass merit have limitations in accuracy. There are four sources of error in a system: (1) Evaluation of an animal at processing time; (2) Errors in the equations that project to future dates; (3) Normal biological variability among animals in growth and development; and (4) Subjectivity of the grading system and differences among packing plants and graders. Present accuracy for predicting quality and cutability grade 60 days after evaluation is about 75%.

It is a difficult task to measure accurately the increase in profit resulting from sorting procedures. It departs from classical experimental protocols because the evaluation is confounded with differences in marketing dates and locations and cattle numbers per pen. It is difficult to create and measure a valid control group. Several hundred cattle are needed for each replication, so the task of collecting high quality data is enormous. Also, the interpretation must include a combination of animal performance and carcass merit. Response will depend on cattle type and variability, as well as price relationships. The best estimate of response, based on both tests at our research facility and also from field experiences, from a three-way sort indicates that profit can be improved $20 per head. That seems very significant considering that feedlot profits appear to average $20 to $30 per head over an extended period. When the payment schedule to producers more nearly reflects the real differences in value among carcasses, profit response to sorting procedures based on carcass merit, such as ultrasound, will be substantially larger.

For the technology to be usable to producers, there are number of essential specifications in a cattle sorting machine. To minimize human input, artificial intelligence is used to process and interpret ultrasound images. That information is passed to an expert system that enables deterministic decision making and provides output meaningful to producers, such as clustering cattle for improved profitability. The system should be dynamic to respond to both user needs and changing price relationships. Focus on carcass merit seems important in the present beef production environment. Sorting should correspond to an existing processing activity, such as reimplanting, and operate fast enough to avoid delaying that procedure. There may be little additional information from serial evaluations, so individual animal identification is optional.

These applications are not limited to feedlot practice. Automated estimates of marbling and backfat with ultrasound can be powerful tools for both seedstock producers and commercial cow/calf operations to select for these important traits. Evaluations of young animals can be used to prescribe appropriate management strategy for the period between weaning to slaughter and identify animals that ought to go directly to the feedlot from those that should enter a growing phase. Feeder cattle can be evaluated and grouped for designation to specific feeding programs. Several breed associations are generating carcass EPD information with ultrasound on live cattle to drastically enlarge breed data sets.

A few years ago, one dared not use the word "sort" among a group of feedlot managers - the perception of logistical problems from those efforts added to the existing burdens of operating a feedlot seemed overwhelming. But, by combining the evaluation procedure with the reimplanting process, achieving 100 head per hour, and using low-cost color tags to identify
marketing groups in the same pen; the procedure is being readily accepted among feedlots in our area.

The beef industry is evolving from selling a commodity to marketing a product. Branded beef programs are emerging rapidly; those have more rigid carcass specifications that require the features of this technology. Hot fat trim procedures overtly penalize over-finished cattle and cause producers to focus on precision feeding.

Few producers now fail to acknowledge the industry problems resulting from the immense diversity in the cattle population. In the past, cattle were forced to try to adopt to whatever management system was convenient for an operation. The industry seems to be making an 180 degree turn toward recognizing and exploiting the variability in the herd and creating production systems that fit the cattle.
CORRELATIONS AND SELECTION FOR PERFORMANCE AND CARCASS TRAITS

Stephen P. Hammack, Professor and Extension Beef Cattle Specialist, Texas A&M University Research and Extension Center - Stephenville

The National Beef Quality Audits of 1991 and 1995 identified numerous factors affecting desirability of beef. Some of these factors are influenced by genetics including size, composition, palatability, and uniformity. Specifically, the audits found significant numbers of carcasses that were too big, too fat, too unpalatable, or too variable.

A 1974 industry survey is available for comparison. From 1974 to 1991 carcass weight increased 80 pounds (and ribeye area increased proportionately), outside fat stayed about the same, yield grades slightly improved, but Choice decreased from 75% to 55%. Between 1991 and 1995 the main changes were that fat decreased about 0.1 inch but Choice also declined, another 7%.

In order to change carcass merit we might ask how much genetic influence is involved in various carcass factors. Research has shown that fat thickness, ribeye area, cutability (yield grade or lean meat percentage), marbling, and tenderness all are moderately heritable. So change should be possible by genetic selection, i.e., choosing parents based on carcass merit. The feedyard traits of average daily gain, feed intake, and feed conversion also are moderately heritable.

What happens to other characteristics if we select only for specific carcass factors? Fat is the most important factor in yield grade. Based on documented genetic relationships, if we select for reduced fat then cutability can be markedly improved, with little effect on ribeye area, tenderness, or gain. Phenotypic relationships between these factors are similar.

There are conflicting estimates on the genetic relationship between fat and marbling, the most important factor in U.S.D.A. quality grade. Summaries of research indicate that marbling will decline moderately as fat is reduced by genetic selection. But some breed associations, in developing values for carcass expected progeny difference (EPD), have shown essentially no genetic relationship within breed between fat and marbling. Phenotypically, reduction in fat has been shown to be correlated with low to moderate reductions in marbling.

If we exercise genetic selection solely to increase marbling we should expect slight reduction in ribeye area, moderate improvement in tenderness, and essentially no effect on gain. Based on research summaries genetic selection for improved marbling would result in slight to moderate reduction in cutability. But the breed association data show essentially no genetic relationship between marbling and cutability. From a phenotypic standpoint, increased marbling is correlated with slight increase in gain, fat, and tenderness, no relationship with ribeye, and slight reduction in cutability.

Several types of information may be available for genetic selection for carcass merit. A
number of breed associations have carcass EPD and additional associations are developing these 
values. Presently, breed association EPD values may be available for carcass weight, ribeye area, 
fat thickness, marbling, and percent retail product (yield grade). The most useful of these EPD 
values are marbling (for quality), and percent retail product (for cutability).

Information feedback on individual herds also can be useful from sources such as Texas 
A&M Ranch to Rail and other steer feed-outs, breed association programs, and the National 
Cattlemen's Beef Association carcass data collection service. We will now examine three 
studies where carcass selection was practiced.

Researchers at the University of Nebraska and the U.S. Meat Animal Research Center 
recently compared six high-marbling and six low-marbling Angus sires A.I.-mated to British-
Continental crossbred cows. Sire groups differed greatly in marbling EPD but were similar for 
birth weight, weaning weight, ribeye, and fat. It was impossible to equalize all factors and the 
low-marbling sires averaged 10 pounds heavier in yearling weight EPD.

Equal numbers from both sire groups were slaughtered at two estimated levels of fat. The 
high-marbling cattle averaged 20 pounds lighter at weaning, gained at about the same rate in the 
feedyard, were slightly more efficient in feed conversion, and were fed 18 days less to reach the 
same fatness, so slaughter weight was 80 pounds heavier for the low-marbling group. Yield 
grades were similar but the high-marbling group had 74% Choice or better compared to 47% for 
the low-marbling group.

Combining all factors and using current feedyard costs and the long-term average Choice-
Select price spread of $5/cwt carcass, there was no difference in financial return between the two 
sire groups. The additional value of the higher grading high-marbling group was offset by the 
extra weight produced by the low-marbling group. If the Choice-Select spread is raised to $10 
the high-marbling group averaged $9 per head more return. Raising the spread to $20, as existed 
during the winter of 1996-97, resulted in $28 per head difference in return.

A similar study was recently conducted by the University of Georgia using Angus sires of 
either high-marbling/low-fat or low-marbling/average-fat on commercial Angus cows. Progeny 
were slaughtered at two different times. In the short-fed cattle the two sire groups were about the 
same in fat thickness and yield grade but the high marbling group had 12% more Choice or 
higher. But in the long-fed cattle the high-marbling/low-fat sire group had about 0.1 inch less fat 
and were improved 0.3 yield grade units. Feeding longer increased percent Choice by 15-20% in 
both groups. So, it is possible, through intensive concurrent genetic selection, to improve both 
carcass quality grade and yield grade.

Finally, a study was conducted by Texas A&M in conjunction with COBA-Select Sires. 
A selection of A.I. sires was made based on several factors, including carcass merit, to be used in 
three herds. In comparison with cleanup bulls the select group gained 0.3 lb/day more, produced 
carcasses 67 lb heavier, and had 83% Choice or higher compared to 27%. Returns were $32 per 
head more from simultaneously improving carcass grade, rate of gain, and feed efficiency.
What level of improvement might be expected by selection of sires within a breed? We can answer this question by examining the range of values in a breed for carcass EPD. For the breeds reporting carcass EPD, the range in marbling between the highest and lowest individuals is a little over one U.S.D.A. degree. If you confine selection to the top 1% of a breed the expected improvement is more than halved. Lowering to the top 5% further halves expected improvement. That is, compared to improvement expected from the individual sire highest for marbling in a breed, a sire at the 5% level in that breed would yield only about one-fourth as much change.

That same relationship holds for other carcass factors. So, to make significant and immediate improvement selecting within a breed, you must have available the top sires for a particular trait, most likely through A.I. For commercial breeders, fastest improvement can be made by introducing superior sires from a breed noted for high expression of whatever trait is involved. But breeders should understand what other changes might accompany a substitution of breeds. A combination of moderate performance levels for important traits is often most beneficial in commercial production.

Many factors affect carcass merit. Researchers at the U.S. Meat Animal Research Center identify the following as some important determinants of tenderness: genetics, age, time on feed, feed rations, growth implant programs, pre-slaughter techniques, slaughter and dressing procedures, electrical stimulation, chilling conditions, calcium chloride injection, blade tenderization, and carcass aging time and conditions. Note that genetics is only one factor. And new technology is sure to be available.

Let us return our attention to the four problem areas of beef acceptability that are under some genetic influence. Can excess size be genetically controlled? The answer is a definite yes! And, in the process of moderating size, cow herd utility and adaptability might be improved.

Can we genetically reduce fat? Yes, very effectively. But we know that easy fleshing is important, under most conditions where beef cows are maintained, for reproductive efficiency. We probably should not reduce inherent fattening ability in the cow herd. So, much of the opportunity to reduce fat through conventional genetic selection will be through terminal crossing, where heifers are not retained for replacements.

Can we improve palatability by conventional genetic selection? Yes, but might non-genetic techniques, some yet to be implemented or developed, offer more opportunity?

Finally, can variability be addressed through genetic selection? Without question, but that does not mean that all cattle produced in this country are going to be alike because there simply are too many variations in production conditions for all cows to be the same.

Will the industry adjust genetic programs to assist in creating a more desirable end product? Yes, if economic signals are strong enough and all segments of the industry work together. Beef products can be improved through genetic change, management alterations, and manipulation of basic biology. Success can come to those who use all these avenues to improve,
document, and merchandise carcass merit.
MEAT TENDERNESS: IT’S IMPORTANCE

The U.S. cattle industry cannot expect improvements in demand for its products/byproducts when “quality” doesn’t warrant such increases. We -- the beef cattle industry -- must measure our quality defects so they can be managed. That was the “take-home” message of the initial National Beef Quality Audit (NBQA—1991). From that audit, the take home message was that the U.S. beef industry must attack waste by reducing excessive external fat, decreasing excessive seam fat (fat located between muscles), improving overall cutability and increasing our understanding of the value of closer-trimmed beef products. During the past five years, economic pressures to reduce carcass waste fats have certainly been successful. According to the most recently completed national audit (NBQA—1995), the average adjusted fat thickness of beef carcasses harvested in the U.S. has deceased from .59 inches in 1991 to .47 inches. However these efforts on attacking waste fat have now challenged the livestock and meat industries to seek ways of producing meat products that will enable the consumer to receive maximum palatability at the lowest cost. Listed below are quotes and findings from several key research projects to document the variation in tenderness which currently exists in the U.S. fed cattle/carcass population:

A. National Beef Tenderness Survey (Morgan et al., 1991):
- Approximately 41 and 63% of all chuck and round cuts, respectively, displayed shear force values categorized as “tough.”
- Postmortem aging times, as a method to assure meat tenderness, ranged from 3 to 90 days.

B. National Beef Tenderness Conference (National Cattlemen’s Association, 1994):
- One tough beef carcass could affect as many as 542 consumers.
- Beef is being cooked to a greater degree of doneness today than in previous years because of concerns about *E. coli* 0157:H7.
- One out of every four steaks is less than desirable in tenderness/palatability.
C. National Beef Quality Audit (Smith et al., 1995):

- One bad dining experience can spread via word of mouth to as many as 950 potential customers.
- During 1995, problems associated with beef toughness cost the U.S. beef industry more than $250 million.
- According to retailers, restaurateurs and purveyors, “Due to the enormous emphasis directed to attacking waste fat, U.S. beef has lost ground in the palatability attributes associated with the taste of fat.”

An example which demonstrates the importance of beef tenderness to consumers and of course the entire beef industry is the fact that beef retail cuts are priced according to their expected tenderness level. For example, tenderloin steaks command between a $2.00 to $3.00/pound premium over top loin steaks despite the fact that these steaks are similar in composition. The price differential between these cuts is directly a reflection of the tenderness advantage associated with tenderloin steaks.

Results from a very interesting study conducted by Boleman et al. (1995) at Texas A&M University suggests that consumers can discern between beef tenderness levels and are willing to pay a premium for guaranteed tenderness. In this three-phase study, top loin steaks were obtained from strip loin subprirnals, cooked and a tenderness value was determined using a Warner-Bratzler shearing device. The remaining steaks were placed into one of the following categories based on their respective shear force values: 1) 5 to 7.9 pounds; 2) 9 to 11.9 pounds; and 3) 13 to 15.9 pounds. Category 1 steaks were color-coded with red labels, category 2 steaks with white labels, and category 3 steaks with blue labels. During phase 1, consumers rated red-coded steaks highest for tenderness, flavor and overall satisfaction compared to blue- and white-coded steaks. Even with a $1.00/pound premium, 94.6% of the consumers chose to purchase “guaranteed-tender” red-coded steaks. Results from this project suggest that consumers can detect and are willing to pay for differences between levels of tenderness. This research demonstrates that an economic incentive is currently present for “guaranteed-tender” beef, and until some measure of real, not perceived, tenderness is identified, the beef industry cannot and will not search for, manage and(or) market “guaranteed-tender” beef.

The Role of Calcium During Meat Tenderization

Certainly one could utilize traditional genetic means to improve meat tenderness. However, according to scientists from the U.S. Meat Animal Research Center in Clay Center, NE, “Due to the time required, progeny testing may not be a practical approach to improve meat tenderness.” In fact
they concluded that approximately 40 years would be required to improve Warner-Bratzler shear force by 2.2 pounds (i.e., 1 kg) in a typical 100-head cow herd.

With this in mind, researchers have been attempting to develop as well as implement various procedures which will enhance beef tenderness in normal, everyday industry operations. One of these first attempts was conducted which accelerated postmortem muscle aging and in turn assured meat tenderness was conducted in 1988 (Koohmaraie et al., 1990). This method, referred to as calcium infusion or calcium injection, introduces exogenous (i.e., foreign or additional) calcium into meat, thus, activating the calcium-requiring tenderizing enzymes known as calpains. The elevated calcium induced rapid and extensive tenderization. Today, this process is known as Calcium-Activated Tenderization (CAT), consists of injecting cuts of meat (either pre- or post-rigor) with a 5% (by weight) of a 2.2% solution of food-grade calcium chloride. Following injection, cuts are vacuum-packaged and refrigerated for seven days prior to storage. The beauty of this process is that in addition to a 30 to 40% increase in tenderness, a “built-in” control system exists, so meat is never over-tenderized as it is with other proteinases such as papain.

In a recently published research project entitled, “Beef Customer Satisfaction” by Reagan et al. (1995) it was discovered that 58% of American consumers are now cooking beef steaks to a degree of doneness of medium-well or greater. Of course food safety concerns regarding \( E \ Coli \ 0157:H7 \) in ground beef have probably encouraged consumers to prepare all meat items to higher degrees of doneness. Certainly, in most cases, as degree of doneness increases, meat palatability (i.e., tenderness) decreases in a linear fashion. Wulf and co-workers (1996) demonstrated that as strip and round steak degree of doneness increased, the tenderness improvement associated with CAT increased, or in other words, CAT lessened the toughening effects of heating (Figure 1; Wulf et al., 1996).

Figure 1. Effects of calcium-activated tenderization (CAT) and degree of doneness on shear force of cooked steaks.
**Vitamin D<sub>3</sub> Supplementation and Meat Tenderness**

As mentioned previously, one of the keys enhancing the beef tenderization process is the elevation of muscle calcium. Early studies of preventing parturient paresis in lactating dairy cows showed that orally administered vitamin D at 5 million IU daily for two weeks prepartum increased serum calcium by approximately 2.1 mg/dl (Hibbs et al., 1951). Hibbs and Pounden (1955) observed that oral supplementation of 5, 10, 20 and 30 million IU per day of vitamin D for 3 to 8 days prepartum increased serum calcium by 1.9, 1.0, 1.9 and 2.3 mg/dl, respectively. In addition to using vitamin D alone to elicit elevated serum calcium levels, many researchers (Bar et al., 1985; Sachs et al., 1987; Hodnett et al., 1992) have demonstrated that single injections of 1α-hydroxyvitamin D<sub>3</sub> (500 or 700 µg) alone or in combination with 25-hydroxyvitamin D<sub>3</sub> (4 mg) will increase serum calcium concentrations 1.8 to 2.4 mg/dl. Therefore, we tested the impact of supplemental dietary vitamin D<sub>3</sub> on ionized blood calcium concentrations and tenderness of longissimus muscle steaks from beef steers.

**Vitamin D Supplementation: Project(s) Protocol**

In experiment 1, 118 steers (average live weight, 1,162 pounds) consisting of 20 Angus-Hereford crossbred steers in Trial 1 and 98 Salers or Charolais-sired steers with Brangus dams in Trial 2, were supplemented with either 0 or 5 million IU/animal/day of vitamin D<sub>3</sub> for 5 days immediately prior to slaughter. In Trial 3, 20 steers were randomly assigned to one of four vitamin D<sub>3</sub> treatments (0, 2.5, 5.0 or 7.5 million IU/animal/day) for 10 days immediately prior to slaughter. In addition to meat tenderness information (7, 14 and 21 days of postmortem aging), blood samples were obtained each day of the supplementation period and analyzed for ionized calcium.

**Vitamin D Supplementation: Results and Discussion**

Vitamin D<sub>3</sub> supplementation resulted in a significant increase in blood plasma calcium levels when compared to non-supplemented levels (Figure 2). Compared to the non-supplemented blood calcium levels, calcium levels were approximately 50% greater after vitamin D supplementation. Additionally, shear force tenderness values for steaks from vitamin D supplemented cattle were much more tender than their conventional steak counterparts (Figure 3). In fact, the percentage of vitamin D steaks having day-7 shear force values greater than 10.0 pounds was less than one-half (approximately 20% tough) of that of the conventional steaks (approximately 50% tough). On average vitamin D supplementation resulted in a 30% reduction in shear force value.
Figure 2. Effects of vitamin D₃ on ionized blood calcium concentration.

Figure 3. Percentage of steaks with shear force values greater than 10.0 pounds stratified by vitamin D₃ supplementation.
In addition to analyzing the impact of vitamin D supplementation on reducing the occurrence of “tough” steaks (i.e., shear force values > 10.0 pounds), information included in Figure 4 overviews how vitamin D supplementation to feedlot steers shifts the entire shear force population to more tender readings compared to steaks from conventionally-fed steers.

Figure 4. Effect of vitamin D₃ supplementation on shear force distribution.

Implications

Dietary supplementation with vitamin D for 5 or 10 days prior to slaughter increased tenderness of longissimus steaks at 7 days of postmortem aging. Optimum dosage levels and times for vitamin D to reduce shear force of the longissimus and other muscle groups remained to be pinpointed.

Literature Cited


Preslaughter Factors Affecting Beef Tenderness

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Introduction

The palatability and uniformity of beef is of major concern to consumers. The primary factor that determines if consumers have a satisfying or dissatisfying eating experience is beef tenderness (Morgan et al., 1991). Miller and coworkers (1995) showed beef flavor also contributed significantly to satisfaction by beef customers. Various postmortem technologies, such as electrical stimulation, calcium chloride injection, and wet aging, have proven effective in improving beef tenderness. Sources of tenderness variation in beef may be attributed to cattle breed differences, management differences, days on feed, age, sex, and antemortem stress (Miller et al., 1996). Many postmortem treatments also affect tenderness, but they will be addressed in another presentation.

Chronological Age The chronological age of a beef animal has a major effect on tenderness. As beef animals increase in chronological age, Warner-Bratzler shear values increase and sensory panel scores for tenderness decrease (Field et al., 1966; Prost et al., 1975; Reagan et al., 1976; Webb et al., 1964). Sliger (1966) found a 30% decrease in meat tenderness of Hereford females from 3 months to 9 years of age. Thus, older animals are tougher. Increasing toughness of beef with age has been
partially attributed to larger fiber diameters (Berry et al., 1972). Also a greater percentage of short sarcomers in older animals as a result of cold shortening resulted in tougher beef for Reagan et al. (1973). Another possible reason for older animals being tougher is an increase in insoluble collagen as noted by Unruh et al. (1986).

The USDA grade change implemented in January, 1997, was based on the increased toughness associated with increased age in carcasses showing B maturity. The inconsistency of tenderness in carcasses from the B maturity classification results in lower customer satisfaction. Differences in beef tenderness associated with animal age result to a large extent from differences in connective tissues. Estimates of the amount and type of collagen in beef generally indicate that high amounts of collagen are associated with toughness (Bailey, 1989; Judge et al., 1989). In tough meat, abundant collagen surrounds the muscle fibers and forms many interfiber connections or cross-links. These “cross-links” are typically heat-stable in mature collagen and retain high residual strength after cooking (Judge et al., 1989).

Sex Effects Cows are noted for being tougher than heifers. While there is clearly a sex effect, increases in collagen as a function of age is the main cause for tenderness differences between cows and heifers. Zinn et al. (1970) indicated that heifers may mature at an earlier age, reaching a peak in tenderness about a month earlier than steers. Nonetheless, Prost et al. (1975) saw no differences in tenderness because of sex of animals. Also, bulls have been shown by Field et al. (1966) to have higher Warner-Bratzler shear values and lower sensory panel scores at 500 to 699 days of age when compared to steers and heifers at the same age. Williams (1965)
found bulls about 17% higher in Warner-Bratzler shear value than steers and heifers of similar age and genetic makeup. Tougher beef from bulls in comparison to steers is most likely due to greater collagen synthesis (Cross et al., 1982).

**Breed Effects** Breed differences and within breed differences result in the variation found in the tenderness of beef. Typically, *Bos indicus* and *Bos taurus* cattle of continental Europe descent increase Warner-Bratzler shear force and beef toughness and the variability in tenderness also increase (Wheeler et al., 1990; Whipple et al., 1990; NCA, 1993). Whipple et al. (1990) noted that *Bos taurus* cattle were more tender than *Bos indicus* cattle because of elevated calpain activities. Thus, *Bos taurus* cattle had greater postmortem protein degradation, which increased the muscle tenderness compared to *Bos indicus* cattle. Wulf et al. (1995) reported higher levels of the calpains inhibitor, calpastatin in *Bos indicus* cattle. The authors concluded that improvements in beef tenderness may be achieved by selecting breeding stock, via progeny testing, on the basis of 24-h calpastatin activity and/or shear force determinations. When compared to British breed types, Continental breed types have been found by researchers to have lower flavor, tenderness, and palatability ratings (NCA, 1993). The NCA (1993) Strategic Alliances Field Study also showed Continental breeds, especially Select grade *Bos taurus* continental cattle, are tougher and have higher Warner Bratzler shear force values than their *Bos taurus* English counterparts.

**Time on Feed** Steaks from Brahman steers improve in tenderness with increased time on feed while Angus steers showed no effects on tenderness with the
same increased times on feed (McKeith et al., 1983). Therefore, the time on feed plays some role in beef tenderness variation. Thomas et al. (1982) found greater time on feed (155 d vs. 98 d) decreased Warner-Bratzler shear values, and Davis et al. (1980) reported that days on feed explained 31 to 25% of the variation in Warner-Bratzler shear values in Bos taurus cattle types. In contrast, Christensen et al. (1978) and Tatum et al. (1980) reported that varied concentrations of feed and times on feed resulted in no effect on Warner-Bratzler shear values or tenderness scores.

Zinn et al. (1970) reported an interaction between time on feed and animal age. During the first 180 d on feed, a beneficial effect on tenderness was apparent in calf-fed steers; however, after 180 d on feed, animal age exerted a great influence in decreasing tenderness and increasing Warner-Bratzler shear values. Tatum et al. (1980) also noted increased time-on-feed was associated with increased maturity and fat deposition. Dolezal et al. (1982) found that, as subcutaneous fat thickness increased, beef tenderness increased and Warner-Bratzler shear values decreased. Thus, there is a fine interplay between animal age, time on feed and fat deposition. As time on feed increases, fat deposition increases, resulting in improved tenderness. At a certain point, the benefits of fat deposition for tenderness decline and maturity effects such as increased collagen, fiber diameter, sarcomere shortening, and differences in muscle fiber types result in a reduction of beef tenderness.

**Implant Management** Concerns have been expressed that various implant programs and combinations of implants may have a detrimental effect on carcass quality grade and tenderness (Samber et al., 1996; Smith et al., 1992). Samber et al.
(1996) reported consecutive implants of Revalor-S to steers increased Warner Bratzler shear values. Foutz et al. (1997) also noted implants of Synovex-S, Revalor, and Synovex-S + Finaplex-S increased shear forces (P < .10) when compared to non-implanted controls. Little information is available comparing programs involving the use of two successive implants and delayed implanting on tenderness. While Unruh et al. (1986) reported Ralgro lowered total collagen and insoluble collagen in beef steaks, concerns still exist that implants containing trenbolone acetate (TBA) may produce less tender beef. However, not enough research has been done in this area to make conclusions about the effect of implants on beef tenderness at the present time.

Stress before to slaughter is another factor in live cattle that can significantly affect beef tenderness. Webb et al. (1964) reported antemortem stress increased Warner-Bratzler shear values and produced tougher beef. Stressing an animal before slaughter can have a number of biochemical effects on muscle and meat. Olsson et al. (1995) reported stressed young bulls had a lower ultimate muscle pH that resulted in a shortening of muscle fibers (sarcomeres), an increase in isometric tension, and an overall toughening of beef. In the 1991 Beef Quality Audit, Miller (1991) reported calf-feds had lower quality grades compared to yearling-fed cattle. While, calf-fed cattle may tend to be tougher than yearling-fed cattle, no conclusive scientific data exists to determine the effects of age on cattle when put on feed on their meat tenderness when harvested.

Summary
Numerous factors may affect the tenderness and Warner-Bratzler shear values of beef. Typically, the older the animal, the tougher it will be. Consequently, because calf-feds are younger at death, they tend to be more tender than yearling-fed animals. Increased time on feed is beneficial to tenderness until age effects take over and begin to reduce tenderness. *Bos indicus* and *Bos taurus* Continental European cattle tend to be less tender and more variable in tenderness than *Bos taurus* English cattle. Bulls, B maturity steers and heifers, and cows are less tender than heifers and steers as a result of increased collagen and decreased soluble collagen. Certain implants and reimplanting programs may reduce beef tenderness, but scientifically based tenderness studies do not exist to allow definitive conclusions. Also, factors such as weather, extended shipping, extended feed or water withdrawal, and poor handling may cause stress and reduce beef tenderness, but the lack of data in these areas make conclusions with regard to their effects not possible at this time.
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CHALLENGES AND TECHNOLOGY FOR THE CATTLE FEEDING INDUSTRY IN THE 21ST CENTURY: REDUCING NUTRIENT FLOWS IN THE FEEDLOT WASTE STREAM

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Challenges Facing the Cattle Feeding Industry

Real, perceived, and potential environmental quality problems have accompanied the changes in agricultural productivity in recent decades. The fed cattle industry of the High Plains has increased in size by about 100,000 head annually for the last 10 years. This increase in production has continued to cause concerns about excessive nutrient accumulation in this important cattle feeding area. Excess nutrients accumulate due to the fact that elemental nutrient import is much greater than nutrient exports in animal products. Excess nutrients can be lost to the environment in a number of ways. Most nutrient losses from the feedlot do not occur directly from the feed or the animal. Rather, it is when the manure is stored or applied to soils that these losses occur. When manure is not handled properly, phosphorus and trace minerals can occur in runoff to surface waters or as percolation to ground waters. Losses of nitrogen can occur from manure as nitrates in ground or surface waters or as ammonia or nitrous oxides in the atmosphere. Losses of carbon can occur as carbon dioxide or methane lost by the animal or during fermentation of feces/urine in stockpiles or lagoons. These nutrients of environmental concern in livestock manure are nutrients that were purchased for the purpose of producing animal products. The inefficiencies in animal production result in excess nutrients leaving the feeding operation in the waste stream. These excess nutrients are potentially recyclable through plants and other products. Proper management practices have the potential to reduce the need for purchased nutrients and/or increase recycling of nutrients, thereby, avoiding losses to the water or atmosphere. Recycling management is complicated by the fact that the ratios of carbon, nitrogen, phosphorus and trace minerals required by plants, the ratios required by most farm animals, and amounts normally present in animal wastes differ. Thus, developing systems that make optimum use of these nutrients is exceedingly difficult.

Feedlot operators are currently faced with a multitude of regulations designed to protect the environment from the unused feed nutrients. Management practices identified through regulations are often design- or structure-based rather than objective-based. Thus, such regulations often have little flexibility and may have unanticipated consequences. Regulations that focus on only one solution or problem may actually transform the problem or precipitate another problem. It is imperative that interactions among these environmental concerns be

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1 Contribution from the Texas Agr. Exp. Sta., Amarillo, West Texas A&M Univ., Canyon and USDA, ARS Conservation and Production Res. Lab., Bushland, TX.
2 The mention of trade or manufacturer names is made for information only and does not imply endorsement, recommendation or exclusion by the Texas A&M Univ. System or USDA,ARS.
evaluated in order to determine whether implementation of different management practices actually improves the environment. 

On average, feedlot cattle excrete about 125 g of nitrogen and 42.6 g of phosphorus per head per day (Overcash et al., 1983). Efficient waste management systems need to be developed that are environmentally friendly, sustainable and beneficial for feedlot owners and managers. Otherwise, waste management systems (practices) will not be implemented until dictated by governmental regulations. A viable waste management system must focus on cost effective measures of decreasing the pollution potential of wastes.

Technology that increases the rate of gain and reduces the feed required per unit of gain will have positive effects on nutrient losses to the environment. Technology developed to reduce environmental pollution will be widely implemented if the technology is cost effective. This will become the driving force dictating which technology is implemented to reduce nutrient losses from the concentrated animal feeding operation. Technologies presently in use by the cattle feeding industry that increase production efficiency and has a positive effect on reducing animal waste includes feed additives (ionophores, probiotics, etc.), implant strategies, and various feeding management strategies. Technology must continue to be developed that increases production efficiency and, thereby, reduce nutrient waste per unit of product produced.

Reduction of Nutrient Flows in the Feedlot Waste Stream: A nutritional perspective

Without a doubt, problems facing animal production are continually changing. Stewart (1995) quoted an article in the yearbook of Agriculture by Schreiner and Anderson (1938) stating “the demand for barnyard manure was so great and the price so high, interest was aroused in utilizing other organic waste sources in compost as “artificial manure”. Our major problem in 1997 is the demand for manure is low and the quantity produced within specific geographical locations is high causing governmental regulations to control the management and disposal of animal waste. Often times the governmental regulations become the factor limiting agricultural production. A serious question to ask is “Will governmental regulations ever dictate feeding dietary levels of nutrients that are below animal requirements?” We have already been faced with addressing this question in selenium supplementation programs. Perhaps regulations controlling nitrogen, phosphorus and trace minerals in the diet are not too far in the future.

As nutritionist and livestock managers, we must change the balance of nutrient flow into and out of concentrated animal feeding operations (CAFO). At present, more nutrients are entering CAFO than are leaving in animal products. As a solution we must:

1. Reduce nutrient input into CAFO while maintaining the same production level.
2. Increase the amount of nutrients leaving in animal products without an increase in nutrient input.
3. Convert excess nutrients excreted as animal waste into value added co-products of the livestock feeding industry.

These areas provide opportunities for the development of technology to reduce nutrient flows in the feedlot waste stream.

**Nitrogen:** Nitrogen (protein) represents the most expensive nutrient per unit of weight fed to livestock. Gilbertson et al. (1970) reported that 3 to 6% of excreted nitrogen was lost in runoff
from the feedlot surface. Bierman (1995) noted similar values for diets containing 8 and 20% roughage, however, when all concentrate diets were fed, nitrogen runoff exceeded 20% of nitrogen excreted, and 10 to 20% of the excreted nitrogen remained in the manure. Much of the excreted nitrogen is lost to the environment via air (dust and ammonia). A reduction in this inefficiency is necessary to become more cost efficient in producing livestock.

Concepts balancing diets to contain adequate amounts of ruminal undegradable intake protein (UIP) and ruminal degradable intake protein (DIP) have advanced our ability to increase the efficiency of nitrogen utilization in feedlot cattle diets. Matching available nitrogen with fermented carbohydrates to enhance the microbial synthesis of amino acids will prove advantageous in reducing nitrogen losses to the environment. Incorporation of technology into feeding systems to advance the control of UIP and DIP in the ruminant diet will provide a positive contribution to reduce excess nitrogen excretion. These technologies may be treated/processed proteins to reduce microbial deamination, deaminase inhibitors, or reduction in the use of protein as a microbial substrate.

Monitoring tools to determine the efficiency of nutrient use will become commonplace. These tools could be metabolic indicators that predict when excess nutrients are being fed and are not being incorporated into animal products. For example, Ferguson and Chalupa (1989) indicated that as nitrogen efficiency is reduced, blood urea nitrogen (BUN) is increased. As BUN increases, milk urea nitrogen (MUN) increases. Our laboratory is presently evaluating the use of MUN from samples analyzed through DHI test to predict inefficient nitrogen usage in dairy cows. This project is being conducted using 9 cooperator dairy herds in Central and East Texas. Chalupa and Ferguson (1995) indicated that feed management strategies could be altered to improve nitrogen balance. They indicated that ration formulation strategies include feed ingredients used, level of non-fiber carbohydrates in rations, and the level of metabolizable protein. The efficiency of ammonia uptake by ruminal bacteria and the efficiency of bacterial growth can affect utilization of nitrogen by ruminal bacteria. Cole (1997) presented data from research conducted with sheep showing a positive effect of feeding management on nitrogen usage. He concluded that alternating levels of dietary protein from 10 to 15% on an every other day basis improved nitrogen balance by 38 and 27% in two experiments. This feeding strategy is probably altering the efficiency of recycled nitrogen into the rumen and its' subsequent use by ruminal microorganisms. The NRC (1985) suggested that, on average, 15% of the intake protein is recycled to the rumen. This value varies from 70% in cattle fed 5% CP diets to 34% in cattle fed 10% CP diets and 12% in cattle fed 15% CP diets. Changing the amount of recycled nitrogen from BUN to the ruminal contents can increase the efficiency of nitrogen use and (or) improve the quality of protein reaching the small intestine.

The Beef Cattle NRC (NRC, 1996) made a significant change in the way we think about feed protein. As these concepts are implemented into beef feeding programs, nitrogen excretion will be reduced per unit of nitrogen intake.

**Phosphorus:** Phosphorus excretion is a major problem in CAFO and occurs because of an excess intake and(or) inefficient utilization. Bierman (1995) reported that from 2 to 5% of phosphorus consumed was lost in runoff from the feedlot surface and approximately 60 to 80% of consumed phosphorus was retained within the soil of the feedlot pen. Balancing the finishing diet relative to the animal's ability to convert phosphorus into a marketable product will increase efficiency of phosphorus utilization. As a result, a greater percentage of dietary phosphorus will
leave the feedlot as animal product and less will remain as waste. Contamination of water bodies with phosphorus exists because of excess land application of animal waste and manure stockpiles. Animal waste is often used as a fertilizer based upon its nitrogen content. Typically, "fresh manure" has a nitrogen:phosphorus ratio of approximately 5.5:1 whereas, manure collected from feedlot pens normally has a ratio of approximately 1:1 (Azevedo and Stout, 1974). Because most crops require a nitrogen:phosphorus ratio of approximately 5 to 8:1, when manure is applied to fields to meet nitrogen requirements of crops, phosphorus application may be excessive. In addition, nitrogen is assimilated into grain crops and forages at a greater rate than phosphorus. Hence, applying manure to crops on a nitrogen basis has resulted in a continual increase in the environmental levels of phosphorus in agricultural lands. When applying the waste as a phosphorus fertilizer, greater amounts of land area are required resulting in a greater trucking expense. As the trucking costs increase, animal waste becomes less economically favorable compared with commercial chemical fertilizers.

Phosphorus is imported into the concentrated animal feeding operation in energy feeds (cereal grains), protein supplements (usually by-products of the oilseeds) and inorganic phosphorus salts. Cereal grains supply approximately 70% of the dietary phosphorus of which a large percentage is bound as phytate. The oil seed meals supply about 15%, and inorganic phosphorus salts supply about 15% of the dietary phosphorus. Dietary requirements for phosphorus change dependent upon physiological stage of maturity and rate of growth. However, in most cases, dietary phosphorus requirement is usually less than .3% of the diet dry matter. Feedlot diets usually contain the same concentration of phosphorus throughout the feeding program regardless of the stage and level of growth. Phosphorus from the energy and protein feeds often meet the animals requirement for this mineral but phosphorus from inorganic salts (originating in mineral mines and processed through chemical plants) is commonly added to diets. This indiscriminate use of dietary phosphorus is contributing to waste management problems associated with feeding cattle. Balancing diets to meet the phosphorus requirement of cattle throughout the feeding program will be a positive step in reducing excess phosphorus excretion. Preliminary research by our laboratory demonstrated that anabolic growth implants increased phosphorus utilization by livestock. Hufstedler and Greene (1995) showed that implanting feedlot wether lambs with 20 mg of zeranol increased intestinal absorption of phosphorus by 170% (.27 g/day vs .73 g/day). In another of our studies with wether lambs (Hutcheson et al., 1992), 20 mg of zeranol increased metacarpal cortical area, breaking load, and metacarpal width compared to non-implanted controls. These data suggest that skeletal tissue increases and serves to accumulate more phosphorus when livestock are implanted with anabolic agents. In a recent study, we implanted 62 Rambouillet wether lambs with 12 mg of zeranol to determine phosphorus excretion in a feedlot environment (Niemann, 1997). Implanting lambs with zeranol decreased phosphorus excretion by 9.2% at 14 days after implanting and 18.6% after 28 days. Beginning at 42 days, the response to the implant began to subside until day 56 when implanted and non-implanted lambs excreted similar amounts of phosphorus. It is interesting to note that the efficiency of phosphorus retention was approximately 50% for days 14, 28, and 42 but decreased to approximately 20% by day 56. Development of implanting strategies that increase the efficiency of phosphorus usage will be advantageous in reducing phosphorus excretion to the environment.

Phytate phosphorus is not digested or absorbed by the nonruminant. Research with ruminants consuming high-roughage diets shows that phytate phosphorus can be digested and
absorbed. However, data suggest that phytase activity is pH sensitive and inactive at a pH of less than 5.5 (Raun et al., 1956). Modern feedlot diets contain approximately 90% concentrate ingredients, often resulting in a ruminal fluid pH below 5.5. In addition, the ruminal microflora population is different in concentrate-fed ruminants compared with those fed high-roughage diets. If phosphorus was more biologically available from cereal grains, inorganic supplemental salts of phosphorus could be eliminated from the diet. Development of technology to increase the efficiency of utilization of feedstuff phosphorus will make advancements in reducing phosphorus contamination of soils and major water bodies.

**Dust/Odors:** Amendments to the Clean Air Act and National Ambient Air Quality Standards (NAAQS) could potentially force feedyards to decrease emissions of dust and odors. As a proportion of nutrients excreted, few of the nutrients excreted by cattle in feedyards leave the yard in dust particles. Although airborne dust is the most noticeable portion of “blowing dust,” in reality, most dust probably leaves the feedyard along the surface just as in most field situations. However, some groups and individuals are concerned about the potential health (and nuisance) effects of feedyard dust on cattle, employees, and the general public. Only about 2.2 to 4% (particle volume basis) of the dust particles emitted by beef cattle feedyards have a mean aerodynamic diameter of less than 2.5 microns (PM$_{2.5}$) (Sweeten et al., 1988). The PM$_{2.5}$ dust particles are considered to be respirable into the lungs and a potential health concern (Rylander, et al., 1986; Schwartz et al., 1996), although some studies debate that conclusion (Barnes, 1994).

Based on cost figures we have obtained from several feedyards, it is estimated that it can cost a feedyard from $1 to $20/head-capacity annually to control dust using water sprinkling alone.

Most offensive odors from feedyards are released as a result of anaerobic fermentation of nitrogen, carbon, and (or) sulfur containing compounds in excreted feces and urine. Feedyard odors are comprised of at least 45 different volatile gases including ammonia, indoles, volatile fatty acids, amines, alcohols, etc. The threshold limit (i.e. concentration at which they are detectable by the human nose) of these odor producing compounds varies greatly. Besides being a potential “nuisance” problem, appreciable amounts of nitrogen, carbon, and sulfur leave the yard in gaseous products that can contribute to odor or other environmental concerns. From 25 % (Hutchinson et al., 1982) to 65 % (Bierman, 1995) of the nitrogen excreted by cattle can be lost as ammonia to the atmosphere. This loss is highly dependent upon the feedlot surface conditions (pH, moisture, temperature, etc.) and can be affected by the diet fed. In general, when the loose surface manure is wet (> 35 % moisture) odor emissions increase, whereas, when the surface is dry (< 25 % moisture) dust emissions increase (Sweeten, et al., 1988). However, the relatively low correlation’s noted between the surface moisture content and dust concentrations ($r^2 = .27$) reported by Sweeten et al. (1988) suggests other factors also play a major role in dust and odor emissions. For example, Jones et al. (1992) noted that feces with higher pH emitted fewer odors. In contrast, lowering the pH of urine decreases ammonia losses but may not affect actual “odor” emissions.

Currently dust and odors are controlled primarily by changing/controlling the moisture content of the feedlot surface. This is done by use of sprinklers, water trucks, mounds in the pens, varying the square footage of pen surface provided per animal, frequent scraping of pens, and other methods. Unfortunately, the success of these methods is highly dependent upon weather conditions, the methods are usually not entirely successful, each method can add a
substantial cost to the feedyard operation, and the return on the investment may be nil. The return on investment might be improved if manure for fertilizer was priced on a sliding scale based on nutrient (especially nitrogen) content.

Some methods that might be used in the future to control nutrient runoff, dust, and odor include the following:

1. Feed additives that, when excreted, prevent the breakdown of urea to ammonia and (or) prevent other anaerobic fermentation in manure.
2. Soil amendments that can be applied to the feedlot surface to prevent ammonia, carbon, and (or) sulfur volatilization. (A number of chemicals have been shown to decrease ammonia volatilization from poultry litter, including alum, and calcium chloride. These have not been adequately tested under “feedyard” conditions).
3. Soil amendments that can be applied to the feedlot surface to bind fine dust particles. (Several chemicals, other than just water, may have potential to decrease fine dust particles emitted from the feedlot surface. Polyacrylamides have been used to decrease irrigation-related erosion in row crops. Cationic and anionic polyacrylamides are used in sewage sludges to agglomerate small particles. Of course any soil amendment would need to be saved if consumed by animals in the pen and would have to have minimal effects on the use of manure as a fertilizer).
4. “Green areas” around feedyards. (These areas could serve several purposes. First, they could collect surface driven dust particles before they leave the feedyard property. They could also assist in removing gases such as carbon dioxide and ammonia from the atmosphere. They also serve as good PR. Trees, shrubs, grasses, etc. could be used in combinations and watered with feedlot runoff if necessary. The use of “fruit trees” might even serve as an additional source of income or an employee benefit).
5. Lagoon additives that decrease release of N, C, and (or) S from lagoons. (A number of commercially available enzyme and (or) microbial products are currently available. Their efficacy is still not clear).
6. Feed additives that, when excreted, bind fine dust particles. (Use of fat in the diet seems to help in decreasing fine dust particles. Preliminary work in our lab suggests that as little as 1% fat in the feces can significantly bind fine dust particles. Some feedyard managers seem concerned that adding fat to the diets may make the pen surface (especially after a rain) more slick and thus pose a safety hazard for employees).
7. A weather station network that provides weather, evapotranspiration, and other data to feedyards for use in scheduling sprinkling and (or) pen cleaning operations based on dust and (or) odor potentials will be valuable in controlling dust and odor. (Dr. Brent Auvermann of TAES is currently working with the Panhandle Evapotranspiration Network (PET) to develop such a system.).
8. Improved feedlot surfaces. (Improved feedlot surfaces could potentially increase the amounts of N, P and other nutrients collected from pens in manure and potentially decrease nutrient losses via percolation and (or) adherence to soil).
9. Dietary regimens to increase nutrient recycling. (The metabolism of the kidney may be studied in more detail because of its role in controlling acid-base balance, urine composition, and nutrient recycling. Recent research (Boukila et al. 1995) suggests that the addition of Ca- and (or) Mg-hydroxides to high-concentrate diets may
conserve N (or decrease the N requirements) by replacing nitrogenous compounds (ammonia, etc.) as a renal buffer. The recycling of P and other minerals, as well as N, may be increased, thus reducing the dietary requirements).

**A Futuristic View?** In the future, feedyards may need to become more diversified operations. Rather than "hoping and praying" that local farmers will purchase (or take) the feedlots' manure, the feedyard may need to provide its own outlet for its co-products. Development of animal waste into value-added co-products of the feedlot industry will help eliminate these problems. This may include using a portion of the manure for fuel either by burning or methane generation. The yard may make its own compost. The yard may be able to grow "specialty crops" or plants that not only help to reduce any environmental concerns but also provide an additional source of income. Several yards may have to form alliances to achieve these goals.

It is interesting to wonder if technologies can be developed that can economically remove nutrients (ie. primarily minerals) from manure so they can be used for other purposes such as supplements, etc. We need to learn if the minerals in manure are in a form that is available to the animal?

It is apparent that to achieve some of our long-range environmental goals, researchers need to work with scientists and engineers in other fields that in the past were not considered agriculturally oriented. These may include chemist, materials engineers, physicists and etc. The time has come to begin preparation for the development and marketing of animal waste products that have a high demand and value.

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BEHAVIOR AND PERFORMANCE OF FEEDLOT AND RANGE CATTLE: IMPLICATIONS FOR MANAGEMENT


Introduction

One of the challenges facing beef cattle producers is to optimize performance of an animal which evolved to consume low quality forages. It has been postulated that cattle evolved in a woodland park habitat, which had wide variations in seasonal forage quality and quantity. This species developed behaviors to increase its chances for survival under those conditions. Current management systems for mature cow herds still include use of rangelands as forage sources although many herds are supplemented to provide adequate nutrients at strategic times. Feedlot cattle are fed grain-based diets which are much higher in energy content and therefore promote more rapid gains.

The purpose of this paper is to explore feeding behavior and social structure of beef cattle and apply that knowledge to current management problems. First, this paper will examine the feeding behavior and social structure of cattle to establish a baseline of normal patterns. The next section will review how supplemental feeding of range beef cows is affected by those behaviors and social organization. Feedlots alter feeding behavior and social structures of cattle. Montana State University has conducted a number of studies over the past few years on rangelands and in feedlots to examine feeding behavior by beef cattle. Through the use of radio frequency technology, we have documented the feeding behavior of every animal in a pen or herd. This knowledge has direct application to the feedlot industry because it can be used to examine a variety of
Social Structure and Behavior of Cattle

Geist (1974) stated that the social behavior of large ruminants is based on the gregarious behavior of individuals. His theory suggested that there are fluctuations in gregariousness in response to habitat changes. There are a number of studies with similar species which suggest that there are no strong associations between females, but rather random associations in large groups (Lott and Minta, 1983) or unstable associations in smaller groups (Schaller, 1967).

One of the most interesting studies conducted in this area was reported by Lazo (1994; 1995). This investigation focused on the social structure and habitat use of "mostrenca" cattle, which have been living in the Donana region of Spain since the 13th century with minimal management. About 140 animals live in the Biological Reserve of Donana where the only recent management has been to remove 30 to 50% of the calves. These animals live on 67 km² (16,555 acres) of marsh and scrublands. The population is organized into four cowherds which are highly stable, closely knit social groups that maintain active spatial and social segregation from other herds (Lazo, 1994). Each herd was composed of an average of 20 adult females, 6 young females, 7 young males, 3 adult males and 13 calves. Cows rarely joined herds other than the one they were born into.

Most of the home ranges of the four herds rarely overlapped except when resources were limited. The study supports the theory that cattle obtain resources through avoidance rather than by direct confrontation. Lazo (1994) suggested there might be two levels of social organization of feral cow herds. Larger bands of feral cattle observed
were held together by food abundance and distribution, reproductive status or other ecological factors. In contrast, herds are maintained by long-term, social bonds (Lazo, 1994). This extensive three-year study suggested that cattle are capable of forming strong social bonds and maintain social stability by means of social isolation.

Grazing behavior by Hereford beef cows has been described in detail by Dwyer (1961). Cows typically began the most active grazing at 0530 and continued until 0800. This was followed by another grazing bout from 0900 to 1100. The third grazing period was usually initiated around 1700 and continued until dark (2000). One final grazing period by range cows usually took place from 2400 to 0100. In this summer study conducted in Oklahoma, cows spent about 8.5 hours or 40% of a 24 h-day grazing. Mature cows spent 25% standing and 31% lying down.

Stricklin et al. (1976) observed feeding behavior by Angus and Charolais x Angus cows during summer and winter. Both breeds averaged almost 9 hours of grazing per day in the summer. Patterns were very similar to those reported by Dwyer (1961). Cows of both breeds grazed approximately 1.5 hours each night. Grazing and resting activities were not correlated with cow weight or calf gain.

Feeding behavior by cattle grazing forage on rangelands appears to be consistent and related to day length. The total time spent grazing however, does not correlate to performance values since intake rates can vary widely. Therefore, it is likely that total feeding time by range cattle is probably a function of forage quality and physiological energy demand. These factors are modified by day length.

Management and Behavior of Beef Cows

Cow-calf producers rely primarily on grazed and conserved forage to supply
dietary nutrients (Galyean and Goetsch, 1993). Dormant range forage is high in fiber and may be deficient in both crude protein and energy for cows during late gestation or early lactation (Krysl and Hess, 1993). Limited forage quality or quantity may necessitate supplemental feeding to maintain a desired level of productivity. Since supplemental feed costs represent one of the greatest variable expenses incurred by cow-calf operators, improvements in supplement management should reduce costs of production.

Supplementation programs rely on the assumption that animals consume a targeted amount of supplement. Intake of supplement is usually measured by dividing supplement disappearance over time by the number of animal-days. This method does not consider variation in intake by individual animals. If animals consume less than the target amount, then formulated nutrient intake is not achieved. If animals consume more than the target amount, supplementation costs are increased and there can be negative impacts on forage intake and digestion. Supplementation programs for grazing ruminants have not always been cost-effective because pregnancy rates, calving intervals or calf or lamb growth have not improved (DelCurto et al., 1990; Miner et al., 1990). This inconsistency may be due to the variation in supplement intake by individual animals.

There are a number of factors which influence individual animal intake of supplements (Bowman and Sowell, 1997), but this section will focus on trough space, supplement allowance, and social interaction.

Changes in trough space per animal can influence competitiveness and variation in supplement consumption. The proportion of sheep not consuming supplement fed once daily in troughs increased from 0 to 31% as trough space was decreased from 24 to 4 cm per animal (Arnold and Maller, 1974). However, excess trough space can increase
variation in hand-fed supplement consumption. Wagnon (1966) observed that with 91 cm of trough space per cow, less fighting and agonistic behavior occurred during supplementation than when 180 cm per cow was allowed. The smaller bunk allowance did not allow cows to fight without backing away from the trough, and therefore fewer animals were pushed away from the supplement. When excessive trough space was allowed, dominant cows chased others away from one side of the trough and spent more time fighting than eating.

Larger quantities of supplement provided per animal can reduce the variation in individual animal consumption and the proportion of non-feeders. Foot et al. (1973) found that the coefficient of variation (CV) of supplement intake was reduced when supplement allowance was increased. Ducker et al. (1981) reported that the proportion of grazing ewes not consuming block supplement was highest when flock supplement consumption was low and decreased as average flock supplement consumption increased. Kendall et al. (1980) combined the effects of trough space and supplement allowance by offering grazing ewes different amounts of supplements with varying trough space. When supplement allowance was high, trough space had little effect on CV of supplement intake. When supplement allowance was low, trough space had a large effect on CV of supplement intake.

Social interactions play an important role in supplement consumption by cattle. Wagnon (1966) reported a strong, stable arrangement of social dominance in a mixed breed cow herd. Hand feeding resulted in many 2- and 3-year-old cows being driven from the troughs before they had the opportunity to feed. Subordinate 4- and 5-year-olds spent less time at the feeders, more time waiting, and gained half as much weight as older
more dominant cows. Wagnon et al. (1966) reported that Angus cows were more
dominant than Shorthorn cows, and both were more dominant than Hereford cows.

Friend and Polan (1974) studied the feeding behavior of 21 Holstein cows and
found dominant ranking cows to occupy feeding stalls adjacent to cows of similar social
rank. Mean time eating ranged from 2.9 to 4.7 h per day and was quadratically related to
social rank. Mid-ranked cows spent the least amount of time eating. The authors
concluded that dominance values failed to predict access to feeding stalls. They also
doubted the existence of a classical social hierarchy in this herd. Rather, they suggested
that cows were driven by physiological demands and that cows operating at peak
production gain access to resources through persistence rather than aggression.

Supplying supplemental protein to cattle grazing low quality forages can increase
forage digestibility and intake (Bowman et al., 1995). Krysl and Hess (1993)
summarized a number of studies which examined how supplementation influenced
grazing behavior by cattle. Protein supplements reduced grazing time by cattle by 1.5
hours compared to unsupplemented cattle. Holt and Knipfel (1993) reported similar
results except they found forage intake was not affected by supplementation.

Daily grazing time by beef cattle in a wide variety of conditions varied from 6 to
12 hours per day (Krysl and Hess, 1993). This wide range of grazing times suggests that
beef cattle grazing time is influenced by forage quantity and quality as well as
physiological demand. The lower limits of feeding time appear to be related to feed
quality whereas upper limits appear to be related to fatigue factors (Stobbs, 1975).

**Management and Behavior of Feedlot Cattle**

Feedlot management of beef cattle represents a large departure from the
evolutionary history of bovids. Large numbers of animals are placed in small pens and offered feed at times that may not correspond with feeding patterns under grazing conditions. Achieving an optimal level of health and performance by cattle throughout the feeding period will play an important role in overall economic return. The role of feeding behavior as modified by human intervention, processing, social organization, and space allocation in this process has not been determined, but health and performance of cattle are directly related to animals achieving an optimal level of nutrient intake.

When cattle are fed ad libitum, the feeding patterns appear similar whether cattle are on pasture or in confinement (Dulphy et al., 1980; Stricklin, 1987; Hicks et al., 1989). This common pattern is diurnal with periods of peak activity occurring at dawn and dusk, and one feeding at solar midnight. For cattle fed in confinement, feeding activity is also related to the temporal and spatial distribution of feed. The presentation of new feed stimulates cattle to initiate feeding activity (Dulphy et al., 1980). In contrast to cattle on pasture who may spend eight to ten hours per day grazing, cattle in feedlots average 1 to 2.5 hours feeding per day (Hicks et al., 1989; Sowell et al., 1997). Sowell et al. (1997) reported an absence of late evening or midnight feeding activity when feedlot cattle were fed three times in the morning. This information would support the premise that total feeding time and feeding activity of feedlot cattle is largely controlled by metabolic demand, feed energy density and feed delivery.

Stricklin (1987) investigated feeding time and intake by cattle when trough space was limited. Six pens of 15 animals were trough-fed, while six pens of 15 animals were fed using Pinpointers®, which restricted access to feed to a single animal at a time. The pens of cattle fed using Pinpointers® occupied the feeding stall to near capacity.
throughout the 24-h day, while the trough-fed animals exhibited typical diurnal feeding patterns. In spite of the reduction in feed access, total intake by individuals under the two systems was not different. This study demonstrates how flexible the feeding behavior of cattle can be in order to maintain intake determined by physiological demands.

Whenever cattle are removed from one group and placed in another there is the potential to reduce animal performance. Nakanishi et al. (1993) demonstrated that introducing a strange animal into a structured herd of Japanese Black cattle increased agonistic behavior four-fold on the day of introduction. Most behaviors returned to normal by the seventh day, but the introduced animal lost considerably more weight and spent more time in locomotion than the other herd members. Several researchers have concluded that aggressive behavior of newly mixed cows, steers and bulls return to normal within 10 to 12 days post-mixing (Tennessen et al., 1985; Kondo and Hurnik, 1990). It is often difficult to determine the effects of mixing beef cattle since they are usually subjected to a number of stressful procedures prior to being placed in a pen, such as processing.

Illness associated with shipping, handling or other factors can change feeding behavior and reduce performance. Hutcheson and Cole (1986) indicated that stressors associated with marketing and transport can greatly depress feed intake during the initial 7 to 14 days after arrival in the feedlot. Morbidity resulting from these stressors reduces the number of cattle which will consume feed compared to healthy cattle. Lofgreen (1983) indicated that another consequence of shipping stress in receiving cattle was a reversal in feeding pattern and dietary preference.

A review of the techniques which have been employed to detect feeding
behavioral changes was presented by Cole (1995). Advantages of systems like the Pinpointer® include the ability to measure individual animal feed intake. Disadvantages include the disruption of social interactions which influence feeding behavior. Recently, a new technology has become available which has the potential to evaluate feeding behavior within commercial feedlot settings. This technology offers managers an opportunity to evaluate the effects of feedlot practices on the feeding behavior of animals.

**MSU Range and Feedlot Research**

*Supplementing Range Beef Cows.* The objectives of this study were to quantify the amount of individual variation in liquid supplement consumed by free-ranging beef cows, and to determine if supplement use could be modified by altering supplement delivery method. This research was partially funded by the American Feed Industry Association. The detailed methods used in this experiment were described by Sowell et al. (1995).

Sixty crossbred 2- and 3-year-old cows (average weight 526 kg) were assigned to one of three treatments to determine the effects of liquid supplementation on individual feeding behavior. Twenty animals (ten 2-year-olds and ten 3-year-olds) were placed in each of three native range pastures for 35 days. Animals in the first pasture (439 ha) were not supplemented. A standard lick-wheel feeder containing a molasses-based liquid supplement (28.5% CP as-fed; 51% CP DM basis) was placed in the second pasture (160 ha). A computer controlling lick-wheel feeder designed to dispense 1 kg·head⁻¹·day⁻¹ in small aliquots every hour during daylight hours was placed in the third pasture. The same liquid supplement was used in both feeders.

There were no differences (P > .20) in grazing time between treatments as
determined by group observations. Cows using the computer-controlled feeder traveled less distance per day ($P < .05$) than cows using the standard feeder, probably due to differences in pasture topography as well as the dispensing intervals of the computer-controlled feeder. Smaller groups of animals at a time used the computer-controlled feeder than the standard feeder. This may have been a result of close proximity of the feeder to preferred grazing areas, as well as the controlled release of liquid supplement.

The total amount of time spent consuming supplement by individual animals varied from 0 to 254 minutes for the eight days observations were made. Two animals, one in each treatment, were never observed at the feeder. There were no differences in the number of days the feeder was visited between animals in either supplement group based on individual observations ($P > .10$). Animals using the computer-controlled feeder came to the feeder more ($P = .001$) frequently per day, spent less ($P = .03$) time per day at the feeder, and had shorter ($P = .0002$) feeding events than animals using the standard feeder. This may have been influenced by feeder distance to bedding areas, and the controlled supplement release. Approximately 25% of the animals in both supplement treatments spent less than 5 minutes per day consuming liquid supplement, and the CV of total feeding time for both treatments averaged 65%.

Cows in both supplement treatments consumed similar amounts of liquid supplement per day, and had similar CVs for supplement intake (average 107%; Bowman et al., 1995). This would indicate that time spent at the feeder is not necessarily related to supplement intake.

Individual observations indicated 2-year-old cows in both treatments visited the feeders on fewer days ($P < .001$), had fewer ($P < .001$) total feeding events, and spent
54% less ($P < .001$) total time at the feeders than 3-year-old cows. There was a treatment by age interaction for time at the feeder per day ($P = .03$), as well as for supplement intake (Bowman et al., 1995). Two-year-old cows spent the same amount of time at the feeder per day, and consumed a similar amount of supplement as 3-year-olds when they had access to the computer-controlled feeder. Two-year-old cows spent half as much time at the feeder per day, and consumed less supplement compared with 3-year-olds when they had access to the standard feeder. These results may be due to fewer animals present at the computer-controlled feeder at a time, which might allow less dominant 2-year-olds more of an opportunity for feeding without being displaced by older, more dominant cows. This indicates that supplement consumption by different ages of cows can be altered through modification of supplement delivery.

**Composition of Feedlot Pens.** Seventy-seven crossbred heifer calves (average weight 256 kg) were used to determine if the social composition of feedlot pens influenced heifer performance. Two types of social composition were examined: 1) all heifers in a pen were raised at the same location; and 2) heifers in a pen were a mixture of individuals raised at two locations. A more complete description of the methodology was given by Milner et al. (1994).

Pen composition had an effect on performance during the first 28 days of the 84-day feeding period. Heifers penned with others raised in the same location gained 45% faster ($P < .01$) than heifers penned with a mixture of individuals from two locations.

**Feeding Behavior by Feedlot Cattle.** Economic losses associated with morbidity in newly received feedlot cattle continue to be a major cost for the commercial cattle feeding industry. In general, response by an individual animal to medical treatment is
more effective the earlier in the disease process it can be initiated. Recognizing which animals within a pen will become sick and require medical treatment is difficult. If feeding patterns in individual animals could be monitored, changes in feeding behavior, such as loss of appetite, may be useful to indicate the onset of illness in cattle before other clinical symptoms become evident.

The long-term objectives of this research are to monitor feeding behavior of newly received feedlot cattle and develop applications to improve animal health and management. The technology used in this research was developed by GrowSafe Systems®, Inc. of Calgary, Alberta, Canada. This equipment was originally developed to improve diagnosis of sickness and reduce chick mortality in ostriches. It was adapted for use with beef cattle in commercial feedlots. With financial support from Roche Animal Nutrition and Health, these studies are being conducted by Montana State University, as well as other universities and commercial feedlots.

The GrowSafe System® consists of four component parts. The passive radio frequency (RF) transponders are molded into a plastic ear tag (Texas Instruments, and Allflex). An energy pulse is sent by the antenna and stored in the transponder by a capacitor. When the capacitor reaches a sufficient charge, the transponder transmits the animal identification code to the reader panel. The reader panel has a unique design (patent pending) that can differentiate multiple transponders at the same time. Information from each transponder is collected every 5.25 seconds when the transponder is within 50 cm of the antenna. The antenna is molded inside a 1 cm neoprene mat which covers 22.5 m of the interior surface of the feedbunk.

The McElhaney feedlot near Wellton, Arizona was the site of this investigation.
The data collection equipment was placed in a pen which measured 30 x 36 m. Feedbunk space was 22.5 m, or .21 m per head, and was similar to other pens in the feedlot. A maximum of approximately 90 animals could feed at the bunk at one time. Fifty-one mixed-breed calves (average weight 146 kg) were used in June and July, 1996 to validate the system. Once the validation was complete, 108 mixed-breed calves (average weight 139 kg) fitted with RF ear tags were studied for a period of 32 days in July and August, 1996. Any animal which was removed from the pen and received medical treatment for any reason during the 32-day period was designated as a morbid animal (n = 55). All calves which were not removed were referred to as healthy animals (n = 53).

Healthy steers spent 104% more (P < .001) time at the feedbunk during the first four days of the study than did morbid steers. Twenty-eight steers were removed from the pen and treated in the first four days. Healthy steers averaged 30% more (P < .001) time at the feedbunk than morbid steers for the entire 32-day feeding period.

The exact time of every feed delivery to the pen was recorded. Most feeding events with large numbers of animals present associated with feed delivery lasted approximately one hour for the first (0600 to 0700) and second (0800 to 0900) delivery times. The third (1100 to 1130) delivery-feeding bout averaged .5 hour. Healthy steers spent more time at the feedbunk after each feed delivery than did morbid steers. Both groups spent less time at the feedbunk with each successive delivery. There was less variation between animals in time spent at the feedbunk during the first feed delivery than the two subsequent delivery times. Healthy steers spent a greater (P < .06) proportion of their total feedbunk time per day at the first and second feedings than morbid steers. Both healthy and morbid steers spent similar proportions of their total feedbunk time at
the bunk during the third feed delivery.

A greater (P = .001) proportion of healthy steers were at the feedbunk during the one hour after the first and second feed deliveries, and during the one-half hour after the third feed delivery, than morbid steers. Ninety percent of healthy steers were present after the first feed delivery, with 78% of morbid steers present at this time. Only 58% of healthy steers, and 47% of morbid steers were present at the feedbunk in response to the third feed delivery. This information suggests that mass mediation programs which top dress rations between the second and third feedings may not benefit morbid animals.

More morbid animals were present at the feedbunk in response to the first feed delivery than the second or third.

General observations have suggested that healthy steers spend more time at the feedbunk than morbid animals shortly after the feed truck arrives, and this rapid response to feed delivery might be used to identify healthy and sick animals. Healthy steers spent more (P < .001) time at the feedbunk in the first 15 minutes of a feeding bout associated with feed delivery compared with morbid steers. The percentage of healthy steers which visited the feedbunk in the 15 minutes following feed delivery was greater (P < .001) than for morbid steers. This information indicates that there might be an advantage to using the first few minutes of feed delivery to identify sick animals (Sowell et al., 1997).

Implications for Management

Modern beef cattle are the product of several million year of natural selection and a few thousand years of domestication. Their social behaviors appear to be similar to feral cattle which have not been domesticated for 700 years. They evolved under forage conditions which promoted mixing of many small herds of animals. Social status of
mixed groups is established quickly and the negative effects on animals is usually transitory. Bovids do not usually defend territories but rather isolate themselves by avoidance. This trait has enabled man to intensively manage this species. The feeding behavior of cattle exhibits a great deal of plasticity as long as the animal can meet its energetic needs.

Providing adequate nutrients to range cows with self-fed supplements reduces labor costs, but can increase variation in supplement consumption. Designing feed delivery methods which promote some degree of competition appears to reduce high individual consumption, but may increase the number of low consumers. These factors may be controlled by supplement allowance and stocking density. Self-fed supplements which are placed in the center of grazing areas will receive more individual use and reduce competition. Using multiple feeders to alter stocking density per feeder is another method to increase or reduce competition. More elaborate feeders may be used in the future, such as those used in automatic milking systems that dispense a daily allotment of supplement to a given animal.

The use of radio frequency technology in the feedlot will be a valuable tool to assess management practices. Information collected with this equipment indicates that mass medication should be administered at the first feeding when the greatest proportion of animals are present. This technology could be used as a tool to identify sick animals earlier than conventional methods. It could be used in a training program to assist pen riders with pulling decisions. As feedlot assess their profitability and medication costs, they may decide that pulling and treating sick animals is more expensive than sorting animals based on their feeding behavior on the first day of arrival.
Literature Cited


Beta-Agonists and Their Effects on Growth and Carcass Quality of Beef Cattle

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Introduction

Efficiency of beef production must continue to improve if cattle are to remain competitive with poultry and pork as a supply of meat to American consumers. Production of excess fat has been identified as a major cost of producing beef (1992 National Beef Quality Audit). A segment of American consumers have indicated that they desire leaner meat products. Carcass composition will become a more important economic factor for beef production as the industry moves towards value-based marketing. Many alternatives are available to alter carcass composition. Use of management of nutrition such as length of feeding and quantity of energy fed; feeding entire males; or killing animals at younger ages have been studied, but usually are not suitable alternatives to optimize economic returns. Crossbreeding with leaner breeds has been widely practiced resulting in considerable variation within the national cattle population. Genetic selection of leaner animals within breeds results in slow rates of change in body composition.

Another approach is to manipulate metabolism pharmacologically to increase muscle and reduce fat. Steroid implants increase muscle mass with little change in total amount of fat deposited in cattle. Administration of exogenous somatotropin specifically increases growth of muscle and reduces accretion of body fat. One of the most striking findings in recent years has been the anabolic action of β-adrenergic agents on body composition of meat animals. Four compounds, Clenbuterol, Cimaterol, L-644,969 and Ractopamine have been studied in feedlot cattle and shown to increase muscle growth and decrease fat accretion. These compounds are structural analogs of the natural catecholamines, epinephrine and norepinephrine. There may be variation among compounds in their reaction with receptors in muscle and fat as well as differences among muscles and adipose depot sites because of number or nature of receptors. The purpose of this paper is to review the effects of β-agonists in cattle with respect to growth and efficiency, carcass composition, and meat quality.

The published data on the effects of administration of β-agonists to feedlot cattle are critically limited. In many of the studies, only a few animals were compared. Many of the studies were conducted in Europe with Friesian or Continental breeds fed rations different from what would be fed in the U.S. Only one study has been done with heifers. No studies have been reported on the interaction of β-agonists with steroid hormone implants.

Growth and Efficiency

The results of the published experiments with β-agonists on growth, feed intake and feed efficiency are summarized in Table 1. Improvements in performance ranged from zero to 50% for gain and zero to 53% for feed efficiency. There was no indication that feed intake was increased by administration of these β-agonists. Improvements in gain and feed efficiency were greatest when the β-agonist was fed for short periods of time, less than 50 days, and declined to nearly no response when fed for 100 days or more. In one study designed to evaluate the effects of duration of cimaterol treatment on performance (6), feeding the β-agonist beyond 100 days resulted in loss of improved gain and feed efficiency. There seems to be some down regulation of receptors in muscle and fat with long-term feeding of β-agonists.
No studies have been reported on in which steroid hormone implants and β-agonists have been studied in a factorial designed experiment to determine if the response to each might be additive. The fact that bulls responded to administration of β-agonists similar to steers suggests that the response to β-agonists will likely be additive to that of steroid hormone implants.

In many of the studies several doses of the β-agonist being studied were compared. The doses giving optimum response are shown in Table 1. Increasing the dose usually resulted in less feed consumption and reduced gain (9,10,11).

No comparisons of more than one β-agonist within an experiment have been reported, so no conclusions can be made about structure and potency relative to stimulation of growth and carcass composition of cattle. In development of the "ideal" β-agonist, rather than selecting the most potent compound it would be more important to select the structure resulting in the desired response, i.e. improved feedlot performance with minimal effects on tenderness and intramuscular fat.

Carcass Composition

The summary of the effects of administration of β-agonists to cattle in the feedlot on carcass composition are summarized in Table 2. Dressing percent was improved in each of these experiments which resulted in increased carcass weight in all of the studies except two studies with clenbuterol. When measured, carcass fat and subcutaneous fat were reduced and ribeye area was increased in each study. Fat measurements were reduced as much as 40% and ribeye area increased up to 40%. In general, changes in carcass composition were less influenced by length of time the β-agonist had been fed as compared with gain and feed efficiency.

The increased muscle accretion resulting from feeding L-644,969 was reported to be due to hypertrophy of αR fibers with no change in percentage of fiber types in the Longissimus (14). In another study (13) feeding cimaterol increased the proportion of Type IIB (fast twitch) and the cross sectional area of Type I and Type IIB fibers in the Longissimus and Semitendinosus. Miller et al. (8) also observed increased diameter of Type II fibers in the Longissimus of heifers fed clenbuterol. Not all muscles respond equally to β-agonists. Moloney et al. (9) found that feeding L-644,969 to Friesian steers resulted in a greater proportion of total muscle in the hip region of the carcass. The changes in muscle fiber type were observed to be more pronounced in the Longissimus than in the Semitendinosus (9). Dawson et al. (4) also observed greater increase in weight and protein content of the Vastus lateralis and Longissimus compared with the Semitendinosus in steers fed cimaterol. Variation in response of different muscles is probably the result of differences in number and type of receptors present. Eisemann et al. (5) reported increased uptake of amino acids by hindquarters of steers fed clenbuterol suggesting an increase in protein deposition. In a more recent study (14) feeding L-644,969 to steers increased fractional accretion rate of protein in skeletal muscle by decreasing fractional degradation of myofibrillar proteins rather than by increasing fractional synthesis of muscle proteins.

The effects of β-agonists on metabolism of adipose tissue is less clear than on muscle. Miller et al. (8) reported smaller adipocytes and reduced concentrations of lipogenic enzymes in subcutaneous and intramuscular fat from heifers fed clenbuterol. These authors suggested that β-agonists may decrease fat accretion by blocking hyperplasia. In a later study with younger steers fed clenbuterol (12) subcutaneous and perirenal adipocytes were smaller in treated animals with no observed difference in rates of lipogenesis or number of adipocytes. Taken together, these two studies indicate a consistent decrease in hypertrophy of adipocytes in cattle treated with β-agonists.
Carcass Quality

As might be expected from the decrease in carcass fat, marbling or percentage of fat in the Longissimus muscle was decreased in cattle fed β-agonists (Table 3). It is difficult to determine from this data set, but there would seem to be a rather significant reduction in quality grade when cattle are fed β-agonists. Because of the larger ribeye and less subcutaneous fat, yield grades are improved. When measured, tenderness of muscle as measured by shear force was consistently reduced.

In a detailed study of muscle protein turnover in steers fed L-644,969, there were no differences in μ- or m-calpain or in cathepsins B or B+L between control and β-agonist-fed steers (14). Calpastatin activity, however, was greater in muscle from β-agonist-fed steers at 0 and 7 days postmortem. These differences in enzyme activity in muscle were positively related to less reduction in shear force and greatly reduced myofibrillar fragmentation in muscle from β-agonist-fed steers from 0 to 14 days postmortem. Total muscle collagen content and percentage of heat-soluble collagen were reduced in steers fed cimaterol (4). In a study with bulls (7) feeding cimaterol increased shear force of the Longissimus muscle and decreased degradation of tropomyosin. Feeding the β-agonist had no effect on cooling rate of the muscle or ultimate pH. These studies indicate that reduced meat tenderness in cattle fed β-agonists is not due to cold shortening or muscle pH, but is probably due to reduced myofibrillar fragmentation with postmortem aging.

Nutritional Implications

The dramatic increase in hypertrophy of skeletal muscle in β-agonist-treated cattle would suggest a greater requirement for dietary protein. The data base is not sufficient to draw definite conclusions with respect to dietary protein requirement. The cattle in most of the experiments were fed a high level of dietary protein. In several of the studies the authors intentionally increased the amount of protein fed in anticipation of greater muscle growth. Most of the gains observed in these experiments were not great enough to stress the dietary protein concentrations being fed. In one study (1) steers fed ractopamine were fed 11% and 14% crude protein with no effect of protein on response to the β-agonist. The 1996 Beef Nutrient Requirement program would call for more dietary protein in the cattle fed β-agonists, but that program does not take into account reduced turnover of muscle protein. Reduced muscle protein degradation in β-agonist-treated cattle would result in more efficient use of absorbed metabolizable protein and thereby possibly no change in dietary protein requirement.

Implications

The published data base on administration of β-agonists to beef cattle is limited at the present time. There is no information on extensive use in heifers, optimized dose for finishing cattle, duration of exposure for optimum response, interaction with steroid hormone implants and effects on nutritional requirements. The use of β-agonists in finishing cattle has many potential positive attributes including improved rate of gain and feed efficiency, increased meat yield and dressing percentage, and decreased fat deposition. Each of these characteristics would help keep beef production competitive with other meat producing animals. Improved yield grade would benefit beef cattle in value-based markets that emphasize retail yield. The decrease in tenderness and carcass quality grades associated with use of β-agonists is consistent with their action in muscle, but raises uncertainty about their widespread use in beef cattle as the industry is working to improve consistency and tenderness of beef. The latter problem may be solved by selecting
compounds that have less effect on skeletal muscle and more on subcutaneous and intermuscular fat depots.

Table 1. Effects of β-agonists on growth and feed efficiency of feedlot cattle.

<table>
<thead>
<tr>
<th>Dose (ppm)</th>
<th>Daily gain, kg</th>
<th>Feed intake, kg/d</th>
<th>Feed efficiency, gain/feed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Clenbuterol</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>350 kg Hereford steers, 98 days, 8 head/treatment (11)</td>
<td>1.10</td>
<td>13.0</td>
<td>.084</td>
</tr>
<tr>
<td>8</td>
<td>1.01</td>
<td>12.1</td>
<td>.083</td>
</tr>
<tr>
<td>393 kg crossbred heifers, 50 days, 7 head/treatment (8)</td>
<td>.81</td>
<td>8.9</td>
<td>.090</td>
</tr>
<tr>
<td>1.4</td>
<td>.76</td>
<td>7.1</td>
<td>.108</td>
</tr>
<tr>
<td>300 kg Angus steers, 50 days, 8 head/treatment (12)</td>
<td>1.48</td>
<td>9.9</td>
<td>.149</td>
</tr>
<tr>
<td>.7</td>
<td>1.99</td>
<td>10.0</td>
<td>.198</td>
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<tr>
<td><strong>Cimaterol</strong></td>
<td></td>
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</tr>
<tr>
<td>529 kg Friesian steers, 91 days, 15 head/treatment (10)</td>
<td>.81</td>
<td>9.5</td>
<td>.085</td>
</tr>
<tr>
<td>5.2</td>
<td>1.05</td>
<td>9.6</td>
<td>.111</td>
</tr>
<tr>
<td>372 kg Belgian White-blue bulls, 127 days, 12 head/treatment (6)</td>
<td>1.40</td>
<td>9.3</td>
<td>.150</td>
</tr>
<tr>
<td>4</td>
<td>1.52</td>
<td>9.06</td>
<td>.168</td>
</tr>
<tr>
<td>412 kg Belgian White-blue bulls, 108 days, 12 head/treatment (6)</td>
<td>1.41</td>
<td>10.0</td>
<td>.141</td>
</tr>
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<td>3</td>
<td>1.45</td>
<td>9.9</td>
<td>.146</td>
</tr>
<tr>
<td>542 kg Belgian White-blue bulls, 136 days, 16 head/treatment (2)</td>
<td>1.28</td>
<td>9.5</td>
<td>.135</td>
</tr>
<tr>
<td>6</td>
<td>1.38</td>
<td>9.5</td>
<td>.146</td>
</tr>
<tr>
<td><strong>L-644,969</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>380 kg Friesian steers, 84 days, 18 head/treatment (9)</td>
<td>.78</td>
<td>7.9</td>
<td>.098</td>
</tr>
<tr>
<td>1</td>
<td>.91</td>
<td>7.4</td>
<td>.122</td>
</tr>
<tr>
<td>345 kg MARK III steers, 42 days, 4 head/treatment (14)</td>
<td>1.25</td>
<td>10.3</td>
<td>.122</td>
</tr>
<tr>
<td>3</td>
<td>1.87</td>
<td>10.0</td>
<td>.187</td>
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<tr>
<td><strong>Ractopamine</strong></td>
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<td>432 kg Hereford steers, 56 days, 40 head/treatment (1)</td>
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<td>1.25</td>
<td>9.4</td>
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<td>30</td>
<td>1.48</td>
<td>9.3</td>
<td>.154</td>
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Table 2. Effects of β-agonists on carcass composition of feedlot cattle.

<table>
<thead>
<tr>
<th>Dose (ppm)</th>
<th>Carcass weight, kg</th>
<th>Carcass Dressing %</th>
<th>Carcass fat, %</th>
<th>Rib fat, cm</th>
<th>REA, cm²</th>
</tr>
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<tbody>
<tr>
<td><strong>Clenbuterol</strong></td>
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</tr>
<tr>
<td>350 kg Hereford steers, 98 days, 8 head/treatment</td>
<td>315</td>
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<td>1.29</td>
<td>79.6</td>
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<tr>
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<td>314</td>
<td>64.5</td>
<td>28.7</td>
<td>.83</td>
<td>88.1</td>
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<tr>
<td>393 kg crossbred heifers, 50 days, 7 head/treatment</td>
<td>273</td>
<td>61.9</td>
<td>1.00</td>
<td>78.6</td>
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<tr>
<td>1.4</td>
<td>271</td>
<td>63.9</td>
<td>.60</td>
<td>92.9</td>
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<td>.78</td>
<td>62.9</td>
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<tr>
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<td>238</td>
<td>60.1</td>
<td>.74</td>
<td>80.6</td>
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<tr>
<td>529 kg Friesian steers, 91 days, 15 head/treatment</td>
<td>340</td>
<td>55.6</td>
<td>22.1</td>
<td>(3.9)a</td>
<td>67.2</td>
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<td>13.8</td>
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<td>94.6</td>
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<tr>
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<td>61.0</td>
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<td>82.3</td>
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*aFat score, 3 = very lean; 5 = very fat.*
Table 3. Effects of β-agonists on carcass quality of feedlot cattle.

<table>
<thead>
<tr>
<th>Dose (ppm)</th>
<th>Shear force, kg</th>
<th>Marbling</th>
<th>% fat in LD</th>
<th>Yield grade</th>
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<td><strong>Clenbuterol</strong></td>
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<td>393 kg crossbred heifers, 50 days, 7 head/treatment</td>
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\textsuperscript{a} Number related to tenderness.
References


