# 2007 Beef Cattle Research in Texas

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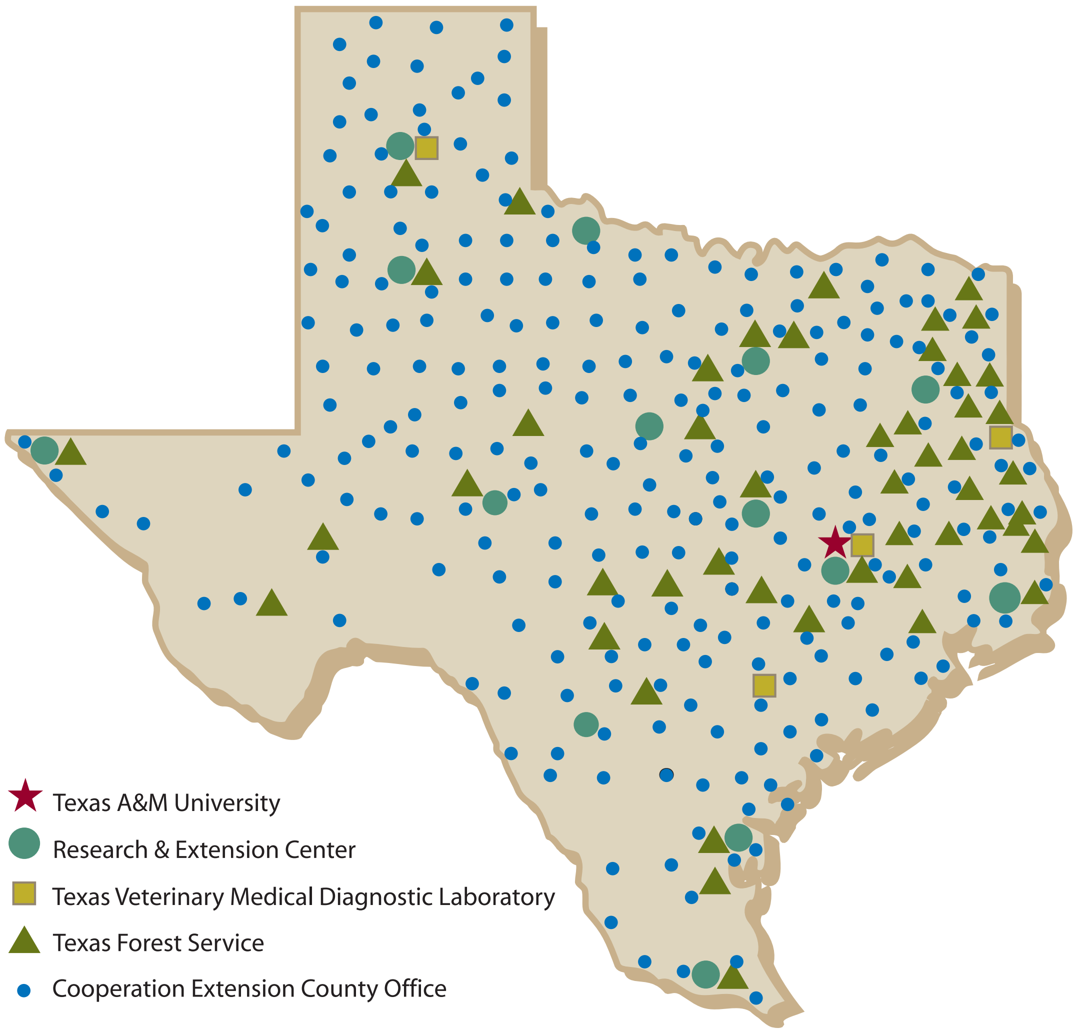


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Most of Texas has seen tremendous rainfall in the first six months of 2007, making for extremely different productions conditions as compared to those in 2006, including dealing with flooding in certain areas. Cattle markets have remained strong, but experts tell us that we are heading into a down turn in national cattle prices the next few years as herds rebuild numbers. Demand and speculation about use of corn for ethanol production has increased cost of feed throughout the industry, but long term impacts of ethanol production on cattle feed costs remain to be seen. As in the past, the Texas beef cattle industry continues to remain strong and have a very important impact on the state economy and the lives of its citizens.

As of January, 2007 there were 14.0 million cattle in Texas. There are approximately 150,000 Texas cattle producers accounting for 5.3 million beef cows and almost 7 million stocker calves that operate under widely varying environments and production systems across the state. There are close to 3 million cattle on feed in Texas feedlots on any given day, and the packing plants within the state have capacity to process approximately 7 million cattle annually. Nationwide, Texas ranks first for numbers of total cattle and calves, beef cows, beef cattle operations, and fed cattle marketed. Texas produces approximately 30% of the beef consumed in the United States. Cash receipts for cattle and calves in Texas is annually over $8 billion.

Many state organizations such as Texas Department of Agriculture, Texas & Southwestern Cattle Raisers Association, Texas Cattle Feeders Association, Texas Farm Bureau, Texas Beef Council, Texas Animal Health Commission, and the Independent Cattlemen's Association of Texas are dedicated to helping Texas cattle producers deal with emerging production issues, improving profitability, and satisfying beef consumers, and, we are grateful to have their support.

The publication highlights some of the projects conducted through the Texas A&M University System Ag Program that can have direct impacts on the Texas beef cattle industry, and beyond. These efforts are due to many scientists, graduate students and staff that care deeply about the continued success and sustainability of the Texas and United States beef cattle industries.

Andy D. Herring
Associate Professor
Holder of John K. Riggs '41 Beef Cattle Professorship

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# THE USE OF NEONATAL BLOOD PARAMETERS TO PREDICT PREWEANING WEIGHT GAIN OF BRAHMAN CALVES

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## Summary

An experiment was conducted to determine the utility of various blood parameters obtained approximately 24 hr after birth to predict future weight gain of beef calves. The effects of cow temperament, cow age, and calf sex on serum protein concentration were also determined. Plasma and serum samples were collected from 111 calves and analyzed for plasma protein, serum protein, IgA, IgM, and IgG concentrations. Based on blood concentration of each parameter, calves were assigned to low, medium, and high groups for each parameter. Of the blood parameters evaluated, only serum protein classification was significantly associated with calf weaning weight. Calves nursing cows classified as temperamental or aged had lower serum protein concentrations than other calves; calf sex had no effect on serum protein concentration. The results of this experiment suggest that serum protein concentration may be the most appropriate measure for predicting future performance of calves.

## Introduction

Gross revenues of cow-calf producers are significantly impacted by pre-weaning morbidity, pre-weaning mortality, and reduced weaning weights of beef calves. Reduced weaning weights may be the result of clinical illness, sub-clinical illness, or a reduction of bioactive substances obtained from colostrum. Recent research reports document that certain calf blood parameters measured 24 hr after birth are positively associated with weaning and yearling weights of calves. The clear determination of which calf blood parameter(s) have the greatest influence on calf growth will allow for the development of feeding and management strategies to increase concentrations of these parameter(s). Thus the objectives of this research were 1) to determine the utility of various blood parameters obtained approximately 24 hr after birth to predict future weight gain of beef calves; and 2) to determine the effects of cow temperament, cow age, and calf sex on serum protein concentration of calves 24 hr after birth.

## Experimental Procedures

During the spring of 2006, plasma and serum samples were collected from 111 Brahman calves approximately 24 hr after birth. Plasma samples were analyzed for plasma protein, and serum samples were analyzed for serum protein, IgA, IgM, and IgG concentrations. All cows and calves were managed as a single group during the experiment. Calf weights were obtained at birth and weaning (average age = 172 days); weaning weights were adjusted to 172 days of age according to BIF guidelines (BIF, 2002). Cows were assigned a temperament score from 1 to 3 (1 being calm, n = 25; 2, n = 61; 3 being temperamental, n = 25). Calves were assigned to one of three temperament groups (calm, n = 21; average, n = 72; and wild, n = 18) based on exit velocity and pen score 28 days before and at weaning. Based on blood concentration of each parameter, calves were assigned to low, medium, and high groups for each blood parameter. For example, calves with plasma protein concentrations less than 1 standard deviation below the mean were assigned to the low group (n = 23), those with concentrations greater than 1 standard deviation above the mean were assigned to the high group (n = 21), and all remaining calves were assigned to the medium group (n = 67). This procedure was repeated for serum protein, IgA, IgM, and IgG. The number of calves in each group along with the mean and standard deviation for each parameter are presented in Table 1. The statistical model for weaning weight included the blood parameter being tested, calf sex, calf temperament, and cow temperament as fixed effects and calf sire as a random effect. Correlation coefficients were also determined for each parameter and adjusted weaning weight.

Using the data from the experiment described above, an additional analysis was conducted to determine the effects of cow temperament, cow age, and calf sex on serum protein concentration of calves 24 hr after birth. Cows were divided into three age groups: young (< 5 yr; n = 53), mature (5 to 10 yr; n = 49), and old (> 10 yr; n = 9). The statistical model for serum protein concentration included cow temperament, cow age, and calf sex as fixed effects.

## Results and Discussion

Of the five blood parameters evaluated only serum protein classification was significantly correlated with calf weaning weight (Table 2). Calves in the high serum protein group were 40 and 20 lb heavier ($P < 0.05$) at weaning than calves in the low and medium group, respectively. Additionally, calves in the medium group were 20 lb heavier at weaning than those in the low group. Correlation coefficients for each blood parameter and weaning weight were: plasma protein (r = 0.11; $P$ = 0.26), serum protein (r = 0.11; $P$ = 0.27), IgA (r = 0.14; $P$ = 0.14), IgM (r = 0.19; $P$ = 0.04), and IgG (r = 0.13; $P$ = 0.17).

Serum protein of calves 24 hr after birth was higher ($P$ < 0.05) for calves nursing dams with a temperament score of 1 or 2 compared with those with a score of 3 (7.02, 7.08, and 5.97 g/dl, respectively; SEM = 0.28). Additionally, serum protein tended ($P$ = 0.10) to be higher for calves nursing young and mature cows compared with those nursing old cows (7.05, 6.93, and 6.08 g/dl, respectively; SEM = 0.42). Calf sex did not influence serum protein concentration 24 hr after birth (6.69 g/dl; $P$ = 0.37).

We are not aware of any published research that has evaluated the effects of calf serum protein concentration measured 24 hr after birth on weaning weight. However, Wittum and Perino (1995) did report that plasma protein concentrations were significantly lower for newborn calves that later experienced neonatal morbidity (5.1 g/dl) as compared with healthy calves (6.1 g/dl); the calves that experienced neonatal morbidity were 35 lb lighter at weaning. Also in agreement with our experiment, Dewell et al. (2006) reported that IgG1 did not influence ADG from birth to weaning.

## Implications

The results of this experiment suggest that of the blood parameters evaluated, serum protein concentration may be the most appropriate measure for predicting future performance of suckling beef calves. These results also indicate that increasing serum protein concentration should result in increased calf performance. The removal of aged or temperamental cows from the herd may result in increased calf serum protein concentration and increased weaning weights.

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Table 1. Calf blood parameter measured 24 hr after birth: mean, standard deviation, and number of calves represented in each blood parameter classification

| | Mean | Standard deviation | Low | Medium | High |
|---|---|---|---|---|---|
| Plasma protein, g/dl | 7.32 | 1.28 | 23 | 67 | 21 |
| Serum protein, g/dl | 7.03 | 1.29 | 22 | 69 | 20 |
| IgA, mg/ml | 0.93 | 0.87 | 8 | 92 | 11 |
| IgM, mg/ml | 1.07 | 1.14 | 0 | 96 | 15 |
| IgG, mg/ml | 28.54 | 15.82 | 22 | 73 | 16 |

Table 2. Effect of blood parameter classification on adjusted 172 day weaning weight, lb

| | Low | Medium | High | SEM[1] | P-value |
|---|---|---|---|---|---|
| Plasma protein | 359 | 381 | 381 | 12.1 | 0.13 |
| Serum protein | 358[x] | 377[y] | 396[z] | 12.3 | 0.03 |
| IgA | 384 | 373 | 392 | 17.2 | 0.32 |
| IgM | - | 375 | 384 | 13.7 | 0.46 |
| IgG | 368 | 375 | 387 | 12.7 | 0.48 |

[1]Most conservative SEM.

[x,y,z]Within a row, means lacking a common superscript differ (P < 0.10).

# EVALUATION OF THE EFFECTS OF TWO COMMERCIALLY AVAILABLE MODIFIED LIVE VACCINES FOR BOVINE RESPIRATORY DISEASE COMPLEX ON NAÏVE BEEF STEERS

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## Summary

Naïve beef steers (n = 107) received either vaccine A, vaccine B, or physiological saline. Animals were fed individually in Calan ™ gates with rectal temperature, body weight, feed intake, BVDV Type 1, BVDV Type 2, and IBR titer responses collected. At d 0, no significant differences in titer responses were detected for the treatments. At d 28 and 42, vaccine B had the highest ($P < 0.01$) BVDV Type 1 titer responses, with vaccine A having higher titers ($P < 0.01$) than non-vaccinates. On d 14, 28, and 42, IBR titer responses differed among treatments ($P < 0.01$), with vaccine A producing higher titers than Vaccine B, and vaccine B producing greater titers than the control. Rectal temperature tended ($P = 0.06$) to be lower in steers treated with Vaccine A on d 14 and 28. A treatment by initial BW interaction occurred for ADG; lighter animals had reduced ADG when vaccinated, while heavier animals had enhanced ADG when vaccinated. Animal body weight may be a consideration in the selection of viral vaccines, although both commercial vaccines generated humoral immune responses, and the net reduction in ADG across all animals was minimal.

## Introduction

Bovine respiratory disease (BRD) is a major challenge in postweaning stages of beef production (NAHMS, 1997). Morbidity associated with BRD reduces performance, efficiency, and product quality; increases input costs and mortality; and results in value loss from $90 to $150 per case (Texas A&M University, Ranch to Rail, unpublished data). Live-virus vaccines are available which produce high and sustained immunological responses to antigens of the respiratory complex (Vaughn and Sweiger, 1997). However, live-virus vaccines may induce a febrile response that, while beneficial to the animal at the cellular level, may result in increased energy expenditure, decreased feed consumption, and thus decreased weight gain. Because different live virus vaccine products contain different antigenic strains, it may be possible for calves to have differential febrile and performance responses to those vaccines. The objective of this trial was to evaluate immunological and production responses by weaned beef calves to two commercially available vaccines.

## Experimental Procedures

Beef steers (n = 107) without prior exposure to viral vaccinations, confirmed to be free from persistent infection (PI) with BVD, and confirmed seronegative to BVD and IBR prior to the initiation of this trial were used. Lack of PI was confirmed through evaluation of an ear notch sample by antigen capture ELISA at Gold Standard Laboratories. Blood samples were tested at the Texas Veterinary Medical Diagnostic Laboratories using serum neutralization tests to confirm seronegativity to BVD and IBR.

Animals were assigned to pens equipped with Calan® gated feed bunks (n = 4 per pen) based on height. Pens were stratified by average body weight and assigned to treatments. Animals receiving different treatments were not commingled within pens to minimize potential artifact seroconversion due to contact among animals receiving different treatments.

Calves within a pen received one of three vaccination treatments: Vaccine A (Type 1 BVD, IBR, PI3, BRSV), Vaccine B (Type 1 & 2 BVD, IBR, PI3, BRSV), or Control (physiological saline). All treatments were applied at 2 ml subcutaneously in the neck, as per label.

Individual intake was measured with the use of the Calan gate system. Prior to the start of the trial, animals were trained to eat out of the individual Calan gates. Treatments were applied after training was complete. Individual feed delivery was based on the prior day's consumption and was recorded daily. Orts were recorded weekly.

Rectal temperature was measured via rectal thermometer on days 0, 1, 3, 7, 14 and 28 following treatment application. Body weight was recorded at day 0, 14, 28 and 42. Blood samples were drawn via coccygeal venipuncture into evacuated tubes on days 0, 14, 28 and 42 and sent to TVMDL for quantification of serum neutralizing antibody titers to BVD Type 1, BVD Type 2, and IBR. On days 0 and 49, fat thickness over the 12$^{th}$ rib (fat thickness), longissimus dorsi face area (ribeye area, REA), and percentage intramuscular fat (IMF) were measured via ultrasonography with an Aloka 500V ultrasound unit fitted with a linear array probe.

Mixed-model procedures of SAS (v. 9.1.3; SAS Institute, Cary, NC) were used for analyses. Rectal temperature (°F) and dry matter intake (percentage of initial BW) were considered repeated measures with pen nested within treatment used as the random subject effect. Due to the unequal spacing of time lags, a spatial power covariance structure was fit to the repeated measures model.

Serum-neutralizing antibody titer count data were transformed to $\log_2$ prior to analyses, and results are expressed in this form. Average daily gain was computed as weight gain (lb) divided by time between weight collections (d) for specific time periods. Time periods were d 0 to 14, d 14 to 28, and d 28 to 42; and overall (d 0 to 42).

Initial body weight of animals varied, while vaccine dosage was constant, so that potential for varying response to treatment as a function of BW at the time of treatment application existed. Therefore, for analyses of all response variables, a multi-step covariance analysis was performed to determine the influence of initial BW on responses, and the equality of covariate slopes and intercepts among treatments using steps outlined by Littell et al. (1996).

When initial weight interacted with treatments (i.e., different slopes), estimates of treatment effects were established at the mean of the initial weight of the animals, one standard deviation above the mean, and one standard deviation below the mean to define the nature of the interaction and produce meaningful representation of treatment effects in the population.

## Results & Discussion

*Dry Matter Intake*

Dry matter intake was evaluated as a proportion of body weight (PctDMI). Time, (P < 0.01) treatment, (P < 0.01) and their interaction (P < 0.01) influenced PctDMI in this experiment (Figure 1). Intake sharply declined within the first six d of the trial, but recovered over the subsequent three d. Because all treatments exhibited a similar response over this time period, this variation in intake was likely due to handling and adaptation to measurement stress rather than to treatment effects. However, from d 10 to 17 intake varied depending on treatment. Cattle vaccinated with Vaccine B had pctDMI intake similar to control cattle. Animals vaccinated Vaccine A with had a second sharp decline in intake from d 9 to d 12, such that PctDMI in steers treated with Vaccine A was lower (P < 0.01) than PctDMI in Vaccine B or Control treated steers, which did not differ (P = 0.42). This was followed by an increase over the next 6 days. From d 18 to the conclusion of the trial, pctDMI did not differ among treatment groups.

*Rectal Temperature*

Rectal temperature had a tendency (P = 0.08) to be affected by treatment and was affected by day (P < 0.01). Rectal temperature was influenced (P < 0.06) by the interaction of treatment and day and the covariate (initial body weight) (P < 0.01). For all days measured after initiation of the project, cattle in the control group had the numerically highest rectal temperatures followed by the cattle receiving the Vaccine B and then by animals receiving Vaccine A. The differences in temperatures did not become statistically different until days 14 and 28 (Figure 2). On d 14 and 28, rectal temperature in cattle receiving Vaccine A was significantly lower (P < 0.01) than cattle in the Control and Vaccine B treatment groups. Cattle receiving the Control and Vaccine B treatments were similar (P > 0.21) for both d 14 and 28.

*Average Daily Gains*

Average daily gain was strongly influenced (P < 0.01) by the interaction between treatment and initial body weight (Figure 3). This caused us to generate among-treatment comparisons for ADG at the mean initial weight, one standard deviation below the mean initial weight, and one standard deviation above the mean initial weight. From these estimates we were able to infer that cattle of different weight classes responded to the vaccinations differently. When treatments were compared in the light weight category (-1 SD) average daily gain was greatest in calves treated with saline (P < 0.01); those vaccinated with Vaccine B or Vaccine A treatments had statistically similar (P > 0.1) ADG. Average daily gain was similar (P > 0.5) among treatments when compared at mean initial BW. When compared within the heavy weight class (+1 SD) cattle that received Vaccine B had greater ADG than those receiving saline injection (P < 0.01). Cattle receiving Vaccine A had ADG similar to those receiving Vaccine B (P = 0.5), and tended (P = 0.11) to have ADG greater than those receiving saline.

*Ultrasound Measurements*

Animal body composition was measured through the use of ultrasonography. Because animals were measured only at day 0 and day 49, a change in the measured values was calculated as the response variable. For the change in ribeye area, no treatment differences were detected (Table 1). Intramuscular fat deposition did not significantly differ due to treatment either (Table 2). No treatment by initial weight interactions occurred for the change in rib-eye area or the intramuscular fat deposition.

There was a difference (P < 0.01) in the change in fat thickness over the 12th rib due to treatment (Figure 4). A significant interaction (P < 0.01) between initial weight and treatment also existed. For lightweight cattle (-1 SD), administration of Vaccine B resulted in a greater (P < 0.01) increase in fat cover over the 12th rib than application of either Vaccine A or control treatments, which were similar (P = 0.76). At mean initial BW, cattle receiving Vaccine B had a greater (P < 0.01) fat thickness increase than the animals in the control group, while animals receiving Vaccine A had fat thickness change intermediate (P > 0.10) to the other treatment groups.

When compared at heavy initial BW, cattle receiving Vaccine A and Vaccine B had similar amounts of fat accretion (P = 0.56), while those receiving the control treatment tended to have a lesser amount (P = 0.09) of fat thickness change.

Findings of the ultransonography measurements are consistent with intake and gain data. The lack of change in rib-eye area based on treatment differences suggests that the treatments did not alter lean tissue deposition. In this experiment, differences in ADG among treatments by initial weight class were reflected in differences among change in subcutaneous fat thickness. This may suggest alterations in nutrient partitioning or efficiency of energy retention.

*Titer Response*

Both treatment (P < 0.01) and the treatment by day interaction (P < 0.01) affected BVD Type 1 titer count (Figure5). Initial body weight was not a significant covariate with titer response for BVD Type 1, Type 2, or IBR (P = 0.83, 0.92, and 0.11 respectively). Animals were confirmed seronegative to BVD Type 1, BVD Type 2, and IBR prior to the initiation of the project. Therefore, on d 0, no treatment differences existed. No measurable increase in BVD Type 1 titer had occurred by d 14. By d 28 vaccinates had measurable antibodies to BVD Type 1. On both d 28 and 42, Vaccine B had the highest (P < 0.01) titer counts followed by Vaccine A, with control treated steers exhibiting no measurable titer to BVD Type 1. On both d 28 and 42, all treatment groups were significantly different (P < 0.01) from each other.

Treatment (P < 0.01) and the treatment by day interaction (P < 0.01) also affected BVD Type 2 titer count (Figure 6). As with BVD Type 1, no animals had measurable antibody production to BVD Type 2 through d 14. By d 28, animals that had received a vaccine had measurable antibody production. Animals that had received Vaccine B had the greatest (P < 0.01) increase in titer counts followed by the cattle that had received Vaccine A. On d 42, animals receiving Vaccine B had the greatest (P < 0.01) titer counts to BVD Type 2; the $\log_2$ titer for Vaccine A treated calves was approximately 40% of that for Vaccine B treated calves. On d 28 and 42, all treatment groups were different (P < 0.01) from each other. These results are consistent with expectations, as Vaccine B vaccine had BVD Type 2 antigen while Vaccine A did not, relying instead upon cross-reacting antibodies generated in response to the BVD Type 1 antigen.

Treatment (P < 0.01) and the treatment by day interaction (P < 0.01) influenced production of antibody against IBR (Figure 7). On d 0, no animals had measurable antibody against IBR. At d 14, animals that had received Vaccine A had higher (P < 0.01) titer counts than those that had received Vaccine B, which in turn had greater (P < 0.01) antibody production than animals receiving the control treatment. These separations persisted at d 28 and d 42.

## Implications

This study emphasized that animals of different sizes can respond differently to vaccinations. Lightweight animals receiving a modified live vaccination had reduced rates of gain compared to non-vaccinates, conversely, vaccination enhanced performance in heavier than average animals. This implies that animal weight needs to be considered in the development of vaccination strategies.

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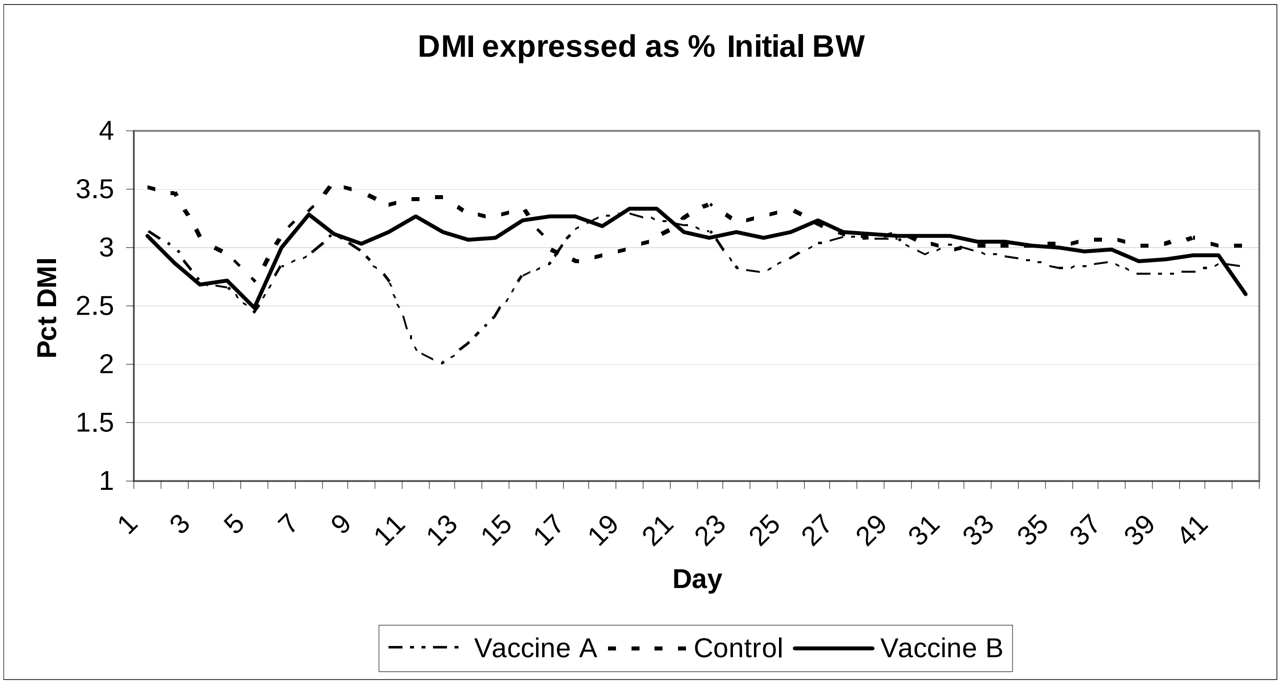


Figure 1. Dry matter intake (% of initial body weight) for steers vaccinated with Vaccine A, Vaccine B, or physiological saline (Control).[a,b,c]

[a]: Time (day) effect, P < 0.01

[b]: Treatment effect, P < 0.01

[c]: Treatment X time effect, P < 0.01; steers treated with Vaccine A had lower intake than steers from other treatment groups from days 10 through 17.

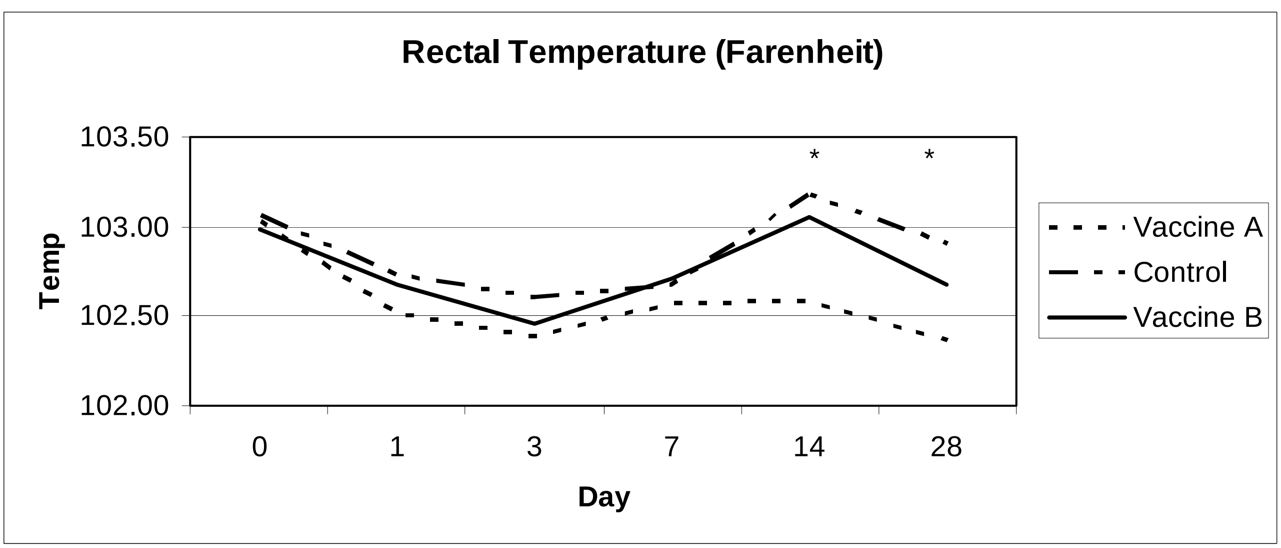


Figure 2. Rectal temperatures over time of steers vaccinated with Vaccine A, Vaccine B, or physiological saline (Control).[a]

[a]: Treatment X time effect, P = 0.06

[b,c]: Steers treated with Vaccine A had lower (P < 0.01) rectal temperature than those treated with Vaccine B or Control, which were similar (P > 0.5)

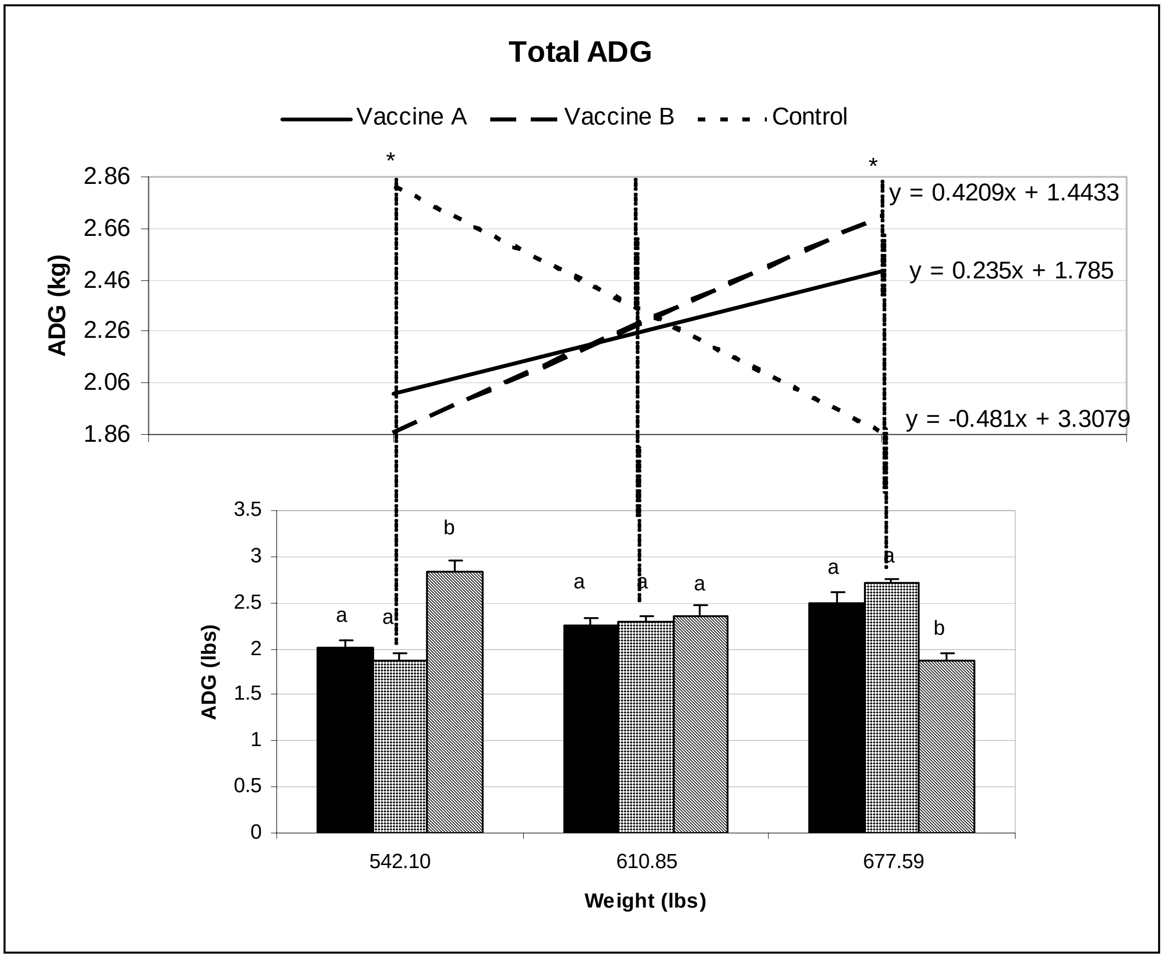


Figure 3. Average daily gain over 42 d of steers vaccinated with Vaccine A, Vaccine B, or physiological saline (Control) compared at initial body weights of -1 SD from mean initial BW, at the mean initial BW, or +1 SD from the mean initial BW.
* Initial body weight X treatment interaction ($P < 0.01$). Treatment comparisons are depicted below, where within weight class, different superscripts differ ($P < 0.05$).

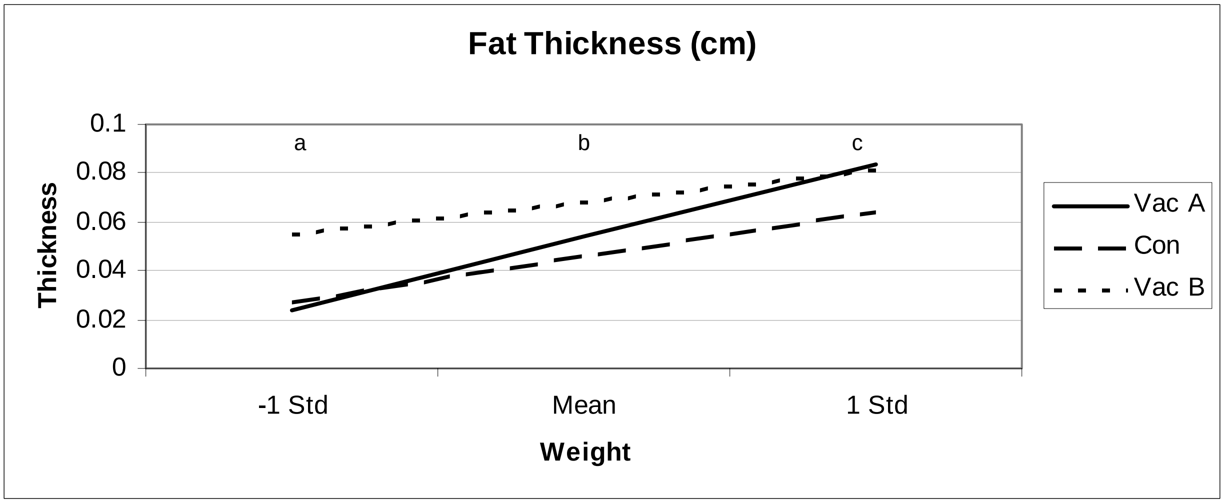


Figure 4. Change in 12th rib fat thickness (cm) over 42 d in steers vaccinated with Vaccine A, Vaccine B, or physiological saline (Control) when compared at initial body weights of -1 SD from mean initial BW, at the mean initial BW, or +1 SD from the mean initial BW.

[a]: Vaccine B greater than Vaccine A or Control, $P < 0.01$; Vaccine A and Control similar ($P = 0.68$).

[b]: Vaccine B greater than Control, $P < 0.01$; Vaccine A intermediate and not different from either Control or Vaccine B ($P > 0.2$).

[c]: Vaccine A and Vaccine B similar ($P = .52$) and greater than control ($P < 0.01$).

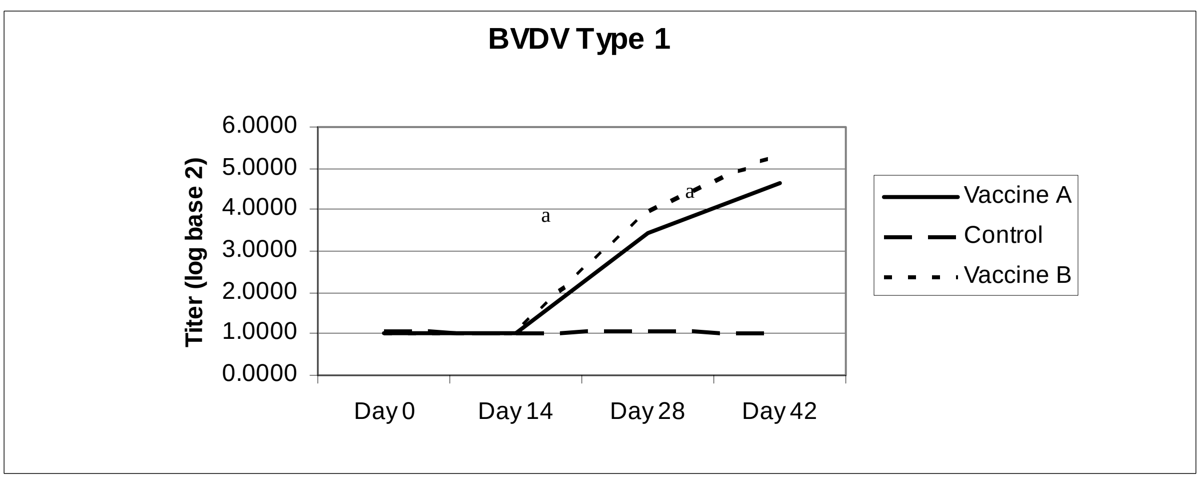


Figure 5. Serum neutralizing antibody titer response ($log_2$) to inoculation with BVD Type 1 in steers vaccinated with Vaccine A, Vaccine B, or physiological saline (Control) over 42 d.

[a]: Treatment X day interaction, $P < 0.01$. All treatments differ, $P < 0.01$.

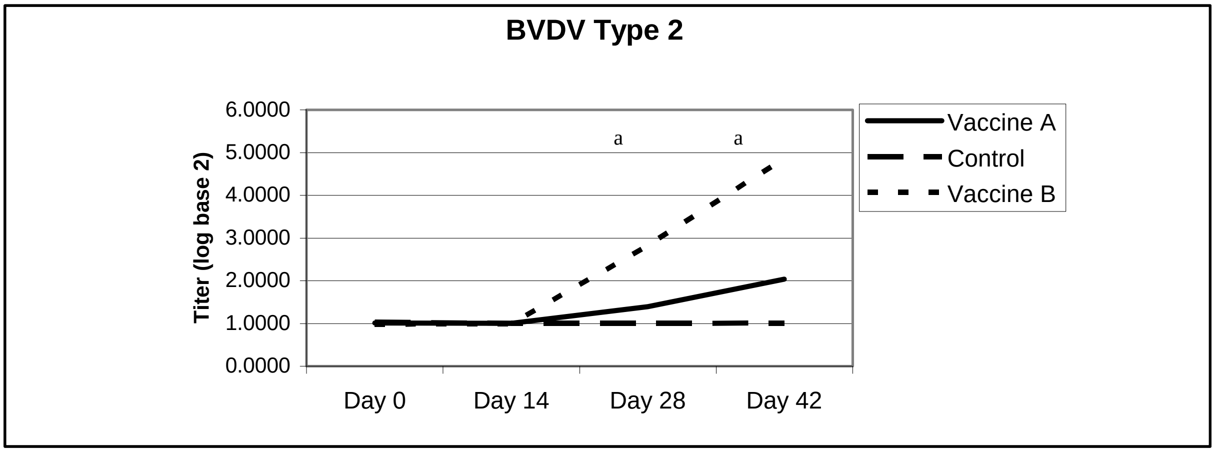


Figure 6. Serum neutralizing antibody titer response ($log_2$) to inoculation with BVD Type 2 in steers vaccinated with Vaccine A, Vaccine B, or physiological saline (Control) over 42 d.
[a]: Treatment X day interaction, P < 0.01. All treatments differ, P < 0.01.

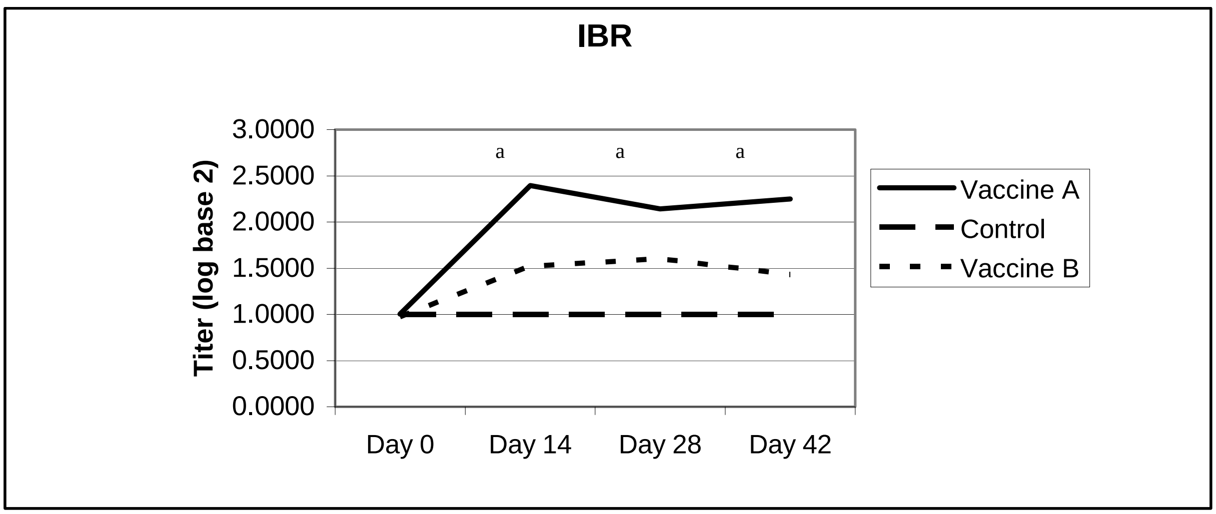


Figure 7. Serum neutralizing antibody titer response ($log_2$) to inoculation with IBR in steers vaccinated with Vaccine A, Vaccine B, or physiological saline (Control) over 42 d.
[a]: Treatment X day interaction, P < 0.01. All treatments differ, P < 0.01.

Table 1. Change in rib-eye area (in$^2$) over 42 d in steers vaccinated with Vaccine A, Vaccine B, or physiological saline (Control).

| | Initial Weight | | | | | |
|---|---|---|---|---|---|---|
| Treatment | -1 Std | SE | Mean | SE | 1 Std | SE |
| Vaccine A | -0.009 | 0.090 | -0.050 | 0.090 | -0.100 | 0.150 |
| Control | 0.380 | 0.130 | 0.230 | 0.090 | 0.070 | 0.140 |
| Vaccine B | 0.510 | 0.100 | 0.500 | 0.080 | 0.480 | 0.090 |

Table 2. Change in intramuscular fat deposition (%) over 42 d in steers vaccinated with Vaccine A, Vaccine B, or physiological saline (Control).

| | Initial Weight | | | | | |
|---|---|---|---|---|---|---|
| Treatment | -1 Std | SE | Mean | SE | 1 Std | SE |
| Vaccine A | 0.030 | 0.005 | 0.060 | 0.005 | 0.080 | 0.010 |
| Control | 0.030 | 0.010 | 0.050 | 0.005 | 0.075 | 0.008 |
| Vaccine B | 0.060 | 0.006 | 0.070 | 0.005 | 0.080 | 0.006 |

# METAPHYLAXIS THERAPY INTERACTS WITH TEMPERAMENT TO INFLUENCE PERFORMANCE OF NEWLY RECEIVED BEEF STEERS

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## Summary

The effects of metaphylactic therapy (Excede®) on growth, intake, and feeding behavior traits were evaluated in low-risk Santa Gertrudis steers that had been preconditioned and weaned for minimum of 28 days. Despite observing a low incidence of morbidity (one clinically morbid calf), metaphylactic treatment positively improved performance, although the beneficial response to the administration of Excede was dependent upon the temperament classification (calm vs excitable) of the steers. Metaphylactic therapy positively affected ADG, dry matter intake and feeding behavior traits for those steers classified as having excitable temperaments (fast exit velocity; EV), whereas, metaphylactic therapy was less effective in steers with calm temperaments (slow EV). These results suggest that temperament classification, based on EV, may be a useful management tool to more effectively administer antimicrobial products to newly received beef calves.

## Introduction

Metaphylactic therapy has been shown to reduce the risk of morbidity in calves that are at high risk for respiratory disease. However, the beneficial responses to the use of antimicrobial products are typically variable, due to lack of complete product-impact projections, inter-animal and herd-level variation in production responses, especially in low-risk calves. When morbidity exceeds 40%, metaphylactic therapy consistently reduces morbidity rates by 20 to 30 percentage units (Galyean et al., 1995). However, because sub-clinical disease also causes significant production losses, impacts of metaphylactic treatments on performance and feed efficiency should also be considered.

Temperament has been defined as an animal's behavioral responses to handling by humans. Burrow et al. (1988) developed an objective assessment of temperament that quantifies the speed an animal exits a squeeze chute (exit velocity; EV). Growing calves identified as having excitable (fast EV) temperaments have consumed less feed and grown slower than calves with more calm or docile (slow EV) temperaments (Brown et al., 2004). Serum cortisol concentrations have been shown to be positively correlated with EV (Curley et al., 2004), and negatively correlated with ADG and feed intake (Thies et al., 2002) in growing steers, suggesting that EV may be a useful indicator of temperament and stress responsiveness in cattle.

Excede® has been shown to be an efficacious metaphylactic treatment in newly weaned beef calves (Bremer et al., 2007). Ideally, metaphylaxis will reduce morbidity, while maintaining or enhancing feed consumption, to add value to an antimicrobial strategy. The effects of Excede® on individual feed consumption have not been extensively evaluated. Moreover, studies have not been conducted to determine if calf temperament influences the effects of metaphylaxis on intake and growth performance of newly received beef calves.

## Experimental Procedures

Santa Gertrudis steers (n = 119; initial BW 584 ± 53 lb) were preconditioned at the King Ranch, transported 350 miles to McGregor, and allowed to rest overnight before processing. At processing, steers were weighed, blocked by weight, and randomly assigned within weight block to receive 1.5 mL/100 lb BW of ceftiofur crystalline free acid (Excede® ; EXC) administered at the base of the ear, or to receive no antimicrobial (CON). Steers within blocks receiving both treatments resided in common pens. Steers were weighed on days 0, 14, and 28. Temperament was assessed on days 0 and 28 of the study, using subjective chute scores (CS; scale 1 = non-aggressive to 5 = aggressive), and using an objective measurement (EV). Exit velocity was measured as time taken to transverse a known distance while exiting the processing facility and was expressed as meters/second. Feed intake and feeding behavior traits of individual animals were recorded continuously from day 7 to 28 using a GrowSafe feeding system. Data were analyzed using a mixed model with treatment as fixed effect and initial temperament traits (CS or EV) used as covariates in separate analyses. An unequal slopes model was fit to examine the interactive effects of treatment and temperament classification on dependent variables. The effects of metaphylactic treatment were tested at the mean EV or CS minus one SD (classified as calm steers), mean EV or CS (classified as moderate steers), and mean EV or CS plus one SD (classified as excitable steers) to examine the nature of the temperament X treatment interactions.

## Results and Discussion

Despite the fact that overall morbidity rate was less then 1% (only one control steer treated for bovine respiratory disease), metaphylactic therapy had a positive effect on performance during the 28-day study. Steers administered Excede had higher ($P < 0.01$) ADG from day 0 to 14 and tended ($P < 0.10$) to have higher ADG during the 28-day study when compared to control steers (Table 1). However, average dry matter intake, feed:gain ratio, bunk-visit and meal durations were not significantly different between EXC- and CON-treated steers. Meal frequency was higher ($P < 0.05$) and bunk-visit frequency tended ($P < 0.10$) to be higher in steers treated with EXC compared to controls.

Subsequent analysis of the data, which included the use of initial EV as a covariate, revealed that there were significant interactions between metaphylactic therapy and temperament classification for most of the performance and feeding behavioral traits (Table 1). These interactions demonstrated that calm steers responded to metaphylactic therapy differently than excitable steers. In steers classified as having calm temperaments (one SD below mean EV), there were no differences in 14-d or 28-d ADG between control and EXE-treated steers (Figure 1). However, in steers with moderate (mean EV) and excitable temperaments (one SD above mean EV), steers treated with EXE had higher ($P < 0.05$) ADG. There were no treatment differences observed in dry matter intake and feed:gain ratio for those steers classified as having calm or moderate temperaments, but metaphylactic therapy resulted in higher ($P < 0.001$) dry matter intakes and a tendency ($P = 0.11$) for improved feed:gain ratios in steers with excitable temperaments (Figure 2).

Within the steers classified as having excitable temperaments, those treated with EXC spent more ($P < 0.05$) time per day at the feed bunk consuming feed, and tended ($P < 0.10$) to visit the feed bunks more frequently compared to control steers (Figure 3). In contrast, metaphylactic therapy had no effect on meal duration or bunk-visit frequency in steers classified as having calm or moderate temperaments.

When subjective chute scores were used to assess temperament, similar interactive effects between metaphylactic treatment and temperament classification were detected for most of the performance traits (data not shown). In general, EV was more effective than chute scores to assess the effects of temperament classification on performance responses to metaphylactic treatment with Excede. Results demonstrate that metaphylaxis resulted in positive effects on ADG, DMI and feeding behavior during the receiving period for steers with excitable temperaments, whereas, metaphylaxis had less utility for steers with calm temperaments.

## Implications

Process-control strategies that quantify and manage inter-animal variation in calf temperament may facilitate more judicious use of antimicrobial products and provide more consistent and predictable responses to metaphylaxis strategies, thereby improving the cost-to-benefit relationship of these technologies.

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Table 1. Effects of metaphylactic treatment and temperament classification on growth performance, intake, and feeding behavior traits in growing steers

| Item | Control | Excede | SE | TRT P-Value | TRT x EV P-Value |
|---|---|---|---|---|---|
| ADG (day 0 to14), lb/d | 4.07 | 4.61 | 0.14 | 0.01 | 0.001 |
| ADG (day 0 to 28), lb/d | 3.16 | 3.38 | 0.08 | 0.06 | 0.001 |
| Dry matter intake, lb/d | 16.6 | 17.1 | 0.34 | 0.35 | 0.001 |
| Feed:gain ratio | 5.43 | 5.12 | 0.13 | 0.16 | 0.11 |
| Bunk visit duration, min/d | 115.6 | 121.6 | 3.56 | 0.23 | 0.01 |
| Bunk visit frequency, events/d | 88.4 | 89.5 | 2.27 | 0.07 | 0.01 |
| Meal duration, min/d | 226.8 | 236.4 | 1.20 | 0.20 | 0.05 |
| Meal frequency, meals/d | 6.53 | 6.93 | 0.13 | 0.04 | 0.68 |

TRT = Treatment, EV = Exit velocity.

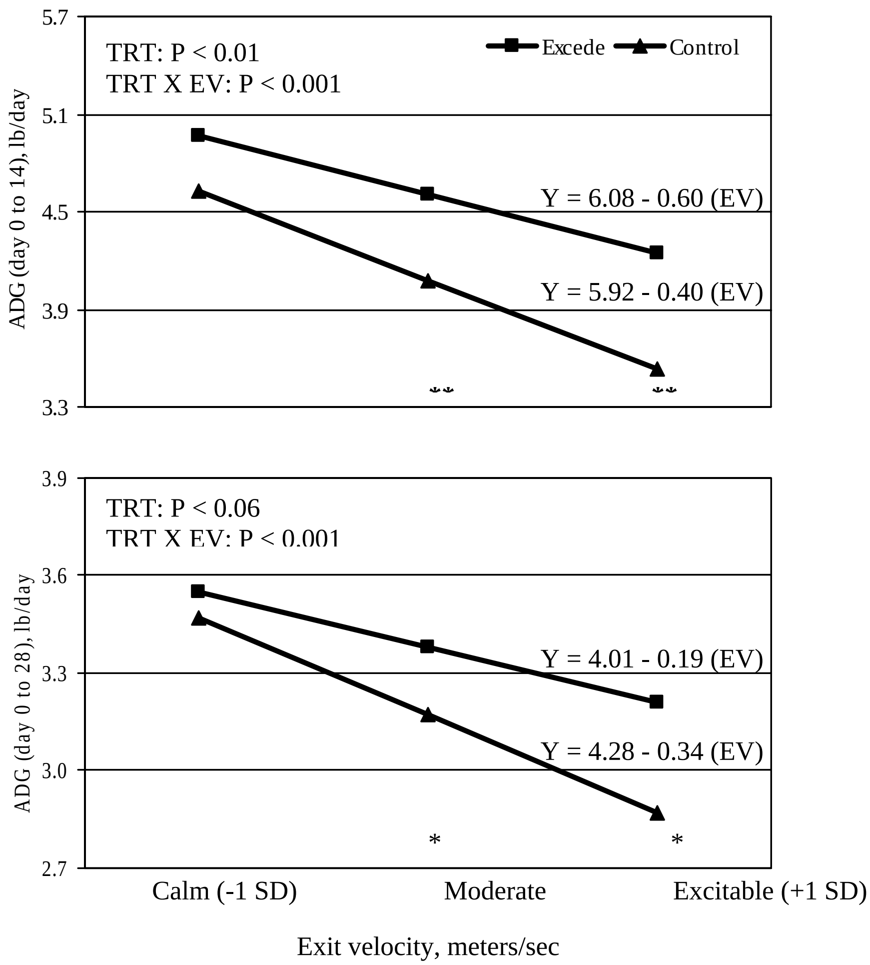


Figure 1. Effects of metaphylactic treatment and temperament classification on growth performance in growing steers. *,**Means differ at $P < 0.05$ and $P < 0.01$, respectively. TRT = Treatment, EV = Exit velocity.

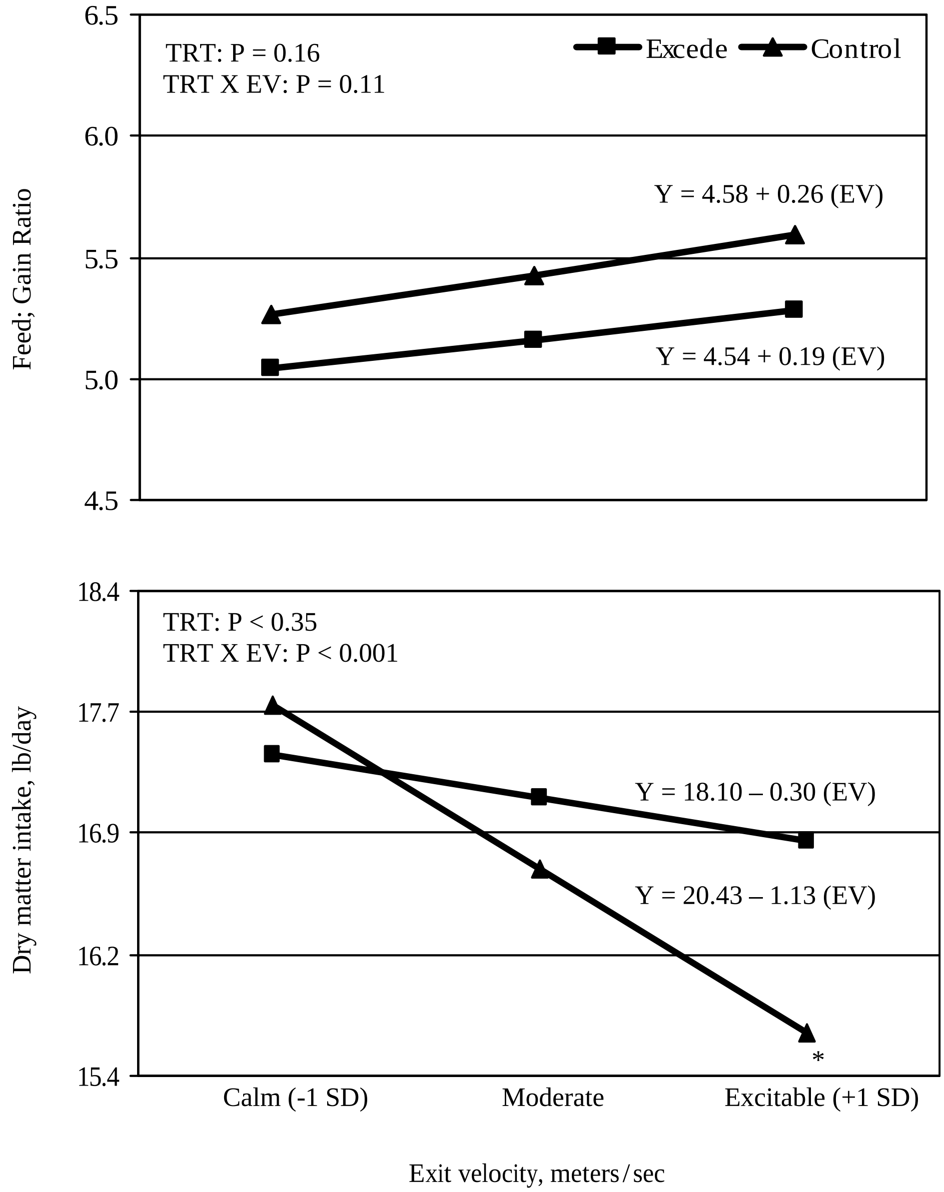


Figure 2. Effects of metaphylactic treatment and temperament classification on intake and feed:gain ratio in growing steers. *Means differ at $P < 0.05$. TRT = Treatment, EV = Exit velocity.

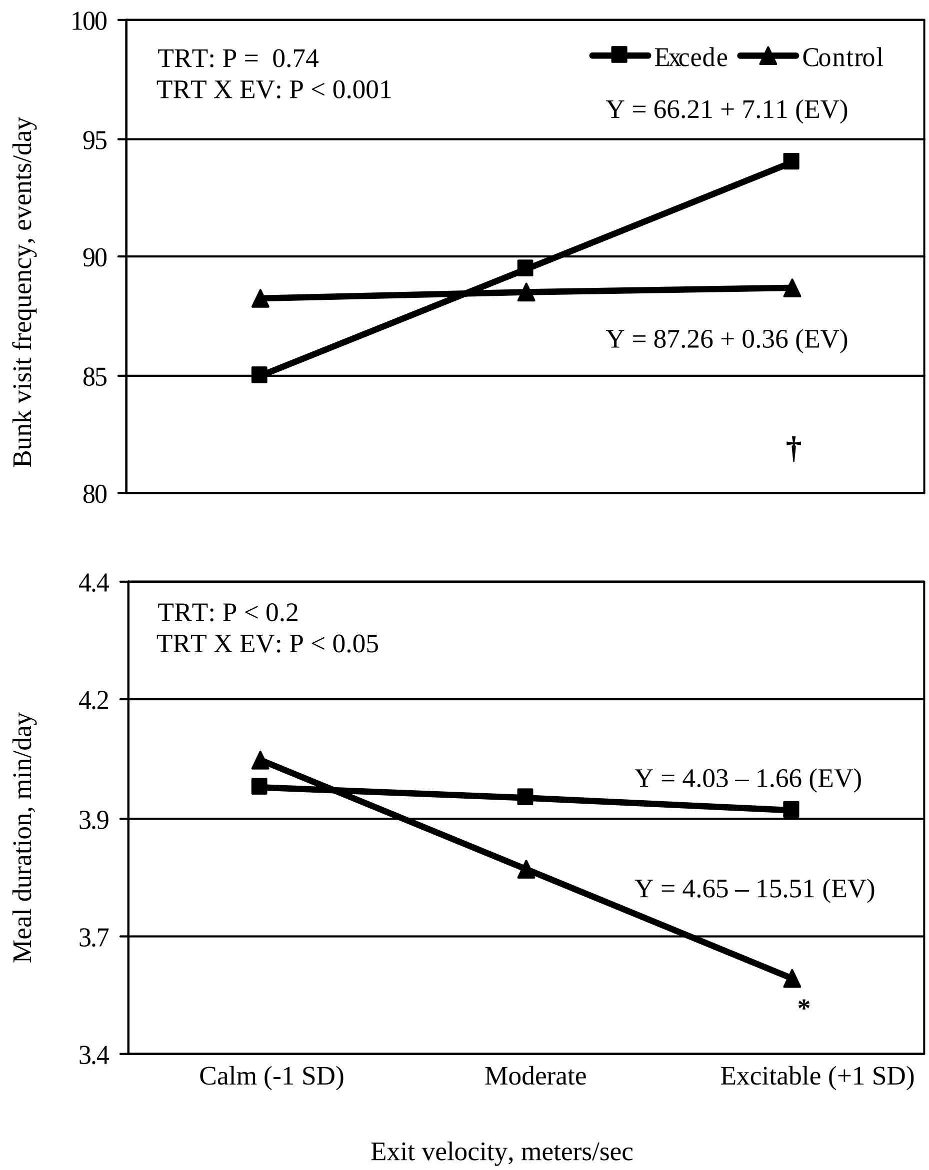


Figure 3. Effects of metaphylactic treatment and temperament classification on feeding behavior traits in growing steers. †,*Means differ at $P < 0.05$ and $P < 0.10$, respectively. TRT = Treatment, EV = Exit velocity.

# Breeding and Genetics

# META ANALYSIS OF THE CARCASS CHARACTERISTICS OF *BOS INDICUS* AND TROPICAL ADAPTED *BOS TAURUS* BREEDS

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## Summary

Data from nine studies were compiled to evaluate the effects of selection for post-weaning weight (**PWW**) in carcass characteristics and meat quality. Measurements of carcass characteristics were part of a selection program at Experimental Station of Sertãozinho in São Paulo, Brazil. The genetic groups evaluated were selected Nellore (NeS) and control Nellore (NeC), Caracu (CaS), Guzerah (GuS), and Gir (GiS). Animals CaS and NeS had heavier carcasses than NeC and GiS. The GuS animals were intermediate. Although the shear force values for NeS, NeC, GuS and GiS were acceptable, the CaS had the least shear force values. Genetic selection for PWW in Nellore cattle improved body size, carcass weight, and meat retail weights without altering the dressing percentage and body fat content.

## Introduction

Beef cattle productivity depends on herd genetic selection once nutritional and health requirements are met. Animals are selected based on performance, reproductive characteristics, conversion of feed into meat, and desirable carcass characteristics. Individual genetic evaluation programs are designed to identify next generation sires and dams, aiming to improve herd production and profitability.

A genetic program for selecting post-weaning growth performance of *Bos indicus* and tropical adapted *Bos taurus* breeds was initiated in 1976 at Experimental Station of Sertãozinho in São Paulo, Brazil. Several studies (Packer et al., 1986; Razook et al., 1998; Mercadante et al., 2003) have found a selection significant effect on ADG and body size, but few studies (Nardon et al., 2001; Razook et al., 2001) have thoroughly evaluated the impact of this selection on carcass characteristics and meat quality. Therefore, the objective of this work was to evaluate carcass characteristics of the selected progeny groups using meta-analysis.

## Experimental Procedures

Selection of *Bos indicus* breeds (Nellore, Guzerah, and Gir) and a tropical adapted *Bos taurus* breed (Caracu) has been conducted for 31 years at the Experimental Station of Sertãozinho in São Paulo, Brazil. Two lines were established for Nellore: a selected Nellore group (**NeS**), using bulls with high selection differential for yearling weight and a control Nellore group (**NeC**), using bulls with selection differential around zero. In contrast, only one line for Guzerah (**GuS**), Gir (**GiS**), and Caracu (**CaS**) breeds was developed using bulls with high selection differential; no control group was established for these herds.

Carcass characteristics measurements were part of the selection program. Samples of males from the progeny groups born from 1992 to 2000, after the feeding performance test, had been finished and slaughtered for carcass characteristics and meat quality evaluation. The samples were composed for animals that represented the average body weight of each herd obtained in the feeding performance test. In this study, nine progeny groups of the NeC, NeS and CaS, eight progeny groups of GuS, and four progeny groups of GiS herds were evaluated. Different treatments (i.e. feeding strategies, supplementation, castration, etc) were adopted in each year of study.

The maturity degree for each animal was computed based on the harvested BW and body composition, and mature body weight. Mature body weight was assumed to be at 22% empty body fat (Tedeschi et al., 2002). Specific equations were used to estimate the amount of carcass fat for animals from 1995 to 2000 progeny groups. The animals from the 1992, 1993, and 1994 progeny groups had the amount of carcass fat measured.

Statistical analyses were performed using the PROC MIXED of SAS (SAS Inst. Inc., Cary, NC). Data were analyzed using a random coefficients model, considering herd as a fixed effect and treatments within year and year as random effects. Either maturity degree (u) or initial BW (iBW) was interchangeably used as covariates. When maturity degree covariate effect was not significant ($P > 0.05$), iBW was the covariate adopted. The interaction between the covariate and genetic groups was tested and removed from the statistical model if not significant at $P < 0.05$. The least-squares means was used in the multiple comparison analysis.

$$Y_{ijkl} = \mu + trt(yr)_{i(j)} + yr_j + herd_k + \beta_i(x_{il} - \bar{x}..) + \varepsilon_{ijkl}$$

where $\mu$ = population average; $trt(yr)_{i(j)}$ = treatment within j<sup>th</sup> year of study; $yr_j$ = j<sup>th</sup> year of study; $herd_k$ = k<sup>th</sup> genetic group of study (NeC, NeS, CaS, GiS, GuS); $\beta_i$ = covariate slope; $x_{il}$ = either u or iBW for i<sup>th</sup> treatment and l<sup>th</sup> value; $\bar{x}$ .. = average of the covariate, and $\varepsilon_{ijkl}$ = uncontrolled, random error.

## Results and Discussion

The quantitative analysis of the carcass characteristics indicated that the selection for post-weaning weight (**PWW**) indirect effect (effects not selected for) had an impact on the selected progeny groups when compared with non-selected progeny groups, after 31 years of selection. The differences between NeS and NeC groups were likely caused by the selection because they originated from the same base population. Although the selection process started at the same time for the CaS, GuS, and GiS groups, most of the differences found reflect the differences between breeds, mainly those related to body size.

The interaction between genetic group and the covariate was significant for initial BW (**iBW**) (*P* = 0.038), hump (*P* < 0.01), shank (*P* = 0.027), hindquarter bones (*P* = 0.003), and rib eye area (*P* = 0.011). For all other variables, the interaction was no significant (*P* > 0.05).

Sire ranking is not an easy task because several carcass traits depend on different slaughter end points (age, carcass weight, fat thickness, fat trim percentage, etc) (Koch et al., 1979; Wheeler et al., 1996). Furthermore, if growth and/or fattening rates differ among breeds, the comparison of breeds at different levels of a physiological end point could result in an unwanted re-ranking the sires or changes in the magnitude of the differences. For this reason, maturity degree was used as a covariate.

Table 1 shows that NeS had higher iBW, final BW (**fBW**), ADG, empty BW (**EBW**), liver weight, HCW, cold carcass weight (**CCW**), carcass length (**CL**), and carcass depth (**CD**) than the NeC. These differences are the direct and correlated responses of the genetic selection for PWW. No differences were observed in KPH and dressing percentage (**DP**) between NeS and NeC groups. This information implied the selection increased the body size of Nellore, without affecting the body fat and carcass yields. Several authors (Nardon et al., 2001; Razook et al., 2001; Vittori et al., 2006) have found similar results comparing selected and non selected Nellore groups.

The CaS was the group with the largest body size, being similar to NeS in most of the variables studied (fBW, ADG, EBW, liver, HCW, CCW, and CD). In general, GuS had an intermediate body size, and GiS was similar to NeC, which had the smallest body size. CaS had the highest CL (lengthiest animals). Nellore had greater DP than CaS and GuS while GiS was intermediate.

No significant differences (*P* = 0.058) among genetic groups were found for forequarter weight and some forequarter meat cuts (Table 2). Significant differences were observed for blade (*P* < 0.01), hump (*P* = 0.045), and shank (*P* = 0.048). The significant difference found for hump for CaS was expected because it is the only *Bos taurus* breed evaluated. Significant differences were detected for hindquarter (*P* = 0.001) and spare ribs (*P* < 0.01). NeS had the heaviest hindquarter. Hindquarter for CaS did not differ significantly from the other groups. CaS had the greatest weight for striploin (*P* < 0.01). This was expected because CaS had the lengthiest carcass and both variables are strongly correlated (Luchiari Filho et al., 1985). No significant differences were found for tenderloin between CaS and NeS. However, the other groups had lighter tenderloins. NeS had the heaviest rump (*P* = 0.010), knuckle (*P* < 0.01), topside (*P* < 0.01), flat (*P* < 0.01) and eye-round (*P* < 0.01). Although CaS was similar to NeS in carcass and forequarter weights, they have less meat in the leg region. This result is similar to those reported by Nardon et al. (2001) and Bonilha et al. (2007). CaS had heaviest spare rib weights. This finding was expected because it is strongly correlated with CL (Luchiari Filho et al., 1985).

Table 3 shows the average of carcass quality characteristics among groups. CaS and NeS had greater REA than GuS, GiS and NeC (*P* = 0.042). No significant differences (*P* = 0.059) were found for fat thickness. This was likely because iBW was the covariate. CaS had the least value for shear force. *Bos indicus* breeds usually have greater and more variable values of shear force (Morgan el al., 1991). Although the shear force was greater than CaS, *Bos indicus* breeds had acceptable values of shear force (bellow 11.0 lb). No significant differences were found for meat quality (evaporation losses (*P* = 0.336), drain losses (*P* = 0.763), and total losses (*P* = 0.790)) among groups.

The examination of tenderness of *Bos indicus* cattle is not a novel topic. Morgan et al. (1991) documented that the origin of the cattle is a source of variation in beef tenderness. Areas having a higher proportion of *Bos indicus* influence usually have greater and more variable values for shear force than areas with less *Bos indicus* influence. Early research indicated that meat from *Bos indicus* cattle was tougher due to lower levels of intramuscular fat and greater connective tissue content when compared to *Bos taurus*. Wheeler et al. (1990) showed that *Bos indicus* cattle had lower levels of µ-calpain and greater levels of calpastatin. They concluded that calpain activity, as modulated by calpastatin, played a major role in the inherent tenderness differences among groups.

## Implications

Selection for post-weaning weight in Nellore cattle increased body size, carcass weight, and retail meat cuts without altering the dressing percentage and body fat content. For CaS, GiS, and GuS groups, differences might be due to inherent variation among breeds. The NeS and CaS had heavier carcasses and retail meat cuts, the GuS had intermediate body size, and NeC and GiS had lighter carcasses and retail meat cuts. Even though CaS, a tropical adapted *Bos taurus* breed, had lesser values of shear force, the *Bos indicus* breeds had acceptable shear force values.

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Table 1. Adjusted body and carcass characteristics for either initial BW (iBW) or maturity degree (u) of five genetic groups

| Variables [x] | Genetic Groups [y] | | | | | SEM | *P*-value | Covariate *P*-value | |
|---|---|---|---|---|---|---|---|---|---|
| | NeS | NeC | CaS | GuS | GiS | | | iBW | u |
| n | 125 | 107 | 116 | 102 | 39 | --- | --- | --- | --- |
| iBW*, lb | 767[b] | 661[d] | 836[a] | 736[bc] | 681[cd] | 28.4 | <0.01 | --- | <0.01 |
| fBW, lb | 1071[a] | 1003[b] | 1102[a] | 1052[ab] | 1003[b] | 32.4 | <0.01 | <0.01 | --- |
| ADG, lb/d | 1.76[a] | 1.51[b] | 1.58[ab] | 1.76[a] | 1.48[b] | 0.234 | 0.002 | --- | 0.002 |
| EBW, lb | 972[a] | 915[b] | 994[a] | 952[ab] | 908[b] | 31.8 | <0.01 | <0.01 | --- |
| Liver, lb | 11.3[b] | 10.5[c] | 13.1[a] | 11.4[b] | 10.8[c] | 0.313 | <0.01 | <0.01 | --- |
| KPH, lb | 17.6[b] | 16.0[b] | 20.9[a] | 16.1[b] | 14.8[b] | 1.53 | 0.001 | --- | <0.01 |
| HCW, lb | 631[a] | 593[c] | 626[ab] | 595[bc] | 584[c] | 21.8 | 0.002 | <0.01 | --- |
| DP, % | 58.9[a] | 59.0[a] | 56.5[c] | 56.7[c] | 57.7[b] | 0.417 | <0.01 | --- | <0.01 |
| CCW, lb | 622[a] | 584[b] | 615[a] | 586[b] | 575[b] | 21.4 | 0.002 | <0.01 | --- |
| CL, in | 49.2[b] | 47.2[c] | 51.2[a] | 50.0[b] | 49.2[b] | 0.460 | <0.01 | <0.01 | --- |
| CD, in | 15.8[b] | 15.7[bc] | 16.2[a] | 15.5[c] | 15.4[c] | 0.133 | <0.01 | <0.01 | --- |

Within a row, means without a common superscript letter differ ($P < 0.05$) by least square-means adjusted for Tukey.

[x]fBW = final BW; EBW = empty BW; DP = dressing percentage; CCW = cold carcass weight; CL = carcass length; and CD = carcass depth.

[y]NeS = Selected Nellore; NeC = Control Nellore; CaS = Selected Caracu; GuS = Selected Guzerah; and GiS = Selected Gir.

*Significant interaction between genetic group and covariate at $P < 0.05$.

Table 2. Adjusted commercial cuts for either initial BW (iBW) or maturity degree (u) of five genetic groups

| Variables | Genetic Groups | | | | | SEM | *P*-value | Covariate *P*-value | |
|---|---|---|---|---|---|---|---|---|---|
| | NeS | NeC | CaS | GuS | GiS | | | iBW | u |
| n | 125 | 107 | 116 | 103 | 39 | --- | --- | --- | --- |
| Forequarter, lb | 127[a] | 121[a] | 128[a] | 122[a] | 121[a] | 4.98 | 0.058 | <0.01 | --- |
| Blade, lb | 23.6[a] | 20.1[c] | 23.2[ab] | 21.4[bc] | 19.3[c] | 0.809 | <0.01 | --- | 0.003 |
| Neck, lb | 11.4[a] | 10.4[a] | 12.4[a] | 11.7[a] | 12.5[a] | 0.897 | 0.225 | 0.001 | --- |
| Chuck, lb | 20.3[a] | 20.7[a] | 24.5[a] | 20.6[a] | 20.1[a] | 1.88 | 0.082 | <0.01 | --- |
| Brisket, lb | 13.1[a] | 13.0[a] | 13.5[a] | 12.5[a] | 12.7[a] | 0.609 | 0.090 | <0.01 | --- |
| Hump*, lb | 7.87[a] | 8.49[a] | 2.23[b] | 8.71[a] | 12.2[a] | 0.805 | 0.045 | <0.01 | --- |
| Shank*, lb | 8.36[a] | 7.50[b] | 7.87[ab] | 7.58[ab] | 7.72[ab] | 0.295 | 0.048 | <001 | --- |
| Bones, lb | 23.2[ab] | 20.6[c] | 23.8[a] | 22.1[bc] | 21.4[bc] | 0.690 | 0.001 | <0.01 | --- |
| Shavings, lb | 17.0[ab] | 15.5[b] | 18.4[a] | 16.1[ab] | 12.2[c] | 1.33 | 0.048 | --- | 0.005 |
| Hindquarter, lb | 143[a] | 134[b] | 138[ab] | 134[b] | 132[b] | 4.17 | 0.001 | <0.01 | --- |
| Striploin, lb | 15.7[b] | 15.2[b] | 18.2[a] | 15.5[b] | 14.9[b] | 0.620 | <0.01 | <0.01 | --- |
| Tenderloin, lb | 4.83[a] | 4.21[c] | 4.81[ab] | 4.39[bc] | 4.06[c] | 0.157 | <0.01 | --- | 0.003 |
| Rump, lb | 13.8[a] | 12.6[b] | 12.8[ab] | 12.7[ab] | 12.1[b] | 0.483 | 0.010 | <0.01 | --- |
| Knuckle, lb | 11.7[a] | 10.3[b] | 10.6[b] | 10.4[b] | 10.6[b] | 0.320 | <0.01 | --- | <0.01 |
| Topside, lb | 19.5[a] | 17.2[b] | 16.8[b] | 17.7[b] | 16.6[b] | 0.553 | <0.01 | --- | 0.001 |
| Flat, lb | 12.7[a] | 11.3[b] | 10.3[b] | 11.1[b] | 11.2[b] | 0.410 | <0.01 | --- | 0.035 |
| Eye-round, lb | 5.58[a] | 4.74[c] | 4.67[c] | 5.03[bc] | 5.38[ab] | 0.203 | <0.01 | --- | 0.004 |
| Flank steak, lb | 2.62[a] | 2.58[a] | 2.51[a] | 2.91[a] | 2.95[a] | 0.256 | 0.138 | <0.01 | --- |
| Leg-end, lb | 8.71[a] | 7.47[c] | 8.31[ab] | 8.09[b] | 7.85[bc] | 0.238 | <0.01 | --- | 0.013 |
| Boneless, lb | 2.05[a] | 1.99[a] | 1.97[a] | 2.17[a] | 2.14[a] | 0.101 | 0.268 | --- | --- |
| Bones*, lb | 26.2[ab] | 24.0[c] | 27.3[a] | 24.7[bc] | 24.3[bc] | 0.622 | 0.047 | <0.01 | --- |
| Shavings, lb | 21.3[a] | 18.7[b] | 21.7[a] | 19.3[ab] | 19.2[ab] | 1.28 | 0.003 | --- | <0.01 |
| Spare ribs , lb | 42.1[b] | 36.8[c] | 47.6[a] | 39.5[bc] | 36.2[c] | 2.36 | <0.01 | --- | 0.001 |
| Beef plate, lb | 29.5[ab] | 29.3[ab] | 32.0[a] | 28.7[b] | 28.7[b] | 2.58 | 0.013 | <0.01 | --- |
| Bones, lb | 5.36[b] | 4.92[b] | 5.95[a] | 5.53[ab] | 5.42[ab] | 0.232 | 0.002 | <0.01 | --- |
| Shavings, lb | 6.39[a] | 5.34[a] | 6.55[a] | 5.78[a] | 5.84[a] | 1.28 | 0.198 | --- | <0.01 |

Within a row, means without a common superscript letter differ ($P < 0.05$) by least square-means adjusted for Tukey.

Table 3. Adjusted carcass quality characteristics for either initial BW (iBW) or maturity degree (u) of five genetic groups

| Variables | Genetic Groups | | | | | SEM | *P* - value | Covariate *P* - value | |
|---|---|---|---|---|---|---|---|---|---|
| | NeS | NeC | CaS | GuS | GiS | | | iBW | u |
| N | 125 | 107 | 116 | 103 | 39 | --- | --- | --- | --- |
| Rib-eye area*, | 10.6[a] | 10.0[b] | 11.2[a] | 10.0[b] | 9.42[b] | 0.260 | 0.042 | --- | 0.002 |
| Fat thickness, | 0.265[a] | 0.240[a] | 0.279[a] | 0.275[a] | 0.269[a] | 0.033 | 0.059 | <0.01 | --- |
| Shear force, lb | 10.1[b] | 9.99[b] | 8.27[a] | 10.2[b] | 10.7[b] | 0.657 | 0.001 | --- | --- |
| Evaporation | 13.0[a] | 12.8[a] | 12.6[a] | 13.0[a] | 14.6[a] | 0.703 | 0.336 | --- | --- |
| Drain losses, % | 12.0[a] | 11.8[a] | 11.8[a] | 11.9[a] | 11.1[a] | 0.669 | 0.763 | --- | --- |
| Total losses, % | 25.1[a] | 24.7[a] | 24.4[a] | 24.9[a] | 25.6[a] | 0.736 | 0.790 | --- | --- |

Within a row, means without a common superscript letter differ ($P < 0.05$) by least square-means adjusted for Tukey.

# EVALUATION OF $F_1$ COWS SIRED BY BRAHMAN, BORAN, AND TULI FOR REPRODUCTIVE AND MATERNAL PERFORMANCE AND COW LONGEVITY

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## Summary

Birth weight (n = 1,277) and weaning weight (n = 1,090) of their calves, calf crop born (n = 1,386), calf crop weaned (n = 1,294), cow weight (n = 1,474) and body condition score (n = 1,473) were evaluated from 1994 to 2006 in 143 $F_1$ cows sired by Brahman, Boran, and Tuli bulls and out of Hereford and Angus cows. Mouth scores (n = 139) were assigned to remaining cows in 2004, 2005, and 2006. Birth weights of calves were not significantly different. Significant differences were found for weaning weight with values of 519.0 lb, 486.4 lb, and 458.5 lb, respectively, for calves out of Brahman-, Boran-, and Tuli-sired cows. Means for calf crop born for Brahman-, Boran-, and Tuli-sired cows were .88, .93, and .89, respectively, with no significant differences; means for calf crop weaned were .85, .90, and .87, respectively, with no significant differences. Brahman-sired cows were significantly heavier than the Boran- and Tuli-sired cows. Boran- and Brahman-sired cows had more desirable mouth scores than Tuli-sired cows. Mature size was more moderate and reproductive rates tended to be higher for Boran-sired cows, but Brahman-sired cows weaned heavier calves.

## Introduction

It has been repeatedly reported that $F_1$ *Bos taurus-Bos indicus* females are superior to the parental breeds in terms of reproductive and maternal performance (Gregory et al., 1985; Trail et al., 1985; Cundiff et al., 1998). Due to the inability of the $F_1$ Brahman-*Bos taurus* female to produce a replacement that equals her production capability, interest in breeds of African origin, such as the Tuli and Boran, has increased (Herring et al., 1996). The Tuli is a Sanga breed developed in what is now Zimbabwe. The Boran is a Zebu breed from East Africa. Comparison of $F_1$ cows sired by Tuli and Boran bulls to those sired by Brahman bulls is an important step in developing alternative *Bos indicus-Bos taurus* crossbreeding systems. The purpose of the present study was to evaluate and compare $F_1$ cows sired by Brahman, Boran, and Tuli bulls for traits representing maternal and reproductive performance and cow longevity.

## Experimental Procedure

A total of 143 $F_1$ Brahman x Hereford, Brahman x Angus, Tuli x Hereford, Tuli x Angus, Boran x Hereford, and Boran x Angus cows born in 1992 (n = 66) and 1993 (n = 77) at the Texas A&M Research Center (TAES) at McGregor were evaluated. The semen of 9 Tuli, 7 Boran, and 16 Brahman bulls was used to breed mature Angus and Hereford cows. Boran and Tuli semen was imported from Australia, and semen from American Brahman bulls considered to be representative of the breed in the early 1990's was used. Herring et al. (1996) reported birth, weaning, and post weaning performance of animals evaluated in the study as well as carcass characteristics of contemporary steers produced from these matings.

As heifers, females were bred to Angus bulls in 1993 and 1994. In 1994, two-year-old cows born in 1992 were bred to Brangus bulls. The cows were then bred to Brangus bulls in 1995, $F_1$ Hereford-Brahman bulls in 1996, $F_1$ Brahman-Angus bulls in 1997, $F_1$ Angus-Brahman bulls in 1998, 3/8 Nellore-5/8 Angus bulls in 1999, $F_1$ Nellore-Angus bulls in 2000, 3/8 Nellore-5/8 Angus bulls in 2001 and 2002, and Angus bulls in 2003, 2004, and 2005. Although cows have been bred to bulls of different breeds in different years, all females were bred to the same breed of sire each year. Calving occurred from approximately February 15 to May 5 each year. Calves born to these $F_1$ heifers and cows from 1994 to 2005 were evaluated. Each calf was weighed and tagged for identification within 48 h of birth, and bull calves were castrated. Calves were weaned in October or November of each year at approximately seven months of age. Calves were not implanted. At the time of weaning, calves were weighed and assigned a body condition score. Cows were palpated for pregnancy at weaning, weighed, and assigned body condition scores. Calving rate and weaning rate were evaluated in the $F_1$ cows as binary (0 or 1) traits using least squares analyses.

In the fall of 2004, 2005, and 2006 at palpation, incisor condition was evaluated with the assignment of mouth scores. Solid mouths had no teeth loose or missing, broken mouths had one or more teeth loose or missing, and smooth mouths had no incisors remaining (or those remaining were small and badly deteriorated). The mouth scores were analyzed as a binary trait, where, in the first case, the smooth mouths were assigned a value of zero and both solid and broken mouths were assigned a value of one. In the second case, both smooth and broken mouths were assigned a score of zero and solid mouths were assigned a value of one. Cows were culled for severe injuries, poor health or at least two failures to have or wean a calf.

The variables considered in this study were analyzed through the mixed model procedure of SAS (1990). Calf's birth weight and weaning weight were evaluated using a model that included the effects of sire breed of dam, dam breed of dam, calf's birth year / age of dam, and calf's sex; dam and sire of dam were included as random effects. In the weaning weight model, weaning age within calf's birth year / age of dam was included as a covariate. Calf crop born, calf crop weaned, and cow's weight at palpation were evaluated using a model that included sire breed of dam, dam breed of dam, calf birth year / age of dam; dam and sire of dam were included as random effects. Sire breed of calf was almost completely confounded with calf's birth year, so the latter was used in the analyses. Additional details concerning the analyses were reported by Ducoing (2002), Cunningham (2005), and Maiga (2006).

## Results and Discussion

No significant differences in birth weight were found among calves out of cows sired by the three breeds. Adjusted means for calves born to Brahman-, Boran-, and Tuli-sired cows were 77.2, 77.6, and 76.8 lb, respectively (Table 1). These values were lower than those obtained by Cundiff et al. (1999). On average, the bull calves were 5 lb heavier at birth than the heifers. The effect of calf's birth year / age of dam was significant, with the adjusted mean weight of calves out of two-year-old dams lower than those out of the other age groups. Birth weight of calf peaked in 2001, when the cows were 8 and 9 years of age, with means of 84.6 lb and 84.1 lb, after which means decreased gradually.

Note that calves born in 2003, 2004 and 2005 were sired by Angus bulls and those born from 1993 to 2002 were sired by *Bos indicus* influenced bulls. This is also consistent with Roberson et al. (1986), where birth weights increased as dam age increased to 7 years of age and declined gradually for older dams. McCarter et al. (1991) also found significant increases in birth weight as dam age increased from 3 to 5 years.

The effect of sire breed of the cow was significant for weaning weight of their calves (Table 1). Calves born to Brahman-sired cows were heavier (519.0 lb) than those out of cows sired by Boran bulls (486.4 lb), and those out of Boran-sired cows were heavier than those out of Tuli-sired cows (458.5 lb). Calf's sex was significant with a difference of 29.5 lb between the adjusted means of the steer and heifer calves. The difference between steers and heifers was 24.1 lb in calves out of Boran-sired cows, and 26.0 lb in calves out of Tuli-sired cows, whereas this difference was 38.4 lb in calves out of Brahman-sired cows. Weights of weaned calf per cow exposed were 440.1 lb, 436.8 lb, and 398.4 lb in Brahman-, Boran-, and Tuli-sired females (Table 2).

Significant differences among the three sire breeds were found for cow's weight at palpation, with the Brahman-sired cows being heavier, on average, than those sired by Boran and Tuli bulls. In the year 2004, adjusted mature weights were 1361.2 lb, 1196.8 lb, and 1167.0 lb for Brahman-, Boran-, and Tuli-sired cows, respectively (Table 2). Cows in the Brahman-sired group had the largest adjusted mean weight for every year of evaluation.

Sire breed of the cow did not have a significant effect on calving rate or weaning rate (Table 3). Cundiff et al. (1999) observed similar results for calf crop at weaning.

Incisor condition was evaluated in 2004, 2005, and 2006. Solid mouths had no teeth loose or missing, broken mouths had one or more teeth lose or missing, and smooth mouths had no incisors remaining (or the few remaining were small and badly deteriorated). The mouth scores were analyzed as a binary trait of females remaining in the herd, where, in the first case, the smooth mouths were assigned a value of zero and both solid and broken mouths were assigned a value of one.. In the second case, both smooth and broken mouths were assigned a score of zero and solid mouths were assigned a value of one. Least squares means for mouth scores and percentages of cows remaining in the herd in 2004, 2005, and 2006 are presented by breed of sire in Table 4. There was a greater proportion of Boran (95%) and Brahman (94%) crosses with either solid or broken mouths than the Tuli crosses (78%). There was a larger proportion of Brahman crosses (53%) having solid mouths than Tuli crosses (24%), and the Boran- sired females were intermediate (39%). Riley et al. (2001) reported similar results to those of the Boran and Brahman crosses. In that study, crosses of several *Bos indicus* breeds with the Hereford were compared to Angus-Hereford $F_1$ crosses. When smooth mouths were scored a value of zero and both solid and broken mouths were scored a value of one, the least squares means at fourteen years of age for the *Bos indicus* crosses were 0.92 to 1.01 compared to the least squares means for the Angus crosses of 0.65. When the smooth and broken mouths were scored as zero and solid as one, the least squares means at fourteen years of age for the *Bos indicus* crosses ranged from 0.32 to 0.57 and the mean for the Angus crosses was 0.13.

## Implications

When Tuli and Boran bulls were crossed with Angus and Hereford females, the resulting crossbred females were more moderate in size than those sired by the American Brahman of the early 1990s. Reproductive rates were higher in Boran-sired cows than in Brahman-sired cows; however, the Brahman-sired cows weaned heavier calves than the other two sire groups. The Tuli cross cows weaned significantly lighter calves and had shorter productive lives than both the Brahman and Boran-sired cows. Boran-sired females were more moderate in mature size and had higher reproductive rates. The Brahman-sired cow's advantage in weaning weight of calf could offer some compensation for their lower reproductive performance. Brahman- and Boran-sired cows had better mouths later in life

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Table 1. Least squares means for calf growth traits

| Sire breed of cows | Birth weight (lb) | Weaning weight (lb) |
|---|---|---|
| Brahman | 77.2 | 519.0 |
| Boran | 76.6 | 486.4 |
| Tuli | 76.8 | 458.5 |

Table 2. Least squares means for mature $F_1$ cow palpation weight (lb) and condition score in the fall of 2004 and pounds of calf weaned per cow exposed by sire breed of cow

| Sire breed of cows | Mature cow weight [a] at palpation (lb) | Cow body condition score [a] at palpation | Pounds of calf weaned per cow exposed |
|---|---|---|---|
| Brahman | 1361.2 | 5.4 | 440.1 |
| Boran | 1196.8 | 5.4 | 436.8 |
| Tuli | 1167.0 | 5.4 | 398.4 |

[a] Adjusted means in the year 2004, when the cows born in 1992 and 1993 were 11 and 12 years of age, respectively.

Table 3. Least squares means for reproductive traits of $F_1$ cows

| Sire breed of cows | Calving rate | Weaning rate |
|---|---|---|
| Brahman | .881 | .848 |
| Boran | .931 | .898 |
| Tuli | .890 | .869 |

Table 4. Least squares means and standard errors for mouth scores and percentage of cows remaining in the herd through 2006 for $F_1$ cows

| Sire breed | Mouth score [a] | Mouth score [b] | No. of original cows | % of cows remaining in 2004 | % of cows remaining in 2005 | % of cows remaining in 2006 |
|---|---|---|---|---|---|---|
| Boran | $0.95 \pm 0.05^{c}$ | $0.39 \pm 0.09^{cd}$ | 36 | 69 | 61 | 56 |
| Brahman | $0.94 \pm 0.04^{c}$ | $0.53 \pm 0.08^{c}$ | 56 | 52 | 43 | 36 |
| Tuli | $0.78 \pm 0.05^{d}$ | $0.24 \pm 0.09^{d}$ | 52 | 50 | 44 | 27 |

[a] Analyzed as a binary trait, where smooth = 0 and broken or solid = 1.
[b] Analyzed as a binary trait, where smooth or broken = 0 and solid = 1.
[c,d] Means in the same column without common superscript differ ($P < 0.05$)

# Carcass and End Products

# HAS BEEF QUALITY GRADE DECLINED?

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## Summary

Recent reports have suggested that quality grade within the United States beef supply has declined dramatically over the last twenty years. Specifically, these reports hypothesize that the apparent decline in the percentage of choice grade beef has been the result of a significant increase in the percentage of select grade beef, and that this has represented a shift downward in overall beef quality. Various production practices and management decisions have been implicated as causative agents for this decline. The continuing trend toward value-based marketing (e.g., grid pricing of carcasses) and relatively high choice-select price spreads, coupled with reports of declining quality grade, have caused beef producers to be concerned that value is being lost through production of lower quality product. Based on evaluation of historical data and economic indicators, it is difficult to support the hypothesis that U.S. beef quality is declining, or that the slaughter mix is decidedly non-optimal.

## Introduction

National Beef Quality Audit (NBQA) data have been published (Lorenzen et al., 1993; Boleman et al., 1998; McKenna et al., 2002) or presented (Griffin, 2006) for years 1991, 1995, 2000, and 2005, respectively. The quality grade data from these reports are shown in Figure 1.

Over the 14-year time span of the NBQA data, there has been variation in the proportions of cattle grading choice and select, but a specific trend is difficult to identify. This is in dramatic contrast to the recent reports based on USDA data which suggest that the proportion of choice carcasses declined from 79% to 57.2% over the same time span. One explanation for this discrepancy is the fact that the historical USDA data are most often expressed as a proportion of the product graded, rather than as a proportion of the total produced. The primary objective of this review was to quantify historical trends in choice and select beef supply based on yearly pounds of federally inspected product (i.e., all beef produced for sale) rather than the standard method based on the percentage of carcasses grading choice of all carcasses graded. This approach allows for a more consistent comparison of historical trends with respect to the increase in total number of carcasses graded and historical increases in carcass weight. Secondary objectives were to explore the short-term demand structures for choice and select product and the economic tradeoffs in altering production strategy to target high levels of choice output as a means of evaluating producer economic incentive to alter production streams.

## Experimental Procedures

Yearly data from 1938 to 2005 were acquired from USDA (USDA, Marketing and Regulatory Programs, AMS, Livestock and Seed Programs, Meat Grading and Certification Branch, 2006), and included pounds of federally graded choice product, pounds of federally graded select product, and pounds of federally inspected beef.

Because these data (e.g., percent choice) are typically expressed as a proportion of graded carcasses, and because there has been variation in the total amount of product graded over time, the amount of choice product and the amount of select product were expressed as a proportion of all federally inspected beef, rather than only as a proportion of graded product, to generate a stable basis for comparison.

Quantity data (e.g., pounds of choice product) were analyzed as time series data using a linear regression model including first- (linear), second- (quadratic) and third-order (cubic) effects of time. Initial analyses were conducted across the entire time span of the data set, and subsequent analyses were conducted across shorter time spans in an attempt to resolve shorter term questions. A time span from 1938 to 1965 was considered representative of "historical" grading standards. Beginning in 1965, carcasses were required to have the face of the rib exposed for grading. Prior to 1965 quality grades were assigned on the basis of external fat cover (USDA, 1997). The second time span considered was 1965 to 1975. In 1975, muscle conformation was removed as a factor influencing quality grade because it was found to be unrelated to palatability (USDA, 1997). Also, quality grade and yield grade were separated in the grading scheme. The third time span considered was 1975 to 1987, because in 1987 the select grade replaced the good grade (USDA, 1997). The fourth time span considered was 1987 to 1997, because of the increased marbling requirement to achieve choice grade for B maturity carcasses (USDA, 1997). Also, 1997 closely corresponds to the escalation in formula-based (i.e., carcass pricing) marketing (Cattle Fax, 2006). The final time span considered was 1997 to 2005, to capture recent changes in supply dynamics. The timeline in Figure 2 summarizes some of these key factors.

Because increases in total output over long time spans may be related to population increases, pounds of federally graded product coupled with historical data for U.S. population (United States Census Bureau) were used to express the quantity of choice or select product available per capita. This expression dampens the effects of both expanding total red meat production and expanding US population over the time period studied, and provides an estimate of the amount of product available to a consumer.

Daily supply and demand data were recorded for the most recent 52 weeks (i.e., May, 25, 2006 to May, 26, 2007) to provide a short term perspective of total product demand. USDA data were collected from both the daily carcass equivalent index (AMS Report # NW_LS410) and the national daily cattle and beef summary (AMS Report # LM_XB403). These data included daily average boxed beef price for the supply and demand of choice and select product and daily load count (i.e., 1 load = 40,000 lb boxed beef equivalent) for choice and select product. Daily data were then aggregated into weekly averages and elasticity estimates were calculated to determine demand sensitivity in relation to price.

## Results and Discussion

*Historical Trends in Quality Grade*

Figure 3 depicts several expressions of the proportion of choice product from 1938 to 2005. The (▬) line is consistent with recent reports, and expresses the proportion of choice product as a percentage of product graded, not as a proportion of the total produced. This proportion reached a peak in 1986 at nearly 94%. Note that across most of the span of the data, the proportion of choice product expressed as a percentage of graded product moves inversely to the proportion of product actually graded. For example, during World War II, the large requirements for food products by the armed forces caused an escalation in the grading of beef, because specifications required that the beef be graded. During this time, the proportion of choice carcasses declined precipitously. Correspondingly, in 1987 a large increase in the proportion of the total slaughter that was actually graded also increased, presumably due to the reclassification of 'good' as 'select' and an increase in the marketability of this product. Again, an apparent decline in the percentage choice of carcasses graded is observed.

However, when the proportion of choice product is expressed as a percentage of the total federally inspected slaughter, a more precise representation of the proportion of the population of beef cattle grading choice, this large apparent decline from 1986 to 1996 is eliminated. Many of the dynamics in the proportion of Choice beef previously reported are a function of the change in the amount of product graded. This is likely because of a change in the incentives of producers and processors to grade all cattle, rather than only those that were most likely to grade choice. Expression as a percentage of the total beef supply provides a more consistent basis of evaluation when grading is a voluntary action. Figure 4 supports this premise. The proportion of Select (Good prior to 1987) beef was low and declining until 1987. This suggests that producers only elected to grade cattle that were likely to grade choice, until an incentive (the enhanced marketability of "Select"; increasing opportunities for value-based marketing) caused a greater proportion of the total supply to be presented for grading.

*Trends in Choice and Select Beef Output*

Annual choice beef production (pounds of choice beef produced) is shown in Figure 5. From 1938 to 2005 there were significant ($P < 0.01$) linear and quadratic effects of time on the amount of choice beef produced. Over this time span, the amount of choice product increased (positive linear coefficient) at a decreasing rate (negative quadratic coefficient). This is opposite to the prevailing perception that quality grade has been in a steady decline for decades.

Annual good/select beef production is also shown in Figure 5. From 1938 to 2005 there were significant ($P < 0.01$) linear, quadratic, and cubic effects of time on the amount of good/select beef produced. The cubic effect is a result of a relatively stable product volume from 1938 to 1986, followed by a rapid escalation until 2000, followed by another period of apparent stability. This rapid shift from one plane to the next characterizes the cubic response, which is the major feature of the dynamics of select beef production over time.

It is important to note that the large increase in Select production during the late 1980's and 1990's does not appear to be offset by reductions in Choice production during the same time span, suggesting that the increase in Select graded product was a result of grading more cattle, not a result if declining overall marbling in the population.

*Dynamics in product availability*

The overall increases in production of both choice and select product over time have occurred at a time of population expansion in the United States. Therefore, it may be most meaningful to express the amounts of choice and select product produced per capita (scaled to the population) as an indicator of product availability (Figure 6). It is important to note that this is not necessarily an expression of consumption, but rather an expression of the availability of product in the marketplace. Consumption would be the per capita production value adjusted for net beef exports, and would be slightly lower than these values.

From 1938 to 2005 there were significant ($P < 0.01$) linear, quadratic, and cubic effects of time on the amount of choice and select beef available per capita. Over this time span, the availability of choice and select products have both increased, although the dynamics and timing of the increases are dissimilar. To further explore these discrepancies, the data can be evaluated across shorter time periods within the overall span of data.

There were no statistically significant ($P = 0.19$) effects observed for choice product availability from 1938 to 1965, although pounds of choice product available to consumers increased from the period low of 1.74 lb per person in 1940 to the period high of 39.84 lb per person in 1965. The only exception to this annual increase was a decline in 1947 to 2.11 lb per person. The average amount of choice beef available to consumers during this time span was 16.78 lb with a CV of 79.8% (if the time trends are ignored). The lack of regression effects is a result of the variation in per capita choice output in the 1940's and early 1950's. There were significant linear ($P < 0.01$), quadratic ($P = 0.01$), and cubic ($P = 0.04$) effects observed for select product availability from 1938 to 1965, as the amount of select product available to consumers increased from a period low of 1.35 lb in 1939 to a period high of 19.84 lb in 1945. From that point, select product availability declined annually to 8.38 lb in 1965. The average amount of select beef available during this period was less than the amount of choice beef available at 9.42 lb annually. This decline, in the face of expanding total beef availability, reflects the low incentive to present cattle for grading that were not highly likely to grade choice.

Choice product availability increased linearly ($P = 0.03$) from 1965 to 1975., The amount of choice product available per consumer steadily increased from 1965 to a period high of 54.51 lb in 1970, but then declined to a period low of 37.09 lb in 1975. The linear effect is positive; the last year observed in this period (1975) exhibited a sharp decline in product availability, but this decline lasted only one year. The average amount of choice beef available during this period was almost three-fold greater than the previous period (48.49 lb annually) with a CV of 11.8%, a substantial reduction in variability compared to the first period evaluated. There were no statistically significant ($P = 0.22$) effects observed for select availability from 1965 to 1975, as the amount of select product per person remained fairly consistent with a period high of 9.05 lb in 1966 to a period low of 6.18 lb in 1975. The average amount of available select beef during this period was slightly less than the previous time span at 8.04 lb annually.

Between 1975 and 1987, there were significant linear ($P = 0.04$) and quadratic ($P = 0.05$) effects on choice availability over time. The amount of available choice product increased from a period low of 37.09 lb in 1975 to a period high of 53.74 lb in 1978, but declined somewhat to 1987. The average amount of choice beef available to the consumer during this period was similar to the previous period at 47.45 lb yearly, with a CV of 10.8%. It should be noted that the percentage decline in period mean choice output (2.1%) across this period is much less than the intra-period variation. There were statistically significant linear, quadratic, and cubic ($P < 0.01$) effects observed for available select beef from 1975 to 1987. Consistent with the amount of select beef produced during this period, select beef availability steadily declined from a period high of 6.18 lb in 1975 to a period low of 1.09 lb in 1987. The average amount of available select beef during this period was also the lowest historically at 2.53 lb annually.

There was a statistically significant linear ($P = 0.03$) and a tendency for a quadratic ($P = 0.09$) effect observed for available choice beef from 1987 to 1997, as the amount of choice beef available remained consistent throughout this period. Initially, there was a slight decline from the period high of 47.55 lb in 1988 to 39.88 lb in 1991, but availability subsequently stabilized with an average of 42.21 lb of available choice beef during this time span. The dynamic in per capita output corresponds closely with the national cow herd inventory during this time period. A reduction in intra-period CV to 7.2% is evidence of some stabilization in availability compared to previous periods. There were statistically significant quadratic and cubic ($P = 0.02$) effects observed for available select beef from 1987 to 1997. From the historical low of 1.09 lb in 1987, available select product increased steadily to a period high of 26.61 lb in 1997. Over this period, the average amount of available select product increased nearly seven-fold to 13.98 lb annually.

There were no significant ($P = 0.21$) effects observed for the amount of choice beef available to consumers from 1997 to 2005. The available amount again remained fairly consistent during this period; however, there was a numerical decline from a period high of 43.42 lb in 1998 to the period low of 37.53 lb in 2004. The average amount of available choice beef throughout this time span was 3.3% less than the previous period, at 40.82 lb annually with a CV of 5.5%. Similar to the results for choice, there were no significant ($P = 0.15$) effects observed for the amount of select beef available to consumers from 1997 to 2005, as available select product remained consistent over this time span. Also similar to choice beef availability, available select product declined from a period high of 29.13 lb in 2000 to a low of 25.48 lb in 2004. The average amount of available select product during this period increased two-fold to a historical high of 27.36 lb yearly. Together (i.e., available choice and available select) this period represents the largest amount of total beef available to consumers.

These data suggest that the addition of the select grade dramatically expanded the availability of that product to consumers without negatively affecting the availability of choice product. Additionally, these data consistently reflect the results presented for the amount of graded beef produced annually, suggesting that the production of graded beef has adjusted with changes in consumer demand.

*Short run demand structure for choice and select beef*

The relative product demand ratio shown in Table 1 was derived from the average weekly percentage change in the individual product category (i.e., choice and select) demand value divided by the average weekly percentage change in total demand value. The relative product demand ratio suggests that for every one unit increase in total product demand, choice product value increased by 1.62 units and select product value increased by 0.16 units. Thus, a weekly increase in total beef demand is more heavily influenced by an increase in choice product demand.

Demand elasticity as shown in Table 1 and illustrated in Figure 7 was derived from (average weekly load count change/average weekly load price change)*(average weekly load price/average weekly load count). The choice load elasticity (-0.39) suggests that there was limited change in the weekly quantity demanded for choice product at any given price level. On the other hand, as weekly supply of select product and subsequent price shifts there is a more dramatic impact on the quantity of select beef demanded (elasticity of -0.90). Collectively, the overall (i.e., choice and select) product demand is intermediate at -0.65.

In the short term, demand for choice product is inelastic and demand for select product is relatively more in nature. As the weekly supply of total graded product increases and decreases and pricing points are discovered for each product category, the amount of choice product demanded remains relatively constant. As supply tightens, the price of either category would be expected to increase. This price increase would have minimum impact on the amount of choice product sold, but might have a large impact on the volume of select product moved. It is important to note that when total product supply increases and price is reduced within both product segments a slightly greater reduction in the price of choice beef compared to select might be expected. This coupled with a limited impact on the quantity of choice demanded (inelasticity) of choice product could reduce total expenditures for beef if the increase in supply is driven by a substantial increase in choice product availability. Alternatively, a stable supply of choice product provides for short term stability in overall beef price. Perhaps this is a possible explanation for the stability in choice supply witnessed over the last two time periods discussed earlier. The large discrepancy in elasticity for the two categories also suggests that choice and select are not necessarily strong substitutes. As supply tightens, the same amount of choice is demanded, albeit at a much higher price. However, as prices increase, the quantity of select product demanded diminishes, suggesting that consumers substitute with non-beef products.

## Implications

There is little evidence that the increase in Select beef output has been the result of declining amounts of choice beef produced. Increases in the amount of select beef produced result from the increase in the proportion of beef that is presented for grading. The increase in the proportion of beef graded is most likely due to the enhanced marketing options available due to the creation of the Select grade and the increase in value-based (e.g., formula or grid) pricing structures in the beef industry. Presentation of historical Choice beef production as a proportion of graded product is misleading, as it does not account for the expansion of total graded carcasses. The high proportions of Choice product previously reported (i.e., 94%) thus reflect a producers ability to sort cattle, not the overall quality of beef produced.

The recent stabilization in the slaughter mix suggests that an optimum is being approached. Evaluation of short-run demand structure supports this premise, and suggests that the products may not be substitutes. It is difficult to support the hypothesis that U.S. beef quality is declining, or that the slaughter mix is decidedly non-optimal.

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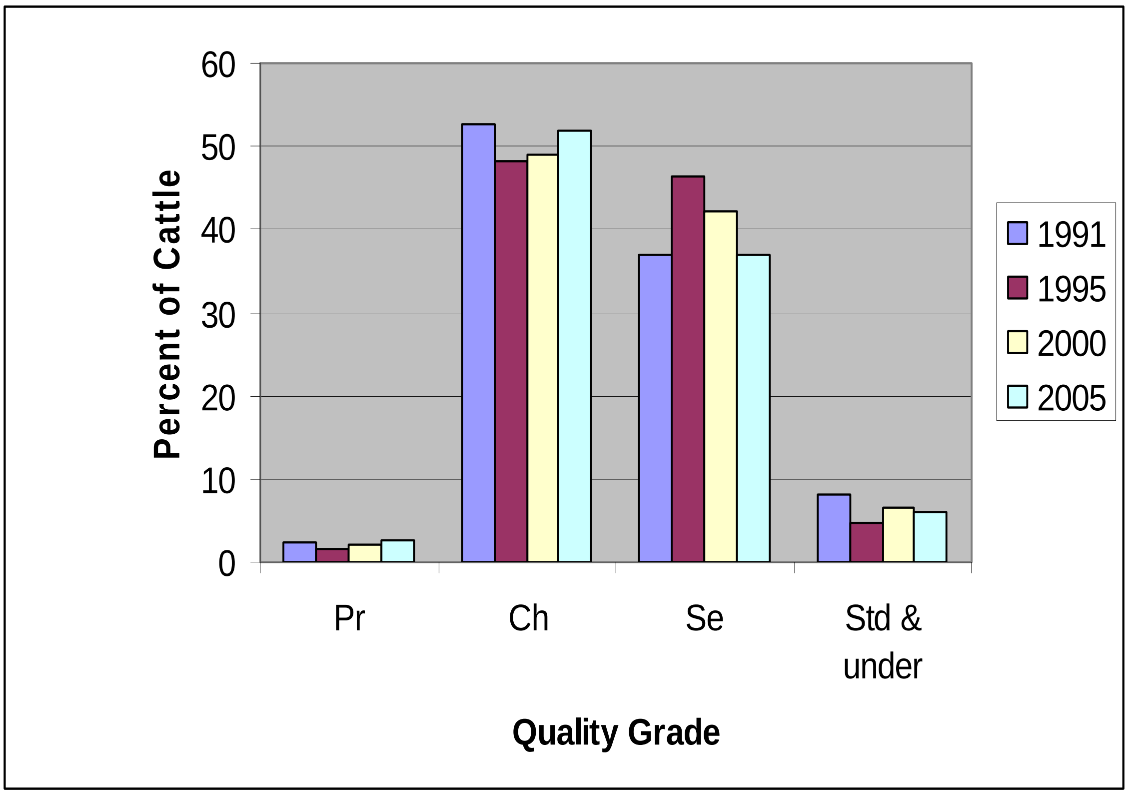


Figure 1. Distribution of beef quality grades in the U.S. fed beef supply (adapted from National Beef Quality audits, 1991, 1995, 2000, and 2005).

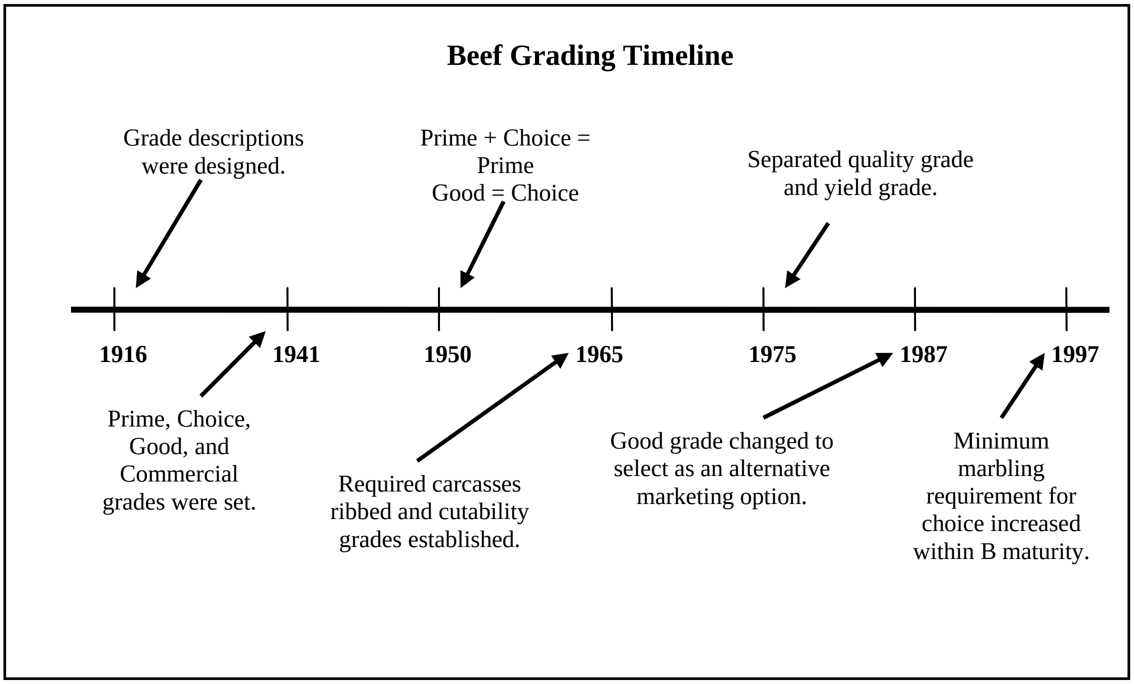


Figure 2. Timeline of key changes in grading standards or practices.

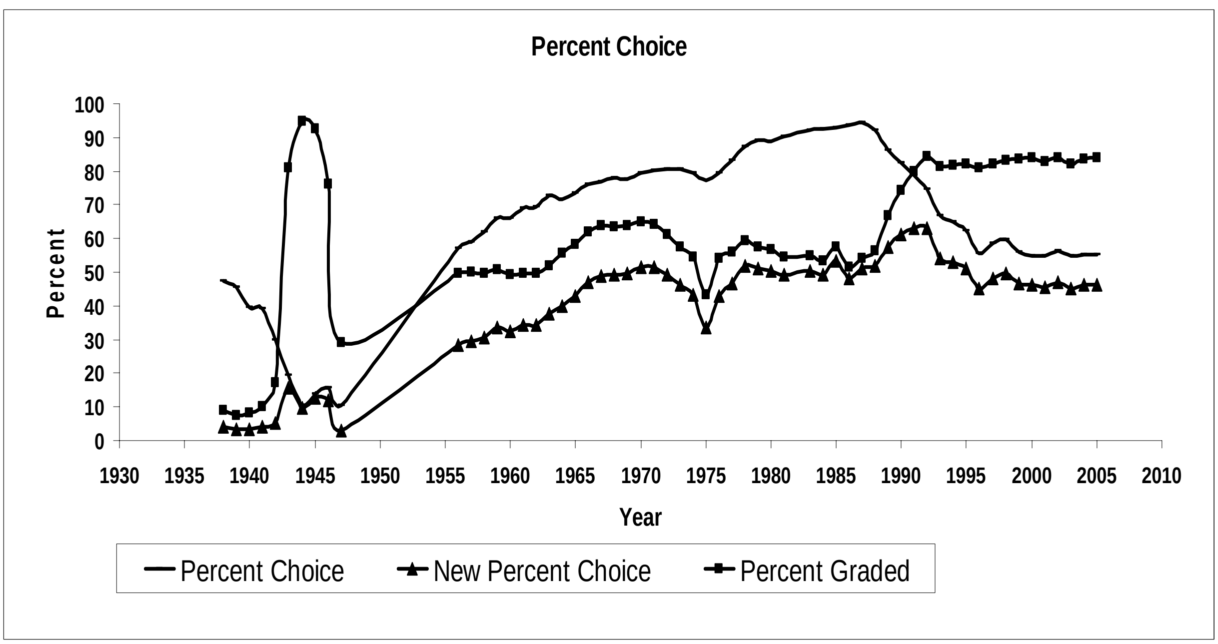


Figure 3. Yearly percent of pounds of beef that graded choice from 1938 to 2005. The (▬) line represents the percentage pounds that graded choice of the total pounds graded. The (■) line represents the percentage of pounds graded of the total pounds. The (▲) line represents the percentage pounds that graded choice relative to the total percentage of pounds graded.

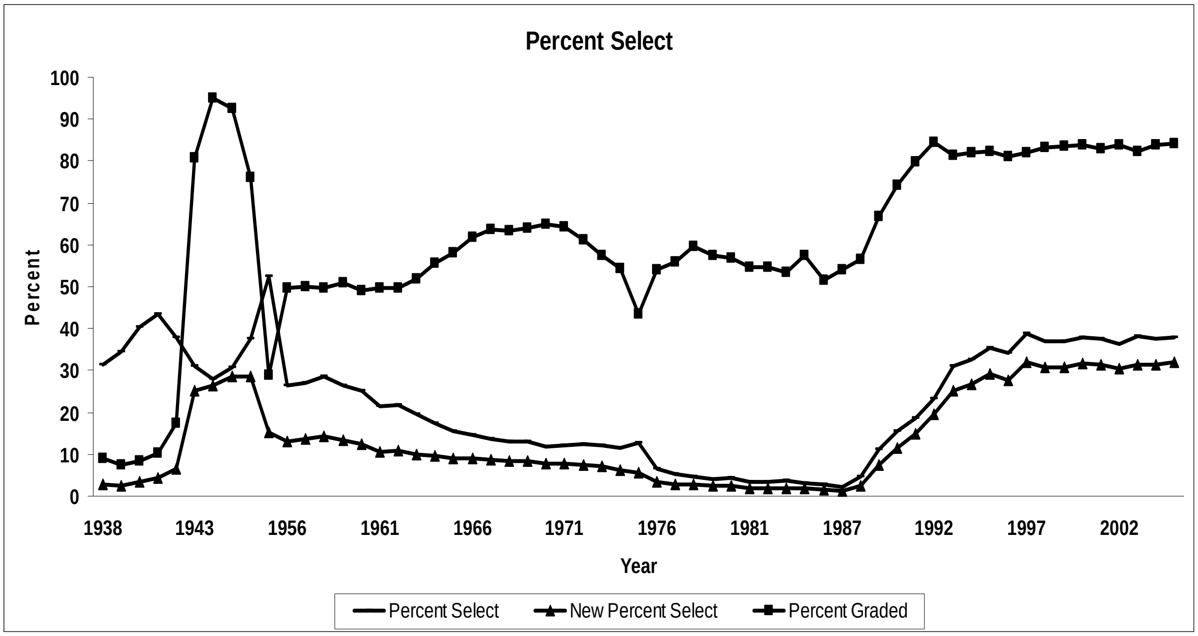


Figure 4. Yearly percent of pounds of beef that graded select from 1938 to 2005. The (▬) line represents the percentage pounds that graded select of the total pounds graded. The (■) line represents the percentage of pounds graded of the total pounds. The (▲) line represents the percentage pounds that graded select relative to the total percentage of pounds graded.

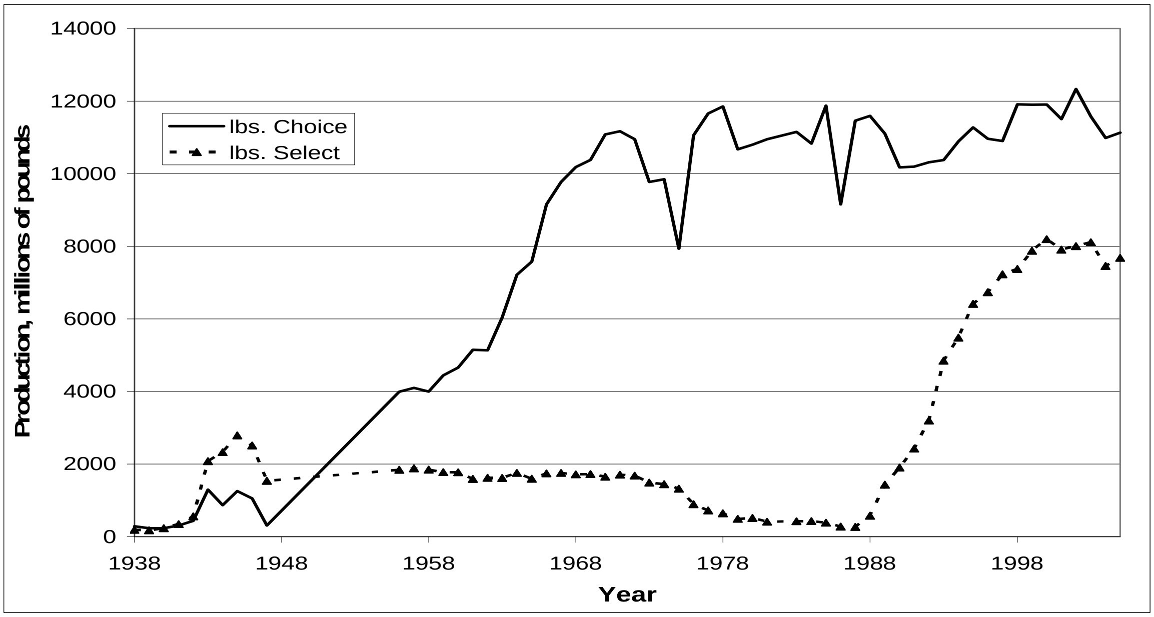


Figure 5. Production of choice- and select- graded product (millions of pounds) from 1938 to 2005.

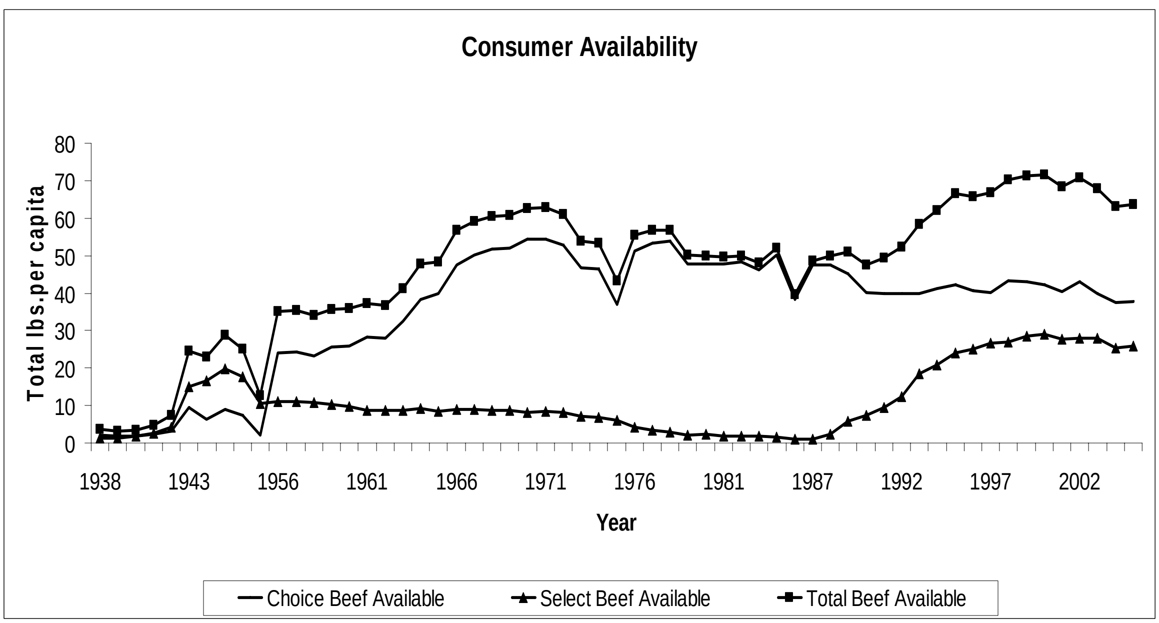


Figure 6. Per capita production (pounds per person) of choice, select, and total beef from 1938 to 2005.

Table 1. Short-run (52-week, May 2006 to May 2007) measures of pricing and demand for choice and select beef.

| Product | Average Price | Average Load Count | Average Total Demand | % Total | Load Elasticity | Relative Product Demand |
|---|---|---|---|---|---|---|
| Choice | $138.27 | 671.1 | $36,923,894 | 56% | -0.39 | 1.62 |
| ST DEV | $7.23 | 121.7 | $6,042,339 | | | |
| Select | $125.18 | 576.2 | $28,691,221 | 44% | -0.90 | 0.16 |
| ST DEV | $8.72 | 102.5 | $4,691,606 | | | |
| Total | $132.10 | 1247.3 | $65,615,116 | 100% | -0.65 | 1.00 |
| ST DEV | $7.63 | 190.7 | $9,182,145 | | | |

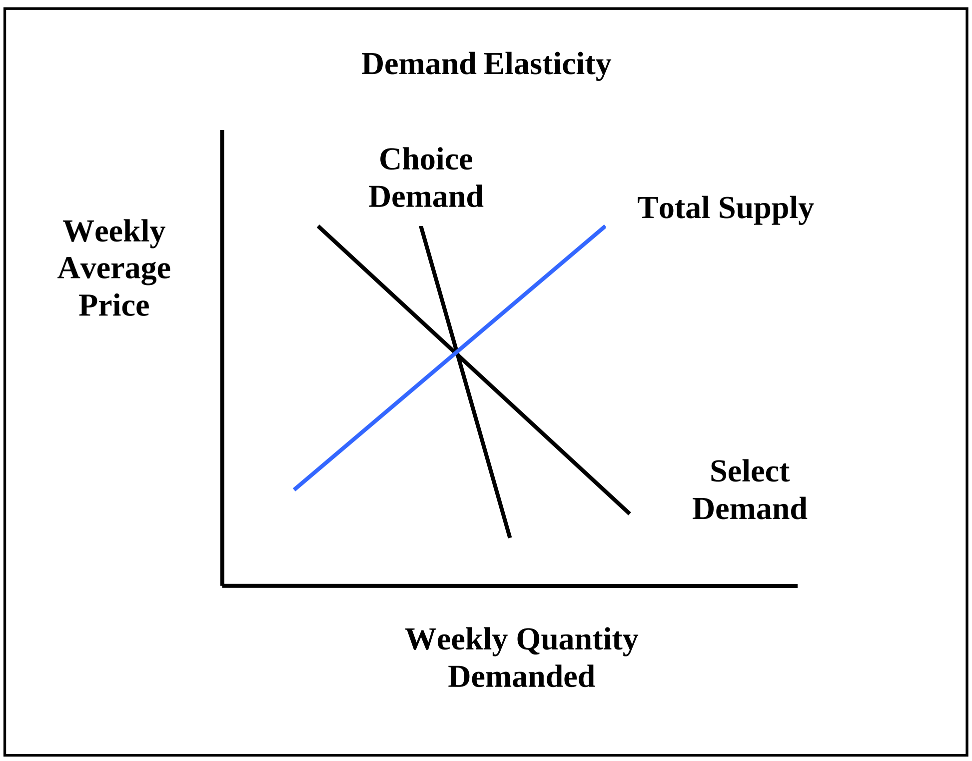


Figure 7. Illustration of the differential demand elasticity of choice and select beef calculated over the period May 2006 to May 2007.

# A NOVEL TECHNIQUE TO ASSESS INTERNAL BODY FAT OF CATTLE USING REAL-TIME ULTRASOUND

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## Summary

The objectives of this study were to describe a system to assess KPH fat using real-time ultrasound (**RTU**) and to develop equations to predict internal fat (**IF**) based on ultrasound KPH measurements. The RTU measurements were collected every 2 mo, with a pre-slaughter scan around 7 d prior to the slaughter time. The RTU measurements consisted of 12-13$^{th}$ rib backfat, 12-13$^{th}$ ribeye area, percent intramuscular fat, and KPH fat, which was measured in a cross sectional image collected between the first lumbar and the 13$^{th}$ rib. The ultrasound probe was placed on the flank region close to the mid line of the animal. Image was frozen in the ultrasound console and measurements are taken between the ventral part of the *Psosas major* muscle and the end of the KPH fat. Data for this study were obtained from 24 Angus steers fed either hay or corn during the backgrounding phase. Steers were serially slaughtered in three groups: a baseline at weaning time, 4 and 8 mo after weaning. A fourth group was composed of four hay-fed steers and steers were slaughtered at approximately 9 to 10 mo after weaning. The relationship between the depth of the KPH between carcass (**cKPHd**) and ultrasound (**uKPHd**) had an $r^2$ of 0.93 with a mean square error (**MSE**) of 1.30 cm. An allometric regression between carcass KPH weight (**cKPHwt**) and cKPHd was identified and the untransformed regression had an $r^2$ of 0.96. The linear regression between total IF and cKPHwt had an $r^2$ of 0.97 with a MSE of 34.55 kg. Our results indicated that uKPHd can accurately and precisely predict cKPHd of steers consuming either high concentrate or forage rations. Results also concurred that cKPHd is high correlated with cKPHwt, which can be used to estimate total IF. More research is needed to further evaluate the technique under different feeding strategies, breeds, and genders.

## Introduction

A persistent positive energy balance leads to the deposition of body fat in the animal. Fat deposition can be chemically characterized by a continued accretion of lipids, primarily in the form of triacylglicerides, and morphologically characterized by hyperplasia and hypertrophy (Nurnberg et al., 1998). In beef cattle, body fat is accumulated in different parts of the body in which organs (kidney, pelvic, and heart; **KPH**) and gastrointestinal tract fat is the first to be deposited, then followed by intermuscular, subcutaneous, and intramuscular fat depots (Gerrard and Grant, 2003; Jones, 2004). Several factors affect the onset and the amount of fat that is deposited such as breed, sex, and level of nutrition. Body fat has an important role in determining body composition and energy requirements of growth in beef cattle (Geay, 1984). Body fat is classified into carcass and internal/organs fat. Ribeiro et al. (2006) indicated that carcass fat can be assessed using real-time ultrasound (**RTU**), which is a non-invasive technique that requires immobilization of the animal for a short period of time. On the other hand, internal fat (**IF**) assessment is difficult, expensive, and usually requires the slaughter of the animal. The RTU technique has been used to measure body composition in beef cattle for more than 50 years (Temple et al., 1956). At that time, only fat and muscle depth were measured. Since the 1950's there has been a great amount of publications (Stouffer and Wellington, 1960; Stouffer et al., 1961; Wilson, 1992; Greiner et al., 2003b) reporting the efficacy of RTU to measure *Longissimus dorsi* area (ribeye area), back fat, rump fat (Realini et al., 2001; Tait et al., 2005), and percent intramuscular fat (Hassen et al., 1999, 2001). However, no technique has been developed to assess internal fat using RTU. The main objective of this paper was to develop a technique that could be employed to assess internal fat based on the measurement of KPH and internal fat using RTU.

## Experimental Procedures

*Animal and Diet Description*

Data for this study were obtained from Angus steers (n = 24) fed either hay or corn during the backgrounding phase at the Texas A&M University Agricultural Research Center at McGregor. Steers were serially slaughtered based on pre-determined BW. Steers were weighed and sorted into three groups: baseline or hay- or corn-fed steer treatments. Baseline animals (n = 4) were slaughtered a week after being weaned. Of the remaining 20 steers, 12 were placed on a backgrounding, hay based diet (Table 1) and 8 on a corn-based diet. Four months after weaning, 8 animals were slaughtered (4 hay- and 4 corn-based diets), and the remainder of the steers were fed hay (n = 8) and corn (n = 4) were placed in the same diet and fed ad libitum. Eight months after weaning, 8 animals were slaughtered (4 hay- and 4 corn-based diets). The remaining four hay-fed steers were slaughtered 40 days after the third slaughter group.

*Ultrasound Data*
The RTU measurements were collected every 2 months, with a pre-slaughter scan around 7 days prior to slaughter. Real-time ultrasound measurements consisted of 12-13th rib backfat, 12-13th ribeye area, percent intramuscular fat, and kidney pelvic and heart fat by an Ultrasound Guidelines Council field certified technician using an Aloka 500-V instrument with a 17-cm 3.5 MHz transducer (Corometrics Medical Systems, Inc., Wallingford, CT, USA). Images were collected and interpreted on site at the ultrasound console and the IMF images were analyzed by the Beef Image Analysis Pro software (Designer Genes Inc., Harrison, AR).

*Real-Time Ultrasound of Kidney, Pelvic, and Heart Fat (uKPH)*
The uKPH image was collected between the first lumbar and the 13th rib. It is a cross sectional image. The ultrasound probe was placed on the flank region close to the mid line of the animal. Hair was clipped if longer than 0.25 inches to increase image quality and oil is used as coupling agent. The ultrasound image was frozen in the ultrasound console. Measurements were taken between the ventral part of the *Psosas major* muscle and the end of the KPH fat as shown in Figure 1a.

*Slaughter Data Collection*
Steers were slaughtered 24 h after arrival at the Rosenthal Meat Science and Technology Center, Texas A&M University, College Station, TX. Live BW and HCW were recorded. Whole GI tract was removed and dissected to obtain internal fat weight. Measurements of carcass KPH depth (**cKPHd**) were taken at the hot carcass using a tape. The measurement was taken from the mid line (vertebrae) to the end of the KPH fat. The whole KPH was removed and weighed from the hot carcass prior to splitting and stored in the cooler. Complete carcass data was recorded after 24 h of slaughter.

*Kidney, Pelvic, and Heart Fat Volume Measurement*
Whole KPH was brought to our lab, and kidneys were removed and weighed. After removal of kidneys, KPH fat and kidneys were placed separately in a device to measure volume based on water displacement technique. The device consisted of a 32-gallon receptacle (Rubbermaid Commercial Products, Inc., Winchester, VA) with a diameter of 51.5 cm and a height of 69 cm. A valve was connected to the receptacle at 44 cm from the top and a hose was connected to the valve. Water near 25 °C was poured in the device until it reached the valve level; then the valve was opened to remove the excess of water. The valve was closed immediately when no more water was escaping. In addition to the receptacle, a metal device, which consisted of a round expanded metal with a holder in the form of a "T" connected to the expanded metal, was built to ensure that materials would be fully submerged. Valve was opened, and water was collected in a graduated beaker until equilibrium was reached. Total water displaced was measured and the volume of the water was assigned to the volume of the material.

*Statistical Analyses*
All statistical analyses were performed using the PROC GLM of SAS software (SAS Institute Inc., Cary, NC). Outliers were tested by plotting studentized residual versus predicted values and removed if the studentized residual was outside the -2.5 to 2.5 range.

## Results and Discussion

Statistical inferences for animal BW and carcass measurements are listed in Table 1. Figure 2 shows the growth of KPH fat weight and cKPHd for steers fed either hay or corn. The development of KPH and cKPHd followed an exponential pattern. This is likely because the rate of accretion of fat increases with maturity (Owens et al., 1995). Steers fed corn deposited more fat than the ones fed hay ($P = 0.0008$), which was expected because corn provides more energy than a hay diet. Figure 3 shows the deposition of internal fat for corn- and hay-fed steers and it follows the same exponential pattern as KPH fat.

Regression equations developed to predict traits of interest are shown in Table 2. Equation 1 can be used to estimate cKPHd from uKPHd with an $r^2$ of 0.93 and root of the MSE of 1.14 cm. The relationship between cKPHwt and cKPHd was nonlinear. Therefore, an allometric equation (Equation 2) was developed and Equation 3 is the antilog version of Equation 2. The cKPHd explained 96 % of the variation in cKPHwt with a root of the MSE of 1.19 kg. Finally, Equation 4 predicts total IF from cKPHwt with an $r^2$ of 0.97 and root of MSE of 5.88 kg.

Results from this study showed that RTU can be used to measure IF in beef cattle. Previous work using ultrasound to predict body composition traits have shown that this technology is useful in measuring body composition. Other studies have shown that RTU can be used to predict carcass weight and percentage of beef carcass retail product (Greiner et al., 2003a), but RTU has not been used to predict non-carcass components. In contrary to our study, Greiner et al. (2003a) indicated that carcass measured traits were better predictors than ultrasound measured traits. In our study, cKPHd and uKPHd were high correlated (0.96) with a small error (1.14 cm).

## Implications

Results from this study indicated that total internal fat can be estimated from ultrasound measurements of kidney, pelvic, and heart fat of steers fed either forage- or corn-based diets. This technique can be used to more accurately and reliably predict empty body fat to improve predictions of mathematical models of animal growth.

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Table 1. Comparison of body and carcass data of steers fed either corn or hay and serially slaughtered

| | Slaughter group [a] | | | | | |
|---|---|---|---|---|---|---|
| | 249 d | 330 d | | 450 d | | 491 d |
| Traits | Baseline | Corn | Hay | Corn | Hay | Hay |
| N | 4 | 4 | 4 | 4 | 4 | 4 |
| Ultrasound BW, kg | 218 ± 34 | 397 ± 21 | 326 ± 34 | 545 ± 23 | 512 ± 37 | 543 ± 47 |
| BW, kg | 175 ± 32 | 376 ± 19 | 298 ± 28 | 488 ± 44 | 514 ± 20 | 504 ± 48 |
| HCW, kg | 103 ± 18 | 220 ± 18 | 173 ± 17 | 314 ± 17 | 292 ± 18 | 318 ± 35 |
| Ultrasound KPH depth, cm | 5.78 ± 0.38 | 12.5 ± 0.92 | 10.3 ± 0.56 | 16.6 ± 1.09 | 16.0 ± 0.66 | 16.9 ± 1.01 |
| Carcass KPH depth, cm | 6.75 ± 6.75 | 12.9 ± 0.85 | 10.1 ± 0.48 | 17.6 ± 1.03 | 15.9 ± 1.44 | 17.9 ± 1.93 |
| KPH weight, kg | 3.08 ± 1.47 | 14.8 ± 3.83 | 6.28 ± 0.53 | 28.4 ± 5.74 | 21.7 ± 5.74 | 25.1 ± 7.07 |
| Internal fat weight, kg | 11.1 ± 4.9 | 55.3 ± 6.7 | 23.0 ± 2.5 | 95.1 ± 10.4 | 80.9 ± 14.9 | 85.4 ± 18.8 |

[a] Values are mean ± SD.

Table 2. Regression equations to predict carcass KPH depth (cKPHd, cm), carcass KPH weight (cKPHwt, kg), and internal fat (IF, kg)

| # | Equations [a] | $r^2$ | SRMSE [a] | N |
|---|---|---|---|---|
| 1 | cKPHd = 0.57131 + 0.99478 × uKPHd | 0.93 | 1.14 cm | 24 |
| 2 | Log(cKPHwt) = -3.46472 + 2.34923 × Log(cKPHd) | 0.96 | 0.176 | 24 |
| 3 | cKPHwt = - 0.0312818 × cKPHd $^{2.34923}$ | | 1.19 kg | 24 |
| 4 | IF = 5.45152 + 3.20578 × cKPHwt | 0.97 | 5.88 kg | 24 |

[a] uKPHd = ultrasound KPH depth, cm; and SRMSE = square root of the mean square error.

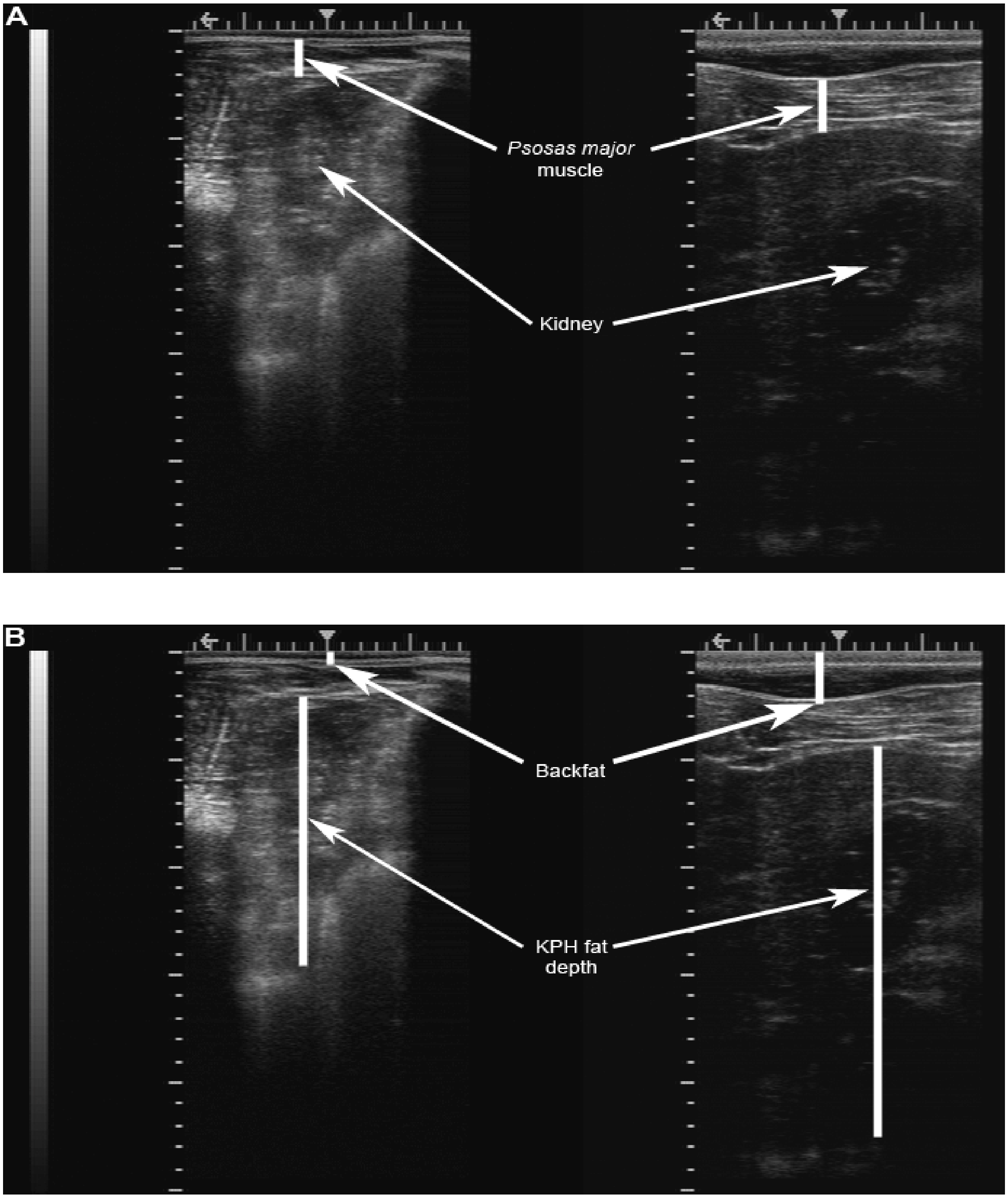


Figure 1. Detailed information of two steers showing (A) the point of measurement of the kidney (between 1st lumbar and the 13th rib) and (B) backfat and KPH fat depth using real-time ultrasound with landmarks

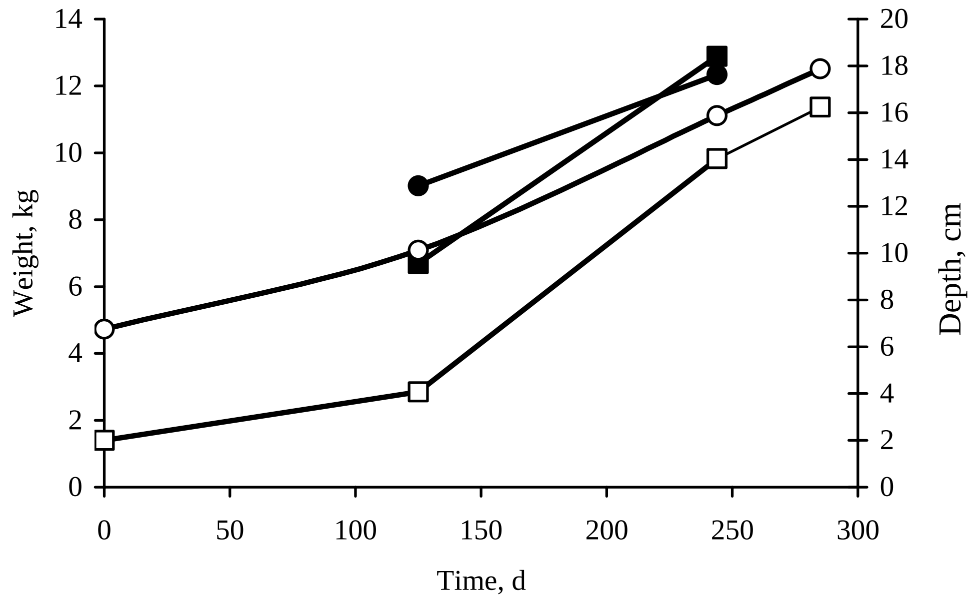


Figure 2. Development of KPH mass (□, ■; kg) and depth (○, ●; cm) for steers fed hay (open symbols) or corn (solid symbols) over time

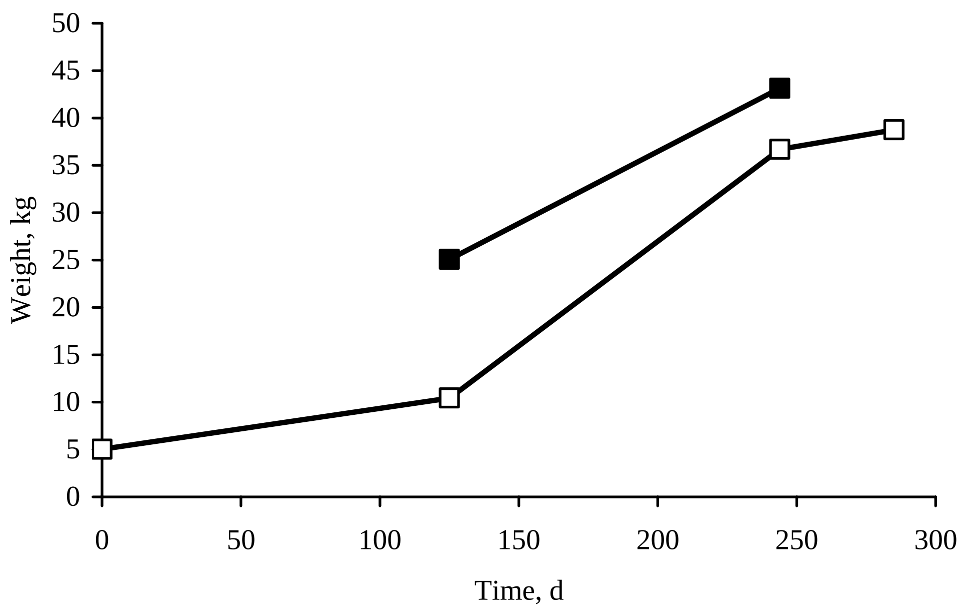


Figure 3. Development of internal fat for steers fed hay (□) or corn (■) over time.

# EVALUATION OF THE RELATIONSHIPS BETWEEN TEMPERAMENT, GROWTH, CARCASS CHARACTERISTICS AND TENDERNESS IN BEEF STEERS

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## Summary

Two experiments were conducted to determine the relationships between behavioral stress responses evaluated at different production stages and growth, carcass characteristics and tenderness. Experiment 1 evaluated stress responses at weaning (October) and at initiation of feeding (May) for Bonsmara crossbred steers. Steers from a Roswell New Mexico ranch (n = 156) and a Cline, Texas ranch (n = 21) were stratified at weaning by weight and source and randomly allotted to winter ryegrass at Uvalde (170 d) or Overton (147 d), Texas followed by feeding in a commercial feedlot at Uvalde, Texas. At weaning and upon entry into the feedlot, cattle were evaluated for exit velocity, pen score, weight, and condition and frame scores. Cattle were harvested at approximately 7 mm 12th rib fat in two groups. Each group was selected by visual assessment based on ultrasound fatness estimates. Carcass data was taken approximately 36 hrs post-mortem and 2.5 cm thick steaks were removed from the 13th rib for Warner-Bratzler shear force (WBS) determination. Experiment 2 involved Bonsmara X Angus (n = 207) steers that were weaned (October) from a Dalhart Texas ranch and grazed on wheat pasture near Dalhart during the winter and fed at a commercial feedlot near Hereford, TX. The steers were evaluated near the beginning and end of the finishing phase for performance (weight and ultrasound measures of fat) and temperament. They were harvested in two groups as in experiment 1. As cattle became acclimated to the production system, temperament measures were less related to performance, carcass characteristics and tenderness. In experiment 1, weaning exit velocity appeared to be more related to ADG (r = -0.26), ribeye area (r = -0.37), and WBS (r = 0.27) than the later measures. However, beginning feedlot exit velocity was associated with feedlot weights (r = -0.30). For experiment 2, measurements were observed later in the production cycle than in experiment 1, and were less related to performance and carcass merit.

## Introduction

A goal of the beef industry is to produce a uniformly palatable, tender, cost efficient product. Inherent genetic variation in the current beef cattle population induces variation in cattle performance, beef palatability and production costs. A component of this variation has been shown to be related to variation among animals in their apparent behavioral unease (Voisinet, et al., 1997 a,b; Brown et al., 2004). Another behavioral component may be the ability of an animal to become at-ease with its environment (Mitlohner et al., 2002). Burrow et al. (1988) and Grandin (1993) reported research indicating that animals become habituated to non-aversive handling over time. Since cattle appear to acclimate to stressful conditions, we hypothesize that measurement of behavior early in production may be more predictive of performance than measurement after acclimation has occurred. Also cattle may vary in ability to habituate (become at-ease) to a production system: some cattle may cope with stress more effectively than others and some may respond to the inherent stress adversely. The purpose of this research was to determine the relationship between measures of temperament made at various times during the production system and subsequent performance and beef quality.

## Experimental Procedures

### *Experiment 1 Production Procedures*

The experimental units consisted of 139 spring-born Bonsmara X Beefmaster (BONB) steers weaned at a Roswell, NM ranch on November 11, 2002, and 21 spring-born Bonsmara X (Tropically Adapted Breed X Angus) (BONX) steer calves that were weaned at a Cline, TX ranch on October 17, 2002. The tropically adapted breeds were Tuli, Senepol, or Brahman. Bonsmara X Beefmaster steers weaned at the NM Ranch were stratified by weight and randomly allocated to ryegrass pasture at Uvalde or Overton, TX for a post-weaning growing phase. Steers allotted to Uvalde were preconditioned at Uvalde allowed *ad libitum* access to sorghum hay and 0.9 kg/hd/d of a 20% crude protein range cube in a dry lot for 35 d prior to allocation to winter pasture on irrigated 'TAM 90' annual ryegrass, *Lolium multiflorum* L. The cattle remained on ryegrass pasture at the stocking rate of 1 steer/ha for 162 d.

Steers assigned to Overton, TX remained in drylot in Roswell, NM for a 25 d preconditioning period similar to that provided for steers allotted to Uvalde and then were transported. Upon arrival at Overton, steers were allowed *ad libitum* Costal bermudagrass hay and 0.9 kg/hd/d of a that provided for steers allotted to Uvalde and then were transported. Upon arrival at Overton, steers were allowed *ad libitum* Costal bermudagrass hay and 0.9 kg/hd/d of a 4:1 (corn:SBM) ration for a 12 d dry lot adjustment period before initiation of a winter pasture (Maton 'rye', *Secale cereale* + 'TAM 90' annual ryegrass, *Lolium multiflorum L.*) grazing experiment. These steers were grazed as a group for 19 d on rye-ryegrass pasture as an adjustment period and then allotted to grazing treatments designed to evaluate two stocking methods x two stocking rates x two stocking strategies. Each of the eight treatment combinations (2 x 2 x 2 factorial arrangement of treatments) had two pasture replicates, for a total of 16 pastures. The first factor was stocking method where cattle were randomly assigned to either continuous stocking or an eight-paddock rotation with an approximate two-day residence and a 14-d rest for each pasture. The second factor was stocking rate whereby pastures were stocked at approximately 0.9 steer/ha at initiation of grazing (low), or at approximately 1.7 steers/ha at initiation of grazing (medium). The third factor was stocking strategy. The two stocking strategies were either fixed stocking rate and not changed during the entire grazing period of January to May, 2003 and variable stocking rate where stocking rate at initiation (both at 0.9 and 1.7/ha) were fixed for 57 d, and then both stocking rates were increased to approximately 3 hd/ac for the remainder of the grazing period 75 d.

Upon completion of the winter grazing, the steers at Uvalde and Overton were transported approximately 50 and 475 km, respectively to a commercial feedyard in Batesville, TX 211 d postweaning for BONX and 186 d for BM steers.

On harvest day, animals were transported approximately 320 km to Sam Kane Beef Processing Facility in Corpus Christi, TX. Steers were harvested using commercial procedures at Sam Kane Beef Processors. Carcasses were electrically stimulated prior to evisceration using 328, 328, and 204 V, sequentially for approximately 5 sec each time. Pre-visceration carcasses were chilled at 0 ± 2° C for approximately 48 h post-harvest. A spray chill was applied at approximately six h post-mortem and then intermittently for the next eight h during chilling.

*Experiment 2 Production Methods*

Two hundred and seven spring-born (2002) Bonsmara X Angus (BA) were weaned from a Dalhart TX ranch in October of 2002 and were wintered on wheat pasture near Dalhart prior to being placed on experiment. The experiment was initiated when steers were placed on a high concentrate diet at a Hereford TX commercial feedyard on May 23, 2003. Cattle were harvested in two groups after 95 (n = 161) and 123 (n = 46) d on feed using commercial procedures at Cargill Meat Solutions (Plainview, TX). Carcasses were electrically stimulated 8 times with 50 V as they passed through a 40 ft section post-visceration. A spray chill (0 ± 4° C) was applied prior to evisceration and then again intermittently for 48 h post-mortem during chilling.

*Data Collection*

For calves at the NM Ranch, body condition score (**BCS**), frame score (**FRAME**), pen scores, escape velocity **(EV)**, weight and order through the chute (**OTC**) were determined at weaning. **EV**, adapted from Burrow et al. (1988), was determined as the rate (m/sec) at which the animals exited the working chute (W-W Livestock Systems, Inc., Thomas, OK), and traversed a 1.83 m distance in front of the chute. Infrared sensors were used to remotely trigger a timing apparatus at the beginning and ending of the run. Pen temperament scores (Hammond et al., 1996, 1-5 with 5 being the most excited, Table 2), BCS (Herd and Sprott, 1998, 1-9 with 9 being the fattest, Table 3) and frame score (Beef Improvement Federation Guidelines, 2005, 1-9 with 9 being the tallest, Table 4) were based on visual assessments of each steer after release from the working chute and while confined with a group in a pen.

After a five-d adjustment period these steers were weighed on experiment while being allowed continuous access to water and feed. At this time ultrasound (Pie Medical Equipment, The Netherlands)[2] measurements for initial backfat prior to grazing were recorded. The imaging of the backfat was performed approximately 5 cm lateral from the spinous processes of the spine and centered over the 12$^{th}$ rib. Vegetable oil was used as a couplant and the probe was placed transversely directly on the hide of the cattle. Total fat depth was determined by measuring the distance from the outer layer of the skin to the interface of the bottom layer of fat and the dorsal surface of the *longissimus* muscle. Steers at TAES-Overton were measured for BF by ultrasound upon initiation of the grazing experiment and after termination of the grazing experiment as previously described.

Seven days after entering the feedlot, steers were evaluated for temperament via pen scores, EV, and OTC. Other measurements included WT and BCS and FRAME. Cattle were herded through a chute system as quickly as possible, without the use of electrical prods, and they were restrained in a hydraulic squeeze chute. Steers exited from a scale-mounted chute where weights were determined into an alley area where EV was measured and PEN were assigned.

While the cattle were restrained in a hydraulic squeeze chute, blood samples (15 ml) were obtained via coccygeal venipuncture. Blood samples were stored on ice to allow for coagulation, and then centrifuged for 15 min at approximately 2200 RPM within 4 h to harvest serum.

procedure adapted from Willard et al. (1995). Rabbit anti-cortisol antiserum (Pantex, Div. of Bio-Analysis Inc., Santa Monica, CA Cat. #P44) was diluted 1:2500 and standards were made by serial dilution (8000 pg/100 mL to 3.9 pg/100 mL) of 4-pregnen-11b, 17, 21-triol-3,20-dione (Steroids Inc., Newport RI, Cat. #Q3880-000) and radio-labeled cortisol ($^{3}$H-Hydrocortisone 1,2-$^{3}$H, NEN, Boston MA, Cat. #NET-185). Cortisol concentrations were calculated using Assay Zap software (Biosoft, Cambridge, UK) and counts per minute (cpm) were obtained from a liquid scintillation spectrometer (Beckman Coulter LS 6500, Fullerton, CA). Cortisol antiserum cross-reactions were corticosterone (60%), deoxycorticosterone (48%), progesterone (0.01%), and estradiol (0.01%) as determined by Pantex. Interassay and intraassay CV were 9.44% and 0.39%, respectively.

After 55 d on feed (DOF), animals were measured for subcutaneous fat thickness at the 12$^{th}$ -13$^{th}$ rib using ultrasound as previously described. Rate of fattening was projected from the sequence of ultrasound BF measurements and harvest endpoints were determined. Cattle were harvested in two groups based on projected BF over the 12$^{th}$ and 13$^{th}$ rib. Therefore, steers were harvested after 88 or 147 DOF (August 12, 2003 and October 17, 2003, respectively) to an approximate 7 mm subcutaneous fat thickness harvest endpoint. Prior to leaving the feedlot for harvest, a final weight was recorded. All weights in the feedlot included allowing the cattle continued access to feed and water prior to handling or weighing.

At approximately 48 hrs post-harvest, carcasses were ribbed at the 12$^{th}$ and 13$^{th}$ rib interphase and hot carcass weight (HCW, kg), 12$^{th}$ rib backfat thickness (BFT, mm), estimated percentage of kidney, pelvic and heart fat (KPH, %), ribeye area (REA, cm$^{2}$), and marbling score (MS) were determined as defined by USDA (1997). Carcass measurements were obtained by trained Texas A&M University personnel following the USDA (1997) guidelines, and Yield and Quality grades were calculated according to USDA (1997) using the carcass measurements. A 2.5 cm steak was removed from the 13$^{th}$ rib for Warner-Bratzler shear force determination at 14 d post-harvest.

Steaks for Warner-Bratzler shear force determination were vacuum-packaged in B620 bags (Cryovac Inc., Indianapolis, IN), boxed and then placed in a cooler for 14 d at 4° C. After aging, the samples were stored at -80° C. Forty-eight h prior to cooking, steaks were placed in a 2° C cooler and allowed to thaw. Steaks were weighed and iron constant thermocouples were placed in the geometric center of each 2.54 cm steak. The steaks were cooked on a Farberware Open-Hearth grill (Faberware Co., Bronx, NY) to a temperature of 35° C, and then steaks were turned. Steaks were removed from the grill when the internal temperature was 70° C. Temperature was monitored using a continuous recording potentiameter. Steaks were weighed after cooking, and cooking loss percentage was calculated by subtracting the raw weight from the cooked weight and dividing the difference by the raw steak weight. Cook time was calculated by measuring the time the steak was placed on the grill until taken off the grill. Steaks were cooled for a minimum of four h at room temperature (20° C) before testing. Six, 1.27 cm cores were removed parallel to the longitudinal orientation of the muscle fiber from each steak. Each core was sheared once using a Universal Testing Instrument (Model SSTM-500, United Calibration Corp., Hunnington Beah, CA) equipped with a V-notch Warner-Bratzler blade, and a 50 kg compression load cell with a cross-head speed of 200 mm/min as defined by AMSA (1995). The average force (kg) required to segment the six cores was reported for each steak and used for data analysis.

*Experiment 2*

Cattle were weighed using a hydraulic squeeze chute (Moly Manufacturing, Inc., Lorraine, KS) and ear-tagged at the initiation of the study, in feedlot traits of beginning WT (kg) and OTC were determined. At 25 DOF, the cattle again were restrained using a hydraulic chute and weight, ultrasound measurement of BF, FACE, and OTC were recorded. Facial whorl distance was measured as in Experiment 1. Cattle were worked quickly and as quietly as possible without the use of electrical prods. Upon exiting the chute, EV was recorded as defined in Experiment 1. Cattle were confined to a pen area where they were assigned PEN and evaluated for BCS and FRAME as in Experiment 1. The measurements taken at this time were defined as beginning feedlot measurements. After 92 DOF, cattle were again processed through the working facility at the feedlot and OTC, EV, pen scores, and weight were determined. Traits measured during this working period were defined as end feedlot measurements.

Body condition scores and ultrasound measurements were used to estimate a harvesting endpoint of 7 mm of subcutaneous fat over the 12$^{th}$ and 13$^{th}$ rib interface. For cattle harvested on 123 DOF weight, BCS, and FRAME were recorded prior to harvest at 117 DOF and defined as final feedlot traits.

Carcasses were ribbed at the 12th and 13th rib interphase and HCW (kg), BFT (mm), KPH, REA, and MS were determined by a trained Excel employee according to USDA (1997). The USDA Yield and Quality grades (1 = Prime; 2 = Choice; 3 = Select; 9 = Standard) were calculated according to USDA (1997) using carcass measurements. A vision yield grade was calculated from video images using a standard 2.5% KPH. Percent marbling also was determined using the Cargill Meat Solutions video image system. A rib section was removed by Cargill personnel, vacuum-packaged then aged at 2° C for 21 d, and placed in a -80° C freezer until used for WBS evaluation as described in Experiment 1.

*Statistical Analysis*

Descriptive statistics were calculated for Experiment 1, 2, and 3 using PROC MEANS. Simple correlation coefficients were determined between temperament measures from Experiments 1 and 2 and live animal performance, carcass characteristics, and tenderness using PROC CORR.

Exit velocity data were converted to discrete data that was defined as exit velocity groups of slow, medium and fast based on <0.5 SD, ± 0.5 SD, and >0.5 SD, respectively, from the mean. Weaning EV categories from Experiment 1 and beginning feedlot EV groups from Experiment 2 were analyzed by Analysis of Variance using PROC GLM procedure of SAS (Version 6.12, Cary, NC, 1998) with EV group described as a main effect. Linear, cubic, and quadratic effects were tested using orthogonal contrasts and there were no significant cubic or quadratic effects. Least squares means were calculated and if differences in EV groups were reported ($P < 0.05$) then least squares means were separated using the standard error PDIFF function.

Exit velocity data were converted to discrete data that was defined as slow less than the mean EV, and fast greater than the mean EV categories. The four categories for Experiment 1 were: 1) Slow/Slow (SS) where mean weaning and beginning feedlot were less than 3.53 m/s for weaning EV and 2.91 m/s for beginning feedlot EV ; 2) Fast/Slow (FS) where mean weaning EV was greater than 3.53 m/s and beginning feedlot EV was less than 2.91 m/s; 3) Slow/Fast (SF) where weaning EV was less than 3.53 and beginning feedlot EV was greater than 2.91; and 4) Fast/Fast (FF) where mean weaning and beginning feedlot EV were greater than 3.53 m/s for weaning EV and 2.91 m/s for beginning feedlot EV. The four categories for Experiment 2 were: 1) Slow/Slow (SS) where mean beginning and end feedlot were less than 2.85 m/s for beginning EV and 2.38 m/s for end feedlot EV; 2) Fast/Slow (FS) where mean beginning EV was greater than 2.85 m/s and end feedlot EV was less than 2.38 m/s; 3) Slow/Fast (SF) where beginning EV was less than 2.85 and end feedlot EV was greater than 2.38; and 4) Fast/Fast (FF) where mean beginning and end feedlot EV were greater than 2.85 m/s for beginning EV and 2.38 m/s for end feedlot EV. To determine the effect of EV categories on live animal performance, carcass characteristics, and tenderness data were analyzed by Analysis of Variance using the general linear model (GLM) procedure of SAS with a predetermined significance level of $P \leq 0.05$. Exit velocity category was defined as a main effect. For variables that were affected by EV categories, least squares means were calculated and differences between means were determined using the standard error pdiff function.

## Results and Discussion

*Descriptive statistics.* In experiment 1 exit velocity was numerically faster at weaning (Table 1) than at the beginning of the feeding period (Table 6; 3.5 vs 2.9 m/s). Cattle in experiment 2 seemed to follow the general trends found in experiment 1. In experiment 2 beginning feedlot EV was 0.48 m/s greater than final feedlot EV (2.85 vs. 2.38 m/s, $P > 0.10$, Table 2). Crookshank et al. (1979) reported that in cattle, agitation and cortisol concentrations decreased with subsequent experiences in the handling facility, because the cattle became habituated. The standard deviation for experiment 1 and 2; however, was larger for subsequent evaluations. This would suggest that, in general, animals acclimated or conformed to the production system, but some did not. Although there may be a decrease in exit velocity over time, cattle that tended to be more flighty early in production tended to remain or become more flighty throughout production. While exit velocity tended to decrease in subsequent evaluations, pen scores increased in time. Pen scores in experiment 1 and 2 measured at early in production (Table 1 and 2) were slightly lower, but similar ($P > 0.1$), than later pen scores measurements (Table 1 and 2). Behavioral indicators of discomfort include attempting to escape, vocalization, kicking, or struggling (Grandin, 1997). Hargreaves and Hutson (1990) likewise showed that getting sheep accustomed to people and reducing their flight zone was somewhat successful at reducing aversion to repeated handling procedures, although not enough to overcome the effects of highly aversive procedures. Habituation to a handling procedure may arise when the animal learns that there is always an eventual escape (Fox, 1984). Thus, habituation may depend on the predictability, controllability, or previous experience of the stressor and thereby its aversive ness (Hargreves and Hutson, 1990). Lyons (1989) reported that the degree of behavioral agitation expressed by animals during routine handling procedures was consistent over multiple handling experiences. Grandin (1993) also found similar results, and concluded that certain individuals have the tendency to become behaviorally agitated and were stable over time. Differences in the results between studies and between animals were likely due to how the animal perceived the aversiveness of a procedure due to previous handling or if it was a novel experience. While some measures of behavior indicate that the animal is adapting, other measures seem to show the opposite and animals get more agitated or do not adapt over time. These responses could be attributed to animal perception and environmental factors. The squeeze chute or handling may be perceived as neutral and non-threatening to one animal; to another animal, it may trigger intense fear (Grandin, 1997). This may also explain why some cattle that perceive the chute or handling as a bad experience, may remember it and become more stressed when handled in the future, while other animal's gentle overtime.

In experiment 1 cattle performance on pasture and in the feedlot was 1.0 kg/d (Table 1) and 1.39 kg/d (Table 1), respectively and feedlot gains for experiment 2 were 1.42 kg/d. The gains reported from these studies were comparable to cattle fed similarly (Coffey et al., 2002). Carcass backfat measurements ranged from 2.5 to 12.7 mm (m = 7.0) in experiment 1 and from 1.0 to 24.0 mm (m = 9.8) in experiment 2, but each experiment averaged the backfat measurement as defined by the design. Mean Warner-Bratzler shear force for experiment 1 (Table 1) was 2.67 kg and ranged from 1.51 to 4.63 kg. Mean shear force for experiment 2.84 and the range in shear force was from 1.76 to 5.22 (Table 2). In both experiments, only four percent of the steaks had Warner-Bratzler shear force values above 3.9 kg, considered tough by Shackelford et al. (1991).

*Simple linear correlations.* Weaning EV was correlated with economically important traits such as on and off rye-ryegrass backfat (r=-0.17, Table 3) and feedlot ADG (r=-0.26, Table 3). Regression analyses indicated that ADG decreased with each 0.09 kg/m/s with each m/s change in weaning exit velocity (Figure 1). We hypothesize that the effects undesirable behavior on ADG were mainly a function of reductions in feed intake and inefficient use of feed. Factors regulating growth are inversely related to the animals stress response or their inability to tolerate stress. These observations agree with Philips (2004) who concluded that more flighty cattle spent less time ruminating and more time vocalizing. Behavioral observations of stress responsiveness upon entry to the feedlot in experiment 1 tended to be more highly related than the same variable for both pre-feedlot (Table 3) and feedlot (Table 3) performance. Beginning feedlot exit velocity tended to have higher correlation values with animal weight prior to entering the feedlot (r = -0.28, Table 3) and in the feedlot (r = -0.30, Table 3) than did beginning feedlot pen scores. Smaller animals on pasture and in the feedlot had greater (P<0.05) beginning feedlot exit velocities, but beginning feedlot EV was not related to pre-feedlot and feedlot ADG. Petherick et al. (2002) used flight speed as a measure of temperament at the beginning of the feedlot period and found more flighty cattle had lighter weights at the end of the feedlot period. Although they also observed the trend that flighty cattle had lower ADG and decreased feed conversion efficiency during the feedlot period. In addition, change in EV was correlated with both pre-feedlot (r = -.30, Table 3) and feedlot (r = 0.20, Table 3) ADG. If cattle cannot adapt to a particular environment then these responses can be sustained over a period of time and cause substantial decreases in production. Fell et al. (1998) found that a significant percentage of animals are unable to adapt successfully and have an unacceptably low weight gain.

Simple linear correlations in experiment 2 were also used to evaluate the relationship between temperament variables, feedlot performance traits. Although all the correlations were relatively low (r < 0.20), all feedlot performance measurements were generally more related to end feedlot behavioral observations than initial feedlot behavioral observations (Table 4). Beginning feedlot EV was not correlated with any feedlot performance measurements, but beginning feedlot pen score was correlated with in feedlot weight (r = -0.15, P = 0.03, Table 4). Although change in exit velocity was not correlated with feedlot performance in experiment 2, the correlation values were approaching significance for out of feedlot weight (r = -0.12, P = 0.08) and (r = -0.13, and P = 0.07).

In experiment 1 weaning exit velocity was correlated with other economically important traits; ribeye area (r = 0.37, Table 3), yield grade (r = 0.29, Table 3), and WBS force (r = 0.27, Table 3). Regression analyses indicated that WBS force increased at the rate of 0.18 kg/m/s (Figure 2) with each m/s change in weaning EV. Brown et al. (2004) reported that exit velocity measured upon entry to the feedlot was negatively correlated ribeye area in Bonsmara bulls. Other investigators have found a low-to-moderate relationship between measures of temperament and Warner-Bratzler shear force (r = 0.24 to 0.35; Vann et al. 2004). Voisinet et al. (1997b) also found more excitable cattle as determined by chute scores measured two weeks prior to entering the feedlot produced steaks that were tougher than steak from calm animals. Other research has found that chute scores were positively correlated with 24-h calpastatin activity and Warner-Bratzler shear force values (r = 0.35 and 0.49, respectively) (Wulf et al., 1997). Beginning feedlot EV was not correlated with carcass characteristics or tenderness in our study (Table 3). Other notable correlations (P < 0.05) included change in EV with REA (r = 0.27, Table 3); yield grade and WBS force (r = -0.25 and r=-0.21, respectively, Table 3).

The relationships between behavioral stress response measures, carcass characteristics and tenderness in experiment 2 were small and generally not significant (P > 0.05, Table 4). Carcass backfat was found to be correlated with beginning feedlot EV (r = 0.15, P = 0.04) and change in EV (r = -0.17, P = 0.02). Other significant correlations included yield grade with end feedlot EV (r = -0.15, P = 0.04). Although simple correlation coefficients did not present strong relationships, there were trends in the data and relationships that warrant further investigation. From this study we hypothesized that multiple behavioral observations measured at different time periods may be more predictive of live animal performance, carcass characteristics and beef tenderness.

*Least square means.* The cattle were also categorized into slow, medium, and fast EV groups based on half a standard deviation from the overall mean weaning EV value (Table 5). These categories were used to identify the extreme exit velocities, or the slow and fast groups. Significant linear effects (P < .05) were observed for weaning EV and off ryegrass backfat, feedlot ADG, carcass backfat, ribeye area, yield grade, and WBS force

(Table 5). Other researchers have used behavioral responses at weaning to sort cattle into feedlot groups (Fell et al., 1999). These researchers classified cattle into nervous and calm groups, and reported that the nervous group had increased cortisol concentrations and decreased weight gain as compared to the calm group.

Least square means were also calculated for pen scores observed at weaning and compared to EV categories. Significant linear effects were not observed for weaning pen scores. Although significant effects were not found for pen scores observed at weaning, there does appear to be numeric trends between pen score categories and cattle performance.

Since weaning EV and change in EV seemed to have similar patterns of correlations across all the traits, and beginning feedlot EV was more highly correlated with pre-feedlot and feedlot traits, weaning and beginning feedlot EV were used to categorize cattle into 4 groups (Figure 3); Slow/Slow, Slow/Fast, Fast/ Fast, and Fast/Slow. Slow/Slow EV categories were used to describe cattle that did not show an undesirable response to handling during the entire production system. Fast/Fast EV was categorized as cattle that responded adversely to both stressful situations. Fast/Slow EV cattle were described as animals that adapted and had a more desirable response each time they were handled. Slow/Fast EV cattle were defined as the group that did not adapt and became more behaviorally agitated over time. Comparisons between behavioral response groups enabled examination of animals that were behaviorally resistant to management compared to those that adapted over time. Some cattle apparently did not conform or acclimate to the production system.

Live animal weight and backfat prior to entering the feedlot were affected by EV categories (Table 6). Weaning PEN were higher for the fast EV cattle at weaning. Although cattle in the Slow/Fast category were numerically lower than the fast EV cattle at weaning they were not statistically different. The Fast/Slow cattle had higher weaning weights and the cattle that had faster EV at weaning had more backfat and higher ADG on ryegrass (Table 6). Cattle that had slow EV at the beginning of the feedlot period had numerically higher weights going onto pasture. Cattle in the SF group had less 12$^{th}$ and 13$^{th}$ rib backfat off pasture (Table 6).

Differences in temperament measures and live animal weight and backfat during the feedlot phase were also affected by EV categories. Pen scores were lower for the Slow/Slow group than the other three groups, and cattle in the Slow/Fast and Fast/Fast numerically had faster EV than the slow beginning feedlot EV groups (Table 6). In addition, cattle demonstrating fast EV at the beginning of the feedlot period had numerically lower weights than their corresponding slow EV counterparts (Table 6). Even though the fast EV cattle tended to be lighter throughout the experiment, there were no apparent differences in weight at the end of the finishing phase (Table 6). Average daily gain during the feedlot phase was the same ($P > 0.10$) for all EV classifications (Table 6). The Slow/Fast group continued to exhibit the lowest weights recorded in the feedlot.

Carcass characteristics and tenderness measures did not differ across EV categories (Table 6). Carcass backfat, marbling score and USDA quality grade were numerically lower for the Fast/Fast EV group when compared to the other groups (Table 6). While no statistical differences were found, cattle with slow EV at weaning still had the lowest WBS force measurements (Table 6). There may have been no statistical differences between the EV categories since there were weak correlation relationships. This did not allow for much variation when EV was categorized.

In experiment 2 exit velocity tended to be the most objective measure of temperament and tended to be related to feedlot performance, carcass characteristics, and tenderness and as relationships were different for beginning EV than for end EV. Therefore, exit velocity was categorized into four groups based on slow and fast beginning and end EV. This was done in order to characterize animals that always were slow or fast (did not adapt to feedlot conditions), as compared to those that decreased (became more gentle) or increased (became more flighty) in EV over the feeding period. The four categories were: 1) Slow/Slow (SS) where mean beginning and end feedlot were less than 2.85 m/s for beginning EV and 2.38 m/s for end feedlot EV (Table 20); 2) Fast/Slow (FS) where mean beginning EV was greater than 2.85 m/s and end feedlot EV was less than 2.38 m/s; 3) Slow/Fast (SF) where beginning EV was less than 2.85 and end feedlot EV was greater than 2.38; and 4) Fast/Fast (FF) where mean beginning and end feedlot EV were greater than 2.85 m/s for beginning EV and 2.38 m/s for end feedlot EV (Figure 4). These categories were used to classify cattle as described in Experiment 1.

Beginning feedlot pen scores increased 1.1 units from the SS to the FF EV categories measured at the beginning of the feedlot, and end feedlot pen scores increased 1.7 units from the SS to the FF EV category measured at the end of the feedlot phase (Table 7). For both beginning and end feedlot pen scores, the Slow/Slow category was significantly different from the other three categories. Beginning feedlot weights tended to be higher for the slow EV groups recorded at the end of the feeding period and for the fast EV groups recorded at the beginning (Table 7).

The EV groups did not differ in carcass characteristics of tenderness (Table 7). When simple correlations coefficients were calculated few relationships were detected between temperament or behavioral traits and carcass characteristics. It is most likely there were no statistical differences between the EV categories as the simple correlation coefficients were low (Table 7). Therefore, EV categories explained very little of the variation in carcass characteristics. Simple linear correlations for temperament response measurements were not correlated with tenderness, and no relationships were detected between EV categories for Warner-Bratzler shear force.

## Implications

While evidence for behavioral and hormonal responses to stress associated with average daily gain, carcass characteristics and tenderness were small; relationships were detected between these traits. The original hypothesis was accepted and it is theorized that the low associations were attributed to the lack of variation in stress responsiveness and productivity within this group of Bonsmara-influenced cattle. However, it did appear that stress responsiveness observed at weaning, upon entry to the feedlot, and at the end of the feedlot phase had different associations with economically important traits.

Weaning measurements tended to have a higher relationship with important production traits, and this indicated a higher relationship for EV early in production between growth, carcass characteristics and tenderness. Weaning can be viewed as a novel experience and these responses measure an initial reaction. Novelty is a very strong stressor (Moberg, 1982) and weaning can be a novel experience for many animals. Weaning may be the first time animals are handled. In the wild, novelty and strange sights or sounds are often a sign of danger (Grandin, 1993). After repeated exposure or handling the response may be masked, and this may be a reason why as cattle progress in the production system, behavioral responses lose their predictive ability.

It is hypothesized that the relationships associated with weaning EV and WBS force are a reflection of ADG in the feedlot and other unknown factors. As calm cattle had increased weights and higher ADG, this allowed for increased growth rates. Miller et al. (1987) reported that steers that produced the lightest and leanest carcasses produced tougher meat. Although, other results have indicated that stress-induced high post-mortem pH increased protease activity and leads to more tender meat (Beltran et al., 2004). The low and weak relationships indicated that stress may impact ADG and subsequently impact meat tenderness through production of lighter carcasses with less fat that are more susceptible to cold shortening. As all of the cattle in this study were electrically stimulated, electrical stimulation could help mask effects or reduce the relationships that were evaluated.

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Table 1. Descriptive statistics for pre-feedlot and feedlot performance, carcass characteristics, and tenderness (Experiment 1)

| Variable | N | Mean | Std Dev | Minimum | Maximum |
|---|---|---|---|---|---|
| Weaning exit velocity (m/s) | 138 | 3.53 | 0.798 | 1.19 | 5.85 |
| Weaning pen score | 138 | 1.4 | 0.60 | 1.0 | 3.0 |
| On pasture backfat (mm) | 147 | 4.5 | 2.09 | 1.3 | 9.0 |
| On pasture wt. (kg) | 159 | 226.9 | 46.39 | 121.2 | 325.5 |
| Off pasture backfat (mm) | 156 | 7.1 | 1.71 | 3.6 | 13.5 |
| Off pasture wt. (kg) | 156 | 362.0 | 54.95 | 254.2 | 517.6 |
| Pasture ADG (kg/d) | 156 | 1.00 | 0.219 | 0.32 | 1.60 |
| In feedlot exit velocity (m/s) | 156 | 2.91 | 0.944 | 1.01 | 5.24 |
| In feedlot pen score | 155 | 1.7 | 0.82 | 1.0 | 4.0 |
| Change in exit velocity (m/s)[a] | 135 | -0.57 | 1.052 | -3.42 | 2.49 |
| In feedlot wt. (kg) | 156 | 344.8 | 50.26 | 249.7 | 488.1 |
| End feedlot wt (kg) | 152 | 494.5 | 37.54 | 381.4 | 626.5 |
| Feedlot ADG (kg/d) | 152 | 1.39 | 0.310 | 0.50 | 2.55 |
| Hot carcass weight (kg) | 88 | 290.4 | 24.91 | 251.5 | 364.6 |
| Carcass backfat (mm) | 88 | 7.0 | 2.47 | 2.5 | 12.7 |
| Ribeye area ($cm^2$) | 88 | 78.65 | 7.805 | 61.92 | 99.33 |
| Yield grade | 88 | 2.2 | 0.398 | 1.1 | 3.3 |
| Warner-Bratzler shear force (kg) | 133 | 2.67 | 0.591 | 1.51 | 4.63 |

[a]In feedlot exit velocity – weaning exit velocity

Table 2. Descriptive statistics for feedlot performance, carcass characteristics and tenderness (Experiment 2)

| Variable | N | Mean | Std Dev | Minimum | Maximum |
|---|---|---|---|---|---|
| In feedlot wt. (kg) | 207 | 385.6 | 39.57 | 255.1 | 499.4 |
| Beginning feedlot exit velocity (m/s) | 205 | 2.85 | 0.897 | 0.79 | 5.74 |
| Beginning feedlot pen score | 206 | 2.1 | 1.01 | 1.0 | 7.0 |
| End feedlot exit velocity (m/s) | 207 | 2.38 | 0.925 | 0.64 | 5.42 |
| End feedlot pen score | 207 | 2.4 | 1.18 | 1.0 | 5.0 |
| Change in exit velocity (m/s)[a] | 205 | -0.48 | 1.030 | -3.40 | 2.87 |
| Harvest feedlot wt. (kg) | 207 | 532.4 | 46.05 | 390.4 | 660.6 |
| Feedlot ADG (kg/d)[b] | 207 | 1.42 | 0.31 | 0.78 | 2.55 |
| Hot carcass wt. (kg) | 207 | 328.6 | 28.66 | 240.9 | 409.1 |
| Carcass backfat (mm) | 207 | 9.8 | 3.47 | 1.0 | 24.9 |
| Ribeye area ($cm^2$) | 207 | 85.08 | 9.172 | 42.57 | 110.94 |
| Yield grade | 196 | 2.1 | 0.37 | 1.0 | 3.0 |
| Warner-Bratzler shear force (kg) | 204 | 2.84 | 0.563 | 1.76 | 5.22 |

[a]End feedlot exit velocity – Beginning feedlot exit velocity
[b](Harvest weight-In feedlot weight)/harvest DOF

Table 3. Simple correlation coefficients for temperament and steer performance (Experiment 1)

| | Weaning exit velocity (m/s) | Weaning pen score | Beginning feedlot exit velocity (m/s) | Beginning feedlot pen score | Change in exit velocity (m/s)[a] |
|---|---|---|---|---|---|
| On pasture backfat (cm) | 0.10[b] | -0.07 | 0.09 | -0.05 | -0.01 |
| | 0.25[c] | 0.39 | 0.28 | 0.58 | 0.88 |
| | 137[d] | 137 | 144 | 143 | 135 |
| On pasture wt. (kg) | 0.01 | 0.04 | -0.28 | -0.18 | -0.25 |
| | 0.91 | 0.63 | 0.0004 | 0.03 | 0.003 |
| | 137 | 137 | 156 | 155 | 135 |
| Off pasture backfat (cm) | 0.17 | -0.01 | -0.02 | -0.06 | -0.17 |
| | 0.04 | 0.90 | 0.80 | 0.48 | 0.04 |
| | 135 | 135 | 156 | 155 | 135 |
| Off pasture wt. (kg) | 0.02 | -0.03 | -0.28 | -0.20 | -0.33 |
| | 0.80 | 0.72 | 0.0004 | 0.01 | 0.0001 |
| | 135 | 135 | 156 | 155 | 135 |
| Ryegrass ADG (kg/d) | 0.02 | -0.15 | -0.13 | -0.09 | -0.30 |
| | 0.80 | 0.08 | 0.11 | 0.26 | 0.0005 |
| | 135 | 135 | 156 | 155 | 135 |
| In feedlot weight (kg) | 0.03 | -0.03 | -0.32 | -0.22 | -0.35 |
| | 0.73 | 0.74 | 0.0001 | 0.006 | 0.0001 |
| | 135 | 135 | 156 | 155 | 135 |
| Out feedlot wt. (kg) | -0.15 | -0.15 | -0.17 | -0.21 | -0.08 |
| | 0.08 | 0.09 | 0.03 | 0.01 | 0.34 |
| | 131 | 131 | 152 | 151 | 131 |
| Feedlot ADG (kg/d) | -0.26 | -0.16 | 0.05 | -0.07 | 0.22 |
| | 0.003 | 0.07 | 0.52 | 0.39 | 0.01 |
| | 131 | 131 | 152 | 151 | 131 |
| Hot carcass wt. (kg) | -0.17 | -0.16 | -0.08 | -0.11 | 0.04 |
| | 0.13 | 0.16 | 0.46 | 0.32 | 0.70 |
| | 78 | 78 | 88 | 87 | 78 |
| Backfat (cm) | 0.02 | 0.06 | -0.03 | -0.17 | -0.01 |
| | 0.89 | 0.60 | 0.80 | 0.11 | 0.90 |
| | 78 | 78 | 88 | 87 | 78 |
| Ribeye area | -0.37 | -0.20 | -0.03 | -0.15 | 0.27 |
| | 0.0008 | 0.08 | 0.80 | 0.16 | 0.02 |
| | 78 | 78 | 88 | 87 | 78 |
| Yield grade | 0.29 | 0.15 | -0.03 | -0.01 | -0.25 |
| | 0.01 | 0.18 | 0.81 | 0.91 | 0.03 |
| | 78 | 78 | 88 | 87 | 78 |
| Warner-Bratzler shear force (kg) | 0.27 | 0.10 | 0.01 | 0.03 | -0.21 |
| | 0.005 | 0.30 | 0.89 | 0.72 | 0.02 |
| | 113 | 113 | 133 | 132 | 113 |

[a](In feedlot exit velocity – Weaning exit velocity)
[b]Correlation coefficient
[c]P-value
[d]Number

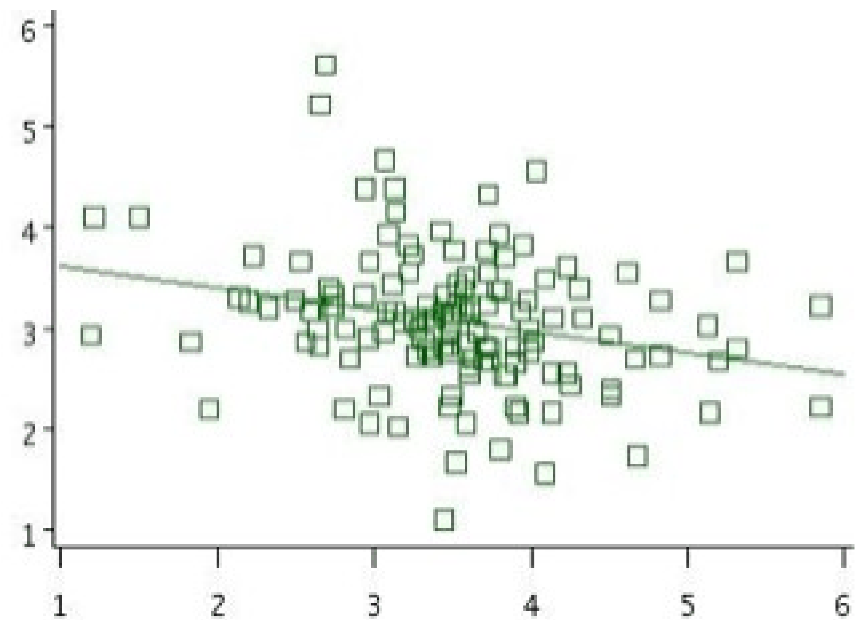


Figure 1. Linear regression line for average daily gain and weaning exit velocity, Experiment 1 [Y=1.74 + (-0.09*weaning EV), $R^2$=0.07, RMSE=0.667]

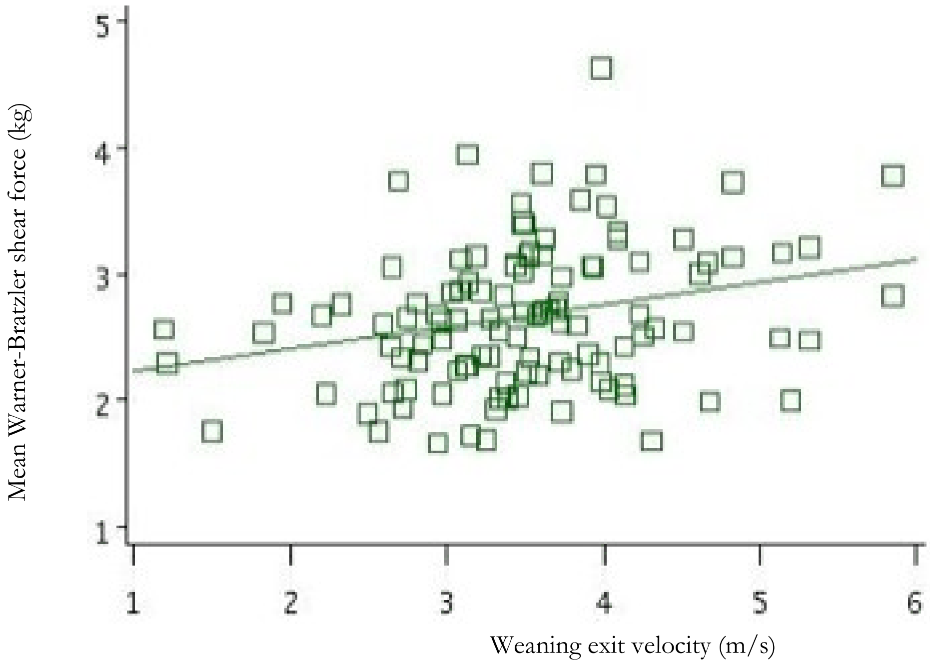


Figure 2. Linear regression line for mean Warner-Bratzler shear force and weaning exit velocity, Experiment 2 [Y=2.04 + (0.18*weaning EV), $R^2$=0.05, RMSE=0.615)]

Table 4. Simple correlation coefficients for temperament and steer performance (Experiment 2)

| | Beginning feedlot EV (m/s) | Beginning feedlot PEN | Out feedlot EV (m/s) | Out feedlot PEN | Change in exit velocity (m/s) |
|---|---|---|---|---|---|
| In feedlot | -0.09[b] | -0.15 | -0.18 | -0.19 | -0.07 |
| wt. (kg) | 0.21[c] | 0.03 | 0.01 | 0.007 | 0.32 |
| | 205[d] | 206 | 207 | 207 | 205 |
| Out feedlot | -0.007 | -0.08 | -0.16 | -0.16 | -0.12 |
| wt. (kg) | 0.92 | 0.25 | 0.02 | 0.02 | 0.08 |
| | 205 | 206 | 207 | 207 | 205 |
| Feedlot | 0.09 | 0.04 | -0.07 | -0.05 | -0.13 |
| ADG | 0.21 | 0.61 | 0.31 | 0.43 | 0.07 |
| (kg/d) | 205 | 206 | 207 | 207 | 205 |
| Hot carcass wt. | -0.05 | -0.10 | -0.13 | -0.11 | -0.06 |
| | 0.49 | 0.17 | 0.06 | 0.12 | 0.39 |
| | 205 | 206 | 207 | 207 | 205 |
| Carcass | 0.15 | 0.01 | -0.05 | -0.01 | -0.17 |
| backfat (cm) | 0.04 | 0.83 | 0.49 | 0.85 | 0.02 |
| | 205 | 206 | 207 | 207 | 205 |
| Ribeye area | 0.009 | -0.02 | 0.05 | 0.01 | 0.05 |
| | 0.90 | 0.77 | 0.46 | 0.83 | 0.50 |
| | 205 | 206 | 207 | 207 | 205 |
| Yield grade | -0.09 | -0.11 | -0.15 | -0.12 | -0.06 |
| | 0.24 | 0.11 | 0.04 | 0.09 | 0.42 |
| | 194 | 195 | 196 | 196 | 194 |
| Warner-Bratzler | 0.10 | 0.05 | 0.02 | 0.11 | -0.06 |
| shear force (kg) | 0.16 | 0.48 | 0.73 | 0.12 | 0.40 |
| | 202 | 203 | 204 | 204 | 202 |

[a](Out exit velocity –Beginning exit velocity)
[b]Correlation coefficient
[c]p-value
[d]number

Table 5. Least square means, standard errors p-values for backfat, weight, average daily gain, carcass characteristics and Warner-Bratzler shear force as effected by temperament
groups in experiment 1

| | Weaning exit velocity groups[a] | | | | | Weaning pen scores | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Number | Slow | Medium | Fast | RMSE[b] | Number | 1 | 2 | 3 | RMSE |
| On pasture backfat, cm | 135 | 0.40 | 0.47 | 0.49 | 0.083 | 135 | 0.47 | 0.46 | 0.38 | 108.05 |
| On pasture weight, kg | 135 | 223.6 | 225.2 | 224.2 | 108.34 | 135 | 222.3 | 230.1 | 220.9 | 108.05 |
| Off pasture backfat, cm | 135 | 0.66$^{c}$ | 0.73cd | 0.76d | 0.171 | 135 | 0.71 | 0.73 | 0.69 | 0.934 |
| Off pasture weight, kg | 135 | 361.3 | 371.1 | 367.9 | 55.63 | 135 | 367.1 | 374.2 | 343.2 | 55.33 |
| Ryegrass ADG, kg/d | 135 | 1.03 | 1.07 | 1.06 | 0.170 | 135 | 1.06 | 1.05 | 0.92 | 0.167 |
| In feedlot weight, kg | 131 | 341.6 | 351.5 | 349.7 | 51.33 | 133 | 347.9 | 354.2 | 327.2 | 51.14 |
| Out feedlot weight, kg | 131 | 507.0 | 492.7 | 494.4 | 38.13 | 133 | 499.4 | 497.7 | 466.5 | 37.81 |
| Feedlot ADG, kg/d | 131 | 1.52$^{c}$ | 1.38d | 1.29d | 24.61 | 133 | 1.42 | 1.37 | 1.20 | 0.309 |
| Hot carcass weight, kg | 78 | 300.1 | 290.4 | 290.0 | 24.61 | 80 | 293.1 | 295.4 | 265.5 | 24.92 |
| Backfat, cm | 78 | 0.76$^{c}$ | 0.59d | 0.74c | 0.230 | 80 | 0.69 | 0.75 | 0.54 | 0.252 |
| Ribeye area, $cm^2$ | 78 | 81.85$^{c}$ | 78.95cd | 74.88d | 7.746 | 80 | 79.47 | 78.05 | 70.95 | 7.950 |
| Yield grade | 78 | 2.2$^{c}$ | 2.0c | 2.4d | 0.35 | 80 | 2.1 | 2.3 | 2.1 | 0.38 |
| Warner-Bratzler shear force, kg | 113 | 2.46$^{c}$ | 2.70cd | 2.83d | 0.556 | 120 | 2.69 | 2.68 | 2.82 | 0.633 |

[a]Slow=<mean - 0.5 SD, Medium=mean – 0.5 SD to mean + 0.5 SD, Fast=>mean + 0.5 SD
[b]Root Mean Square Error from Analysis of Variance table
[cd]Least squares means with different superscripts with a row and temperament group differ, P<0.05, from the model Y=on pasture backfat, on pasture wt., off pasture backfat, off
pasture wt., ryegrass ADG, In feedlot wt. out feedlot weight, feedlot ADG, hot carcass wt., backfat, ribeye area, yield grade, Warner-Bratzler shear force

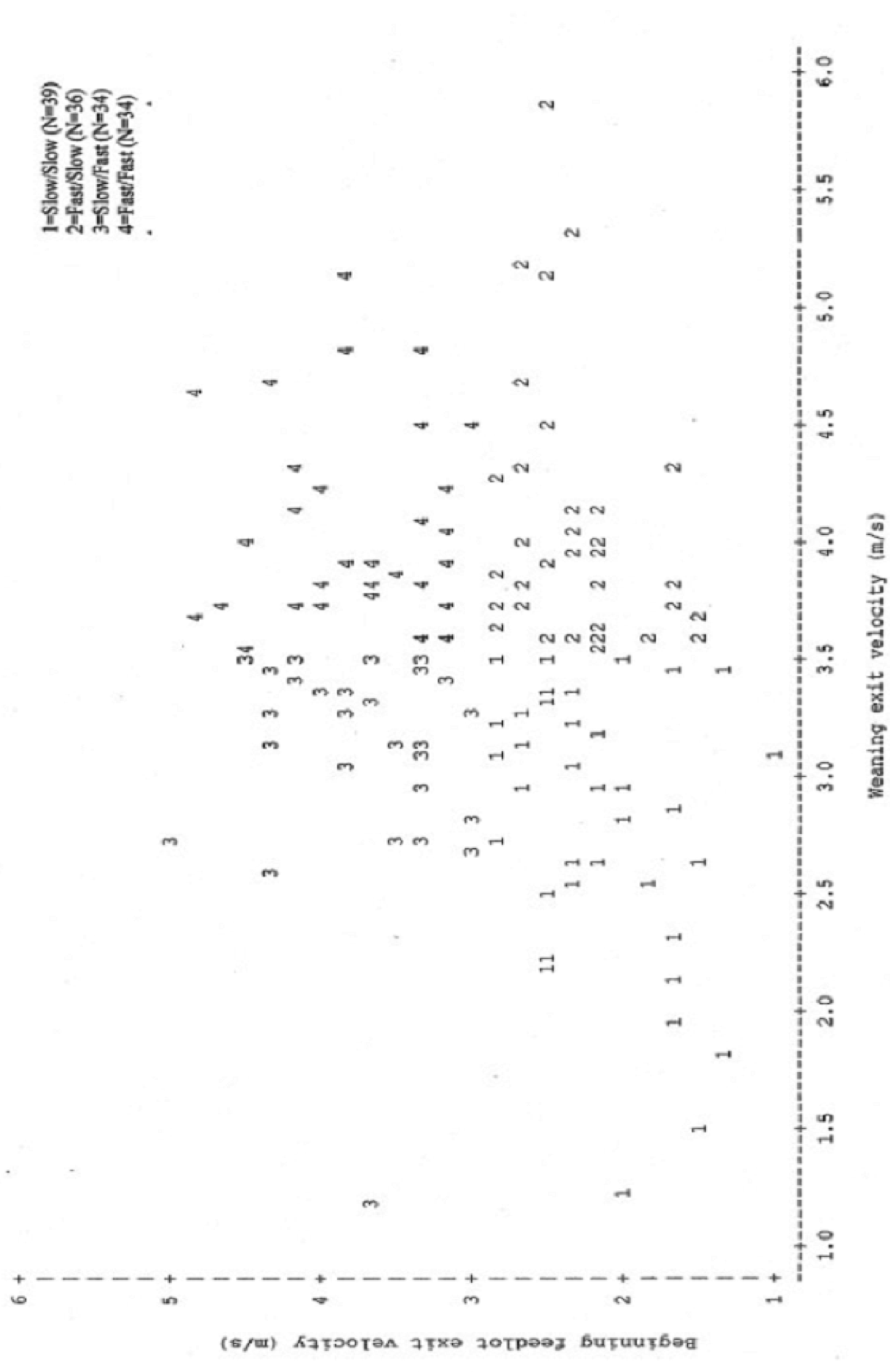


Figure 3. Beginning feedlot exit velocity and weaning exit velocity denoted by exit velocity category (Experiment 1)

Table 6. Least squares means and standard error for pre-feedlot and feedlot performance, carcass characteristics, and tenderness as effected by exit velocity categories at weaning and beginning of the feedlot period (Experiment 1)

| Weaning exit velocity (m/s)<br>Beginning feedlot exit velocity (m/s) | Number | Slow<br>Slow | Fast<br>Slow | Slow<br>Fast | Fast<br>Fast |
|---|---|---|---|---|---|
| Weaning exit velocity (m/s) | 137 | 2.84[a] ± 0.085 | 4.08[c] ± 0.092 | 3.11[b] ± 0.101 | 4.15[c] ± 0.093 |
| Weaning pen score | 137 | 1.1[a] ± 0.090 | 1.7[b] ± 0.10 | 1.4[ab] ± 0.11 | 1.5[b] ± 0.10 |
| On pasture backfat (mm) | 146 | 3.9 ± 0.30 | 4.7 ± 0.35 | 4.5 ± 0.37 | 5.1 ± 0.35 |
| On pasture wt. (kg) | 158 | 233.7[b] ± 6.10 | 238.6[b] ± 7.82 | 219.7[ab] ± 7.71 | 211.4[a] ± 7.83 |
| Off pasture backfat (mm) | 155 | 6.6[a] ± 0.23 | 7.7[b] ± 0.28 | 3.7[a] ± 0.28 | 7.5[b] ± 0.28 |
| Off pasture wt. (kg) | 155 | 362.1[a] ± 7.28 | 389.6[b] ± 9.09 | 342.3[a] ± 8.96 | 354.5[a] ± 9.09 |
| Pasture ADG (kg/d) | 155 | 0.95[a] ± 0.028 | 1.12[b] ± 0.035 | 0.91[a] ± 0.035 | 1.04[b] ± 0.03 |
| Beginning feedlot exit velocity (m/s) | 156 | 2.13[a] ± 0.070 | 2.31[a] ± 0.087 | 3.77[b] ± 0.086 | 3.82[b] ± 0.087 |
| Beginning feedlot pen score | 155 | 1.3[a] ± 0.11 | 1.7[b] ± 0.13 | 1.8[b] ± 0.13 | 2.2[c] ± 0.13 |
| In feedlot wt. (kg) | 156 | 348.3[b] ± 6.57 | 371.1[c] ± 8.20 | 323.0[a] ± 8.09 | 335.5[ab] ± 8.20 |
| Out feedlot wt. (kg) | 152 | 497.6 ± 5.13 | 502.2 ± 6.71 | 483.8 ± 6.31 | 493.6 ± 6.50 |
| Feedlot ADG (kg/d) | 152 | 1.39 ± 0.042 | 1.34 ± 0.055 | 1.49 ± 0.052 | 1.34 ± 0.053 |
| Hot carcass weight (kg) | 88 | 291.2 ± 4.37 | 294.2 ± 5.48 | 285.1 ± 5.48 | 290.8 ± 6.97 |
| Backfat (mm) | 88 | 7.1 ± 0.043 | 7.1 ± 0.055 | 7.0 ± 0.055 | 6.6 ± 0.070 |
| Ribeye area ($cm^2$) | 88 | 79.92 ± 4.005 | 76.63 ± 1.709 | 79.14 ± 1.709 | 77.53 ± 2.167 |
| Yield grade | 88 | 2.1 ± 0.07 | 2.3 ± 0.09 | 2.1 ± 0.09 | 2.2 ± 0.11 |
| Warner-Bratzler shear force (kg) | 133 | 2.61 ± 0.083 | 2.82 ± 0.109 | 2.55 ± 0.105 | 2.80 ± 0.122 |

[abc] Least squares means with different superscripts within a row and exit velocity category differ, $P<0.05$, from the model: Y=weaning exit velocity, weaning chute score, weaning weight, weaning pen score, weaning order through the chute, on ryegrass weight, on ryegrass backfat, off ryegrass weight, off ryegrass backfat, beginning feedlot pen score, beginning feedlot exit velocity, beginning feedlot cortisol, beginning feedlot chute score, facial whorl distance, change in exit velocity, average exit velocity, beginning feedlot weight, beginning feedlot order through the chute, mid-feedlot order through the chute, mid-feedlot backfat, mid-feedlot weight, end feedlot weight, end feedlot order through the chute, average daily gain on ryegrass, average daily gain in the feedlot, hot carcass weight, dressing percent, carcass backfat, adjusted preliminary yield grade, ribeye area, kidney pelvic and heart fat, marbling score, quality grade, yield grade, hump height, lung score, and mean shear force

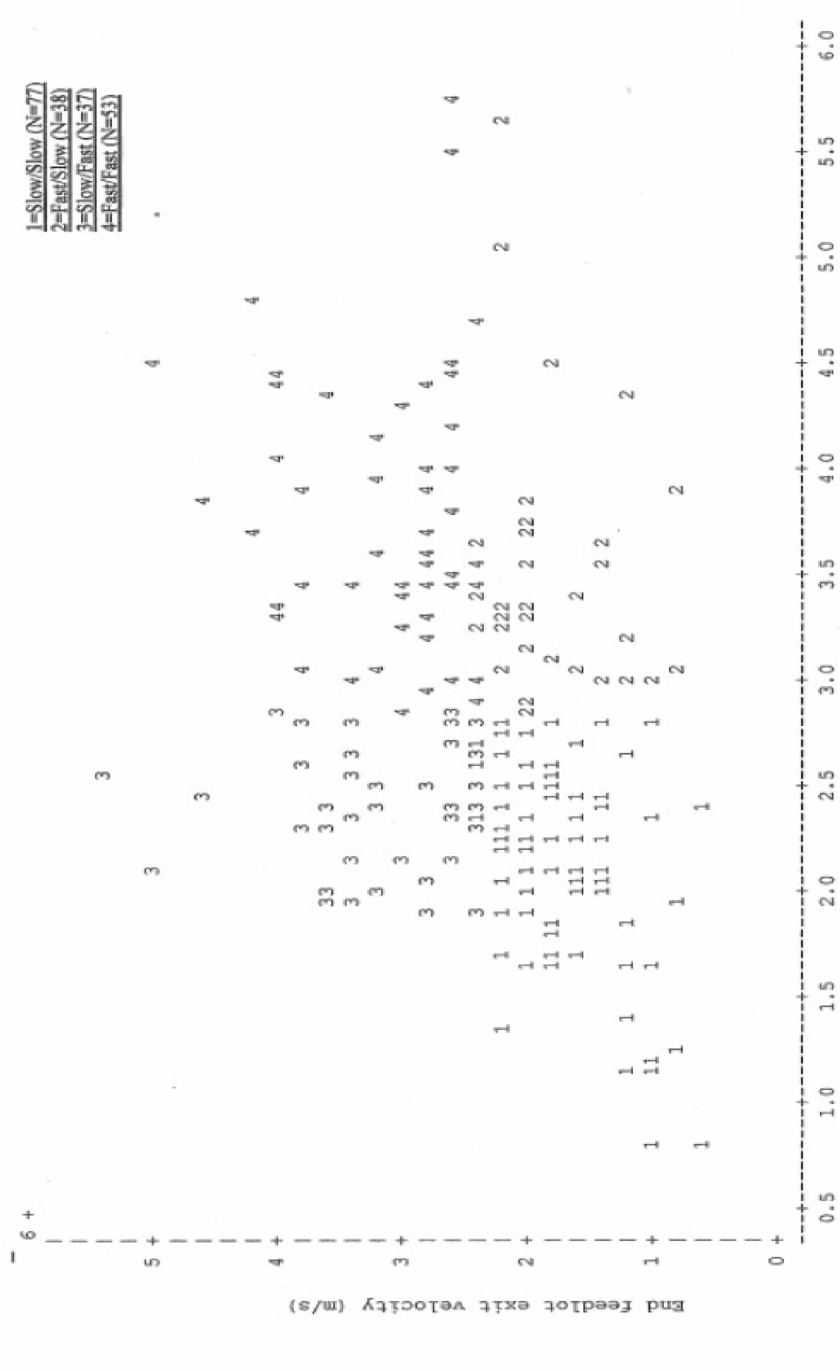


Figure 4. End feedlot exit velocity and beginning feedlot exit velocity denoted by exit velocity category (Experiment 2)

Table 7. Least squares means and standard error for feedlot measurements, carcass characteristics, and tenderness as effected by exit velocity categories at the beginning and end of the feedlot period (Experiment 2)

| Beginning feedlot exit velocity (m/s)<br>End feedlot exit velocity (m/s) | Number | Slow<br>Slow | Fast<br>Slow | Slow<br>Fast | Fast<br>Fast |
|---|---|---|---|---|---|
| In feedlot wt. (kg) | 207 | 387.7 ± 4.49 | 394.8 ± 6.40 | 377.7 ± 6.32 | 381.8 ± 5.42 |
| Beginning feedlot exit velocity (m/s) | 205 | 2.13[a] ± 0.060 | 3.45[c] ± 0.086 | 2.39[b] ± 0.087 | 3.78[d] ± 0.072 |
| Beginning feedlot pen score | 206 | 1.6[a] ± 0.10 | 1.8[a] ± 0.14 | 2.4[b] ± 0.14 | 2.7[b] ± 0.12 |
| End feedlot exit velocity (m/s) | 207 | 1.69[a] ± 0.065 | 1.81[a] ± 0.093 | 3.23[b] ± 0.092 | 3.16[b] ± 0.079 |
| End feedlot pen score | 207 | 1.5[a] ± 0.10 | 2.1[b] ± 0.15 | 3.2[c] ± 0.15 | 3.2[c] ± 0.12 |
| Final feedlot wt. (kg) | 207 | 534.3 ± 5.19 | 545.9 ± 7.39 | 518.4 ± 7.30 | 530.2 ± 6.26 |
| Feedlot ADG (kg/d) | 207 | 1.42 ± 0.035 | 1.49 ± 0.050 | 1.34 ± 0.050 | 1.42 ± 0.043 |
| Change in exit velocity (m/s)[e] | 205 | -0.44[b] ± 0.080 | -1.65[a] ± 0.144 | 0.83[c] ± 0.116 | -0.63[b] ± 0.097 |
| Hot carcass weight (kg) | 207 | 327.0 ± 3.25 | 338.2 ± 4.62 | 326.7 ± 4.56 | 325.6 ± 3.91 |
| Carcass backfat (mm) | 207 | 9.5 ± 0.39 | 10.7 ± 0.56 | 9.1 ± 0.55 | 10.1 ± 0.47 |
| Ribeye area ($cm^2$) | 207 | 84.17 ± 1.045 | 86.24 ± 1.490 | 86.17 ± 1.471 | 84.88 ± 1.264 |
| Yield grade | 196 | 2.1 ± 0.04 | 2.0 ± 0.06 | 2.0 ± 0.06 | 2.0 ± 0.05 |
| Warner-Bratzler shear force (kg) | 204 | 2.13 ± 0.042 | 2.03 ± 0.063 | 2.03 ± 0.058 | 2.02 ± 0.053 |

[abcd]Least squares means with different superscripts within a row and exit velocity category differ, $P<0.05$, from the model Y=in feedlot weight, beginning exit velocity, beginning pen score, beginning backfat, beginning feedlot weight, end exit velocity, end bucket score, end pen score, end feedlot weight, final feedlot weight, days on feed, beginning feedlot ADG, feedlot ADG, change in exit velocity, average exit velocity, hot carcass weight, carcass backfat, ribeye area, hump height, quality grade, yield grade, percent marbling, vision yield grade, average shear force

[e]End feedlot exit velocity – Beginning feedlot exit velocity

# Economics

# THE ECONOMIC IMPACT OF FEEDING ETHANOL BY-PRODUCTS IN FEEDLOT DIETS

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## Summary

This research used published nutrition research combined with costs of feeding cattle in Texas, Colorado, Kansas, and Nebraska to examine the economic impact of including ethanol by-product feeds in feedlot diets. The partial budget model shows that wet distiller's grain (WDGS) and dried distiller's grain (DDGS) help offset higher corn prices, as they can be fed at a lower cost of gain than the base ration, even for feedlots located 200 to 300 miles from ethanol production. But, the gain in cattle performance is critical to the success of these rations. This research relies on limited feedlot nutrition studies regarding the use of ethanol co-products. The existing feeding infrastructure is an important determinant in the success of by-product feeding. As seen in the analysis, cattle performance makes the difference between alternative scenarios including WDGS as the least and the highest cost rations.

## Introduction

By-products have long been a feed source for livestock. From the time cattlemen started "cattle feeding", by-products have been utilized to reduce the cost of gain, especially in the finishing ration. With the current expansion of the ethanol industry, another by-product feed, or co-product of ethanol production, distiller's grains, is becoming more available to livestock feeders.

This research evaluated the potential impact of increasing distiller's grains production on the beef cattle feeding industry. Geographic differences and specific regional implications for beef cattle feedlots in the top four cattle feeding states are analyzed. Implications for the feed deficit states (Texas and Colorado), were compared with those that have abundant distiller's grains production (Nebraska and Kansas). Regional differences in feedlot equipment, ration composition, and distance to distiller's grains production were included in the analysis.

## Experimental Procedures

Historical data were used to develop a feedlot partial budget model. Stochastic simulation was used to incorporate risk in the deterministic feedlot model by estimating a variable's probability distribution. The partial budget included ration and feeding (yardage) costs representing Colorado, Kansas, Nebraska, and Texas feedlots. Ration costs are a function of ingredient prices, ration composition, and cattle performance. Historical price data were used to estimate ration ingredient prices. Feedlot data from Professional Cattle Consultants (PCC) were used to estimate feed efficiency, average daily gain, dry feed conversion, daily dry matter intake, veterinary/medical expenses, and other key variables for each region.

Changes in cattle performance resulting from feeding two different levels of WDGS and one level of DDGS were estimated by adjusting historical average daily gain, feed efficiency, and dry matter intake. Nutrition research results account for the regional changes in cattle performance with the corresponding ration composition incorporating distiller's grains.

Base regional ration ingredients were adjusted to incorporate DDGS at 15% and WDGS at 15 and 30% of the diet dry matter. Feed costs were estimated for a base ration without DGs, and wet and dry distiller's grains at two dietary inclusion rates in a total of four rations for Kansas and Nebraska, and seven rations for Colorado and Texas, where steam-flaked corn (SFC) based rations were compared to dry-rolled corn (DRC) based rations. Steam flaking and dry rolling corn processing costs were estimated from Macken et al. (2006). Natural gas, electricity price, and trucking costs were obtained from the Department of Energy (US DOE, 2006) and the Agricultural Marketing Service Grain Transportation 1st Quarter 2006 Report.

Changes in infrastructure or equipment costs were accounted for to determine whether cost savings exist for feeding DRC with WDGS. Additional costs included investment in Roto-Mix® mixer/delivery box trucks, labor costs for Roto-Mix® drivers and front end loader operators, fuel, insurance, and maintenance costs.

Increased feeding time and handling costs were estimated based on the increasing amount of weight hauled to the feedlot and fed each day when incorporating WDGS. The feed cost equation estimated by Vander Pol et al. (2006b) was used to determine the percentage increase in feeding costs for each inclusion rate of WDGS. The percentage increase in feeding costs was calculated from the change in as-fed feed when incorporating WDGS as compared to the base ration.

Steam flaked corn was fed in the base, 15% DDGS scenario, and the 15% WSDGS scenario for the Texas feedlot model. DRC is fed in the 15 and 30% WDGS scenarios. The 15 and 30% WDGS rations were estimated by primarily substituting DRC for SFC in the base scenario and replacing a portion of the DRC with WDGS. Cattle performance, specifically ADG, for the 15 and 30% WDGS rations was estimated from Vander Pol et al. (2006a). Nebraska ration scenarios were estimated from Vander Pol et al. (2006a,c). All Nebraska rations contain DRC, and the 30% WDGS DRC:HMC (High Moisture Corn) contained a combination of DRC and HMC.

## Results and Discussion

*Colorado Results*

Cost of gain was lowest for the ration scenario including 15% WDGS fed with DRC. Thirty percent WDGS/DRC was the next lowest cost of gain ration. The rations with the highest cost of gain were those using 30% WDGS fed in a steam-flaked corn based ration. The major cost difference between the 30% WDGS/DRC and 30% WDGS/SFC scenarios is cattle performance, specifically ADG, where the total pounds gained were lower for the cattle fed WDGS/SFC than those fed WDGS/DRC based rations. Steam-flaking costs were higher than dry-rolling costs, increasing the cost of gain in the WDGS/SFC rations.

At a distance of 25 miles from an ethanol plant, the 15% WDGS/DRC ration still had the lowest cost of gain but, the 15% DDGS/SFC was the second lowest cost of gain scenario. Feedlots located 300 miles from ethanol production could still lower their cost of gain by feeding 15% WDGS/DRC. The next best alternatives are 15% DDGS/SFC and the base ration scenario. The 30% WDGS/DRC ration is now clearly not preferred as a cost-minimizing scenario. Those rations combining SFC with WDGS remain the highest cost of gain alternatives.

The increased transportation costs for the feedlot 300 miles from the ethanol plant when compared to the feedlot 25 miles from an ethanol plant was approximately $0.02 and $0.05 more per pound of gain for 15 and 30% WDGS inclusion rates, respectively. The 15% WDGS/DRC ration still had the lowest cost of gain at a distance of 300 miles from ethanol production. Also, WDGS transportation costs for the 30% WDGS inclusion rates were about twice as much, per head, as those for the 15% inclusion rates.

*Kansas Results*

Kansas results were similar to those from the Colorado model. The 15% WDGS/DRC, followed by the 30% WDGS/DRC were the least cost of gain ration scenarios. When WDGS must be hauled 100 miles to the feedlot the 15 percent WDGS/DRC ration still had the lowest cost of gain, but the 30% WDGS/DRC scenario became less feasible.

Even when a feedlot was located 200 to 300 miles from ethanol production, the 15% WDGS ration yielded the lowest costs. The 15% DDGS/SFC ration was the next lowest cost of gain alternative, followed by the base ration for both the 200 and 300 mile locations.

*Nebraska Results*

The 15% WDGS/DRC, followed by the 30% WDGS/DRC ration were the lowest cost scenarios. At a distance of 25 miles from ethanol production, Nebraska cattle feeders can still feed 15% WDGS/DRC at the lowest cost of gain, and the 30% WDGS/DRC had a similar cost of gain to the base scenario.

When transporting WDGS 60 miles, the 30% WDGS/DRC scenario is no longer preferred over the base scenario, but the 15% WDGS/DRC remains the least cost of gain option. The results for Nebraska feedlots located 60, 100, and 200 miles from ethanol production were similar. At each distance from ethanol production, WDGS can be fed at 15% inclusion to obtain the lowest cost of gain. The base ration of DRC has the second lowest cost of gain at all three distances. It is important to note that cattle feeders in eastern Nebraska are feeding WDGS at inclusion rates greater than 15% of ration dry matter.

*Texas Results*

When located at an ethanol plant, 15 or 30% WDGS can be fed with DRC to decrease cost of gain when compared to the base, 15% DDGS/SFC, and 15 percent WDGS/SFC rations. However, the Texas base scenario and the 15% WSDGS scenario included SFC, while the 15 and 30% WDGS rations included DRC instead of SFC.

SFC costs more to process than DRC, which increases total costs for both the base and 15% WSDGS scenarios. In addition, ADG for cattle fed 15% WDGS with SFC was lower than for cattle fed 15% WDGS with DRC. Even when feedlots are located at an ethanol plant, the highest cost of gain scenario occurred when WDGS is fed in SFC-based rations instead of DRC-based rations.

When WDGS must be hauled 300 miles from an ethanol plant to a feedlot, it can still be fed at 15% of the dry matter ration. The 15% WDGS ration had a similar cost of gain as the base ration and the 15% DDGS ration. At distances greater than 100 miles from ethanol production, the 30% WDGS ration would no longer be preferred as a least cost of gain ration.

Table 1 contains the cost savings from feeding 15% WDGS/DRC instead of the base ration in each state, when located at the plant and 100 miles from the ethanol plant. The cost savings are also listed by placement month because those placed on feed in May are on feed for fewer days (fewer total pounds of gain) than those placed at a lighter in-weight in October.

When WDGS was fed with DRC at 15% of the ration dry matter, primarily replacing a portion of the DRC, cost of gain savings can range from $7.30 to $2.73 per 100 pounds of gain for cattle feeders located at an ethanol plant. Even when transporting WDGS 100 miles, costs per 100 pounds of gain can be decreased by $5.93 to $1.42.

## Implications

This research incorporates current nutrition research in a feeding cost model. The results indicate that both wet and dry distiller's grains can reduce cost of gain and feeding efficiency. Efficiency gains enable the financial feasibility of shipping WDGS even further distances. Reductions in efficiency gains feeding steam flaked corn and wet distiller's grains has economic competitiveness implications for cattle feeding in the Texas panhandle and other regions.

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Table 1. Average Cost Savings per 100 Pounds of Gain When Feeding 15% WDGS/DRC.

| | Placements | At Plant | 100 miles |
|---|---|---|---|
| CO | May | $5.46 | $3.51 |
| | October | $6.22 | $4.43 |
| KS | May | $6.33 | $5.05 |
| | October | $7.30 | $5.93 |
| NE | May | $4.16 | $2.80 |
| | October | $4.44 | $3.08 |
| TX | May | $2.73 | $1.42 |
| | October | $3.41 | $2.24 |

Note: Cost savings = Average(Base COG-15%WDGS/DRC COG)*100 using the average of 500 iterations.
COG = Cost of gain including WDGS investment costs for CO, KS, and TX.
At plant costs include $0.15 corn basis.

# ECONOMIC ANALYSIS OF FEEDYARD DUST SUPPRESSION USING A TRAVELING GUN(S) SPRINKLER SYSTEM

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## Summary

Dust suppression is an issue for many Texas Panhandle feedyards. Failure to control dust can lead to health and performance problems in cattle. An economic analysis consisting of estimating the investment, annualized fixed and operational costs associated with one potential dust control method, a traveling gun(s) sprinkler system was conducted. The initial investment cost was estimated at $45,292, $96,306 and $150,763 for 10,000, 30,000 and 50,000 head capacity feedyards, respectively. The annualized fixed cost per head capacity based on a 20-year equipment life was $0.62, $0.44 and $0.41 with an associated annual operating cost of $1.05, $0.94 and $0.95 for the same size feedyards. These costs compare favorably to the more commonly used solid-set sprinkler. However, the inability to qualify for government cost-share programs coupled with the increased management, labor and maintenance requirements of the system relative to solid-set sprinkler(s) will likely limit adoption.

## Introduction

Confinement cattle feeding in the Texas Panhandle became widely accepted in the 1950s. Consequently, numerous feedyards were constructed during the 1960s and early 1970s, indicating a significant upswing in the cattle feeding industry (TCFA, 2007). As the industry matured, feedyard dust that affected both feedyard neighbors and cattle health became a growing concern of owners. Dust suppression can be accomplished by moistening pen surfaces. According to Lorimor (2003), the optimum moisture level in an open-lot feedyard is 25% to 40%. At approximately 40% moisture, odor and flies become a problem. At less that 25% moisture, dust can be the significant, negative health issue. Three methods are currently used to apply water to control dust; solid-set sprinkler system, traveling gun(s) sprinkler system and water trucks. This study analyzed costs associated with installing and operating a traveling gun(s) sprinkler system.

## Experimental Procedures

Fixed, operational and total costs were estimated for a traveling gun(s) sprinkler system for dust control in 10,000, 30,000, and 50,000 head capacity feedyards. The initial investment costs associated with the traveling gun system included the traveling gun, booster pump, pipeline, and freight for all components. Fixed costs for a traveling gun(s) sprinkler system were comprised of the initial investment expenditure for each size feedyard annualized over an assumed 20-year useful life. The associated depreciation was calculated using the straight-line method with no salvage value assumed after the useful life of the system. Cost estimates from industry provided the capital expenditure data for similar equipment to apply 1/8 inch of water per day to the feedyard surface. Booster pump costs included the investment cost of the pump plus installation and foundation expenses. All cost streams were put into current dollars utilizing a 6% discount rate.

Booster pump costs included the investment cost of the pump plus installation and foundation expenses. Industry sources recommended a booster pump, on average, require replacement every 10 years. In this study, it was assumed a well was available with a sufficient flow capacity to operate multiple systems; therefore, expenditures did not include the installation of a new well to pump groundwater. There were no costs included for the installation of an irrigation reservoir.

Operational costs are a direct function of the number of hours the traveling gun(s) sprinkler system is operated. Annual operational costs for the traveling gun(s) sprinkling system included energy, labor and system maintenance and repairs. Energy costs are the expenditures required to pump the water and were determined utilizing the following formulas:

$$KW = (.746 * \text{Motor Horsepower}) / 90\% \text{ motor efficiency}$$

*Where: KW = kilowatt. # kilowatts per hour*

$$\text{Total Energy Cost} = KW * \text{electricity cost} * \text{hours per year operated}$$

Two energy sources provided electricity costs and were averaged at $0.09 per Kwh The 10,000 head yard operates one traveling gun seven hours plus three-man hours per day to move the equipment. Similarly, the 30,000 head yard operates two traveling guns 10.5 hours plus nine-man hours per day to move the equipment. The 50,000 head yard operates three traveling guns 14 hours with 15-man hours per day to move the equipment. The traveling gun(s) sprinkler system functions approximately six months of the year, April 15 to October 15, for a total of 184 days (B. W. Auvermann, TAES, Amarillo, personal communication).

Cost estimates were also calculated on a per head marketed basis. This was accomplished by utilizing the Southwestern Public Service Company Fed Cattle Survey for 1996 – 2000 to determine the five-year average cattle turnover rate for the 10,000, 30,000 and 50,000 head feedyards. A sensitivity analysis was conducted using three turnover rates (1.75, 2.00, and 2.25) to adjust dollars per head capacity to dollars per head marketed for total costs.

## Results and Discussion

The initial investment costs of a traveling gun(s) sprinkler system were comprised of the traveling gun, booster pump, pipeline and freight for all components. Estimated total investment cost to make the system operational for a 10,000 head feedyard was projected at $45,292. This cost in addition to the purchase of one traveling gun, booster pump and freight included trenching and installation of the pipeline. Similarly, the 30,000 head feedyard was estimated to have investment costs of $96,306 and included two traveling guns, booster pump, trenching and installation of pipeline, and freight. In the 50,000 head feedyard, three traveling gun sprinkler systems were utilized at a cost of $150,763 (Table 1).

High-pressure pipelines are necessary in larger feedyards. This results in increasing the pipeline cost almost five-fold between the 10,000 head ($5,292) and 30,000 head ($24,026) feedyards, Table 1. Pipe diameter size in the 10,000 head yard was six inches, whereas, it was six and eight inches with a larger portion being eight inches in the 30,000 head yard. In comparison, the 50,000 head yard ($51,220) pipe expenditures increased nearly ten-fold as opposed to the 10,000 head yard ($5,292). In the 50,000 head yard, six, eight and ten inch pipe is used with a majority being eight and ten inches (Table 1).

Fixed costs for the traveling gun(s) sprinkler system were comprised of the initial investment, depreciation and interest. Depreciation was calculated using a straight line method assuming a 20-year useful life. All costs were expressed in current dollars utilizing a 6% discount rate. Total annualized fixed costs in the 10,000 head yard were estimated at $6,213, or $0.62 per head capacity, whereas, the 50,000 head feedyard had projected total annualized fixed costs of $20,682, or $0.41 per head capacity. This was a difference of $0.21 per head capacity in the two side feedyards (Table 2).

Operational costs included annual labor, energy, and maintenance and repairs for the traveling gun(s) sprinkler system. Total annual operational costs were estimated at $10,458, $28,306 and $47,392 for the 10,000, 30,000 and 50,000 head feedyards, respectively (Table 3). The economies of scale did not increase between the 30,000 and 50,000 head yards. Any gain in economy of scale in the larger yard created by lower pump and traveling gun costs per head was mostly offset by larger, more costly pipe.

Labor cost is the single largest expense for the three size feedyards followed by energy and repairs and maintenance costs. In the 10,000 head yard, annual operational costs were $1.05 per head capacity as opposed to $0.94 per head capacity in the 30,000 head yard (Table 3).

Projected fixed and operational costs were combined to determine the total annual costs to operate a traveling gun(s) sprinkler system to control feedyard dust emissions in the three size feedyards. The annualized fixed costs were $0.62, $0.44, and $0.41 per head capacity for 10,000, 30,000, and 50,000 head feedyards, respectively (Table 4). The operational costs varied from $1.05 per head capacity for the 10,000 head feedyard to $0.95 per head capacity for the 30,000 head feedyard. Total cost in dollars per head capacity ranged from $1.67 for the 10,000 head feedyard to $1.36 in the 50,000 head feedyard.

The Southwestern Public Service Company Fed Cattle Survey for 1996-2000 was used to establish the five-year average cattle turnover rate for the three size feedyards to calculate cost estimates on a per head marketed basis. Three turnover rates, 1.75, 2.00, and 2.25, were used to adjust dollars per head capacity to dollars per head marketed. A 10,000 head feedyard at a 1.75 turnover rate had fixed costs at $0.36 and operational costs at $0.60 for a total of $0.95 per head marketed to install and operate a traveling gun(s) sprinkler system (Table 5). A 50,000 head feedyard at the same turnover rate, 1.75, had fixed costs at $0.24 and operational costs at $0.54 for a total of $0.78 per head marketed.

A consideration when purchasing a traveling gun(s) sprinkler system for feedyard dust suppression is existing governmental cost-share programs that may assist in purchasing the equipment. Prior to 2003, the Environmental Quality Incentive Program (EQIP) funding was available for farmers, ranchers, and small animal feeding operations on a cost-share basis. In 2003, USDA Natural Resources Conservation Service (NRCS) designated EQIP monies for larger, Concentrated Animal Feeding Operations (CAFOs) to address environmental issues. “The first area of emphasis for Texas’ CAFO program under EQIP was atmospheric resource quality management, or ARQM, focusing exclusively on dust control from open-lot feedyards” (Auvermann and Sweeten, 2005). However, since that time, no known organizations in the Texas Panhandle have applied for EQIP funds to utilize traveling guns. It is anticipated that no EQIP funding will be available for their use in the future (G. L. Sokora, Natural Resources Conservation Service, Lubbock, Texas, personal communication).

## Implications

Total annual costs of a traveling gun(s) sprinkler system for dust control were estimated to be $1.67, $1.38 and $1.36 per head for a 10,000, 30,000 and 50,000 capacity feedyards, respectively. This compares favorable to the solid-set sprinkler where total annual costs ranged from $2.70 to $2.09 (Guerrero et al., 2006) for similar sized feedyards. A portion of the cost advantage is lost if feedyards utilize EQIP cost-share available for solid-set sprinklers that traveling guns are not currently qualified for. In addition, the increased management, labor and maintenance requirements of the system relative to solid-set sprinkler(s) will likely limit adoption.

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Table 1. Estimated investment costs for traveling gun(s) sprinkler system for 10,000, 30,000 and 50,000 head capacity feedyards

| Head capacity | Traveling gun | Freight | Booster pump | Pipeline | Total cost | Total cost ($/head capacity) |
|---|---|---|---|---|---|---|
| 10,000 | $33,025 | $2,190 | $4,785 | $5,292 | $45,292 | $4.53 |
| 30,000 | $59,445 | $4,235 | $8,600 | $24,026 | $96,306 | $3.21 |
| 50,000 | $84,214 | $6,280 | $9,050 | $51,220 | $150,763 | $3.02 |

Table 2. Projected annualized fixed cost for traveling gun(s) sprinkler system over a 20-year useful life for three sized feedyards

| Head capacity | Total cost | Annualized fixed cost | Annual depreciation | Total annualized fixed cost | Annualized cost ($/head capacity) |
|---|---|---|---|---|---|
| 10,000 | $45,292 | $3,949 | $2,265 | $6,213 | $0.62 |
| 30,000 | $96,306 | $8,396 | $4,815 | $13,177 | $0.44 |
| 50,000 | $150,763 | $13,144 | $7,538 | $20,682 | $0.41 |

Table 3. Projected annual operational costs for traveling gun(s) sprinkler system over a 20-year useful life for three sized feedyards

| Head capacity | Energy cost | Traveling gun & pump maintenance & repairs | Labor cost | Operational cost | Operational cost ($/head capacity) |
|---|---|---|---|---|---|
| 10,000 | $1,943 | $1,891 | $6,624 | $10,458 | $1.05 |
| 30,000 | $5,044 | $3,390 | $19,872 | $28,306 | $0.94 |
| 50,000 | $9,608 | $4,663 | $33,120 | $47,392 | $0.95 |

Table 4. Estimated fixed, operational and total annual costs for traveling gun(s) sprinkler system based on a 20-year useful life for three-sized feedyards

| Head capacity | Fixed Cost $/head capacity | Operational cost $/head capacity | Total cost $/head capacity |
|---|---|---|---|
| 10,000 | $0.62 | $1.05 | $1.67 |
| 30,000 | $0.44 | $0.94 | $1.38 |
| 50,000 | $0.41 | $0.95 | $1.36 |

Table 5. Total annual costs for traveling gun(s) sprinkler system based on a 20-year useful life for three sized feedyards and turnover rates

| Head capacity | Turnover rate (head marketed/head capacity) | Fixed cost ($/head marketed) | Operational cost ($/head marketed) | Total Cost ($/head marketed) |
|---|---|---|---|---|
| | 1.75 | $0.36 | $0.60 | $0.95 |
| 10,000 | 2.00 | $0.31 | $0.52 | $0.83 |
| | 2.25 | $0.28 | $0.46 | $0.74 |
| | 1.75 | $0.25 | $0.54 | $0.79 |
| 30,000 | 2.00 | $0.22 | $0.47 | $0.69 |
| | 2.25 | $0.20 | $0.42 | $0.61 |
| | 1.75 | $0.24 | $0.54 | $0.78 |
| 50,000 | 2.00 | $0.21 | $0.47 | $0.68 |
| | 2.25 | $0.18 | $0.42 | $0.61 |

# Feeding and Nutrition

# EVALUATION OF THE CVDS MODEL TO ESTIMATE TOTAL FEED FED TO SANTA GERTRUDIS STEERS AND HEIFERS BASED ON PERFORMANCE AND DIET COMPOSITION

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## Summary

The Cornell Value Discovery System (CVDS) was developed to predict growth and body composition based on animal, diet, and environment information. This model has been adapted to facilitate individual management of pen-fed cattle, and to harvest animals at the most profitable endpoint based on the USDA quality and yield grade. The CVDS is also used to allocate feed to individual cattle fed in pens. The objective of this study was to evaluate the model's effectiveness in predicting total dry matter feed required (DMR) for Santa Gertrudis steers and heifers (n = 457) fed in five separate pens at the King Ranch feedyard. The cattle were fed three step-up rations and one finishing ration, that ranged from 1.04 to 1.28Mcal ME/lb. Performance and carcass traits were used to compute the BW at 28% empty body fat (EBF) for each animal. The CVDS model was used to predict individual DMR and to estimate total DMR of the pen. The mean bias, calculated as the mean difference between DMR and total dry matter feed provided to each pen divided by DMR, was 4.64% and 1.46% for heifers and steers respectively, with an overall value of 2.43%. A sensitivity analysis of the dietary ME (± 5 and ± 10%) indicated the accuracy decreased when dietary ME used was lower or higher than the CNCPS predicted value. No interaction was observed between ranking DMR and different values of dietary ME. Our findings suggested the CVDS accurately predicted feed requirements for Santa Gertrudis steers and heifers.

## Introduction

The conversion of feed into animal products during the post-weaning growth phase has a large influence on the cost of producing beef (Herd et al., 2003). The beef industry is moving steadily toward a system where cattle and carcasses are managed and marketed on an individual rather than pen basis (Cross and Whitaker, 1992). Individual Cattle Management

Systems (ICMS) may aid in improving profitability, minimizing excess fat produced, and improving product consistency by decreasing individual animal variability within a pen. As cattle from multiple owners and biotype are often fed together within a single pen, successful implementation of ICMS would require more accurate predictions of feed inputs of individual calves based on performance data (Fox et al., 2001).

The Cornell Value Discovery System and its more recent version Cattle Value Discovery System (CVDS; http://nutritionmodels.tamu.edu/cvds.htm) were developed to predict growth and feed requirements of individual growing and finishing cattle fed in groups based on animal performance, diet, and environment information (Tedeschi et al., 2004), and to estimate carcass composition with known diet information (Perry and Fox, 1997). The objectives of this study were to evaluate the CVDS model's effectiveness in predicting total DM required (DMR) for Santa Gertrudis steers and heifers, and to evaluate the effects of errors in ME values on the model's predictions of DMR.

## Experimental Procedures

The cattle in the evaluation database consisted of five pens of Santa Gertrudis steers and heifers (n= 457) fed at the King Ranch feedyard. Table 1 summarizes the calves used in the evaluation. Pens 1 and 4 contained only heifers, while pens 3 and 5 contained only steers, and pen 2 contained both steers and heifers. Average initial BW ranged from 446 to 654 lb. Cattle were slaughtered over four dates from June 15 to August 18.

The cattle were fed three step-up rations and one finishing ration that ranged from 1.04 to 1.28 Mcal ME/lb. The finishing ration consisted of 67% milo, 9% pressed brewer's grain, 7% premix, 6% molasses, 5.5% whole cottonseed, 2.5% cotton burrs, 2% fat, and 1% cottonseed meal. Dietary ME was calculated using actual feed analysis in the Cornell Net Carbohydrate and Protein System (CNCPS; Fox et al., 2004) model.

For each pen, model inputs included dietary ME, days on each ration, and number of animals fed each ration. Individual animal performance and carcass information that were input into the model included: sex, implant status, breed type (beef or dairy, and hide thickness), initial date of feeding period, approximate age, BCS, initial and final BW, yield grade, hot carcass weight, 12th rib fat thickness (FT), marbling (MRB) class and percentile, and rib-eye area (REA). Additionally for each individual animal in the dataset, BW and carcass composition (HCW, LMA, FT, and MRB) were used to predict a BW at 28% empty body fat (EBF). Empty BW (EBW) is computed from HCW, and adjusted final shrunk BW at 28% fat (AFSBW) was then computed using carcass information as described by Guiroy et al. (2001), which is estimated using the relationship between EBF and EBW. The CVDS model with the adjustment of ME to NE efficiency for composition of gain was used to predict individual DMR and to estimate total DMR of the pen.

The CVDS model's effectiveness was evaluated using mean bias, which is calculated as mean difference between observed and model-predicted values as a percent of predicted values. As well, a sensitivity analysis was conducted to test the effects of over and under-estimation of diet ME values. ME values were evaluated at 5 or 10 percent below or above actual ME values.

## Results and Discussion

The 90% confidence interval for predicted EBF at the harvest body weight ranged from 25-36% fat, and was similar for both steers and heifers. In an evaluation of the relationship between quality grade and EBF, Guiroy et al. (2001) noted that at a target quality grade of low choice the mean EBF percent was 28.61%, which is in agreement with the value of 27.8% fat at low choice reported by the NRC (2000).

The total feed fed to pen 1 was 258,250 lb for the entire feeding period, and the model's prediction of DMR was 274,602 lb. This indicated a model over-prediction, with a mean bias of 6.22%. For pen 2, total feed fed was 371,412 lb, and DMR predicted was 370,957 lb. This indicated a slight under-prediction, with a mean bias of -0.12%. Pen 3 received 304,611 lb of feed over the period, and predicted DMR was 300,765 lb, with a mean bias of -1.26% indicating a slight model under-prediction. Total feed fed to pen 4 was 345,816 lb, and the CVDS predicted a DMR of 357,615 lb, with a mean bias of 3.41%. Pen 5 received 232,623 lb of feed, and the CVDS predicted a DMR of 241,135 lb, which indicated an over-prediction of 3.66%. These predictions indicated that for this evaluation, the CVDS model was more accurate for some pens than for others. The model had a mean bias of 4.64% and 1.46% for heifers and steers respectively, and with an overall value of 2.43% the model was highly accurate across pens. Guiroy et al. (2001) indicated that an under-prediction bias of up to 2% may be expected in DMR due to feed delivered to the pen that was lost or not consumed by the cattle. When Perry and Fox (1997) compared DMR to DMI of individually fed steers, a bias of 3% was noted, which is very similar to the overall bias in this analysis.

In Guiroy et al. (2001), a dataset of 12,105 feedlot cattle was used to evaluate the model in real world situations, and a mean bias of -0.91% and 0.89% for steers and heifers respectively was observed. The values noted in this evaluation were slightly higher than those reported by Guiroy et al (2001), which may be due to the size of the database in each evaluation. In this evaluation, only 5 pens with a total of 457 steers and heifers were used, while Guiroy (2001) utilized a feedlot dataset of 12,105 steers and heifers.

The results of the ME sensitivity analysis are reported in Figure 1. The sensitivity analysis revealed that the model tended to under-predict DMR when ME values were over-estimated, and tended to over-predict DMR when ME values were under-estimated, as was expected. If ME values are over-estimated the model calculates DMR based on a greater amount of available energy from the feedstuff that would have been utilized in the resultant composition, and therefore predicts that the animal would have consumed a lower amount of feed than was actual, with the opposite being true when ME is under-estimated. However, there appears to be no interaction between the mean bias of model predicted intake for the total pen and accuracy of ME used in the predictions, as the ranking of pens when ME was adjusted above or below the actual value did not change. This indicates that even if estimates of dietary ME values are incorrect the CVDS model will still rank feed required for pens and individual cattle in the same order. This is an important aspect of the CVDS model when it is used in genetic predictions. Kirschten et al. (2006) evaluated the model for genetic purpose using the individually fed steer contemporaries of the cattle used in this evaluation. Strong genetic relationships were observed between DMI, DMR calculated from ultrasound traits, and DMR calculated from carcass traits. Kirschten et al. (2006) also noted minimal re-ranking of sires, which is extremely desirable in genetic predictions.

## Implications

This evaluation of the CVDS model revealed that accurate prediction of individual DMR of pen-fed cattle is possible. This suggests that the CVDS model may be a useful tool to successfully implement ICMS, although further research is needed to improve inconsistencies in mean bias of DMR prediction. The sensitivity analysis of dietary ME values revealed that the model tends to consistently over- and under-predict DMR when the ME values are under- and over-estimated, respectively. However the ranking of pens was not affected by this mis-estimation of diet ME, which suggests that the CVDS prediction of DMR may also have utility in the prediction of feed inputs for genetic evaluation.

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Table 1. Summary of pens used in the model evaluation [1]

| Pen | Sex[2] | N | DOF | iBW | fBW | REA | FT |
|---|---|---|---|---|---|---|---|
| | | | days | lb | lb. | $in^2$ | in |
| 1 | H | 84 | 180-208 | 584.9 | 1094.3 | 11.6 | 0.66 |
| 2 | S & H | 109 | 223-243 | 445.5 | 1012.5 | 11.1 | 0.57 |
| 3 | S | 85 | 180-223 | 653.6 | 1238.0 | 12.0 | 0.55 |
| 4 | H | 110 | 208 | 515.6 | 1050.0 | 11.1 | 0.72 |
| 5 | S | 69 | 208-223 | 568.9 | 1169.0 | 12.1 | 0.56 |
| Mean | | | 208 | 553.7 | 1112.8 | 11.6 | 0.61 |

[1]DOF = days on feed; iBW = initial body weight; fBW = final body weight; REA = ribeye area; FT = 12[th] rib fat thickness.
[2]S = steer; H = heifer

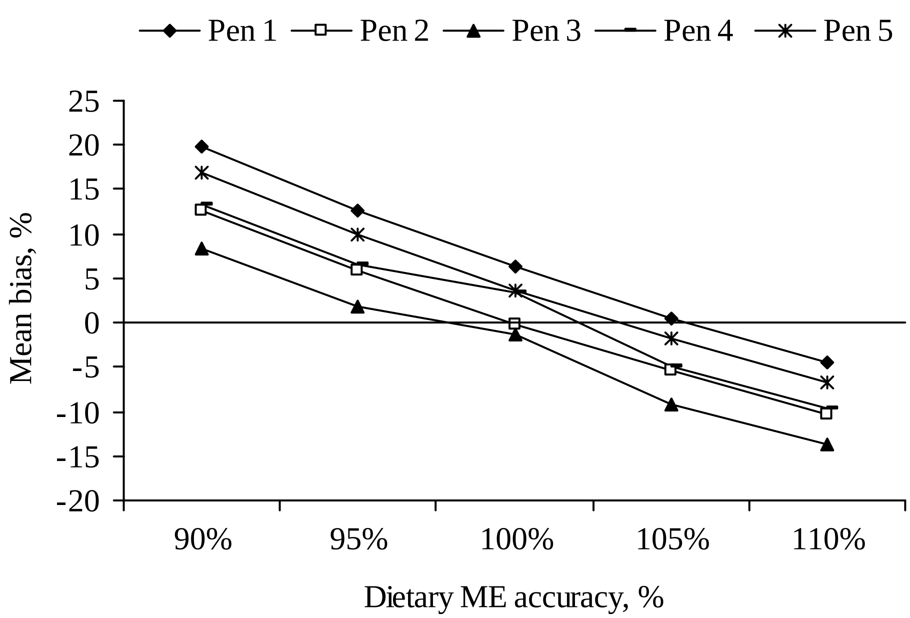


Figure 1. Relationship between accuracy of ME values in the CVDS model's prediction of DMR and the mean bias of model predictions

# INFLUENCE OF COPPER AND ZINC CHELATED MINERALS AND AN ORAL NUTRIENT GEL ON GROWTH PERFORMANCE AND HEALTH OF BEEF CALVES

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## Summary

Five hundred sixty eight crossbred calves (68% bulls, 32% steers) were fed diets for 28 days containing either no supplemental copper (**NC**), 20 ppm of copper from $CuSO_4$ (**CS**), 20 ppm of copper from a copper chelate (**CC**; MAAC CU 16), a 50:50 blend of CS and CC (**BL**), or a combination (**GC**) of a nutrient paste (Replamin) on arrival and 10 ppm of CS, 10 ppm of CC, 50 ppm of zinc from $ZnSO_4$, and 50 ppm of zinc from a zinc chelate (MAAC Zn 20). Overall dry matter intake (DMI), ADG, and feed efficiency were not altered by treatment. The incidence of morbidity from respiratory disease was low (6%), and calf health was not altered by treatment. Serum copper concentration was greater for cattle receiving supplemental copper, regardless of the source used. Providing 20 ppm of supplemental copper in the diet increased serum copper, but did not alter growth or health by calves with a low incidence of respiratory disease.

## Introduction

It is well established that trace mineral deficiencies can adversely impact humoral and cellular immune responses. Reduced immune function can directly increase costs of medical treatment and indirectly reduce growth performance. Previous data indicate that copper status can influence the ability of neutrophils to destroy certain pathogens, chemical messenger production by monocytes, and antibody production against antigens (Spears, 2000). However, relating these laboratory measures and antibody titers to economically meaningful implications for health and performance in commercial production is difficult. The objective of the present experiment was to determine the effects of copper and zinc source and a nutrient gel on growth performance and health of beef calves.

## Experimental Procedures

Five hundred sixty-eight crossbred male calves were procured from sale barns in central and east Texas. Calves were transported 392 miles from the order buyer facility in Santo, TX in 8 shipments; duration of transit averaged 7.5 hours. The first shipment of calves was received on 17 October 2005 and the final shipment was received on 8 January 2006. Calves were processed on arrival and allocated to treatments at processing.

Processing included individual identification, vaccination against viral antigens of IBR, $PI_3$, BRSV, and BVD type I and II and bacterial antigens of *M. hemolytica* and *P. multocida* (Vista Once), implanting with Revalor-G, administration of a clostridial bacterin-toxoid (Vision 7 with Spur), treatment for internal and external parasites (Ivomec Plus and Safe-Guard), horn tipping to a diameter of approximately 1 inch, castration by knife, and administration of Excede (1.5 mL/cwt). A 10-mL sample of whole blood was collected by jugular venipucnture from each animal on arrival. Calves were housed in 50 pens containing 10 to 12 animals each.

Calves were offered 2 lb/animal of long-stem prairie hay (7.2% CP, 62.2% NDF, and 32.7% ADF on a DM basis) for 3 to 7 days. A 60% concentrate diet containing a supplement specific to each treatment was offered ad libitum throughout the study. Dietary treatments included no supplemental copper (**NC**), 20 ppm of supplemental copper from $CuSO_4$ (**CS**), 20 ppm of copper from a chelated source (**CC**; MAAC Cu16, Albion Advanced Nutrition), a 50:50 blend of CS and CC (**BL**), or a combination (**GC**) of a nutrient paste (Replamin; Albion Advanced Nutrition) on arrival and 10 ppm of CS, 10 ppm of CC, 50 ppm of zinc from $ZnSO_4$, and 50 ppm of zinc from a zinc chelate (MAAC Zn 20; Albion Advanced Nutrition). The NC, CS, CC, and BL treatments each contained 100 ppm of zinc from $ZnSO_4$.

Corn was processed approximately twice weekly by steaming tempered grain (19% moisture, 18-hour soak) for approximately 40 minutes before flaking to 27 lb/bu. Samples of diets were collected weekly from the bunk after feed delivery; dry matter was determined on a subsample and remaining sample was composited gravimetrically within treatment over the entire study. Dry matter of steam-flaked corn was determined 5 days/week and the 5-day average was used to update as-fed diet composition each week, whereas dry matter content of remaining ingredients was determined once/week.

Calves were revaccinated (Vista 5) after weighing on approximately day 14 (ranged from day 12 to 16). In addition, one sample of whole blood (10 cc) was collected from each animal by jugular venipuncture at revaccination and at the end of the study. Serum was harvested after centrifugation, composited within pen, and stored frozen until assayed for copper by atomic absorption.

Performance and serum copper data were analyzed as a randomized complete block design using mixed procedures of SAS. Health data were analyzed using Glimmix procedures of SAS.

## Results and Discussion

Two steers were deemed to be noncompetitive and were removed from the study, and an additional two steers died during the study. Feed intake for the home pen of dead steers was adjusted by subtracting DM based on the pen average. Feed intake for the home pen of removed steers was adjusted by deducting feed needed to meet maintenance energy needs because both steers lost weight during the study.

Composite samples of the NC diet contained 8 ppm Cu, and remaining treatment diets contained 20 to 24 ppm in addition to copper provided by basal ingredients (Table 1). It is not clear why the assayed values for nutrients were generally lower for CC.

Neither health performance nor growth performance (Table 2) were altered by treatment in the present study ($P > 0.10$). Although 68% of the calves received were castrated on arrival, morbidity was less than 10%. Serum copper concentration responded similarly across time (day x treatment, $P > 0.10$) for all treatments (Figure 1). An increase in serum copper was evident after day 14 regardless of treatment. The main effect of treatment is reflected in Figure 2. Serum copper concentration was lower for NC than for remaining treatments ($P < 0.001$). The SE for serum copper was lower than anticipated, and seems to support our sampling approach. It is likely that collecting blood samples from all cattle rather than a subset within each pen eliminated the possibility of confounding respiratory disease incidence by individuals with serum copper.

There are surprisingly few published production studies assessing health and performance implications of copper sources. Salyer et al. (2004) supplemented heifer calves with 10 ppm of copper from either $CuSO_4$ or a copper polysaccharide complex for 35 days. Morbidity from respiratory disease was not altered by copper source (65 vs 60% for $CuSO_4$ and copper polysaccharide, respectively) even though heifers receiving $CuSO_4$ had higher antibody titers to ovalbumin at 14 and 21 days. Overall performance was similar among treatments. Galyean et al. (1995) indicated a tendency for lower morbidity by steer calves supplemented with 5 ppm of copper from copper lysine compared to steers supplemented with 3.25 ppm of copper from CuO (13.9 vs 20%). The time-course of serum copper in the present study was quite similar to that observed by Salyer et al. (2004). In their study, copper source did not alter serum copper and averaged 0.58, 0.83 and 0.94 ppm on days 1, 14, and 28.

## Implications

Steer calves experiencing a low incidence of respiratory disease that did not receive supplemental copper performed as well as steer calves receiving supplemental copper from either $CuSO_4$, MAAC Cu 16, or MAAC Cu 16 and Replamin gel. However, the higher serum copper concentration exhibited by calves receiving supplemental copper suggests that copper status was improved by supplementing copper.

## Acknowledgements

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Table 1. Ingredient and chemical composition of diet dry matter

| Item | Treatment[a] | | | | |
|---|---|---|---|---|---|
| | NC | CS | CC | BL | GC |
| Ingredient composition | | | | | |
| Steam-flaked corn | 46.2 | 46.2 | 46.2 | 46.2 | 46.2 |
| Supplement[b] | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| Cottonseed meal, 41% | 5.3 | 5.3 | 5.3 | 5.3 | 5.3 |
| Steep liquor:molasses (70:30)[c] | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 |
| Yellow grease[d] | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| Alfalfa hay | 40.0 | 40.0 | 40.0 | 40.0 | 40.0 |
| Chemical composition[e] | | | | | |
| CP, % of DM | 14.2 | 14.4 | 13.7 | 14.7 | 14.6 |
| NEm, Mcal/lb | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 |
| NEg, Mcal/lb | 0.58 | 0.58 | 0.58 | 0.58 | 0.58 |
| Potassium, % of DM | 1.35 | 1.29 | 1.18 | 1.35 | 1.38 |
| Calcium, % of DM | 0.78 | 0.72 | 0.64 | 0.78 | 0.77 |
| Copper, ppm | 8 | 32 | 28 | 31 | 30 |
| Molybdenum, ppm | 0.9 | 1.3 | 1.5 | 0.9 | 0.8 |
| Zinc, ppm | 90 | 99 | 93 | 110 | 107 |

[a]NC = basal diet without supplemental copper, CS = 20 ppm of supplemental copper from $CuSO_4$, CC = 20 ppm of copper from a chelate (MAAC Cu 16), BL = a 50:50 blend of CS and CC, and GC = a combination of a nutrient paste (Replamin) on arrival and 10 ppm of CS, 10 ppm of CC, 50 ppm of zinc from $ZnSO_4$, and 50 ppm of zinc from a zinc chelate (MAAC Zn 20).
[b]Contained copper and zinc as per treatment and the following (DM basis): 8.17% Ca, 0.11% P, 8.14% K, 1.78% Mg, 2.39% S, 10.0% salt, 12.1 ppm Co, 1822 ppm Fe, 40.0 ppm I, 3214 ppm Mn, 10.0 ppm Se, 140,000 IU vitamin A/kg, 4000 IU vitamin E/kg, 800 g monensin/ton, 880 g dequinate/ton, 1.0% mineral oil, and 33.44% ground corn.
[c]Propionic acid was added at 0.5% (w/w) to prevent mold growth during storage.
[d]Rendox AET (Kemin Americas, Des Moines, IA) was added at 0.1% (w/w) to prevent oxidation.
[e]All values except NE were determined analytically from triplicate aliquots of composite diet samples collected from the bunk weekly; NE values were calculated from tabular values (NRC, 1996).

Table 2. Effect of copper source and an oral nutrient gel on feedlot performance and health of beef steers

| | Treatment[a] | | | | | |
|---|---|---|---|---|---|---|
| Item | NC | CS | CC | BL | GC | SE[b] |
| Pens | 10 | 10 | 10 | 10 | 10 | - |
| Animals | 113 | 115 | 113 | 114 | 113 | - |
| Initial weight, lb | 395 | 396 | 404 | 397 | 398 | 6.1 |
| Ending shrunk weight, lb | 443 | 439 | 447 | 443 | 445 | 8.7 |
| Day 1 to 28 | | | | | | |
| DMI, lb/d | 8.66 | 8.45 | 8.59 | 8.48 | 8.72 | 0.34 |
| ADG, lb/d | 1.79 | 1.58 | 1.58 | 1.73 | 1.76 | 0.13 |
| Feed efficiency | 5.01 | 5.57 | 6.30 | 4.98 | 5.17 | 0.56 |
| Morbidity, % | 5.4 | 3.5 | 8.0 | 7.0 | 6.1 | - |
| Retreatments, % | 0.9 | 0.9 | 2.6 | 1.7 | 0.9 | - |

[a]NC = basal diet without supplemental copper, CS = 20 ppm of supplemental copper from $CuSO_4$, CC = 20 ppm of copper from a chelate (MAAC Cu 16), BL = a 50:50 blend of CS and CC, and GC = a combination of a nutrient paste (Replamin) on arrival and 10 ppm of CS, 10 ppm of CC, 50 ppm of zinc from $ZnSO_4$, and 50 ppm of zinc from a zinc chelate (MAAC Zn 20).
[b]Standard error of the least squares mean, n = 10.

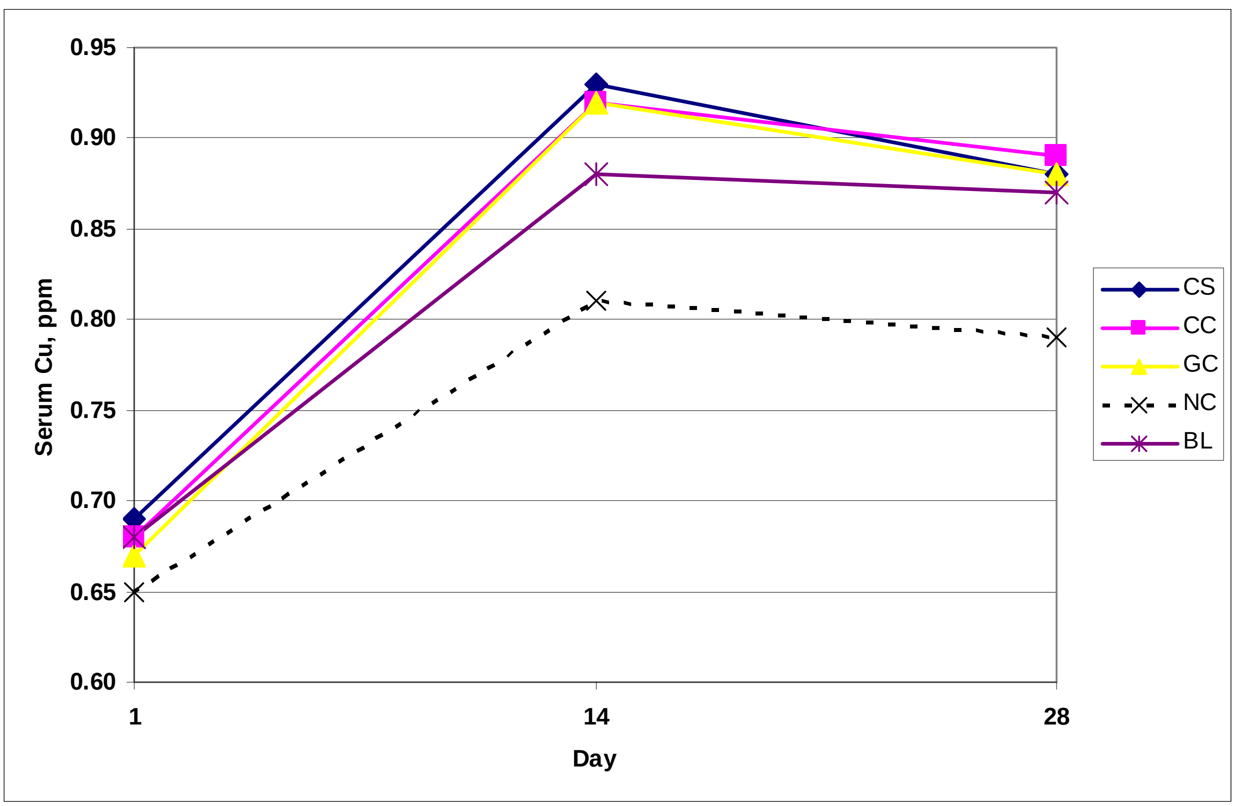


Figure 1. Effect of copper source on serum copper concentration across time. Day x treatment (P > 0.80). NC = basal diet without supplemental copper, CS = 20 ppm of supplemental copper from $CuSO_4$, CC = 20 ppm of copper from a chelate (MAAC Cu 16), BL = a 50:50 blend of CS and CC, and GC = a combination of a nutrient paste (Replamin) on arrival and 10 ppm of CS, 10 ppm of CC, 50 ppm of zinc from $ZnSO_4$, and 50 ppm of zinc from a zinc chelate (MAAC Zn 20).

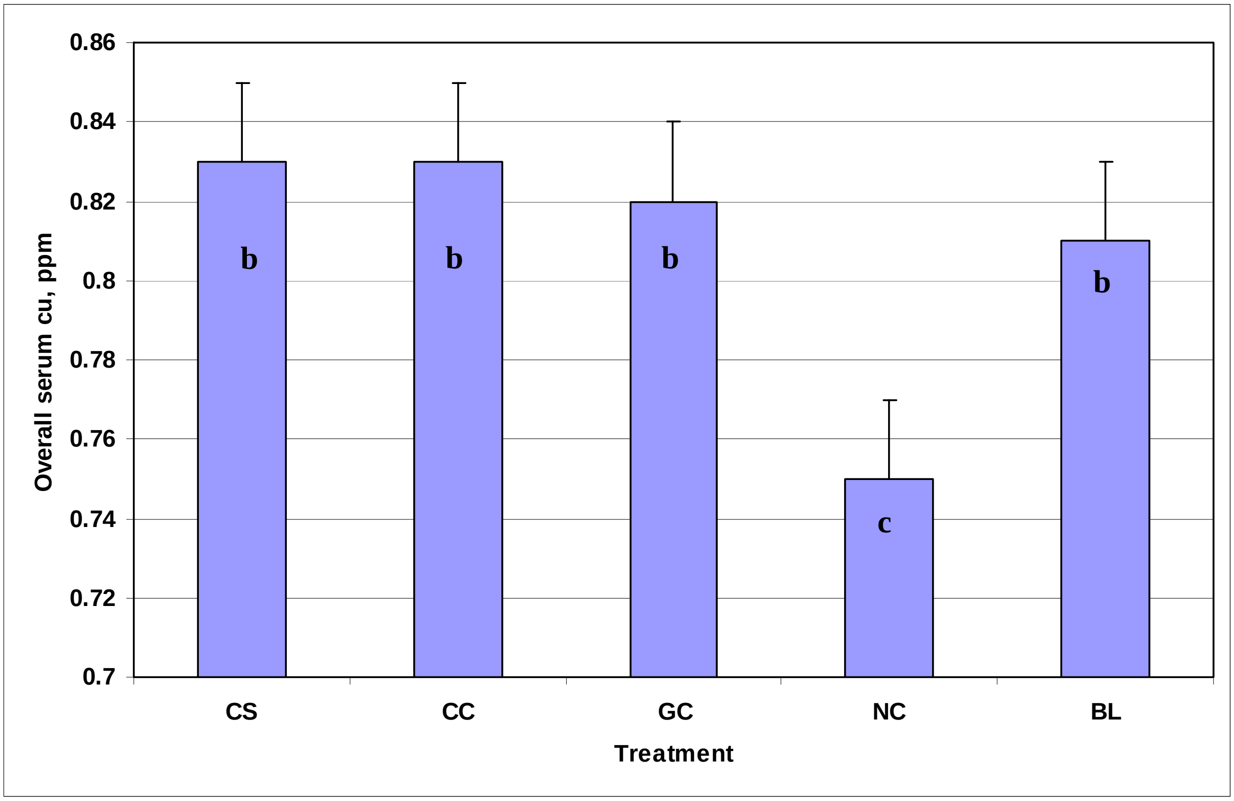


Figure 2. Effect of copper source on serum copper concentration averaged across time (arrival, revaccination, and end of study). NC = basal diet without supplemental copper, CS = 20 ppm of supplemental copper from $CuSO_4$, CC = 20 ppm of copper from a chelate (MAAC Cu 16), BL = a 50:50 blend of CS and CC, and GC = a combination of a nutrient paste (Replamin) on arrival and 10 ppm of CS, 10 ppm of CC, 50 ppm of zinc from $ZnSO_4$, and 50 ppm of zinc from a zinc chelate (MAAC Zn 20). Serum copper was lower for NC than for remaining treatments ($P < 0.001$).

# EFFECTS OF A SACCHARIN-CONTAINING ADDITIVE (SUCRAM) ON TOTAL TRACT DIGESTIBILITY, PLASMA METABOLITES, AND URINE ORGANIC ACID EXCRETION BY STEER CALVES

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## Summary

Fifteen steer calves received treatments of ad libitum access to a 60% concentrate diet (**NC**), ad libitum access to NC + 180 grams of Sucram C-150 (97% sodium saccharin)/ton (**AS**), or NC + 180 grams of Sucram C-150/ton with intake paired to that of steers receiving NC (**PS**). As designed, steer dry matter intake did not differ between PS and NC (42 and 44 ± 1.8 grams of dry matter/lb of metabolic weight), but DMI tended ($P$ = 0.14) to be greater for AS (47.6 g/lb of metabolic weight) than for NC. Treatments did not alter ($P > 0.10$) apparent total tract nutrient digestibility. Plasma homocysteine concentration was reduced ($P < 0.03$) by feeding saccharin (PS and AS vs NC). Steers fed PS had a greater ($P = 0.02$) urine vanillymandelic acid concentration than steers fed NC and tended ($P < 0.12$) to have a greater urinary concentration of ethylmalonic and 5-hydroxyindolacetic acids. Saccharin supplementation of calves reduced plasma homocysteine and increased excretion of the neurotransmitter metabolites, vanillymandelic and 5-hydroxyindolacetic acid.

## Introduction

In a previous experiment (Brown et al., 2004), we observed greater dry matter intake (17%) by stressed calves receiving 176 g of Sucram C-150/ton (97% sodium saccharin) during a 56-day feeding period during the summer. McMeniman et al. (2006) noted a tendency for stressed calves fed Sucram to gain more rapidly during the first 56 days, but growth performance during the subsequent finishing period was not altered by feeding Sucram.

Sodium saccharin has been implicated as a potential activator of the reward system in rats. The reward system is mediated by the neurotransmitters dopamine, serotonin and other neuropeptides, primarily in the brain. Dopamine and opioids have been generally characterized as stimulators of feeding, while serotonin is generally thought to be inhibitory to feeding. However, these metabolites exhibit complex interactions.

The mode of action of these compounds in ruminants has received little attention. Although McMeniman et al. (2006) did not observe a dietary preference by cattle fed Sucram, we examined whether saccharin consumption influenced digestion or aspects of physiology.

## Experimental Procedures

Twenty-five recently weaned Holstein bull calves were purchased from a calf raiser near Dimmitt, TX and delivered to the study site. Animals were processed on the day of arrival; and processing included ear tagging, vaccination for viral antigens (IBR, BVD type I and II, BRSV, and $PI_3$; Titanium 5, Agri Laboratories), vaccination against *Mannheimia haemolytica* and *Pasteurella multocida* (Once PMH; Intervet), administration of a clostridial bacterin-toxoid (Vision 7 with Spur; Intervet), and treatment for internal and external parasites (Ivomec Plus, Merial and Safe-Guard, Intervet). Two weeks after arrival, calves were surgically castrated and allowed an additional four weeks to acclimate to the facility. Steers were then housed in individual soil-surfaced pens, allowed ad libitum access to a 60% concentrate diet, and trained to lead over approximately four weeks.

Fifteen steers were selected for the study and randomized to one of three treatments. Treatments included ad libitum access to a 60% concentrate diet (NC), ad libitum access to NC + 180 g of Sucram C-150 (97% sodium saccharin; Pancosma SA, Switzerland)/ton of DM (AS), and NC + 180 g of Sucram C-150/ton of DM with feed intake paired to NC (PS). The experiment involved a treatment adaptation period (with or without saccharin) of at least 28 days followed by a 10-day metabolilsm period. Steers were housed in soil-surfaced individual pens during saccharin adaptation before being housed in metabolism crates for the 10-day collection of feces and urine. If a PS animal in a block was not able to consume as much DM as the NC animal it was paired with, feed intake of the NC animal was not reduced be equal to the PS because it would potentially exaggerate the relative response by AS.

Urine was collected into plastic containers containing 2 quarts of 25% (vol/vol) HCl to keep urine pH $\leq$ 2. Collected urine was mixed thoroughly, pH determined, volume and weight were recorded, and an aliquot of 800 cc was refrigerated until composited within steer and stored at -80°C until analysis. Acidified urine was assayed for several organic acids by GC-MS at a commercial catheters and one 10-cc blood sample was collected at 30-minute intervals for 4 hours (1 h before feeding and 3 h after feeding) to assay plasma amino acids. Postprandial samples for plasma amino acids were composited within steer and stored at -80°C until analysis by cation exchange chromatography using a Beckman model 63100. Data were analyzed as a randomized complete block design using Mixed procedures of SAS.

## Results and Discussion

Dry matter intake did not differ between steers receiving PS and NC (Table 1); however, steers receiving AS tended to consume more DM (P = 0.14) than steers fed NC (8%). Brown et al. (2004) studied the effect of 0, 88, 176 or 264 g of Sucram C-150/ton of DM using 220 newly received male calves. Animals received treatments during 56 days in the summer and received a concentrate diet (50% for 14 days, 70% 14 days, and 90% thereafter) supplemented with the additive. Steer DMI was increased by 17% for steers fed 176 g of Sucram C-150/ton compared to the control. No effects of treatments were found for ADG, feed efficiency, or morbidity. An additional receiving study during the winter season testing a 65% concentrate diet supplemented with or without Sucram C-150 (200 g/ton) also has been reported (McMeniman et al., 2006). Feed intake and performance were not different from d 1 through 28, but feed intake was greater from day 29 to 56 for cattle receiving Sucram. Trends were detected for increased ADG by calves fed saccharin during the 56 days of experiment. Increased gain efficiency was evident for cattle fed saccharin from d 1 to d 28 only, but saccharin did not affect morbidity.

Treatment did not alter (P > 0.10) apparent total tract nutrient digestibility (Table 1) or the concentration of large neutral amino acids in plasma (Table 2). Tryptophan is the precursor of serotonin. Fernstrom and Wurtman (1972) determined a positive correlation of 0.89 between brain serotonin and the ratio of tryptophan:large neutral amino acids in rats. Among the large neutral amino acids, isoleucine, leucine and valine are also known as branched-chain amino acids and have been shown to reduce tryptophan uptake into the brain. The plasma tryptophan:branched chain amino acid ratio was not affected by treatment.

The concentrations of citrulline and homocysteine were lower for steers receiving AS (P = 0.03) compared to NC. Steers fed PS also had lower plasma homocystine concentration than steers fed NC, whereas plasma citrulline concentration tended (P = 0.13) to be lower for PS than for NC. Citrulline is an important intermediate in the process of urea synthesis, whereas homocysteine is an intermediate in the metabolism of methionine. The present data might indicate reduced urea excretion in light of higher energy and protein intake by AS, but also suggest a direct effect of saccharin. It is unclear at present of what role saccharin may play in governing homocysteine concentration, but this may relate to an indirect reduction from methionine use in protein synthesis.

Urine concentration of ethylmalonic acid, vanillymandelic acid, and 5-hydroxyindolacetic acid (Table 2) were higher (P < 0.06) for steers receiving AS than for steers receiving NC; steers fed PS had a greater (P = 0.02) urine concentration of vanillymandelic acid than steers fed NC. The metabolite 5-hydroxyindolacetic acid is the main end product of the catabolism of serotonin. Current results might indicate greater synthesis of serotonin or increased serotonin turnover when saccharin is consumed. Vanillymandelic acid is the final metabolite in the catabolism of epinephrine and norepinephrine, and higher urine concentrations of vanillymandelic acid by steers receiving saccharin in this study might indicate higher rates of epinephrine and/or norepinephrine formation.

## Implications

Dietary saccharin (180 g of Sucram C-150/ton of dry matter) tended to increase dry matter intake by 8%, but did not alter total tract nutrient digestibility. Present data suggest that ad libitum access to feed containing saccharin reduces plasma homocysteine concentration, whereas saccharin alone seems to either increase synthesis or turnover of epinephrine and/or norepinephrine. Further research is needed to characterize the linkage between neurotransmitter turnover and feeding behavior of cattle supplemented with saccharin.

## Acknowledgements

The authors gratefully acknowledge MicroBeef Technologies, Nutri-Chem, and Ferrell-Ross for providing feedmill equipment and Intervet for supplying pharmaceutical supplies.

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Table 1. Effects of Sucram and level of intake on dry matter intake, nutrient digestibility, and blood and urine metabolite concentrations.

| | Treatment[a] | | | | Contrast P-value[b] | |
|---|---|---|---|---|---|---|
| Item | NC | PS | AS | SE | 1 | 2 |
| Animals (n) | 4 | 5 | 5 | - | - | - |
| Dry matter intake, g/lb $BW^{0.75}$ | 44.0 | 42.2 | 47.6 | 1.8 | 0.14 | 0.34 |
| Total tract digestibility, % | | | | | | |
| Dry matter | 74.6 | 75.6 | 76.5 | 0.9 | 0.17 | 0.46 |
| Organic matter | 76.5 | 77.3 | 77.5 | 0.8 | 0.27 | 0.45 |
| Crude protein | 68.3 | 70.0 | 69.4 | 1.6 | 0.47 | 0.29 |
| Neutral detergent fiber | 55.2 | 55.8 | 58.7 | 3.0 | 0.33 | 0.86 |
| Plasma concentration, µg/cc | | | | | | |
| Citrulline | 14.7 | 12.8 | 11.7 | 0.8 | 0.03 | 0.13 |
| Homocysteine | 0.57 | 0.39 | 0.44 | 0.04 | 0.03 | 0.01 |
| Tryptophan | 6.72 | 6.52 | 6.26 | 0.25 | 0.12 | 0.45 |
| Leucine | 20.56 | 20.74 | 20.38 | 1.57 | 0.93 | 0.93 |
| Valine | 30.20 | 30.10 | 30.79 | 2.12 | 0.83 | 0.97 |
| Tyrosine | 9.31 | 9.46 | 9.30 | 0.71 | 0.99 | 0.88 |
| Phenylalanine | 9.21 | 9.03 | 9.65 | 0.51 | 0.54 | 0.81 |
| Tryptophan:LNAA[c] | 0.083 | 0.080 | 0.076 | 0.005 | 0.34 | 0.71 |
| Tryptophan:BCAA[d] | 0.11 | 0.10 | 0.10 | 0.01 | 0.56 | 0.91 |
| Urinary concentration, mmol/mol creatinine | | | | | | |
| 3-indolacetic acid | 1.40 | 1.70 | 1.39 | 0.20 | 0.98 | 0.30 |
| Ethylmalonic | 3.88 | 5.91 | 6.43 | 0.89 | 0.06 | 0.12 |
| Homovanillic acid | 1.58 | 1.81 | 1.64 | 0.26 | 0.86 | 0.53 |
| Vanillymandelic acid | 0.68 | 1.65 | 1.47 | 0.23 | 0.04 | 0.02 |
| 5-hydroxyindolacetic acid | 0.07 | 0.13 | 0.15 | 0.03 | 0.06 | 0.12 |

[a]NC = ad libitum access to the basal diet, PS = NC + 180 g of Sucram C-150/ton of DM with feed intake paired to NC, and AS = ad libitum access to NC + 180 g of Sucram C-150/ton of DM.
[b]Contrast 1 = AS vs NC; contrast 2 = PS vs NC.
[c]LNAA = large neutral amino acids ([leucine] + [Isoleucine] + [Valine] + [phenylalanine] +[Tyrosine]).
[d]BCAA = branched-chain amino acids ([leucine] + [Isoleucine] + [Valine]).

# EFFECTS OF DIETARY FAT AND WET SORGHUM DISTILLER'S GRAINS PLUS SOLUBLES ON FEEDLOT PERFORMANCE AND CARCASS CHARACTERISTICS OF FINISHING HEIFERS

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## Summary

Four hundred yearling heifers in two experiments were fed for an average of 106 days. Treatments included 0% wet sorghum distiller's grains plus solubles (WSDGS) and 0% yellow grease (fat), 0% WSDGS and 3% fat, or 15% WSDGS and either 0, 1.5, or 3% fat. The WSDGS replaced steam-flaked corn and cottonseed meal. Overall dry matter intake (DMI) was 5% greater ($P < 0.01$) for heifers fed 15% WSDGS than for those fed 0% WSDGS. Among heifers fed WSDGS, DMI was greatest for heifers fed 1.5% fat ($P = 0.04$; quadratic). Overall ADG was 5% greater ($P = 0.04$) for 15% WSDGS compared to 0% WSDGS. Among WSDGS, ADG tended to be greater for 1.5% fat ($P = 0.12$; quadratic). Feed efficiency did not differ between 0 or 3% fat when 0% WSDGS was fed, nor was feed efficiency altered by replacing a portion of flaked corn with WSDGS ($P > 0.36$). However, feed efficiency was improved as more fat was added to WSDGS diets ($P = 0.06$). Heifers fed WSDGS had a higher DMI and greater ADG than heifers fed flaked corn, but feed efficiency did not differ. Adding more than 1.5% fat to diets containing WSDGS tended to reduce growth performance.

## Introduction

A growing body of information is available describing the feeding value of wet corn distiller's grains plus solubles, primarily in diets based on dry-rolled corn. In the Southern Great Plains, wet corn distiller's grains are not locally available at this time, but wet sorghum distiller's grains plus solubles are currently produced in the region.

Daubert et al. (2005) fed heifers 0, 8, 16, 24, 32 or 40% WSDGS for 58 days in diets based on steam-flaked corn without supplement fat. Feed efficiency was improved 9% for heifers fed 16% WSDGS, and efficiency became similar to the control heifers after diets contained more than approximately 24% WSDGS. Vasconcelos et al. (2007) fed steers 0, 5, 10, and 15% WSDGS in diets with added tallow. Feeding more than 10% of diet DM as WSDGS reduced cattle performance. Most Southern Plains feedlots possess the ability to include supplemental fat in the diet, and information is needed on the relative feeding value of WSDGS in diets containing added fat and steam-flaked corn.

## Experimental Procedures

Four hundred yearling heifers in two experiments were fed for an average of 106 days. Heifers were processed on arrival and adapted to a common 92% concentrate diet before treatments were imposed. Processing included individual identification with a numbered ear tag, vaccination against viral pathogens (Vista 5), administration of a clostridial bacterin-toxoid (Vision 7 with Spur), pregnancy determination by rectal palpation, treatment for internal and external parasites (Ivomec Plus and Safe-Guard), horn tipping, and implanting with Revalor-H. Only nonpregnant heifers were enrolled in the study. Treatments included 0% wet sorghum distiller's grains plus solubles (WSDGS) and 0% yellow grease (fat), 0% WSDGS and 3% fat, or 15% WSDGS with either 0, 1.5, or 3% fat. The WSDGS effectively replaced a combination of 2/3 steam-flaked corn and 1/3 cottonseed meal (Table 1).

The WSDGS was obtained from the US Bioenergy plant in Portales, NM on multiple occasions and stored in 10-foot diameter silage bags throughout the study. All diets were mixed and fed once daily. Corn was processed approximately twice weekly by steaming tempered grain (19% moisture, 18-hour soak) for approximately 40 minutes before flaking to 27 lb/bu. Samples of diets were collected weekly from the bunk after feed delivery; dry matter was determined on a subsample and remaining sample was composited gravimetrically within treatment over the entire study. Dry matter of steam-flaked corn and WSDGS was determined 5 days/week and the 5-day average was used to update as-fed diet composition each week, whereas dry matter content of remaining ingredients was determined once/week. Data were analyzed as a replicated randomized complete block design using Mixed procedures of SAS. Block and experiment were considered random effects and treatment served as a fixed effect.

## Results and Discussion

Two heifers died during the study, and data for the affected pens were adjusted based on average feed intake by the pen before the date of death. Diets containing WSDGS were wetter (Table 1), but were also more dense ($P < 0.01$) than the diets that did not contain WSDGS.

Heifers fed 15% WSDGS consumed approximately 5% more DM ($P < 0.05$; Table 2) than heifers fed 0% WSDGS, and DMI among heifers fed 15% WSDGS was greatest for heifers fed 1.5% fat ($P < 0.10$). Heifer ADG on both a live and carcass-adjusted basis was greater for those fed 15% WSDGS ($P < 0.05$) than for those fed 0% WSDGS, but ADG was not altered by adding fat to diets with 15% WSDGS. However, feed efficiency on either a live or carcass-adjusted basis was not different between heifers 0 and 15% WSDGS. Feed efficiency was improved in a linear manner as fat was added to diets with 15% WSDGS ($P < 0.06$). Hot carcass weight was increased an average of 11 lb ($P = 0.05$) when WSDGS replaced a portion of steam-flaked corn and cottonseed meal in the diet, but carcass weight was greatest for heifers fed WSDGS with 1.5% fat ($P = 0.09$, quadratic). Heifers fed 0% WSDGS without fat had a larger ribyea area, lower marbling score, less rib fat, and a lower yield grade ($P < 0.08$) than heifers fed 0% WSDGS with 3% fat. Heifers fed 15% WSDGS had more rib fat and a higher yield grade ($P < 0.03$) than heifers fed 0% WSDGS. Carcass quality grade distribution was not altered by treatment in the present study.

Diet energy values were determined (Table 2) based on actual cattle performance and calculated carcass fatness using the equation of Guiroy et al. (2001). The net energy values were then determined for yellow grease based on actual performance, whereas the NE values for WSDGS were determined by the process of substitution. Assuming that whole corn contains 0.68 Mcal of NEg/lb (NRC, 1996), the NEg determined for WSDGS was approximately 91% of the NEg of whole corn.

The inclusion of a wet ingredient such as WSDGS can also alter feed manufacturing and delivery needs in a commercial feedlot. Thus, projections for these needs were developed based on data generated in the present study (Figure 1). If feed trucks were loaded to the same net volume with 15% WSDGS compared to 0% WSDGS, a feedlot would need to deliver approximately 10% more loads of feed per day. If feed trucks were loaded to the same net weight, a feedlot would need to deliver approximately 23% more loads of feed per day.

## Implications

Heifers fed wet sorghum distiller's grains plus solubles consumed approximately 5% more feed and gained weight approximately 5% more rapidly. However, feed efficiency was similar whether or not wet sorghum distiller's were included in the diet. The wet sorghum distiller's grains fed in the present studies replaced a blend of approximately 2/3 steam-flaked corn and 1/3 cottonseed meal. Under these conditions, the NEg value of the distiller's equated to 91% of the tabular NEg of whole corn.

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Table 1. Ingredient and chemical composition of diet dry matter

| | Wet sorghum distiller's grains plus solubles, % | | | | |
|---|---|---|---|---|---|
| | 0 | 0 | 15 | 15 | 15 |
| | Yellow grease, % | | | | |
| Item | 0 | 3 | 0 | 1.5 | 3.0 |
| Ingredient composition | | | | | |
| Steam-flaked corn | 80.4 | 76.7 | 69.9 | 68.4 | 66.9 |
| Supplement | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 |
| Urea | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| Cottonseed meal, 41% | 4.5 | 5.2 | - | - | - |
| Wet sorghum distiller's plus solubles | - | - | 15.0 | 15.0 | 15.0 |
| Steep liquor:molasses (70:30)[a] | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 |
| Yellow grease[b] | - | 3.0 | - | 1.5 | 3.0 |
| Alfalfa hay | 4.6 | 4.6 | 4.6 | 4.6 | 4.6 |
| Cottonseed hulls | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Chemical composition | | | | | |
| CP, % of DM | 13.5 | 13.5 | 16.0 | 16.0 | 16.0 |
| Diet dry matter, % | 83.2 | 83.6 | 67.7 | 67.6 | 67.5 |
| Diet density, lb/cu ft | 14.1[c] | 14.3[c] | 16.5[d] | 16.6[d] | 16.7[d] |

[a]Propionic acid was added at 0.5% (w/w) to prevent mold growth during storage.
[b]Rendox AET (Kemin Americas, Des Moines, IA) was added at 0.1% (w/w) to prevent oxidation.
[c,d]Means differ ($P < 0.01$).

Table 2. Effect of dietary fat and wet sorghum distiller's grains plus solubles on feedlot performance and carcass characteristics of heifers and on ingredient net energy values

| | Wet sorghum distiller's grains plus solubles, % | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 0 | 15 | 15 | 15 | |
| | Yellow grease, % | | | | | |
| Item | 0 | 3 | 0 | 1.5 | 3.0 | SE[a] |
| DMI, lb/d[b,c] | 18.28 | 18.36 | 19.21 | 19.83 | 19.25 | 1.61 |
| Live ADG, lb/d[b] | 3.08 | 3.12 | 3.17 | 3.38 | 3.29 | 0.20 |
| Feed efficiency[d] | 5.95 | 5.89 | 6.09 | 5.90 | 5.88 | 0.17 |
| Adjusted ADG, lb/d[b] | 3.06 | 3.13 | 3.10 | 3.36 | 3.30 | 0.20 |
| Adjusted feed efficiency[d] | 6.00 | 5.86 | 6.23 | 5.90 | 5.84 | 0.19 |
| | | | | | | |
| Hot carcass wt, lb[c] | 733 | 737 | 735 | 754 | 748 | 24.59 |
| Dressing, % | 63.83 | 64.08 | 63.59 | 63.96 | 64.08 | 0.37 |
| Longissimus area, $in^2$ [e] | 14.6 | 13.80 | 14.12 | 14.11 | 14.22 | 0.28 |
| Marbling score[f, e] | 41.53 | 43.39 | 43.04 | 43.03 | 42.83 | 1.28 |
| Ribfat thickness, in[b, e] | 0.44 | 0.52 | 0.54 | 0.53 | 0.54 | 0.04 |
| Yield grade[b, e] | 2.06 | 2.58 | 2.53 | 2.58 | 2.53 | 0.16 |
| | | | | | | |
| ≥ Low Choice, % | 58.61 | 73.47 | 82.50 | 74.31 | 68.68 | - |
| Select, % | 40.14 | 26.53 | 17.50 | 25.60 | 30.07 | - |
| Standard, % | 1.25 | 0 | 0 | 0 | 1.25 | - |
| | | | | | | |
| Observed diet NEm[g], Mcal/lb | 0.98 | 1.00 | 0.96 | 0.98 | 0.99 | - |
| Observed diet NEg, Mcal/lb | 0.67 | 0.69 | 0.66 | 0.67 | 0.68 | - |
| Ingredient NE, Mcal/lb | | | | | | |
| Yellow grease NEm[h] | - | 2.15 | - | 2.15 | 2.15 | - |
| Yellow grease NEg | - | 1.59 | - | 1.59 | 1.59 | - |
| WSDGS NEm[i] | - | - | 0.94 | 0.93 | 0.92 | - |
| WSDGS NEg | - | - | 0.62 | 0.62 | 0.62 | - |

[a]Standard error of the least squares mean, n = 8.
[b]0 vs 15% WSDGS ($P < 0.05$).
[c]Quadratic effect of yellow grease among 15%WSDGS ($P < 0.10$).
[d]Linear effect of yellow grease among 15% yellow grease ($P < 0.06$).
[e]0% WSDGS, 0% yellow grease vs 0% WSDGS, 3% yellow grease ($P < 0.10$).
[f]Slight = 300 to 399, Small = 400 to 499, etc.
[g]Determined using the standard reference weights of 435, 462, and 478 for < 26.8, 26.8 to 27.7%, and > 27.7% empty body fat (NRC, 1996) as determined by the equation from Guiroy et al. (2001; JAS 79:1983).
[h]Actual NEm and NEg were determined by replacement of the corn + fat portion only of WSDGS-containing diets because these carcasses demonstrated similar fatness. Steam-flaked corn NE and NEg used were 1.09 and 0.766 Mcal/lb, respectively, based on a previous estimate in the same facility.
[i]Actual NEm and NEg were determined by replacement using the NE value for steam-flaked corn and yellow grease as described and assuming that cottonseed meal contained 0.81 and 0.52 Mcal/lb of NEm and NEg, respectively (NRC, 1996).

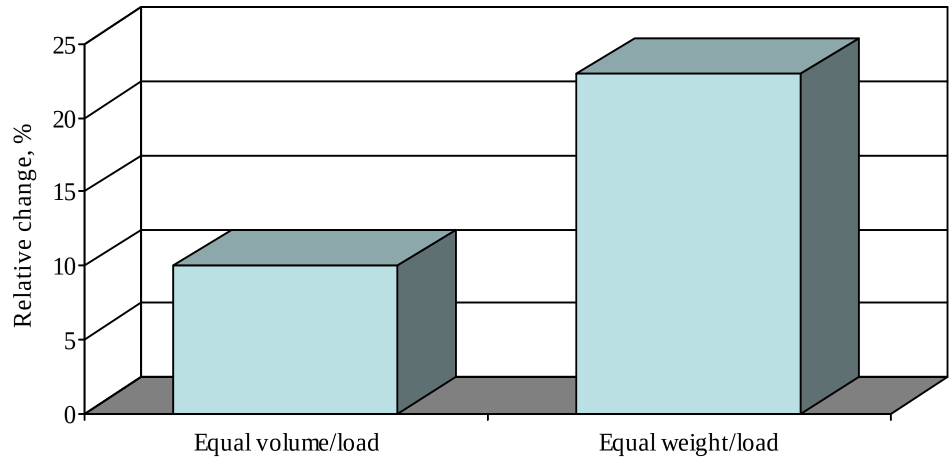


Figure 1. Increase in number of loads (900 $ft^3$ each) required for diets containing 15% wet sorghum distiller's grains plus solubles (WSDGS) if feed trucks are loaded to a constant volume or a constant weight/load. These data assume DMI, diet density, and diet DM of 20 lb/day, 14.2 lb/ $ft^3$, and 83.37%, respectively, for 0% WSDGS and 21 lb/day, 16.6 lb/ $ft^3$, and 67.63%, respectively, for 15% WSDGS diets.

# EVALUATING FACTORS THAT IMPACT THE DYNAMICS OF IN VITRO FERMENTATION USING GAS PRODUCTION TECHNIQUE. 1. FORAGE PARTICLE SIZE

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## Summary

The objective of this experiment was to investigate the effects of particle size (**PL**) on the dynamics of *in vitro* fermentation of two forages. A factorial design with five PL (0.5, 1.0, 2.0, and 3.0 mm and a chopped form - particles usually bellow 10 mm) and two forages (alfalfa hay - *Medicago sativa* - and Bermuda grass hay - *Cynodon sp.*) was used. Bermudagrass hay was collected in January 2007 from a pasture located in the Southern region of Texas, and alfalfa hay sample was from the TAMU Horse Center. For each treatment, 200 mg of forced-air dried sample was fermented for 48 h in 125-ml Wheaton bottles with continuous monitoring of gas production, which was automatically and continuously recorded by a computer. The rumen fluid utilized to incubate the forage samples was collected from a nonlactating, rumen-cannulated Jersey cow (600 kg BW) grazing grass at the USDA/ARS facility. There was an interaction between forage type and PL on the total amount of gas produced ($P$ = 0.0039). PL ($P$ = 0.0166) and forage type ($P$ < 0.0001) affected the fractional rate of degradation. There was an effect of forage type on the lag time ($P$ = 0.0107). Further work is needed to evaluate other forages and different seasons of the year, across multiple years, to develop a robust and consistent database for improving feeding strategies.

## Introduction

The *in vitro* digestibility is a technique that has been used to assess ruminal digestibility of feeds due to its high correlation with *in vivo* digestibility (Tilley and Terry, 1963). The great merit of *in vitro* methodology is that microorganisms and enzymes are sensible to factors not detected by chemical methods that could influence the degradation length and rate, in this aspect the method surpasses the chemical analyses, which in fact, cannot detect the interactions between the cell wall components. Van Soest (1994) stated that even though systems of chemical analyses are fast and accurate, they do not reflect the biological reality that can be reached with *in vitro* systems. Pell and Schofield (1993) modified the *in vitro* digestion technique by creating a computerized gas measurement system in which gas produced by microbial fermentation of forage samples is kept in a closed system and the pressure inside the system is continuously measured by pressure sensors connected to a computer. The objective of this study was to compare the effects of particle size on the dynamics of fermentation of two commonly fed forages to cattle in Texas.

## Experimental Procedures

In this experiment, we measured gas pressure using a computerized monitoring system between alfalfa hay (*Medicago sativa)* and Bermuda grass hay (*Cynodon sp.*) with five particle sizes. Forages were ground through a 0.5, 1.0, 2.0, or 3.0 mm screens in a ball mill, or chopped (particle length less than 10 mm), after drying in a 65° C oven. The technique measures gas pressure (mostly $CO_2$) due to the fermentation of carbohydrate by bacteria that produces $CO_2$ directly and indirectly by the release of $CO_2$ from the media due to the production of volatile fatty acids. All fermentations were done in anaerobic conditions within the Wheaton bottles and the temperature of the chamber was maintained at 39° C all the time.

*Samples.* The alfalfa hay was collected at the TAMU Horse Center (harvested in January 2007) and contained 89.3% DM, 33.95% ADF, 50.76% NDF, 19.4% CP, and 56.9% *in situ* DM digestibility. The Bermuda grass was collected at the King Ranch in the Southern region of Texas in January 2007. It contained 90.84% DM and 71.02%NDF, and 45.55%ADF.

*Sample preparation.* The ruminal fluid inoculum was obtained from a nonlactating, rumen-cannulated Jersey cow (600 kg BW), which had free access to medium quality mixed forages (mostly grasses) and was fed once daily with a commercial ration for nonlactating cows. The ruminal fluid was filtered through four layers of cheesecloth and then through glass wool. The ruminal fluid was mixed continuously with $CO_2$ to minimize changes in microbial populations and to avoid $O_2$ contamination. At collection, the pH of the ruminal fluid was measured using a portable pH meter and averaged 6.42. The *in vitro* medium used was the phosphate-bicarbonate medium and reducing solution of Goering and Van Soest (1970). Forages (200 mg) of all particle sizes were transferred to a 125-ml Wheaton bottle, which contained a small stir covered with Teflon inside. Samples were wetted with 2.0 ml of boiled distilled water that had been cooled to room temperature; the water was used to avoid particles dispersion, and discounted by the media. The medium was ventilated with $CO_2$ all the time. It was heated separately to just below boiling temperature and then cooled to room temperature. At this point, cysteine hydrochloride was added. The media pH and $CO_2$ saturation were controlled by color change of resazurin indicator from purple to pink/colorless; the optimum pH utilized was between 6.8 and 6.9. Each bottle was filled with 14 ml of this media. Strict anaerobic technique was employed in all transfers (Bryant, 1972; Hungate, 1950). The bottles were closed with previously unused, lightly greased, butyl rubber stoppers, and crimp sealed. All bottles were placed in the fermentation chamber and the respective sensor for each bottle was inserted with needles. When the fermentation chamber reached 39° C, 4 ml of the filtered mixed ruminal bacteria inoculum was injected into the bottles. The fermentation chamber was closed and when the internal temperature reached 39 °C pressure inside each bottle was zeroed by puncturing the stopper with a needle for 5 seconds. The fermentation chamber was closed and when the temperature reached 39 °C, the recording of the pressure was initiated. The atmospheric pressure was collected in the beginning of all rounds (14.684 psi).

*Fermentation chamber*. The fermentation chamber was similar to that described by Pell and Schofield (1993). It included an incubator (chamber) with a multiplace stirrer, pressure sensors attached to the incubation flasks, an analog to digital converter device, and a computer with software. The pressure was collected by computer software every 5 minutes, automatically. After 48 h of fermentation (2880 samples were taken by the computerized system), each bottle was depressurized, the pH was measured (averaged 6.661), and 40 ml of neutral detergent solution (Van Soest et al., 1991) was added to each bottle. The Wheaton bottles were crimp sealed and cooked in an autoclave for 60 min at 105° C to determine the undegraded fiber, filtered by gravimetric method using a Whatman 54 filter paper, and dried in oven.

*Statistical design.* The experimental arrangement was factorial (5 particle sizes x 2 forages) in a randomized complete block design (2 blocks over time). Two replicates for each size and forage combination per block were used. Therefore, 22 bottles were used: 20 bottles with samples (5 x 2 x 2) and 2 blanks (only medium and ruminal fluid to measure the gas production of the contents of the fluid in solution). The statistical model is shown in Eq. 1 and the statistical analysis was performed using PROC MIXED of SAS (SAS Inst. Inc, Cary, NC).

$$Y_{ijkl} = \mu + Forage_i + Size_j + Forage_i{*}Size_j + Block_k + \varepsilon_{ijkl} \quad \text{[Eq. 1]}$$

The voltage measured in each bottle was adjusted for the voltage measured of the blank bottles (average of two), converted to gas volume (ml), and standardized to 100 mg of samples. The data of each bottle were fitted to an exponential function with a lag parameter (Eq. 2) using the PROC NLIN of SAS (SAS Inst. Inc, Cary, NC). The parameters (*a*, *b*, and *c*) obtained from the fitting of Eq. 2 were analyzed using the statistical equation ($Y_{ijkl}$) shown in Eq. 1.

$$Gas_t = a\times(1 - \exp^{-b\times(t-c)}) \quad \text{[Eq. 2]}$$

Where gas is measured in ml; *a* is the asymptote (maximum gas production), ml; *b* is the fractional rate of gas production, $h^{-1}$; *c* is the lag time, h; and *t* is time of fermentation, h.

## Results and Discussion

There were two 2 samples that were removed from the statistical analysis. Therefore, 38 samples were converged and analyzed.

*Accumulated gas produced (a, ml).* The BIC and -2Log were 110.0 and 109.3, respectively. There was a significant interaction between forage type and particle size on the accumulated gas produced ($P$ = 0.0039) (Table 1). Alfalfa gas production tended to increase as particle size decreased. Alfalfa at 0.5 mm produced more gas than 1, 2, and 3 mm, and chopped form. In contrast, bermudagrass gas production was not consistent; the 3 mm of PL produced more gas than the chopped form ($P$ = 0.0014).

*Fractional degradation rate (b, $h^{-1}$).* The BIC and -2Log were -128.5 and -129.9, respectively. There was no interaction between forage type and particle size ($P$ = 0.186). However, particle size and forage affected the fractional rate of degradation. Alfalfa hay had a greater fractional rate of fermentation than bermudagrass hay (10.54 versus 5.53 %/h, respectively, $P < 0.0001$). This was expected because of the difference in the mesophyll between legumes and grasses (Van Soest, 1994; Wilson, 1993) that facilitates the colonization by the ruminal microbes. The fractional degradation rate was 10.86[a], 7.98[b], 7.51[bc], 8.0[b], and 5.8[c] %/h for 0.5, 1, 2, and 3 mm, and chopped size. There was a linear ($P$ = 0.0166) and quadratic ($P$ = 0.0179) relationship between 0.5, 1, 2, and 3 mm particle size. This finding was expected because small particle size increases surface area.

*Lag time (c, h).* The BIC and -2Log were 87.3 and 85.9, respectively. There was an effect of forage on lag time ($P$ = 0.0107) in which bermudagrass hay took longer than alfalfa hay to start the fermentation (1.4 versus 0.63 h, respectively).

## Implications

The *in vitro* fermentation chamber can be used to determine kinetics of fermentation of forages. Forage type and particle size may affect the dynamics of fermentation of legume and grass hay. Further work is needed to evaluate other forages and different seasons of the year, across multiple years, to develop a robust and consistent database for improving feeding strategies.

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Table 1. Interaction of the accumulated gas production (a, ml)

| Size | Alfalfa hay | Bermudagrass hay |
|---|---|---|
| 0.5 | 21.88 ± 0.672[a] | 8.58 ± 0.672[de] |
| 1.0 | 18.92 ± 0.672[bc] | 9.91 ± 0.672[d] |
| 2.0 | 19.19 ± 0.672[bc] | 9.54 ± 0.776[de] |
| 3.0 | 18.73 ± 0.776[bc] | 11.23 ± 0.672[d] |
| Chopped | 17.06 ± 0.672[c] | 7.88 ± 0.672[e] |

[a-c, d-e]Means within forage type with different superscripts statistically differ.

# EVALUATING FACTORS THAT IMPACT THE DYNAMICS OF IN VITRO FERMENTATION USING GAS PRODUCTION TECHNIQUE. 2. RUMEN FLUID DONOR AND SAMPLE INCUBATION METHOD

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## Summary

The objectives of this study were to investigate the effects of rumen fluid donors (**FD**) (Trial 1) and different incubation methods (**IM**) (Trial 2) on the dynamics of *in vitro* fermentation. In trial 1, alfalfa hay (89.3% DM, 2 mm) was fermented using rumen fluid from 5 different cows. In Trial 2, alfalfa hay (1 mm) was allocated either inside 125-mL Wheaton bottles (**FREE**) or inside ANKOM F57 filter bags (**BAG**), which were placed inside 125-mL Wheaton bottles for subsequent fermentation. In each trial, 200 mg of forced-air dried sample was fermented for 48 h with continuous measurement of gas pressure using a computerized monitoring system. There was no FD effect on total gas production (**a**, ml; $P = 0.25$), lag time (**c**, h; $P = 0.32$), or fractional rate of degradation (**b**, %/h; $P = 0.84$), suggesting that possible differences in the rumen bacteria population of cows grazing mixed pasture may not affect *in vitro* fermentation dynamics. However, in the IM analysis, *a* ($P = 0.003$) and *c* ($P = 0.026$) estimates differed, suggesting fermentation inside a polyester/polyethylene-type bag may yield different fermentation kinetics.

## Introduction

The *in vitro* DM digestibility system is highly correlated with *in vivo* digestibility (Marten and Barnes, 1980). *In vitro* cumulative gas production techniques were developed to predict fermentation patterns of ruminant feedstuffs. When feedstuffs are incubated with buffered rumen fluid, the degraded carbohydrate fraction may either contribute to carbon dioxide, methane, and volatile fatty acids (acetic, propionic, and butyric) or be incorporated into microbial biomass (Rymer et al., 2005).

The inoculum is the single largest source of variation in measuring gas production profile (Rymer et al., 2005) likely because the variability of the rumen fluid. This variability is caused by different sampling schedules and different rations fed to the donor animals. Therefore, variable ratios of rumen fluid to the medium must be selected such that microbial activity is sufficiently high to prevent alterations in the rate and extent of the *in vitro* fermentation (Rymer et al., 2005). The dietary fiber in the donor's ration may also affect the *in vitro* DM digestibility, even when chemical composition of the diets is similar (Cherney et al., 1993).

The objectives of this study were to investigate the effects of (1) different rumen fluid donors and (2) incubation methods (outside versus inside polyester/polyethylene-type bags) on the dynamics of the *in vitro* fermentation of alfalfa hay using a computerized monitoring anaerobic fermentation chamber.

## Experimental Procedures

*Trial 1.* In this trial, we compared inoculums from five different nonlactating cows (600 kg BW) that had access to medium-quality pasture and were fed dry cow ration once a day. The ruminal fluids were collected at the same time at the USDA/ARS in College Station, TX.

*Trial 2.* In this trial, two different incubation methods were compared: (1) samples were placed inside ANKON F57 bags (with the goal of reducing loss during filtration and to evaluate an easier procedure to determine indigestible NDF of fermented samples) and then placed inside 125-ml Wheaton bottles (**BAG**) or (2) samples were freely placed inside 125-ml Wheaton bottles (**FREE**).

For both trials, the gas pressure produced by the anaerobic fermentation of alfalfa hay (*Medicago sativa)* was measured using a computerized monitoring system. Alfalfa hay was ground through either 1.0-mm (Trial 2) or 2.0-mm (Trial 1) screen in a ball mill, after forced-air drying in a 65°C oven. The alfalfa hay was collected at the TAMU Horse Center (harvested in January 2007) and contained 89.3% DM, 33.95% ADF, 50.76% NDF, 19.4% CP, and 56.9% *in situ* DM digestibility.

*Sample preparation.* Sample preparation was identical to that described in a companion paper by da Silva et al. (2007). The pH of the ruminal fluid was measured using a portable pH meter and averaged 6.06 for Trial 1 and 6.08 for Trial 2. Samples of 200 mg of alfalfa hay were transferred to a 125-ml bottle, which contained a small stir covered with Teflon inside or placed inside ANKON F57 bags with the stir and the bag transferred to 125-ml Wheaton bottles. The atmospheric pressure was collected at the beginning of the fermentation (14.623 psi). The undigested residue was filtered by gravimetric method in a Whatman 54 filter paper, dried in oven, and weighed (Trial 1 and treatment FREE of Trial 2). For the treatment BAG of Trial 2, the ANKON F57 bags were dried in oven directly and weighed.

## Results and Discussion

*Trial 1.* The average gas production for both treatments is shown in Table 1. The average of total gas production was 17.6 ml/100 mg of DM and it was not different between treatments ($P$ = 0.25). Pell and Schofield (1993) showed that 100 mg alfalfa hay fermented inside 50-ml bottles would have about 18 ml of gas production. Our finding was very similar to their results.

The fractional degradation rate among donors was not different ($P$ = 0.836). The values ranged from 9.17 to 10.4%/h. According to Mehrez and Ørskov (1977), the variability among animals, as assessed by the *in situ* technique, can be higher than day variation within animals. Williams et al. (2000) suggested that ruminal fluid samples should be collected from several animals, and then combined, to reduce animal variation. Similarly, there was no difference in lag time ($P$ = 0.317) among animals. Van Soest (1994) indicated that when ruminants eat scaled amounts of the same diet (with same quality ingested) there is no difference in the fermentation pattern.

Therefore, our finding does not support the concept that different donors have to be used, suggesting that variation due to donors may not affect the *in vitro* fermentation pattern of alfalfa hay when donors are consuming forage-based diets.

*Trial 2.* There was no effect of IM on total gas production ($P$ = 0.6). There was an effect of incubation method (inside bag vs. free in the bottle) on fractional degradation rate ($P$ = 0.0037) (Table 1). The average values were 13.2 and 5.84% for FREE and BAG treatments, respectively. This result suggested that samples incubated inside polyester/polyethylene-type bags will have different fermentation profile.

Even though the lag time was different ($P$ = 0.03) with values of 0.48 and 1.01 h for FREE and BAG treatments, respectively, this might be an artifact of the small sample size. We hypothesize that lag time for samples in the BAG treatment would have a greater lag time because the microorganisms would take longer to attach to the feed particles.

## Implications

Measures of gas production of *in vitro* fermentation chamber with different rumen fluid donors did not affect the pattern of fermentation. Fermentation inside a polyester/polyethylene-type bags in an *in vitro* fermentation scenario was not effective when compared with the traditional method. Polyester polyethylene bags may not be suitable to determine the dynamics of *in vitro* fermentation of alfalfa hay. Further work is needed to evaluated different pore size bags and different forages.

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Table 1. Average values for total gas production (a), fractional degradation rate (b), and lag time (c) for each rumen fluid donor (Trial 1)

| Items | Cows | | | | | SE | *P*-value |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | | |
| a, ml | 17.7 | 16.6 | 17.2 | 17.5 | 18.9 | 0.658 | 0.250 |
| b, %/h | 9.16 | 9.62 | 10.01 | 10.43 | 9.61 | 0.799 | 0.837 |
| c, h | 0.152 | 0.569 | 0.323 | 0.598 | 0.562 | 0.168 | 0.317 |

Table 2. Average values for total gas production (a), fractional degradation rate (b), and lag time (c) for two incubation methods (Trial 2)

| Treatment | Bag | Free | SE | *P*-value |
|---|---|---|---|---|
| a, ml | 18.0 | 18.5 | 0.621 | 0.6000 |
| b, %/h | 5.84 | 13.2 | 1.130 | 0.0037 |
| c, h | 0.48 | 1.10 | 0.150 | 0.0267 |

# A GENERALIZED MODEL FOR DESCRIBING FIBER DYNAMICS IN THE RUMINANT GASTROINTESTINAL TRACT. 1. THE HETEROGENEITY OF THE POOL OF FIBER PARTICLES IN THE RUMINORETICULUM

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## Summary

Data from 15 studies with sheep and cattle consuming at least 25% of forage in the diet were gathered to evaluate the current concept of a uniform fiber pool in the ruminoreticulum (RR). Variables analyzed were dry matter intake, fiber intake (NDFI), body weight (W), fresh rumen contents ($Q_{FC}$), dry matter of $Q_{FC}$ and the ruminal fiber mass ($Q_{NDF}$), including 27 and 43 averages of the measured variables for sheep and cattle respectively. Variables were scaled to W and the Lucas test applied to both scaled $Q_{NDF}$ and NDFI by assuming steady-state conditions. Robust nonlinear and linear estimation procedures were employed. All variables were scaled to $W^1$ and the relationship between $Q_{NDF}$ and NDFI yield parameter estimates that violated current assumptions. This result implied that more than one fiber pool based on the RR digesta stratification should be modeled to calculate the nutritive value of forage-based diets.

## Introduction

Ruminants that consume forage-based diets typically have two distinguishable solid phases within the ruminoreticulum (RR) compartment: the rumen floating mat (raft), formed by newly ingested particles of the diet, and a pool of small particles dispersed within the fluid phase ventrally to the raft (Hungate, 1966; Sutherland, 1989). Exceptions to this rule occur when feeding behavior is somewhat constrained leading to exclusion of coarse fiber from the diet (Hoffman, 1989; Van Soest, 1996). Despite the digesta stratification, its fiber mass is treated as a single pool in the most accepted paradigm concerning fiber dynamics in the RR. However, an alternative modeling approach was proposed by Ellis et al. (1994) based on the natural stratification of fibrous particles in the RR observed in forage fed ruminants. At this point, our primary objective was to evaluate the steady-state assumptions related to the model that considers the fiber mass in the RR as a single pool.

## Experimental Procedures

Data used in the present study were the same gathered by Cannas et al. (2003). Results from 15 studies containing 27 and 43 averages for sheep and cattle, respectively, of body weight (W, kg), dry matter intake rate (DMI, g/d), NDF intake rate (NDFI, g/d), fresh rumen contents ($Q_{FC}$, g) and either the dry matter ($Q_{DM}$, g) or the NDF ($Q_{NDF}$, g) contents of the RR digesta were analyzed. The most important criteria established by those authors was that forages must have constituted at least 25% of the dry matter consumed.

The strategy of scaling variables in relation to W was adopted to reduce size effects on their behaviors and the general power function was employed (see Appendix for details):

$$Y = A \times W^b \quad \text{(Eq. 1)}$$

In the Eq. 1, A is a scaled constant expressed as the dependent variable unit per unit of W raised to power b. The scaled variable Y, i.e. scaled pool sizes or intake rates, was obtained by the quotient $Y / W^{\hat{b}}$ .

The NDF pool size of the rumen ($Q_{NDF}$) can be considered uniform if, and only if, the Lucas test yields reasonable estimates for the relationship between $Q_{NDF}$ and NDFI according to Eq. 2 (Van Soest et al., 1992):

$$Q_{NDF} = T_{NDF} \times NDFI + M_{NDF} \quad \text{(Eq. 2)}$$

Where $T_{NDF}$ is the true NDF turnover and $M_{NDF}$ is the metabolic portion of the NDF digesta in the RR. The criteria of linearity, low standard deviations for regression and slope ($T_{NDF}$), and zero intercept must be held in order to assume that $Q_{NDF}$ behaves as a single uniform pool of fibrous particles.

Nevertheless, to avoid distortions due to size effects, the both scaled NDF pool size ($Q_{NDFS}$) and NDF intake rate (NDFI) were analyzed according to the linear model (Eq. 2), since it could be demonstrated that scaling of variables do not interfere in the general assumption of linearity, provided that both variables scale with the same power of W (Eq. 3):

$$Q_{NDFS} = T_{NDFS} \times NDFI_S + M_{NDFS} \quad \text{(Eq. 3)}$$

in which subscript *S* denotes that the variable was scaled to W by an appropriate power. It could be checked that $T_{NDFS} = T_{NDF}$ whether estimates of the powers of W for $Q_{NDF}$ and NDFI are exactly the same, since $T_{NDF} = Q_{NDF}/NDFI$. This property could be considered as an additional criterion ($\hat{T}_{NDF} = \hat{T}_{NDFS}$) to check whether assumptions regarding the Lucas test were not violated.

All statistical analyses were performed with SAS (SAS Inst., Cary, NC). In order to obtain iteratively reweighted nonlinear least-squares estimates of the parameters of Eq. 1, a robust regression criteria published by Beaton and Tukey (1974) was used. Similarly, Eq. 2 and 3 were fitted according to robust linear regression procedures to properly weight for outlier's effects and heterogeneity of variances for higher response levels of $Q_{NDF}$ and $Q_{NDFS}$ (see Appendix for details).

## Results and Discussion

The robust nonlinear parameter estimates presented high negative correlations ($r_{A,b} \cong -0.99$) for all variables (pool sizes and intake rates) after fitting Eq. 1. A large variation was observed, particularly in the cattle data set, but b estimates were all different from zero (Table 1). Pool sizes $Q_{FC}$ and $Q_{DM}$ scaled to a power of W lower than one. A larger variation was observed for b of $Q_{NDF}$, but consistently to the hypothesis that NDF gives a major contribution to the bulky of digesta, the estimate did not differ from unity, i.e. was isometric with respect to W (Van Soest et al., 1992; Van Soest, 1996).

Intake rates had exponents not different from unity (Table 1), indicating that intake rates probably achieved its potential, despite that forages contributed significantly to the NDF of the reported diets (Illius and Gordon, 1991; Ellis et al., 1994). Inferences concerning estimates of A should be done carefully. Besides large variations observed, pool sizes are actually a result of trends in the RR capacity. Such biological rhythm is dictated by homeorhetic mechanisms evolved for survival and reproductive purposes (Mertens, 1996).

Van Soest et al. (1992) emphasized that the Lucas test allows identifying possible heterogeneous pools within the RR digesta. Application of robust regression procedures yielded estimates that violated assumptions regarding uniformity of the pool of fiber particles within the RR. Firstly, a metabolic component was estimated for the fiber fraction (NDF) within the rumen either for the as measured and the scaled NDF pool sizes (Table 2), violating the principle that animals can not secrete fiber in the gastrointestinal tract; it derives entirely from the diet. Another criterion is that the regression line must present a good overall fit to the data; although the robust regression procedure employed yielded precise parameter estimates, the poor $R^2$ for both the scaled or not variables do not met the quality of fit criteria established by Lucas and co-workers early in 1961 (cited by Van Soest et al., 1992), which means low residual mean square for the regression and a high coefficient of determination ($R^2$).

Another result that substantially violated intrinsic assumptions related to the single pool model is the fact that the true turnover estimates are statistically distinct because confidence intervals did not overlap (Table 2). If $Q_{NDF}$ and NDFI were scaled to the same power of W, i.e. b = 1 (Table 1), then the scaled true turnover should be the same of the as measured turnover as shown in Eq. 4.

$$T_{NDF} = (Q_{NDF}/NDFI) = (Q_{NDF}/W^1)/(NDFI/W^1) = T_{NDFS} \qquad \text{(Eq. 4)}$$

Let us assume that the variables did not scale to the same power of W, instead, $Q_{NDF}/W^{\alpha}$ and $NDFI/W^{\beta}$ are the scaled NDF pool size ($Q_{NDFS}$) and intake rate (NDFIS), respectively. Let us assign $\Delta = \alpha - \beta$, then the scaled turnover becomes:

$$T_{NDFS} = T_{NDF} \times W^{-\Delta} \qquad \text{(Eq. 5)}$$

In fact, the scaled turnover becomes a function dependent on W and not a constant which, by its turn, premise Eq. 2 and 4. The lack of consistency among estimated slopes and powers of W is an additional indication that the single pool model was not sufficient to describe the nature of the fibrous digesta (Tables 1 and 2).

Other factors might also explain this anomalous behavior: different diet compositions, variation within (dairy vs. beef) and between (sheep vs. cattle) species, variation in the physically effectiveness of the NDF, physiological stage, and between study effects. These factors were not considered in the analysis performed, but they might interfere on parameter estimates at a certain degree. Nevertheless, despite large variations observed in the interval estimates for parameter A (Table 1), a reasonable estimate of the scaled NDF pool size under unrestricted feeding conditions was obtained. Although we recognize that the intake rate is rather a behavioral output resulting from complex interactions between the animal and its environment, we found exactly the same estimate of 1.2% of live weight for the NDF intake as suggested by NRC (1996).

The non conformity to the premise concerning the Lucas test should be interpreted as an existing heterogeneous pool of the RR fibrous digesta. The common separation of particles in the ruminant forestomach led to the hypothesis that a sequence of two pools, an unmixing pool formed by particles not eligible to leave the RR because of their resistance to flow (rumen mat or raft), and a second pool located ventrally to the raft: a mixing

The combined kinetic forces of hydration, solubilization, and rumination in the raft enhance accessibility and adhesion to inner feed particles by microbes due to physical breakdown. The propelling forces produced by rumen motility interact with structural anatomy of the particles (three dimensional structure and array of tissues), its chemical composition and intrinsic degradation rates (plant leafs *vs.* stems). The resultant of such interaction is the entrapment of fermentation gases within the food particles increasing their buoyancy. In fact, the net balance among these competing forces is the progressive transfer of matter from the unmixing or non-escapable pool of particles to the mixing or escapable pool of fluid diluted particles. There is not a clear cut between these two pools and migrating particles are actually commingled (Sutherland, 1989; Ellis et al., 1994). Henceforth, a mechanism operating as an ageing chain process takes place as kinetic actions that promote breaking down and flow overcome the buoyancy forces that offer flowing resistance of particles, which urges a more comprehensive approach.

## Implications

It is noteworthy that the most accepted paradigm concerning the way that fiber is retained within the ruminoreticulum could yield biased estimates of the flux mechanisms representative of the digestion and passage processes in ruminants eating enough amounts of forage. Models should be developed to accommodate the unmixing/mixing pools concepts as well as an aging chain process to improve current recommendations to yield better estimates of the nutritive value of forage-based diets and ultimately, the prediction of the animal performance.

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Table 1. Nonlinear robust estimates of the parameters regarding body weight (W) scaling to the variables fresh ($Q_{FC}$), dry matter ($Q_{DM}$) and neutral detergent fiber ($Q_{NDF}$) contents (g) of the ruminoreticulum, and to the intake rates (g/d) of dry matter (DMI) and neutral detergent fiber (NDFI).

| Variable | Parameter[3,4] | Estimate | Approx. ± SE | Approximate 95% Confidence Limits: Lower | Approximate 95% Confidence Limits: Upper | Estimated[5] RSD | Reference[6] RSD |
|---|---|---|---|---|---|---|---|
| $Q_{FC}$[1] | A | 558 | 157 | 245 | 872 | 6191 | 5000 |
| | b | 0.74 | 0.04 | 0.65 | 0.82 | | |
| $Q_{DM}$[1] | A | 51 | 23 | 4 | 98 | 1239 | 1000 |
| | b | 0.79 | 0.07 | 0.65 | 0.94 | | |
| $Q_{NDF}$[1] | A | 24 | 21 | – 17 | 64 | 1107 | 1000 |
| | b | 0.79 | 0.14 | 0.53 | 1.07 | | |
| DMI[2] | A | 18 | 17 | – 16 | 51 | 2565 | 2000 |
| | b | 1.01 | 0.15 | 0.72 | 1.30 | | |
| NDFI[2] | A | 12 | 9 | – 6 | 30 | 1018 | 800 |
| | b | 0.95 | 0.12 | 0.71 | 1.18 | | |

[1] Pool sizes expressed in mass units;
[2] Intake rates expressed in mass units per unit of time;
[3] The parameter A related to pool size variables is expressed in mass units per unit of body weight mass raised to power b;
[4] The parameter A related to intake rates is expressed in mass units per unit of body weight mass raised to power b per unit of time;
[5] Estimated residual standard deviation (RSD), expressed in the same units of the related variable;
[6] Reference value of the RSD as an initial estimate in the robust regression procedure, with a tuning constant of 1.96×3 was assumed as well.

Table 2. Final weighted linear robust least-squares estimates regarding NDF pool size, as measured ($Q_{NDF}$) and scaled ($Q_{NDFS}$) to the unity power of body weight (W), as a linear function of NDF intake rate (NDFI) scaled or not to the unity power of W

| Variable | Parameter[1,2] | Estimate | ± SE | 95% Confidence Limits: Lower | 95% Confidence Limits: Upper | $R^2$ |
|---|---|---|---|---|---|---|
| $Q_{NDF}$ | $M_{NDF}$ | 700 | 6 | 688 | 712 | 0.63 |
| | $T_{NDF}$ | 0.959 | 0.001 | 0.956 | 0.961 | |
| $Q_{NDFS}$ | $M_{NDFS}$ | 4.2 | 0.3 | 3.6 | 4.9 | 0.37 |
| | $T_{NDFS}$ | 0.608 | 0.03 | 0.549 | 0.667 | |

[1] The parameters $M_{NDF}$ and $M_{NDFS}$ represent metabolic amounts of NDF with the same unit of the as measured NDF pool and scaled to the power one of body weight (valid estimates should not differ from zero);
[2] The parameters $T_{NDFS}$ and $T_{NDF}$ correspond to the true turnovers of NDF respectively scaled or not to W within the ruminoreticulum. It is worthy to note that $T_{NDF} = T_{NDFS}$ when $Q_{NDF}$ and NDFI scales to the same power of body weight (see details in the text).

# APPENDIX

A.1) The SAS statements related to the estimation of the reweighted nonlinear least squares estimates presented in Table 1 (observations within parenthesis). Note that Qndf = $Q_{NDF}$ and BW = W.

```
proc nlin data=test best=5 method=marquardt nohalve;
parms a=15 to 30 by 1 b=.5 to 1.5 by .1;
model Qndf=a*BW**b;
resid=qndf-model.qndf;
sigma=1000; (sigma = estimated RSD in Table 1)
c=1.96*3; (c = tuning constant)
w = abs(resid/sigma);
if w <= c then _weight_ = (1-(w/c)**2)**2;
else _weight_ = 0;
output   out = d   r = rbi;
run;
data d;
set d;
sigma = 1000;
b = 1.96*3;
w = abs(rbi/sigma);
if w <= c then _weight_ = (1-(w/c)**2)**2;
else _weight_ = 0;
proc print;
run;
```

(The lines from "w = abs(resid/sigma);" to "run;": these lines establish robust criteria)

A.2) The SAS statements related to the estimation of the final weighed least squares estimates presented in Table 2.

```
proc robustreg data=test fwls;
   model qndf = ndfi/diagnostics;
   weight qndf;
   output out=ric2 r=resid sr=stdres;
 run;
```

A.3) If a power scale parameter estimate do not differ from unity, accurate estimates for A could be obtained with the following SAS statement:

```
proc robustreg data=test fwls;
   model Qndf = BW/noint diagnostics; (noint = non intercept model)
   weight Qndf;
   output out=ric2 r=resid sr=stdres;
 run;
```

A.4) Derivation of the “Scaling Function” or the so called “Allometric” equation. We prefer “Scaling Function” because of its scaling purpose between variables and because a given variable could be isometric when a “dependent” variable scales to the same power of the "independent" variable. We recommend Bioenergetics and Growth, by Samuel Brody (1945), as a further reading on the subject. Let us assume that our independent variable is body weight (W) and a given body part F, for instance the maximum NDF holding capacity of the ruminoreticulum, is our dependent variable, and both are functions of time:

$$\dot{W} = k_1 \cdot W \qquad \text{(Eq. 1A)}$$

$$\dot{F} = k_2 \cdot F \qquad \text{(Eq. 2A)}$$

After integrating with respect to time, the state trajectory functions or transition functions of W and F could be described by the following equations:

$$\ln(W/W_0) = k_1 \cdot t \qquad \text{(Eq. 3A)}$$

$$\ln(F/F_0) = k_2 \cdot t \qquad \text{(Eq. 4A)}$$

If we divide Eq. 4A by Eq. 3A, the following result could be obtained:

$$\frac{\ln(F/F_0)}{\ln(W/W_0)} = \frac{k_2 \cdot t}{k_1 \cdot t} \Rightarrow F = F_0 \cdot \left(\frac{W}{W_0}\right)^{\frac{k_2}{k_1}} \qquad \text{(Eq. 5A)}$$

If we consider parameter $b = k_2/k_1$ and parameter $A = F_0/(W_0)^b$, we finally arrive to Eq. 1, which scales body parts to the whole:

$$F = A \cdot W^b. \qquad \text{(Eq. 6A)}$$

# A GENERALIZED MODEL FOR DESCRIBING FIBER DYNAMICS IN THE RUMINANT GASTROINTESTINAL TRACT. 2. ACCOUNTING FOR HETEROGENEOUS POOLS IN THE RUMINORETICULUM

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## Summary
There is considerable empirical evidence that at least two fiber pools might be encountered in forage-fed ruminants based on the digesta stratification within the ruminoreticulum. A mathematical model is proposed based on a generalized conceptual compartmental model to accommodate the heterogeneous nature of the digesta. Preliminary results agreed with behavioral concepts based on literature data. The model predicted a specific situation when ruminant diets are constrained enough to virtually avoid the formation of the rumen mat or raft. Such situations would include feedlot cattle eating large amounts of concentrates or small ruminants in which body size constrains intake to a selective feeding behavior that excludes coarse fiber from the diet. The simulation results indicated that the amount of digested fibrous carbohydrate and the fiber pool size in the ruminoreticulum are mostly affected.

## Introduction
The most accepted paradigm concerning fiber retention and degradation dynamics treats the digesta fiber mass as a single pool. Nonetheless, there is an increasing number of studies suggesting the existence of anomalous observed behaviors that deviate from predictions based on a single pool model (Ellis et al., 1979; 2002; Huhtanen and Kukkonen, 1995; Vieira et al., 2000; Poppi et al., 2001; Lund et al., 2007). The fiber pool is heterogeneous whenever ruminants eat enough fiber to promote a natural stratification of the digesta. This phenomenon is believed to occur in larger species of ruminants such as cattle (Van Soest, 1996; Vieira et al., 2007). Therefore, an alternative model was developed and discussed in this paper to accommodate the digesta stratification that could be resolved either for steady-state or dynamic conditions; basically by treating the fiber mass in the ruminoreticulum as a sequential of two pools of fibrous particles.

## Experimental Procedures
The concepts outlined below were used to develop the mathematical model. The bulk of the food matter consumed ($\dot{F}$, fiber intake rate, lb/h) is the fiber content of the j$^{th}$ feedstuff ($[NDF]_j$) times its intake rate ($\dot{X}_j$, lb/h):

$$\dot{F} = \sum_j \left( [NDF]_j \cdot \dot{X}_j \right)$$
(Eq. 1)

We assume that neutral detergent solubles contribution to fill is negligible. Conceptually, fiber is a nutritional entity that contributes to the bulk of digesta by providing potentially digestible fibrous carbohydrates, and a remnant of the physical and chemical breakdown processes: an ideal nutritional entity called indigestible fibrous matter. Each feedstuff has its characteristic potentially digestible ($f_{d,j}$) and indigestible ($f_{i,j}$) fiber fractions that additively constitute the respective dimensionless potentially digestible ($f_d$) and indigestible ($f_i$) components of the diet, but constrained to $f_d + f_i = 1$.

The masticated food particles produced during eating will form the rumen floating mat, which is considered an unmixing pool of particles (RP, lb) that is formed by newly ingested and older, aged particles (such particles are usually larger in size). Older particles are derived from preceding meals that still remain in the RP. A recently ingested particle is not readily available for chemical breakdown via microbial digestion. Hydration, solubilization of digestion inhibitors, and microbial attachment and colonization of feed particles by rumen microbes are events that have to occur prior to digestion itself. These processes transform the unavailable potentially digestible RP entity into a form prone to be digested: an available entity of the same raft particle ($RP_d$, lb). The ideal indigestible entity of the raft particles ($RP_i$, lb) is recalcitrant to microbial enzymes in anoxic environments such as the rumen. Henceforth, it could only be broken down by rumination. The $RP_d$ becomes available to be degraded by microbial enzymes after completion of the events above mentioned. The digestion process was kinetically described by the rate $k_d$, assumed to be exponentially distributed over time.

The RP particles are not eligible to escape the rumen. Instead, a transfer mechanism operates as an ageing chain process counterbalancing the RP buoyancy (resistance to flow) and the propelling forces produced by rumen motility and physical and chemical breakdown (increases flow) of RP. This results in the progressive transfer of matter between the RP to the mixing pool of fluid diluted particles (MP, lb). There is not a clear cut between these two pools and migrating particles (RP $\rightarrow$ MP) are commingled, but the pools were distinctly treated to simplify the model. The resultant of these processes was aggregated in a single rate, $k_r$, that is assumed to have a gamma distribution over time with parameters $\lambda_r \in \Re^+$ and $N_r \in \Im^+$, with $\bar{k}_r = \hat{\lambda}_r / N_r$.

The MP pool ventral to the RP pool contains particles eligible to leave the rumen. Particles of the MP pool share a remnant of the original potentially digestible entity of RP that remains to be digested at a $k_d$ rate, or leave the rumen along with its indigestible counterpart. The escape process of MP is kinetically described by the rate $k_e$, that is assumed to be exponentially distributed over time.

## Results and Discussion

Transfer mechanisms from the RP to the MP pools are as follows:

$$\dot{RP}_d = f_d \cdot \dot{F} - (k_r + k_d) \cdot RP_d$$
(Eq. 2)

$$\dot{RP}_i = f_i \cdot \dot{F} - k_r \cdot RP_i$$
(Eq. 3)

$$\dot{MP}_d = k_r \cdot RP_d - (k_d + k_e) \cdot MP_d$$
(Eq. 4)

$$\dot{MP}_i = k_r \cdot RP_i - k_e \cdot MP_i$$
(Eq. 5)

$$\dot{D} = k_d \cdot (RP_d + MP_d)$$
(Eq. 6)

Terms not yet defined were $\dot{D}$, the rate of digested amounts (lb/h), and $MP_d$ and $MP_i$, the potentially digestible and indigestible fiber fractions of the MP pool. The dot above variables represents a differential with respect to time. The visual scheme of Eq. 2 to 6 is shown in Figure 1 using the stock and flow diagram of Vensim® (Ventana Systems Inc, Harvard, MA 01451) and Figure 2 depicts a simulation using the dynamic model.

Under the assumption of Steady-State, however, the following conditions are expected:

$\dot{RP}_d = \dot{RP}_i = \dot{MP}_d = \dot{MP}_i = 0$, $\dot{F} \cong \bar{F}$ (constant intake rate, $\dot{X} \cong \bar{X}$), $E(k_r) = \bar{k}_r = \dfrac{\hat{\lambda}_r}{N_r}$, $E(k_e) = k_e$, $E(k_d) = k_d$, $E(f_d) = f_d$, and $E(f_i) = f_i$. Therefore, the steady-state solution of the model allows solving for the digestible amounts and pool sizes:

$$\text{DIGESTIBILITY} = \frac{\dot{D}}{f_d \cdot \bar{F}} = \frac{k_d}{k_d + \bar{k}_r} \cdot \left(1 + \frac{\bar{k}_r}{k_d + k_e}\right)$$
(Eq. 7)

The dimensionless digestibility (Eq. 7) resumes to the single pool solution whenever conditions leading to the raft elimination operates in practice. Mathematically, mechanisms responsible by raft formation occurs so fast that $E(k_r) \rightarrow \infty$, and Eq. 7 becomes:

$$\text{DIGESTIBILITY} = \frac{k_d}{k_d + k_e}$$
(Eq. 80.21")

Here, $k_e$ has the same meaning of the well known $k_p$ for the single pool model.

The maximum fiber holding capacity of the ruminoreticulum (RR) scales isometrically (W to power one) with respect to size (Van Soest, 1996; Vieira and Tedeschi, 2007). The ruminal fiber mass (RFM, Eq. 9) provides a mean to estimate the amount of fiber that a given diet fills the RR.

$$RFM = \lim_{t \to \infty} (RP_d + RP_i + MP_d + MP_i) = \bar{F} \cdot \left[ f_d \frac{k_d + k_e + \bar{k}_r}{(k_d + \bar{k}_r) \cdot (k_d + k_e)} + f_i \left( \frac{1}{\bar{k}_r} + \frac{1}{k_e} \right) \right]$$
(Eq. 9)

If a given RFM predicted for the formulated diet is greater than the fiber holding capacity of the ruminoreticulum (FHCRR) determined for a given animal in a specified physiological condition, two constraints should be accommodated in current feeding systems for diet formulation and optimization:

$$\sum_j \left\{ [\mathrm{NDF}]_j \cdot \bar{X}_j \cdot \left[ f_{d,j} \frac{k_{d,j}+k_{e,j}+\bar{k}_{r,j}}{(k_{d,j}+\bar{k}_{r,j})\cdot(k_{d,j}+k_{e,j})} + f_{i,j}\left(\frac{1}{\bar{k}_{r,j}}+\frac{1}{k_{e,j}}\right)\right]\right\} \le \text{Max FHCRR}$$

(Eq. 10)

$$\frac{\bar{F}}{\sum_j \bar{X}_j} \ge \text{Min DIET}[\mathrm{NDF}]$$

(Eq. 11)

Subscript j refers to the j[th] feedstuff, and Max is the maximum FHCRR. In Eq. 11, the minimum requirement of fiber is Min DIET [NDF] and dry matter intake is

$\sum_j \bar{X}_j$ .

Meanwhile, $k_r$ and $k_e$ could be estimated by fitting compartmental models to time excretion profiles of particulate markers in the feces. We assumed that larger retention pools are either within the rumen, and that caudal segments of the gastrointestinal tract promotes a random walk flow of the digesta with a mean retention time equals to $\tau$ (Ellis et al., 1994).

$$C(t)=C(0)\left\{\delta^{N_r}\exp[-k_e(t-\tau)]-\exp[-\lambda_r(t-\tau)]\sum_{i=1}^{N_r}\delta^i[\lambda_r(t-\tau)]^{N_r-i}/(N_r-i)!\right\}$$

(Eq. 12)

Where C(t) and C(0) are the respective marker concentrations in the feces and in the unmixing compartment, $\delta=\lambda_r/(\lambda_r+k_e)$ and $\lambda_r$, $N_r$ and $k_e$ were as specified previously.

Passage estimates could be obtained by administration of marked feedstuffs to animals and inferences should not extrapolate the physiological stage of the animal, e.g. during the course of lactation, growth, or late pregnancy.

The $k_d$ seems to be the same rate as in the single pool model. However, fractional degradation rates have different estimates in practice and the reader should be aware of that. We discussed methods to estimate rates of degradation within the proposed model in a companion report.

Blaxter et al. (1956) derived mathematical relationships of the passage of food residues through the gastrointestinal tract of sheep. They ascribed first-order kinetic rates respectively to the emptying of the rumen and the abomasum, although they were well aware about inexistence of experimental proof regarding rate association to a specific segment of the tract at that time. Grovum and Williams (1973) studying the flow of markers through segments of the sheep digestive tract concluded that the first-order rates (analogous to $\lambda_r/1$, i.e. $N_r = 1$, and $k_e$) should be ascribed to the rumen (the lower rate, usually $k_e$), and to the cecum and proximal colon (the faster rate, usually $\lambda_r/1$).

Theoretical Simulation

Let us assume that a late spring pasture with a non-limiting crude protein content (65% NDF with a $k_d$ = 4%/h) was grazed by a 990 lb cow. A hypothetical sample of the grazed pasture was taken from an esophageal cannulated steer and the extrusa marked with chromium mordant ($Cr_2O_7^{-2}$) was fed to the cow and yielded estimates for passage parameters of 20%/h for $\lambda_r$ and 3%/h for $k_e$. Let us assume that $N_r$ = 1. In such situation, the digestibility amounted to 0.54 or 54%, according to Eq. 8 (single pool model).

The $k_d$ estimate used in the proposed model is quite different from the single pool model, although they share the same biological meaning. The same hypothetical *in vitro* kinetic analysis used to obtain the single pool $k_d$ estimate was used and yielded a $k_d$ = 5%/h to be used in the generalized model. This resulted in a digestibility estimate of 70%, according to Eq. 7. Even if the estimate of 5%/h is used in Eq. 8, the digestibility achieved would be 63%, still lower than the integrated kinetic flow estimates of the generalized model (Eq. 7).

If only cattle data of Cannas et al. (2003) were used, assuming that FHCRR scales to $W^1$, the hypothetical cow could hold 0.010 lb per lb of W or 9.9 lb of NDF. In addition, her NDF intake scaled to the same power was expected to be 0.010 lb per lb of W per day or 9.9 lb/d. Additionally, if we assumed the NDF of our pasture had $f_d$ and $f_i$ values of 0.7 and 0.3, it will fill the cow's rumen with 9 lb or .009 lb per lb of live weight according to Eq. 10. This value is lower than 0.010 lb/lb of W and intake is not expected to be limited (Figure 3a) unless other constraints force an increase in intake such as metabolic demand for energy of lactating cows. Similar calculations performed within the single pool solutions would render a 0.008 lb/lb of W, which means one fill lower than that estimated with the proposed model. The lower flow estimates are (↓ $k_r$ and ↓ $k_e$) the greater will be the filling effect of the diet (Figure 3c) and this situation probably occurs with less digestible forages (↓ $k_d$ and higher ↑ $f_i$, Figures 3b and 3d).

## Implications

A generalized model based on the natural stratification of the ruminoreticular digesta was developed and preliminary results are in concordance with literature concepts. Nevertheless, proper evaluation methods should be performed to verify its broader applicability.

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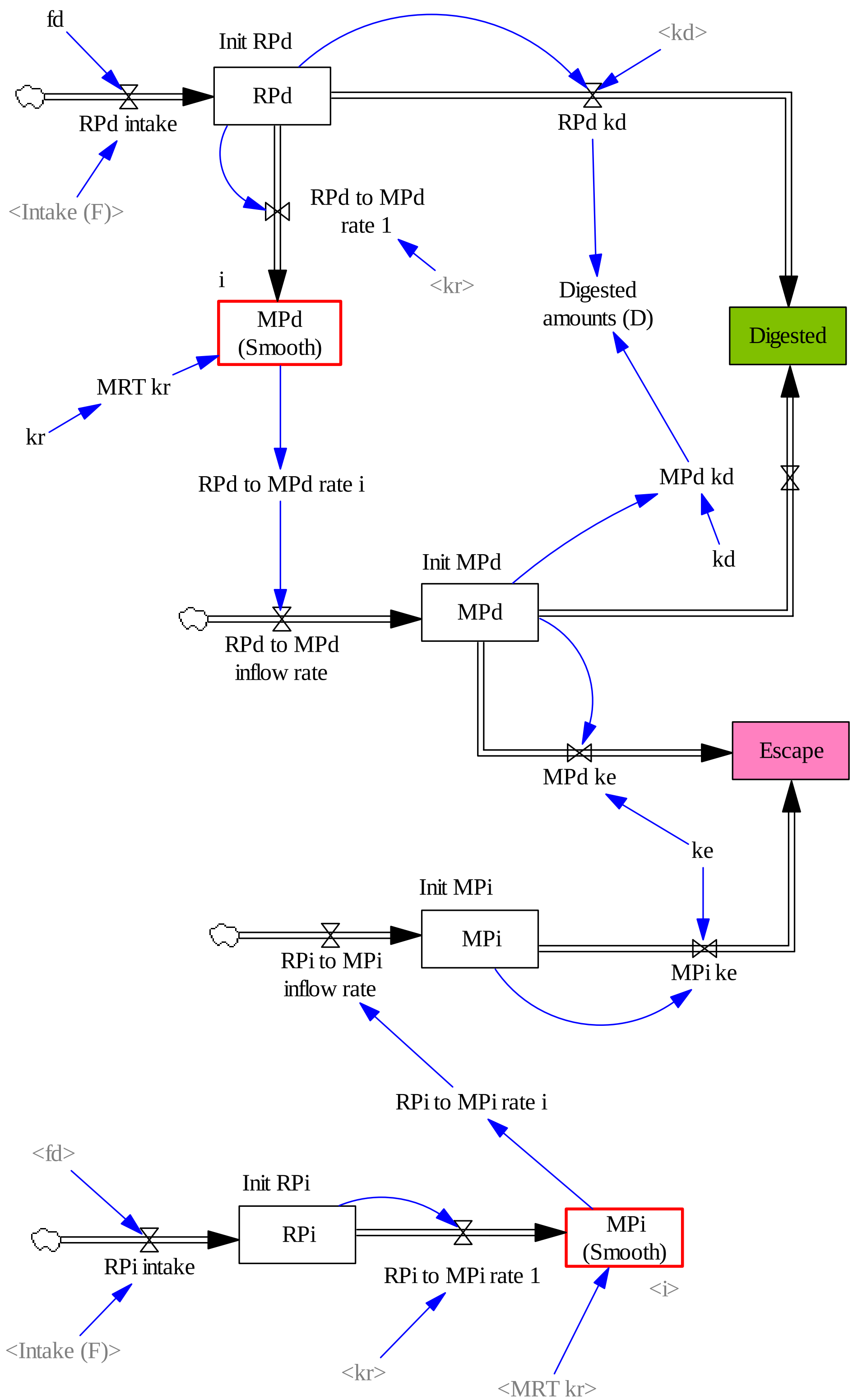


Figure 1. Schematic representation of the dynamic model to predict flow of fiber particles from the rumen using stock and flow diagram.

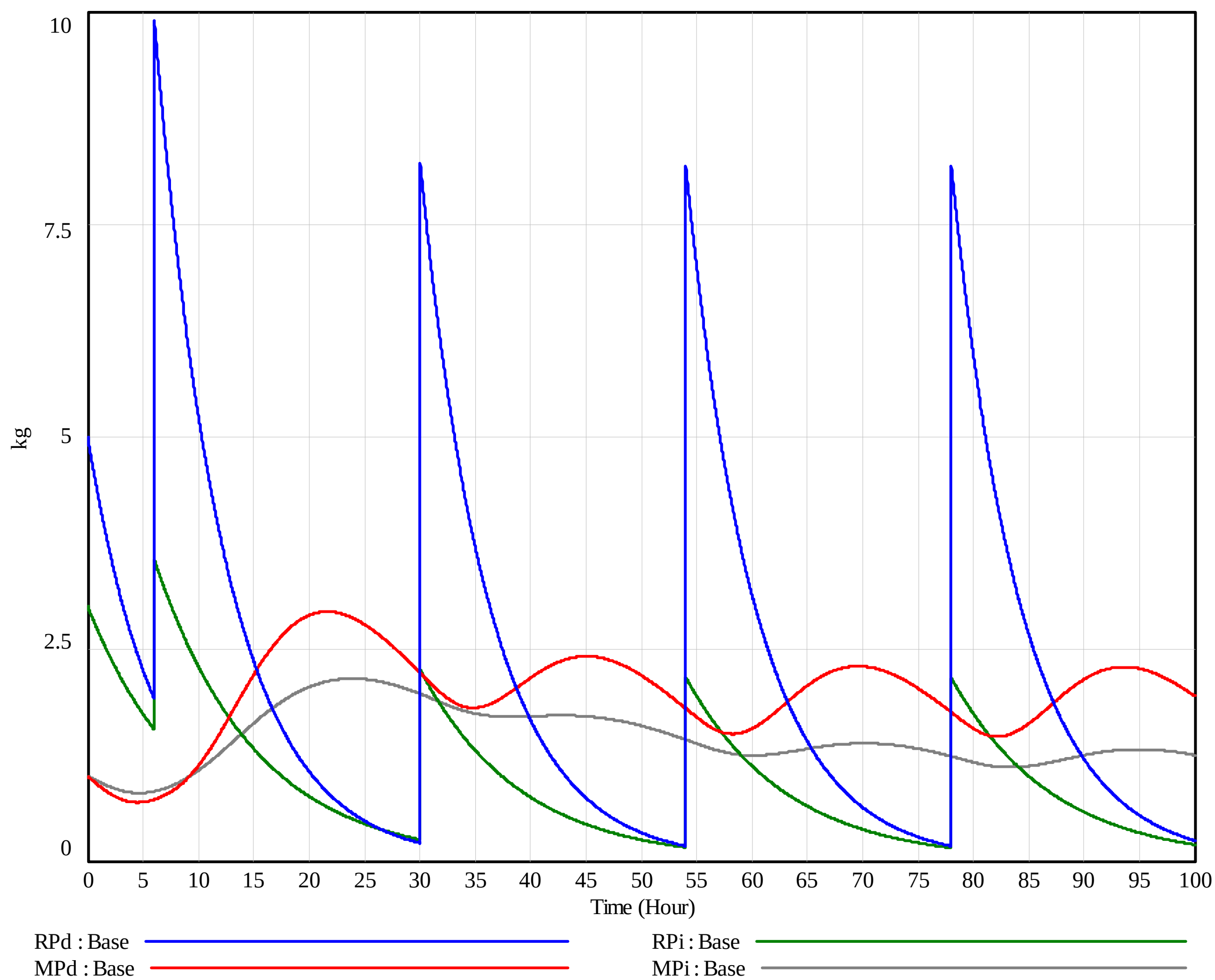


Figure 2. Simulation using the dynamic model assuming intake of 10 kg/d (22 lb/d) of fiber, initial $RP_d$, $RP_i$, $MP_d$, and $MP_i$ of 5 (11 lb), 3 (6.6 lb), 1 (2.2 lb), and 1 kg (2.2 lb), respectively, $k_d$ of 5%/h, $k_r$ of 11%/h, $k_e$ of 7%/h, and four multi-compartments (i = 3 in the MPd smooth stock). The average digested amount ($\dot{D}$) was 0.21 kg/h (0.46 lb/h) and varied from 0.096 (0.21 lb/h) to 0.53 kg/d (1.17 lb/h).

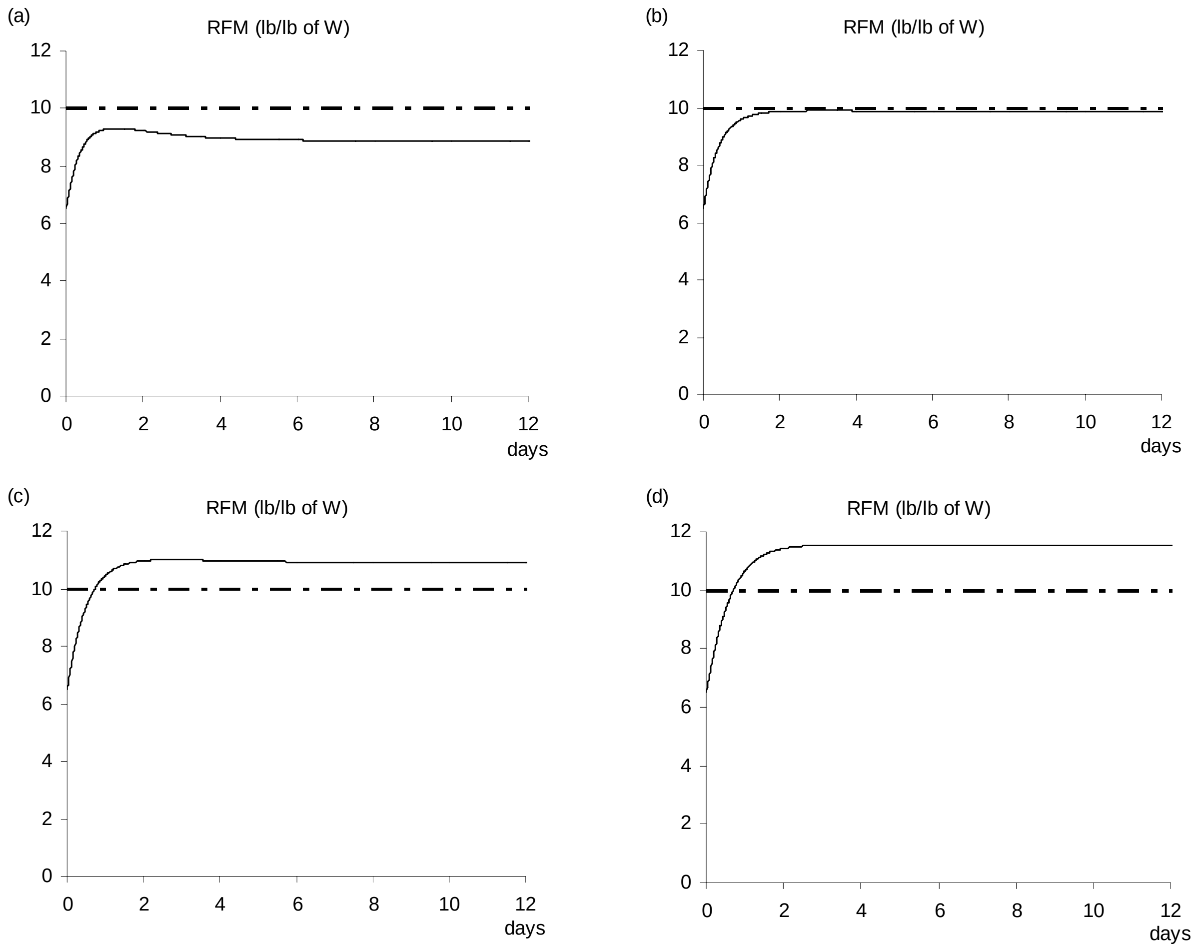


Figure 3. Simulated behaviors of the ruminoreticular fiber mass (RFM). The solid curves represent RFM (lb/lb of W) and the dashed lines represent the fiber holding capacity of the ruminoreticulum (FHCRR) from our hypothetical cow. Plots were obtained according to the following parameters: in (a), fd = 0.7, fi = 0.3, $\lambda r$ = 0.2, ke = 0.03 and kd = 0.05; in (b), only fd = 0.6 and fi = 0.4 were different from (a); in (c), only $\lambda r$ = 0.15 and kd = 0.04 were different from (a); and in (d), fd = 0.6, fi = 0.4, $\lambda r$ = 0.15 and kd = 0.04 were different from (a). Note that the pasture consumed could not fill the FHCRR in the cases (a) and (b), but the pasture in the cases (c) and (d) could. A limitation on intake is thus expected according to Eq. 10.

# A GENERALIZED MODEL FOR DESCRIBING FIBER DYNAMICS IN THE RUMINANT GASTROINTESTINAL TRACT. 3. ESTIMATING DIGESTION-RELATED KINETIC PARAMETERS

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## Summary

A generalized compartmental model of digestion based on gamma time dependency of lag phenomena ($G_NG_1$) was applied to estimate kinetic parameters of forage digestion in ruminants. Overall qualities of fit of four possible versions of the model for N compartments varying from one to four were evaluated. Parameter estimates were affected by forage quality, particularly the indigestible fraction and the fractional degradation rate. The relationship between time dependency and quality deserves further investigation. Nevertheless, the model had a high goodness-of-fit and comparable estimates could be obtained for comparison purposes with single pool models.

## Introduction

The digesta stratification in the ruminoreticulum of forage-fed ruminants occurs whenever environmental and animal characteristics do not constrain intake to a selective eating behavior for a diet rich in neutral detergent solubles (Van Soest, 1996). Hence, domestic ruminants that depend on roughage resources have heterogeneous pools (Vieira et al., 2007a). Events related to the dynamic nature of fibrous digesta particles were discussed in a companion report (Vieira et al., 2007b).

Systems dynamics has evolved in parallel to computational resources; consequently complexity of natural phenomena can be conceptualized and simulated more reliably. Transfer mechanisms between system variables and interchange flows can be modeled by accommodating delays. In ruminant nutrition, pioneering studies in this field (Blaxter et al., 1956; Matis, 1972; Pond et al., 1988; Van Milgen et al., 1991) provided a theoretical description of the biological processes involved. In this report, we presented a quantitative description of events related to digestion kinetics in the ruminoreticulum.

## Experimental Procedures

The theoretical basis of the degradation model is outlined as follows. When a large fibrous particle enters the rumen several processes must occur prior to its digestion (Vieira et al., 2007b). These processes are aggregated and represented by a single kinetic rate named $k_a$, assumed gamma distributed over time ($\Gamma(N_a, \lambda_a, t)$) with parameters $\lambda_a \in \Re^+$, $N_a \in \Im^+$, and $E(k_a) = \bar{k}_a = \hat{\lambda}_a / N_a$ under the assumption of steady-state. The newly ingested particle could be schematically divided into three conceptual compartments: an unavailable ($U_d$) and an available ($A_d$) potentially digestible and an indigestible (I) fractions. Deserve prominence, however, the fact that both $U_d$ and $A_d$ are physically the same entity, but divided schematically to represent lag transfer phenomena that promote the gradual availability of $U_d$ into $A_d$. In advance, the latter is degraded by microbial enzymes following first-order kinetics as shown in Figure 1.

Although treated separately, the processes described by the kinetic rate $k_a$ (Figure 1) are part of the processes represented by the $k_r$ parameter described by Vieira et al. (2007b), and it is assumed that $k_a > k_r$. The rates $k_a$ and $k_d$ could be estimated by fitting the generalized compartmental model ($G_NG_1$, of Eq. 1) to fiber degradation profiles obtained from *in situ* or *in vitro* studies.

$$\begin{cases} R(t) = U_d(0)\left\{\delta^{N_a} \exp(-k_d t) + \exp(-\lambda_a t)\left[\sum_{i=0}^{N_a-1}\left(1-\delta^{N_a-i}\right)\gamma_i\right]\right\} + I(0) \\ \delta = \dfrac{\lambda_a}{\lambda_a - k_d} \text{ and } \gamma_i = (\lambda_a t)^i / i! \end{cases}$$

(Eq. 1)

The Eq. 1 is a transition function that represents the amount of residual feedstuff matter after *in situ* or *in vitro* incubation. It is analogous to the transition function presented by Pond et al. (1988), who described the total dose of a marker remaining in a system of two sequential compartments when a gamma time dependency is included.

Comparable results to first-order models could be obtained numerically from the first and second derivatives of Eq. 1:

$$\frac{dR(t)}{dt} = -U_d(0)\left\{\delta^{N_a} k_d \exp(-k_d t) + \lambda_a \exp(-\lambda_a t)\left[\left(1-\delta^{N_a}\right) + \varphi\right]\right\}$$

(Eq. 2)

$$\varphi = \sum_{i=0}^{N_a-1}\left\{\left(1-\delta^{N_a-1-i}\right)\gamma_i\left[\frac{\lambda_a t}{(i+1)} - 1\right]\right\}$$

(Eq. 3)

$$\frac{d^2R(t)}{dt^2} = U_d(0)\left\{\delta^{N_a} k_d^2 \exp(-k_d t) + \lambda_a^2 \exp(-\lambda_a t)\left[\left(1-\delta^{N_a}\right) + \left(1-\delta^{N_a-1}\right)(\lambda_a t - 2) + v\psi\right]\right\}$$

(Eq. 4)

$$\psi = \sum_{i=0}^{N_a-2}\left\{\left(1-\delta^{N_a-2-i}\right)\gamma_i\left[\frac{(\lambda t)^2}{(i+2)(i+1)} - 2\frac{\lambda t}{(i+1)} + 1\right]\right\}$$

(Eq. 5)

In which $\delta$ and $\gamma_i$ are auxiliary terms defined in Eq. 1. The auxiliary variables $\varphi$ and $\psi$ were employed to simplify mathematical description. The comparable first-order digestion rate or fractional specific digestion first-order rate ($k_f$) could be defined as follows.

$$k_f = -\frac{dR(t_i)/dt}{U_d(0)}$$

(Eq.6)

being $t_i$ the abscissa coordinate at the inflection point. By its turn, $t_i$ could be estimated numerically or graphically by solving for the roots of $t_i$ that satisfies Eq. 7.

$$\frac{d^2R(t_i)}{dt^2} = 0 \quad \text{(Eq. 7)}$$

To demonstrate the flexibility of the model to fit degradation profiles, *in vitro* incubations of two grasses (orchardgrass, *Dactylis glomerata*, and timothy, *Phleum pretense*) and two legumes (alfalfa, *Medicago sativa*, and red clover, *Trifolium pretense*) were gathered from Mertens (1973). The chemical composition in terms of crude protein (CP), neutral detergent fiber (NDF), sulfuric acid lignin ($H_2SO_4$ Lignin), insoluble nitrogen in neutral (NDIN) and acid (ADIN) detergents, neutral detergent insoluble ash (NDIA), ash and silica ($SiO_2$) were reported (Table 1). Forages were chosen according to three levels (low, medium, and high) of sulfuric acid lignin content in the DM to account for quality variability. A total of 12 degradation profiles were analyzed by fitting the general compartmental model of digestion (Eq. 1) by using the Marquardt algorithm of the NLIN procedure of SAS (SAS Inst. Inc., Cary, NC). A description of SAS routines could be found in the Appendix. The quality of fit criterion was subjectively based on the minimum sum of squares of error (SSE), or whether a minimum was not reached, a minimum of 10% reduction in SSE of the preceding $G_{N-1}G1$ should be obtained after fitting the $G_NG_1$ model for N varying from two to four.

## Results and Discussion

With the exception of alfalfa, observed trends in CP along with the $H_2SO_4$ Lignin content in NDF were indicative of the forage quality variability (Table 1). Incrustation of cell wall by lignin also lowers nitrogen availability as revealed by the ratio of acid detergent insoluble nitrogen to the total nitrogen content (Table 1).

A recently ingested particle is not readily available for microbial breakdown. Hydration, solubilization of digestion inhibitors, and accessibility and colonization of feed particles by rumen microbes are events that have to occur prior to digestion itself. These processes transform the unavailable potentially digestible large particle entity ($U_d$, Figure 1) into a form prone to be digested, an available entity of the same large particle named $A_d$ (Figure 1). It is reasonable to expect that chemical composition and ultra-structural characteristics of forage tissues (Akin, 1979; Wilson, 1993), probably constrain the transfer mechanisms and delays the rate of availability of the substrate to be digested (Ellis et al., 2005). Additionally, a discrete lag time ($\tau$) could be incorporated in the model described by Eq. 1 so that its effect on order of time dependency could be evaluated, i.e. the quality of fit of higher order models corrected for a discrete lag (substitute t in Eq. 1 by $t - \tau$).

It should be recognized, however, that the processes associated to the forage tissues disruption during ingestive mastication as described by Pond et al. (1984), could not be simulated by using the *in vitro* incubation because of the required fine grinding of forage samples. Nevertheless, all *in vivo* digestion estimates are expected to be higher than those estimated with techniques based on an unconstrained particle size (Huhtanen et al., 2007).

The difference in quality was also demonstrated by the increased percentage of estimated indigestible NDF and the trends of the $k_d$ estimates in becoming lower as quality decreases, irrespective of model used and forage evaluated (Tables 2 and 3). Nevertheless $\lambda_a$ estimates did not share a regular trend pattern with respect to quality and further investigations with a larger data set are necessary.

Models chosen to represent degradation profiles according to the established criteria varied according to the order of gamma time dependency. As an additional criterion, whenever the estimates of parameter $\lambda_a$ approached $k_d$, the goodness-of-fit was considered inappropriate and higher order models were further evaluated according to the previously established SSR criteria. For Orchardgrass of low, medium and high $H_2SO_4$ Lignin in the DM, selected models were $G_3G_1$, $G_2G_1$ and $G_2G_1$, respectively. The respective choices regarding the same quality classes for timothy grass were $G_2G_1$, $G_2G_1$ and $G_3G_1$ (Table 2). Models chosen to represent alfalfa profiles were $G_1G_1$, $G_3G_1$ and $G_2G_1$, and just one version of the model ($G_2G_1$) was selected to describe degradation kinetics of the three quality classes of red clover. Here, there was no apparent relationship between order of time dependency and quality, with the exception of the timothy grass. The expected $k_a$ values, i.e. $\overline{k}_a$ estimates for each chosen model within each forage and quality class were presented graphically. No apparent relationship could be inferred; nevertheless, a more detailed investigation is needed because systematic reductions in $\overline{k}_a$ between the low and high lignin content in forages are likely (Figure 2).

The most striking characteristics that reflected quality were the indigestible fraction and the first order degradation rate, which varied systematically (Tables 2 and 3 and Figure 3). The $U_d$ fraction consequently was also affected, since it is calculated by the difference between the observed residue at t = 0 and the estimate of the indigestible fraction. Nutritionists should be aware that considerable biases could be impinged to the truly indigestible fraction by short term incubations such as those used in the present study (Van Soest et al., 2005; Ellis et al., 2005).

The ideal indigestible entity of large particles (I, Figure 1) can not be digested by rumen microbes. On the other hand, $U_d$ becomes available to be degraded after completion of the events described by $k_a$ as above mentioned. The digestion processes promoted by microbial enzymes are kinetically described by the rate $k_d$, assumed to be exponentially distributed over time (first-order). As the ageing chain of processes related to the transfer of particles from the large particles pool into the pool of small particles succeeds, the indigestible entity and the available potentially degradable fraction ($A_d$) remnants constitute the fibrous mass of small particles, i.e. $U_d$ was completely transformed into $A_d$ (Figure 1). Since events that occur prior to digestion represented by $k_a$ occurred in the raft, the kinetic forces of first-order digestion and escape of particles are the remaining actions concurring to the clearance of small particles from the ruminoreticulum (Vieira et al., 2007b).

There are considerable empirical evidences that the indigestible entity is not accurately estimated by short fermentation times. Biases could be reduced by fitting models that account for heterogeneous potentially digestible fiber fractions or a gamma mixture of exponentials (Van Soest et al., 2005; Ellis et al., 2005). Henceforth, if long *in vitro* incubation times could not be performed due to medium limitations in maintaining microbial numbers and good anaerobic conditions, or if particle losses with the *in situ* technique either hamper accurate measurements of long incubation times, then perhaps the combined powers of concepts that leads to the construction of Eq. 1 with those that leads to models that account for heterogeneous pools may be useful to produce estimates of the indigestible entity. As a corollary, heterogeneous potentially digestible fractions and its dynamic lags and degradation rates could be more properly estimated as well. However, such estimates need to be evaluated in terms of relevant scientific and economical variables of the ruminant production system.

## Implications

The generalized compartmental model ($G_NG_1$) of digestion could be used to estimate parameters related to time degradation profiles. The model presented an overall good quality of fit and adherence to time profiles. Further studies are required to the estimation of heterogeneous potentially degradable fractions and accurate estimates of the indigestible fiber. These estimates could be applied to simulate the dynamic behavior of the fiber in the gastrointestinal tract of ruminants, but evaluations of predictions based on such estimates are still required.

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Table 1. Chemical composition[1,2] of orchard grass (*Dactylis glomerata*), timothy grass (*Phleum pretense*), alfalfa (*Medicago sativa*), and red clover (*Trifolium pretense*) used to generate time degradation profiles[3], distributed according to the $H_2SO_4$ Lignin content in the dry matter

| Forage[4] | CP | NDF | $H_2SO_4$ Lignin | Lignin (%NDF[5]) | NDIN | ADIN | ADIN/NC (%NC[6]) | NDIA | Ash | $SiO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Orchardgrass | | | | | | | | | | |
| Low | 27.7 | 48.2 | 2.1 | 4.36 | 1.76 | 0.11 | 2.48 | 3.4 | NR | 2.3 |
| Medium | 8.4 | 68.5 | 4.3 | 6.28 | 0.56 | 0.12 | 8.93 | 0.8 | 6.4 | 0.8 |
| High | 6.8 | 78.0 | 6.6 | 8.46 | 0.41 | 0.12 | 11.03 | 1.1 | NR | 0.4 |
| Timothy | | | | | | | | | | |
| Low | 23.9 | 47.6 | 2.4 | 5.04 | 1.17 | 0.08 | 2.09 | 1.3 | NR | 0.8 |
| Medium | 14.3 | 62.4 | 4.2 | 6.73 | 0.77 | 0.14 | 6.12 | 0.9 | 6.2 | 0.7 |
| High | 10.8 | 68.2 | 6.0 | 8.80 | 0.78 | 0.23 | 13.31 | 0.9 | 5.8 | 1.2 |
| Alfalfa | | | | | | | | | | |
| Low | 25.0 | 31.5 | 5.0 | 15.87 | NR | NR | – | 2.2 | 12.4 | 1.5 |
| Medium | 19.3 | 47.2 | 7.3 | 15.47 | 0.54 | 0.22 | 7.12 | 1.1 | 7.9 | 0.6 |
| High | 16.4 | 50.8 | 8.1 | 15.94 | 0.34 | 0.21 | 8.00 | 0.5 | 9.2 | 0.1 |
| Red clover | | | | | | | | | | |
| Low | 14.4 | 58.3 | 4.0 | 6.86 | 1.14 | 0.17 | 7.38 | 0.9 | 8.0 | 1.0 |
| Medium | 13.7 | 69.4 | 5.5 | 7.93 | 1.25 | 0.26 | 11.86 | 1.5 | 7.8 | 1.4 |
| High | 10.9 | 66.1 | 7.8 | 11.80 | 0.84 | 0.33 | 18.92 | 1.1 | 5.6 | 1.2 |

[1]Expressed in % of the dry matter unless otherwise specified.
[2]Acronyms are crude protein (CP), neutral detergent fiber (NDF), sulfuric acid lignin ($H_2SO_4$ Lignin), insoluble nitrogen in neutral (NDIN) and acid (ADIN) detergents, neutral detergent insoluble ash (NDIA), ash and silica ($SiO_2$), and when a value was not reported, NR was displayed.
[3]Data obtained from Mertens (1973).
[4]Divided according to the $H_2SO_4$ Lignin in the dry matter.
[5]$H_2SO_4$ Lignin in the NDF.
[6]Percentage of the nitrogen content (NC), i.e. CP/6.25.

Table 2. Parameters estimates (± asymptotic standard errors) and sum of squares of error (SSE[1]) after fitting a generalized compartmental model ($G_NG_1$) to *in vitro* degradation profiles of orchard and timothy grasses

| Forage[2] | Parameter[3] | $G_1G_1$ | $G_2G_1$ | $G_3G_1$ | $G_4G_1$ |
|---|---|---|---|---|---|
| **Orchardgrass** | | | | | |
| | SSE | 132.1 (100%) | 90.8 (69%) | 77.8 (59%) | 72.0 (54%) |
| | $U_d$ (%NDF) | 86.95 | 86.90 | 86.99 | 87.09 |
| Low | I (%NDF) | 13.15 ± 1.31 | 13.10 ± 1.26 | 13.01 ± 1.31 | 12.91 ± 1.35 |
| | $\lambda_a$ (1/h) | 0.4182 ± 0.1345 | 0.9282 ± 0.2055 | 1.4789 ± 0.3074 | 2.0553 ± 0.4177 |
| | $k_d$ (1/h) | 0.1155 ± 0.0157 | 0.1114 ± 0.0107 | 0.1089 ± 0.0098 | 0.1073 ± 0.0093 |
| | SSE | 593.1 (100%) | 417.3 (70%) | 372.7 (63%) | 361.4 (61%) |
| | $U_d$ (%NDF) | 63.60 | 63.66 | 63.69 | 63.72 |
| Medium | I (%NDF) | 36.40 ± 2.46 | 36.34 ± 1.90 | 36.31 ± 1.75 | 36.28 ± 1.69 |
| | $\lambda_a$ (1/h) | 0.1072 ± 0.1220 | 0.2858 ± 0.0747 | 0.4441 ± 0.0894 | 0.5988 ± 0.1076 |
| | $k_d$ (1/h) | 0.0748 ± 0.0709 | 0.0625 ± 0.0126 | 0.0610 ± 0.0097 | 0.0605 ± 0.0087 |
| | SSE | 181.2 (100%) | 178.7 (99%) | 189.2 (104%) | 196.4 (108%) |
| | $U_d$ (%NDF) | 48.20 | 48.20 | 48.20 | 48.20 |
| High | I (%NDF) | 51.80 ± 1.11 | 51.80 ± 0.89 | 51.80 ± 0.80 | 51.80 ± 0.78 |
| | $\lambda_a$ (1/h) | 0.3070 ± 0.1011 | 0.6301 ± 0.1309 | 0.9558 ± 0.1660 | 1.2832 ± 0.2029 |
| | $k_d$ (1/h) | 0.0489 ± 0.0055 | 0.0486 ± 0.0037 | 0.0485 ± 0.0032 | 0.0484 ± 0.0029 |
| **Timothy** | | | | | |
| | SSE | 71.3 (100%) | 55.8 (78%) | 70.6 (99%) | 84.0 (118%) |
| | $U_d$ (%NDF) | 86.95 | 87.12 | 87.25 | 87.34 |
| Low | I (%NDF) | 13.05 ± 0.74 | 12.88 ± 0.65 | 12.75 ± 0.74 | 12.66 ± 0.78 |
| | $\lambda_a$ (1/h) | 0.1828 ± 1329 | 0.5968 ± 0.0598 | 0.9852 ± 0.0930 | 1.3732 ± 0.1319 |
| | $k_d$ (1/h) | 0.1828 ± 1329 | 0.1287 ± 0.0084 | 0.1221 ± 0.0073 | 0.1193 ± 0.0072 |
| | SSE | 171.5 (100%) | 122.7 (72%) | 123.3 (72%) | 131.0 (76%) |
| | $U_d$ (%NDF) | 74.00 | 74.07 | 74.14 | 74.17 |
| Medium | I (%NDF) | 26.00 ± 1.06 | 25.93 ± 0.86 | 25.86 ± 0.86 | 25.83 ± 0.89 |
| | $\lambda_a$ (1/h) | 0.2932 ± 0.0819 | 0.6583 ± 0.0999 | 1.0282 ± 0.1372 | 1.4051 ± 0.1819 |
| | $k_d$ (1/h) | 0.0931 ± 0.0123 | 0.0890 ± 0.0064 | 0.0875 ± 0.0056 | 0.0866 ± 0.0054 |
| | SSE | 231.5 (100%) | 123.8 (53%) | 96.4 (42%) | 87.4 (38%) |
| | $U_d$ (%NDF) | 65.59 | 65.71 | 65.74 | 65.80 |
| High | I (%NDF) | 34.41 ± 1.39 | 34.29 ± 0.96 | 34.26 ± 0.83 | 34.20 ± 0.80 |
| | $\lambda_a$ (1/h) | 0.1905 ± 0.0670 | 0.4399 ± 0.0680 | 0.6838 ± 0.0812 | 0.9288 ± 0.0976 |
| | $k_d$ (1/h) | 0.0704 ± 0.0139 | 0.0660 ± 0.0056 | 0.0649 ± 0.0043 | 0.0642 ± 0.0038 |

[1]Values within parenthesis are percentages (%) in relation to the SSE estimate after fitting the G1G1 model.
[2]Divided according to the sulfuric acid lignin (Lignin $H_2SO_4$) content in the dry matter.
[3]Parameter U doest not present an SE estimate because it was indirectly estimated from R(0) – I for each profile.

Table 3. Parameters estimates (± asymptotic standard errors) and sum of squares of error (SSE[1]) after fitting a generalized compartmental model ($G_NG_1$) to *in vitro* degradation profiles of alfalfa and red clover

| Forage[2] | Parameter[3] | $G_1G_1$ | $G_2G_1$ | $G_3G_1$ | $G_4G_1$ |
|---|---|---|---|---|---|
| **Alfalfa** | | | | | |
| | SSE | 17.2 (100%) | 22.4 (131%) | 25.8 (150%) | 27.4 (160%) |
| | $U_d$ (%NDF) | 59.22 | 59.35 | 59.41 | 59.48 |
| Low | I (%NDF) | 40.78 ± 0.52 | 40.65 ± 0.65 | 40.59 ± 0.65 | 40.52 ± 0.65 |
| | $\lambda_a$ (1/h) | 0.4159 ± 0.0852 | 1.0060 ± 0.1661 | 1.6370 ± 0.2697 | 2.2795 ± 0.3740 |
| | $k_d$ (1/h) | 0.1242 ± 0.0113 | 0.1159 ± 0.0081 | 0.1127 ± 0.0076 | 0.1111 ± 0.0074 |
| | SSE | 97.4 (100%) | 50.6 (52%) | 38.4 (39%) | 33.4 (34%) |
| | $U_d$ (%NDF) | 47.76 | 47.72 | 47.81 | 47.85 |
| Medium | I (%NDF) | 52.24 ± 1.02 | 52.28 ± 0.88 | 52.19 ± 0.74 | 52.15 ± 0.69 |
| | $\lambda_a$ (1/h) | 0.1081 ± 719 | 0.3182 ± 0.0613 | 0.5148 ± 0.0694 | 0.7090 ± 0.0814 |
| | $k_d$ (1/h) | 0.1081 ± 719 | 0.0812 ± 0.0124 | 0.0770 ± 0.0079 | 0.0752 ± 0.0065 |
| | SSE | 27.1 (100%) | 34.1 (126%) | 42.0 (155%) | 47.4 (175%) |
| | $U_d$ (%NDF) | 39.77 | 40.02 | 40.18 | 40.23 |
| High | I (%NDF) | 60.23 ± 0.46 | 59.98 ± 0.63 | 59.82 ± 0.67 | 59.77 ± 0.71 |
| | $\lambda_a$ (1/h) | 0.1216 ± 637 | 0.4326 ± 0.0730 | 0.7114 ± 0.1177 | 1.0016 ± 0.1645 |
| | $k_d$ (1/h) | 0.1216 ± 637 | 0.0812 ± 0.0088 | 0.0764 ± 0.0074 | 0.0744 ± 0.0069 |
| **Red Clover** | | | | | |
| | SSE | 238.2 (100%) | 123.6 (52%) | 108.0 (45%) | 110.6 (46%) |
| | $U_d$ (%NDF) | 77.83 | 77.94 | 78.09 | 78.17 |
| Low | I (%NDF) | 22.17 ± 1.46 | 22.06 ± 1.09 | 21.91 ± 0.98 | 21.83 ± 1.01 |
| | $\lambda_a$ (1/h) | 0.1123 ± 1219 | 0.3483 ± 0.0521 | 0.5551 ± 0.0636 | 0.7622 ± 0.0809 |
| | $k_d$ (1/h) | 0.1123 ± 1219 | 0.0809 ± 0.0089 | 0.0777 ± 0.0064 | 0.0761 ± 0.0057 |
| | SSE | 194.0 (100%) | 80.1 (41%) | 76.2 (39%) | 87.0 (45%) |
| | $U_d$ (%NDF) | 72.78 | 72.58 | 72.81 | 72.94 |
| Medium | I (%NDF) | 27.22 ± 1.25 | 27.42 ± 0.89 | 27.19 ± 0.85 | 27.06 ± 0.89 |
| | $\lambda_a$ (1/h) | 0.0918 ± 798 | 0.2675 ± 0.0299 | 0.4358 ± 0.0377 | 0.6008 ± 0.0506 |
| | $k_d$ (1/h) | 0.0918 ± 798 | 0.0696 ± 0.0066 | 0.0655 ± 0.0047 | 0.0638 ± 0.0044 |
| | SSe | 412.8 (100%) | 371.0 (90%) | 357.8 (87%) | 353.8 (86%) |
| | $U_d$ (%NDF) | 59.32 | 60.20 | 60.37 | 60.43 |
| High | I (%NDF) | 40.68 ± 3.06 | 39.80 ± 2.71 | 39.63 ± 2.61 | 39.57 ± 2.54 |
| | $\lambda_a$ (1/h) | 0.0992 ± 0.0817 | 0.2897 ± 0.0888 | 0.4572 ± 0.1191 | 0.6211 ± 0.1503 |
| | $k_d$ (1/h) | 0.0548 ± 0.0348 | 0.0438 ± 0.0092 | 0.0426 ± 0.0076 | 0.0421 ± 0.0071 |

[1]Values within parenthesis are percentages (%) in relation to the SSE estimate after fitting the G1G1 model.
[2]Divided according to the sulfuric acid lignin (Lignin $H_2SO_4$) content in the dry matter.
[3]Parameter U doest not present an SE estimate because it was indirectly estimated from R(0) – I for each profile.

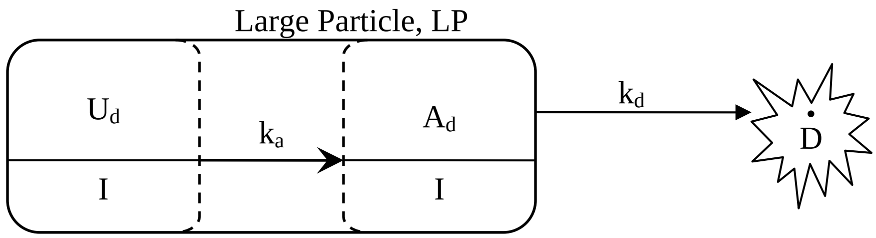


Figure 1. Schematic representation of the kinetic processes suffered by large particles in the rumen mat. Adapted from Allen and Mertens (1988). See details in the text and in a companion report (Vieira et al., 2007b).

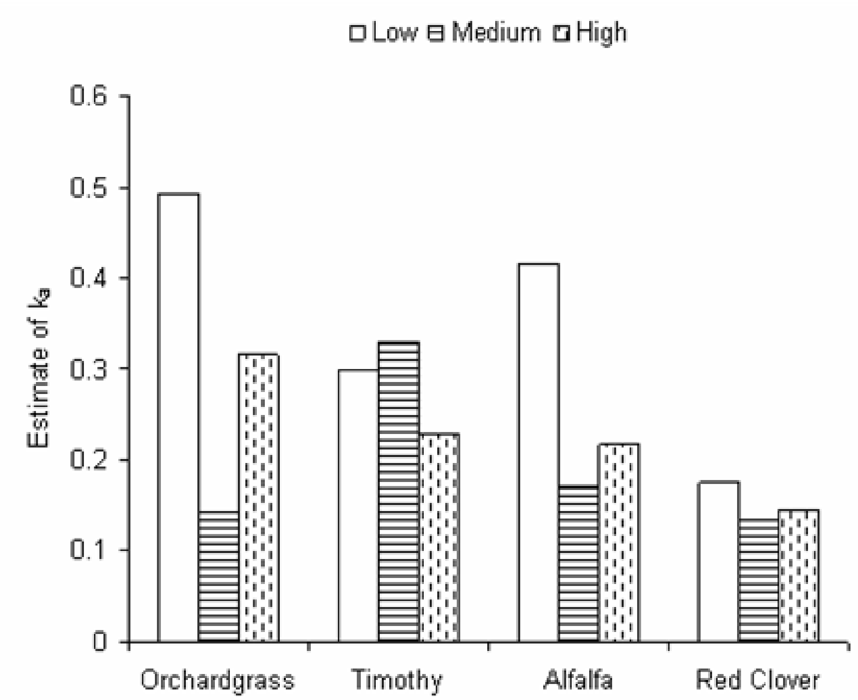


Figure 2. Estimates of $\bar{k}_a$ ($\hat{\lambda}_a / N_a$) for each forage and class of quality (low, medium and high lignin content in the dry matter), according to the quality of fit criteria for choosing a specific version of the generalized compartmental model.

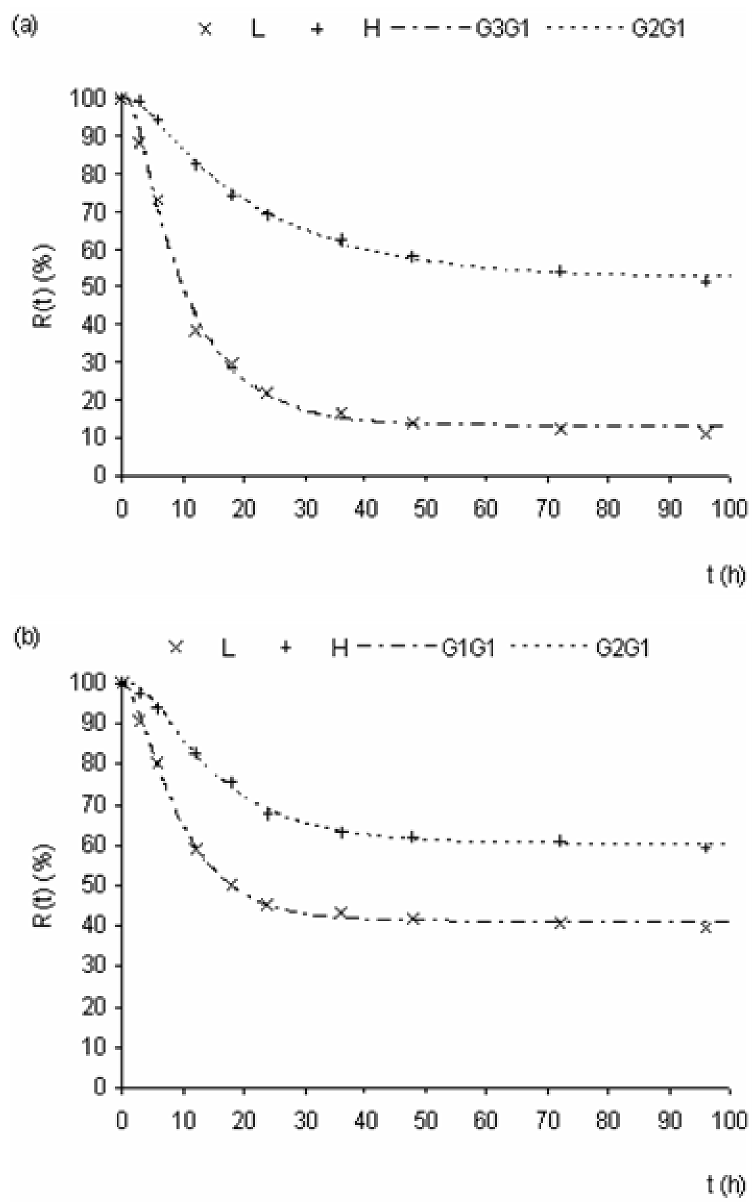


Figure 3. Degradation profiles of orchard grass (a) and alfalfa (b). Letters L and H are related to low and high sulfuric acid lignin in the dry matter. The lines - – - – and - - - - represent the resultant fitted generalized compartmental model $G_NG_1$ to data.

## APPENDIX

### A.1) SAS procedures for NLIN fitting of G1G1 model:

```
proc nlin best=5 method=marquardt;
parms
i=10 to 150 by 2
l=.01 to 1 by .05   (obs.: l = represents lambda)
k=.001 to .2 by .005;
bounds 0<k, 0<l, 0<i;
z=l/(l-k);
e1=exp(-k*t);
u=l*t;
e2=exp(-u);
model Y=(266.6-i)*(z*e1+e2*(1-z))+i;
output out=g1g1 h=ha r=aresid student=rsa;
run;
proc print;
data g1g1;
run;
```

### A.2) SAS procedures for NLIN fitting of G2G1 model (see and repeat abbreviations in G1G1):

```
proc nlin best=5 method=marquardt;
parms
i=10 to 150 by 2
l=.01 to 1 by .05
k=.001 to .2 by .005;
bounds 0<k, 0<l, 0<i;
model Y=(306.8-i)*(z**2*e1+e2*((1-z**2)+(1-z)*u))+i;
output out=g2g1 h=hc r=cresid student=rsc;
run;
proc print;
data g2g1;
run;
```

### A.3) SAS procedures for NLIN fitting of G3G1 model (see and repeat abbreviations in G1G1):

```
proc nlin best=5 method=marquardt;
parms
i=10 to 150 by 2
l=.01 to 1 by .05
k=.001 to .2 by .005;
bounds 0<k, 0<l, 0<i;
model Y=(304.5-i)*(z**3*e1+e2*((1-z**3)+(1-z**2)*u+(1-
z)*u**2/2))+i;
output out=g3g1 h=hb r=bresid student=rsb;
run;
proc print;
data g3g1;
run;
```

### A.4) SAS procedures for NLIN fitting of G4G1 model (see and repeat abbreviations in G1G1):

```
proc nlin best=5 method=marquardt;
parms
i=10 to 150 by 2
l=.01 to 1 by .05
k=.001 to .2 by .005;
bounds 0<k, 0<l, 0<i;
model Y=(266.6-i)*(z**4*e1+e2*((1-z**4)+(1-z**3)*u+(1-
z**2)*u**2/2+(1-z)*u**3/6))+i;
output out=g4g1 h=ha r=aresid student=rsa;
run;
proc print;
data g4g1;
run;
```

# RELATIONSHIPS OF FEED EFFICIENCY WITH CARCASS AND NON-CARCASS TISSUE COMPOSITION IN ANGUS BULLS AND HEIFERS

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## Summary

Objectives of this study were to characterize feed efficiency traits and examine their relationship with carcass and non-carcass tissue composition in Angus bulls and heifers. Individual dry matter intake (**DMI**) was measured in Angus bulls and heifers fed a corn-based diet (ME = 2.85 Mcal/kg) for 70 d using Calan-gates. Net feed intake (**NFI**) was computed as the residual from the linear regression of DMI on mid-test $BW^{0.75}$ and ADG within gender. Within bulls and heifers, calves were separated into two groups: high and low RFI (n = 8/gender). Low NFI calves consumed 17% less feed than high NFI calves, but had similar ADG and BW. Upon harvest, gastrointestinal tract (**GIT**) and visceral organs were removed, dissected, and weighed. The 9-11$^{th}$ rib tissue was analyzed for protein and lipid content. There were no significant differences between low and high NFI calves for final BW (792.6 ± 17.2 lb), HCW (568.9 ± 12.7 lb) and empty BW (**EBW**; 844.2 ± 18.8 lb). Also, total dissectible internal fat (8.36 ± 0.22% of EBW), and carcass lipid content (30.6 ± 0.95%) were similar for low and high NFI calves. Low NFI calves had greater ($P < 0.05$) carcass protein content than high NFI calves (15.7 vs. 15.1%). Net feed intake calves had similar liver (1.35 ± 0.02% of EBW) and heart weights (0.37 ± 0.01% of EBW), however calves with low NFI had lower weights of empty GIT (9.93 vs. 10.36% of EBW). As expected, heifers had more carcass lipid (35.3 vs. 25.9 ± 1%) and total dissectible internal fat (10.1 vs. 6.6 ± 0.22% of EBW) than bulls. Calves with low NFI had increased carcass protein, and lower GIT weights than calves with high NFI, although no differences in carcass or non-carcass fat content were detected between NFI groups.

## Introduction

Amount and type of feed consumed, breed, age, sex, and environmental conditions are all known to contribute to between-animal variation in efficiency of feed utilization for maintenance and growth (Channon et al., 2004). Feed conversion ratio (**FCR**) is typically used as the measure of feed efficiency. However, FCR is negatively correlated with growth such that selection for low FCR will result in increased mature cow size, and thus, increased feed requirements for maintenance (Herd and Bishop, 2000). Net feed intake (**NFI**) is an alternative feed efficiency trait that measures the variation in feed intake beyond that needed to support maintenance and growth requirements. NFI has been shown to be moderately heritable and genetically independent of growth and body size. Thus, NFI has potential to be used in a selection program to improve feed efficiency without impacting cow mature size (Herd and Bishop, 2000) and growth performance (Arthur et al., 2001). Herd et al. (2004) estimated that approximately one third of the biological variation in NFI could be explained by differences in digestion, heat increment of feeding and activity, and that the other two thirds was likely due to differences in heat production (mechanisms unknown). In addition, Basarab et al. (2003) found that low NFI cattle had lower proportion of gastrointestinal tissue per unit of EBW than high NFI cattle. Visceral organ metabolism has been shown to be a major contributor to whole body energy expenditure (> 40%, Webster, 1981), which could explain why low NFI cattle are more efficient. NFI has been shown to be weakly correlated with carcass fat composition in growing calves (Herd and Bishop, 2000; Fox et al., 2004). Therefore, the objectives of this study were to examine relationship between NFI and carcass and non-carcass tissue deposition.

## Experimental Procedures

Angus bulls (n = 27) and heifers (n = 29) from a divergent selection study (Eastern Agricultural Research Station, Ohio State University) for insulin-like growth factor-I (**IGF-I**) were used in this study. At approximately 10 months of age calves were transported to the O.D. Butler Jr. Animal Science Complex in College Station. Calves were fed a corn-based diet (ME = 2.85 Mcal/kg DM), and individual feed intake was measured using Calan-gate feeders. Feed intake and BW were measured weekly. On day 70 of the test period ultrasound measurements of 12-13$^{th}$ rib backfat (**UBF**), 12-13$^{th}$ ribeye area (**UREA**), and percent intramuscular fat (**UIMF**) were obtained by an Ultrasound Guidelines Council field certified technician using an Aloka 500-V instrument with a

17-cm 3.5 MHz transducer (Corometrics Medical Systems, Inc., Wallingford, CT, USA). Images were collected and stored by Beef Image Analysis Field software (Designer Genes Inc., Harrison, AR), and sent to The National Centralized Ultrasound Processing Lab, Ames, IA, for processing.

Initial and final BW and ADG were computed by linear regression of BW on day of test. Net feed intake was computed as the residual from the linear regression of DMI on mid-test $BW^{0.75}$ and ADG within gender. Calves were ranked by NFI within gender and the eight most and eight least efficient calves within gender were selected for subsequent carcass and non-carcass measurements.

Calves were harvested at the Rosenthal Meat Science and Technology Center. Heifers and bulls were harvested 48 and 64 d after the 70 d test period, respectively. Upon harvest, gastrointestinal tract (**GIT**) and visceral organs were removed, dissected, and weighed. Empty GIT, heart, liver and total dissectible internal fat were weighed and expressed per unit of EBW. Carcass data consisting of ribeye area (**CREA**), backfat thickness (**CBF**), and marbling score were collected 48 hours after harvest, and the 9-11th rib section was removed. The 9-11th rib sections were dissected into separable fat, lean and bone tissue, and moisture, protein and lipid content of separable fat and lean assayed to determine carcass chemical analyses according to Hankins and Howe (1946). Protein was determined using a Leco analyzer, and fat content determined by Soxhlet procedures (AOAC, 1990). Data were analyzed using the PROC GLM model of SAS that included fixed effects of NFI group, gender and NFI group x gender interaction.

## Results and Discussion

Performance and feed efficiency traits are presented in Table 1. Low NFI calves consumed 17% less feed but had similar ADG and IBW compared to high NFI calves. As expected bulls were heavier, gained faster, consumed more DMI and had a lower FCR than heifers. Due to the fact that NFI was computed separately for bulls and heifers, average NFI were similar for bulls and heifers.

There were no significant differences in ultrasound traits between low and high NFI calves (Table 2). Ribeiro et al. (2006) reported similar results in Brahman heifers, however most studies have found that carcass backfat thickness is slightly lower in low vs. high NFI calves (Fox et al., 2004; Lancaster et al., 2005). Low NFI calves had greater ($P < 0.05$) carcass protein (15.7 vs. 15.1%) but similar carcass lipid compared to calves with high NFI, which is in contrast to data of Basarab et al. (2003), who reported greater carcass lipid but similar protein in high NFI steers. Richardson et al. (2001) reported similar results to our study in Angus steer progeny from parents selected for low and high NFI. As expected, bulls had larger UREA, and less UBF and UIMF then heifers on day 70 of the study. Despite the fact that bulls were harvested 16 days later than the heifers, CREA and carcass protein content were greater for bulls than heifers. Bulls also had less carcass fat than heifers, although CBF was similar between the two genders.

Non-carcass traits are presented in Table 3. There were no differences in final BW, EBW, or proportional weights of internal fat, liver or heart between calves with low and high NFI. Basarab et al. (2003) found that low NFI steers had 7.7% smaller liver then high NFI steers. Calves with low NFI had 4.1% smaller proportional GIT weights than calves with high NFI. Basarab et al. (2003) reported similar results, showing that low NFI calves had 7.5% smaller GIT when compared to high NFI calves. Non-carcass fat content (dissectible fat) was also similar between high and low NFI groups. Heifers had higher proportional GIT weights, but smaller proportional liver and heart weights than bulls. Heifers had 34.7% more non-carcass internal fat then bulls.

## Implications

Results from this study demonstrate that variation in carcass and non-carcass composition had minimal impact on accounting for inter-animal variation in NFI. The incorporation of NFI into breeding programs will facilitate selection of calves with improved feed efficiency independent of changes in body size or rate of gain. Moreover, selection for NFI will have minimal effects on composition of carcass or non-carcass composition of growth.

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.

Table 1. Performance and feed efficiency traits for Angus bulls and heifers with low and high net feed intake

| | NFI Group | | | Gender[a] | | |
|---|---|---|---|---|---|---|
| Traits | Low | High | SE | Bulls | Heifers | SE |
| n | 16 | 16 | -- | 16 | 16 | -- |
| Initial BW, lb | 619.6 | 623.5 | 16.46 | 669.8[x] | 573.3[y] | 16.62 |
| Average daily gain, lb/day | 3.46 | 3.53 | 0.11 | 3.99[x] | 2.98[y] | 0.11 |
| Dry matter intake, lb/day | 20.83[x] | 24.42[y] | 0.46 | 23.67[x] | 21.58[y] | 0.46 |
| Feed Conversion, DMI/ADG | 6.18[x] | 7.09[y] | 0.18 | 5.99[x] | 7.28[y] | 0.18 |
| Net feed intake, lb/day | -1.63[x] | 1.81[y] | 0.22 | 0.15 | 0.02 | 0.22 |

[x,y] Least square means within a row with different superscripts differ ($P < 0.05$)

[a] Bulls were harvested on day 134 and heifers on day 118 of the study

Table 2. Characterization of ultrasound and carcass traits in Angus bulls and heifers with low, and high NFI

| | NFI Group | | | Gender[a] | | |
|---|---|---|---|---|---|---|
| Traits | Low | High | SE | Bulls | Heifers | SE |
| *Ultrasound measurements on day 70* | | | | | | |
| Ribeye area,in$^2$ | 10.46 | 10.39 | 0.21 | 11.54$^x$ | 9.31$^y$ | 0.22 |
| Back fat thickness, in | 0.26 | 0.28 | 0.02 | 0.23$^x$ | 0.31$^y$ | 0.02 |
| Intra-muscular fat, % | 3.55 | 3.72 | 0.13 | 3.04$^x$ | 4.23$^y$ | 0.13 |
| Carcass data | | | | | | |
| Hot carcass weight, lb | 568.9 | 568.9 | 12.74 | 657.5$^x$ | 480.3$^y$ | 12.85 |
| Ribeye area, in$^2$ | 11.17 | 10.67 | 0.23 | 12.57$^x$ | 9.27$^y$ | 0.23 |
| Back fat thickness, in | 0.40 | 0.42 | 0.03 | 0.37 | 0.44 | 0.03 |
| Marbling score, %[b] | 5.63 | 5.80 | 0.23 | 5.30$^x$ | 6.13$^y$ | 0.23 |
| Carcass lipid, % | 29.91 | 31.29 | 0.95 | 25.89$^x$ | 35.31$^y$ | 0.96 |
| Carcass protein, % | 15.70$^x$ | 15.08$^y$ | 0.22 | 16.64$^x$ | 14.13$^y$ | 0.22 |

$^{x,y}$ Least square means within a row with different superscripts differ ($P < 0.05$)
[a] Bulls were harvested on day 134 and heifers on day 118 of the study
[b] Slight$^{00}$ = 4.00, Small$^{00}$ = 5.00, Modest$^{00}$ = 6.00

Table 3. Characterization of non-carcass traits in Angus bulls and heifers with low, and high NFI

| | NFI Group | | | Gender[a] | | |
|---|---|---|---|---|---|---|
| Traits | Low | High | SE | Bulls | Heifers | SE |
| Final BW, lb | 788.66 | 796.44 | 17.19 | 865.58$^x$ | 719.52$^y$ | 17.35 |
| Empty BW, lb | 843.58 | 844.73 | 18.76 | 965.68$^x$ | 722.63$^y$ | 18.93 |
| Empty gastrointestinal tract, % of EBW | 9.93$^x$ | 10.36$^y$ | 0.15 | 8.98$^x$ | 11.30$^y$ | 0.15 |
| Total internal fat, % of EBW | 8.22 | 8.49 | 0.22 | 6.60$^x$ | 10.11$^y$ | 0.22 |
| Liver, % of EBW | 1.35 | 1.35 | 0.02 | 1.45$^x$ | 1.25$^y$ | 0.02 |
| Heart, % of EBW | 0.37 | 0.38 | 0.01 | 0.38 | 0.38 | 0.01 |

$^{x,y}$ Least square means within a row with different superscripts differ ($P < 0.05$)
[a] Bulls were harvested on day 134 and heifers on day 118 of the study

# Physiology

# THE RELATIONSHIP BETWEEN TEMPERAMENT AND CONCENTRATIONS OF STRESS-RELATED HORMONES IN THE NEONATAL CALF

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## Summary

The inter-relationships of temperament, performance and concentrations of stress-related hormones in neonatal calves was assessed. Blood samples were collected periodically (from 0-to-28 days of age) and analyzed for serum cortisol (CS), and plasma epinephrine (EPI), and norepinephrine (NE) concentrations. Body weight (BW) was measured weekly from birth through day 21-to-24 to calculate average daily gain (ADG). Calves were ranked (calm, intermediate, or temperamental) based on their exit velocity (EV), which was determined at 21-to-24 days of age. As expected, early calf BW (day 0-to-24) increased over time and was affected by sex. Concentrations of CS decreased after birth and were not affected by TEMP or sex. Concentrations of EPI and NE were not affected by TEMP, or sex. Concentrations of NE decreased after day 7 of age, and there was a tendency for temperamental calves to have greater NE when compared with calm calves. Peak cortisol in the calf was negatively associated with ADG of the calf from birth through d21-to-24 ($r = -0.20$, $P < 0.05$); however, there was no relationship between early performance of the calf and concentrations of EPI, NE, DA, or TEMP ($P > 0.05$). Collectively, these results suggest that temperament can be assessed at a very early age (day 21-24), and elevated concentrations of cortisol may negatively impact growth rate.

## Introduction

Cattle are subjected to handling and management by humans on a regular basis. This includes, for example, feeding, cleaning, processing, and immunizations. An animal's behavioral response to handling and management procedures greatly affects productivity. In cattle, the behavior response, or reactivity to the human element, is labeled temperament (Fordyce et al., 1988). Temperament can effect virtually all aspects of cattle production, including growth, reproduction, and immunity (Fordyce et al., 1985; Voisinet et al., 1997; Petherick et al., 2003; Müller et al., 2006). Although the specific physiological mechanism(s) mediating the effects of temperament on performance are not entirely clear, increasing evidence has suggested a link between an animal's temperament and its "responsiveness" to stress (Curley, 2004; King et al., 2006). Although temperament is often measured at weaning, it is important to determine if it would be beneficial to make this determination at an earlier stage in the production cycle.

## Experimental Procedures

*Animals and Experimental Design.* This study utilized Brahman cows (n = 116) and their calves (born Spring 2006; n = 60 males and 56 females). Calves were pastured with dams until weaning at the Texas A&M University Agricultural Research and Extension Center in Overton. Blood samples (2 x 10 mL) for both plasma and serum were collected via jugular venipuncture from calves as soon as possible following birth and before nursing (day 0) and on days 1, 2, 7, 14, between 21-to-24 days after calving. Calf samples were analyzed for serum cortisol (CS), and plasma concentrations of epinephrine (EPI) and norepinephrine (NE). Calves were weighed at 0, 7, 14, and between 21-to-24 days of age for calculation of average daily gain (ADG). Exit velocity (EV) was determined as a measurement of temperament at 21-to-24 days of age.

*Cortisol and Catecholamine Concentrations.* Serum concentrations of cortisol were determined using a radioimmunoassay (cat # DSL-2100-5; DSL, Webster, TX). Plasma concentrations of EPI and NE were determined by enzyme immunoassay (EIA) (cat # 014-EA63-228; Alpco Diagnostics, Boston, MA).

*Temperament.* Exit velocity was calculated as a measurement of temperament at 21-to-24 days of age as previously described (Burrow et al., 1988; Curley et al., 2006; King et al., 2006). Briefly, the time (in seconds) required for the calf to transverse 1.83 m following its exit from a working chute was determined using two infrared sensors (FarmTek Inc., North Wylie, TX) and used to calculate velocity [velocity = distance (m) / time (s)]. Exit velocity data are presented as the velocity in m/s. Calves were then ranked based on this exit velocity (TEMP) with calves 1 standard deviation slower than the mean ranked 1 (calm), calves 1 standard deviation faster than the mean ranked 3 (temperamental), and all remaining calves ranked 2 (intermediate) (Figure 1).

*Statistical Analysis.* Calculations for area under the curve (AUC) were determined using the trapezoid method of SigmaPlot (Systat Software, Inc., San Jose, CA). Data for weight, EV, cortisol, EPI and NE were analyzed using the proc MIXED procedure of the Statistical Analysis System specific for repeated measures (SAS 9.1, SAS Inst., Inc., Cary, NC.) The AUC data were analyzed using the proc MIXED procedure of SAS. Sources of variation included sex, TEMP, time, and their interactions. Specific treatment comparisons were determined using Fisher's Protected Least Significant Difference with comparisons of $P < 0.05$ considered significant.

## Results and Discussion

*Growth.* Calves gained weight from birth through day 21-to-24 of age ($P < 0.01$; Figure 2). Bull calves weighed more than heifer calves at all time points examined ($P < 0.05$). Weight gain was not affected by calf TEMP or cow temperament ($P > 0.05$). Calf ADG increased with age ($P < 0.01$; Figure 3).

*Stress hormones.* Concentrations of cortisol peaked at birth (d0) before decreasing through d14 of age ($P < 0.01$; Figure 4). The decay of cortisol is in agreement with published literature in pigs and cattle in which cortisol concentrations decreased during the first 7 days after birth (Brown-Borg et al., 1993; Blum and Hammon, 2000). High serum cortisol concentrations in the calf at birth are expected due to the high concentrations of cortisol secreted by the fetus to induce parturition (Mastorakos and Ilias, 2003). High concentrations of cortisol at birth are also required for the maturation of the lungs, kidney, gastrointestinal tract, and liver, which is especially important for preterm neonates (Schmidt et al., 2004; Owen et al., 2005). Owen et al. (2005) also suggested a role of cortisol in the maturation and development of the brain and neuroendocrine connections. Serum cortisol concentrations during the first 21-to-24 days of age were not affected by sex (bull vs. heifer) or TEMP ($P > 0.05$).

To more fully study the stress hormones, concentrations of the catecholamines were also determined. Plasma concentrations of EPI did not change over time ($P > 0.05$; Figure 4) and were not affected by sex or TEMP ($P > 0.05$). However, beginning at 2 days of age temperamental calves had numerically greater concentrations of EPI when compared with calm calves. Concentrations of NE changed over time ($P < 0.05$; Figure 5) with greater concentrations during the first week of life before decreasing. High concentrations of NE at birth are required to stimulate the neonate to become alert, stimulating the calf to begin nursing (i.e., survival behavior; Herlenius and Lagercrantz, 2004). Plasma concentrations of NE were not affected by sex ($P > 0.05$). However, there was a tendency for temperamental calves to have greater concentrations of NE when compared with calm calves ($P < 0.09$). Also, temperamental calves tended to have a greater area under the curve (AUC) concentration of NE when compared to calm calves ($P < 0.10$).

## Implications

Cattle temperament may impact all phases of the production cycle, and thus the profitability of cattle operations. The development of efficient methods for assessing cattle temperament could be an economic benefit as they would provide the producer with an additional tool for selection of replacement animals. As with any selection tool, being able to use the tool at an early age is advantageous, as it allows the producer to make timely management decisions (e.g., which calves to implant, castrate, etc). The current study has demonstrated that calf temperament can be measured as early as day 21-to-24 after birth. However, application of this technique at such an early age is unlikely to be of benefit as a selection tool if it does not accurately "predict" differences in subsequent calf performance. The negative correlation between cortisol and growth rate may be viewed as an indicator of the influence of stress-responsiveness or temperament on performance. Furthermore, the propensity to secrete stress-related hormones evident early in life maybe an indication of the temperament of the calf later in life.

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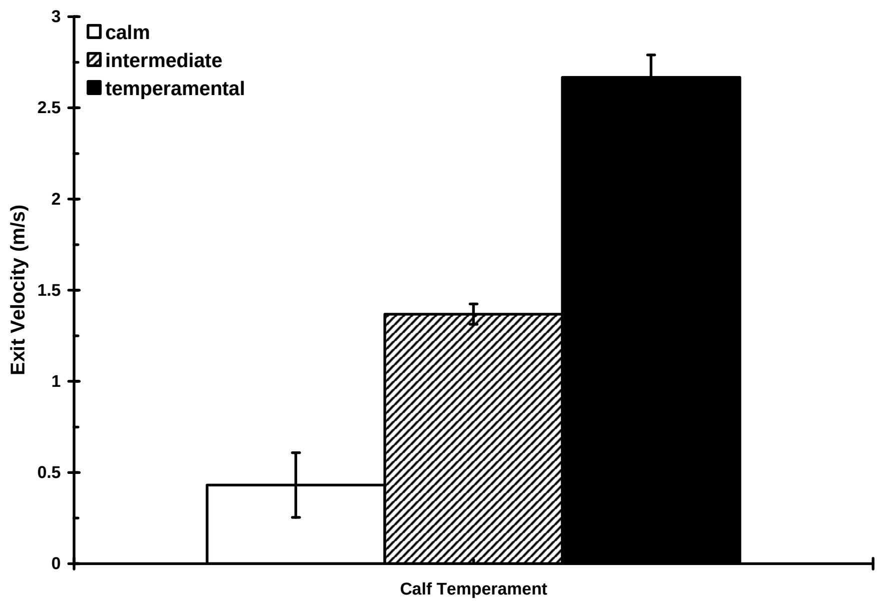


Figure 1. Calf temperament day 21-24 of age. At 21-24 days of age calf exit velocity was determined. Calves were ranked based on their exit velocity, with calm calves being those 1 SD slower than the mean (n = 17; 0.43 ± 0.18 m/s), temperamental calves being those 1 SD faster than the mean (n = 19; 2.67 ± 0.12 m/s), and intermediate calves being all remaining calves (n = 80; 1.37 ± 0.06 m/s).

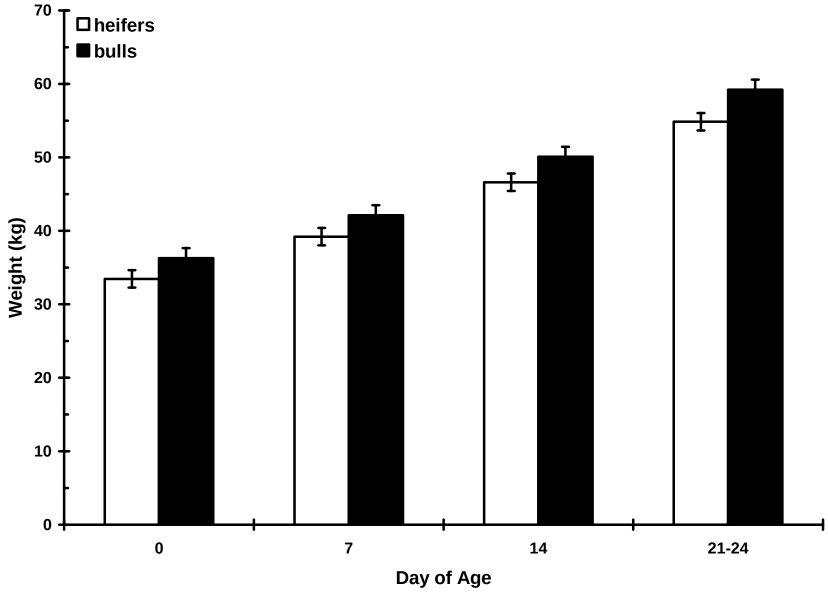


Figure 2. Calf body weight from birth through day 24. Calves gained weight throughout the study, as expected (P < 0.01). Bulls weighed more than heifers at all time points (P < 0.05). Weight gain was not affected by TEMP (P > 0.05).

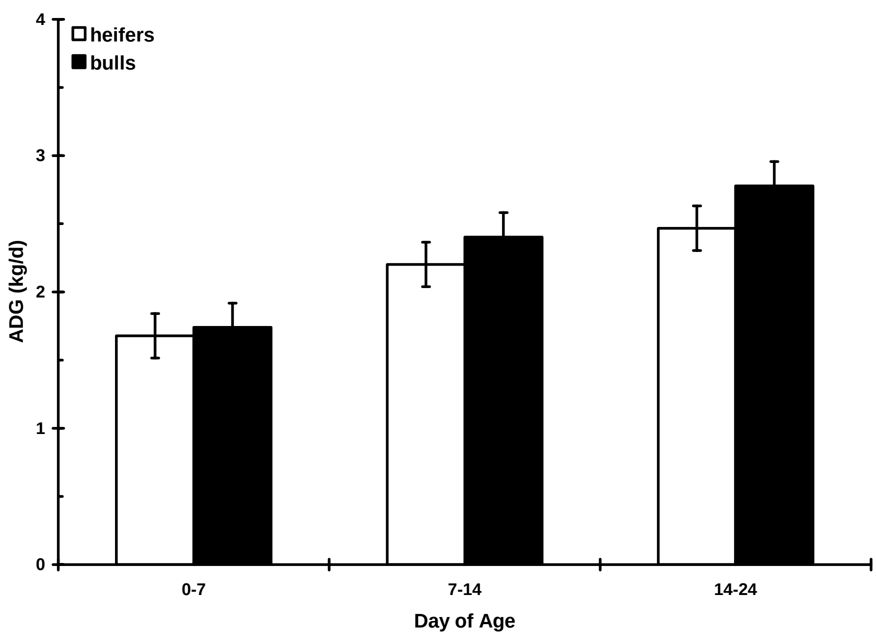


Figure 3. Weekly average daily gain (ADG) of calves from birth through day 24. Calf ADG increased over time (P < 0.01) but did not differ by sex nor TEMP (P > 0.05).

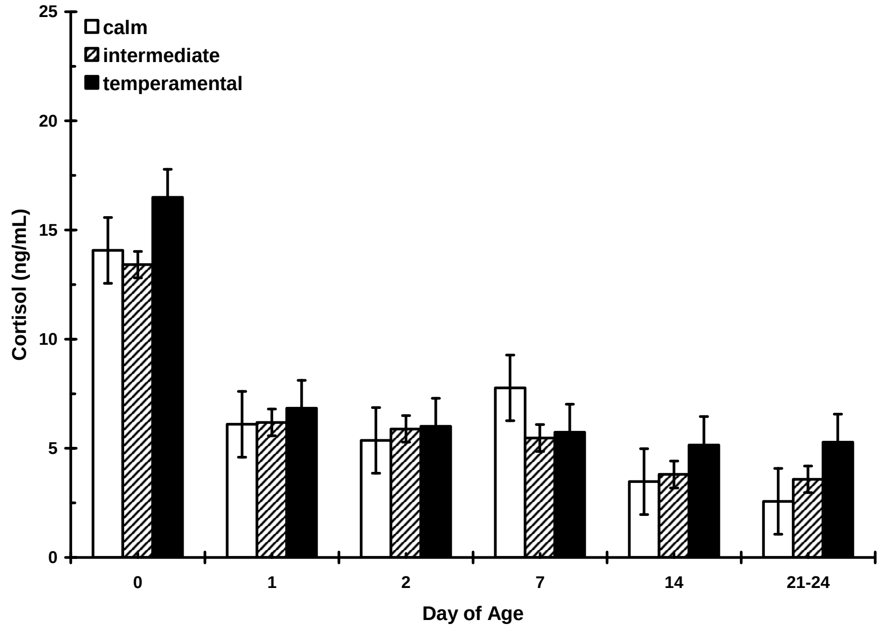


Figure 4. Effect of temperament on serum cortisol concentrations from birth through day 24 of age. Serum concentrations of cortisol peaked at birth (d0) before decreasing through d14 ($P < 0.01$). There was no effect of sex nor TEMP on cortisol concentrations ($P > 0.05$)

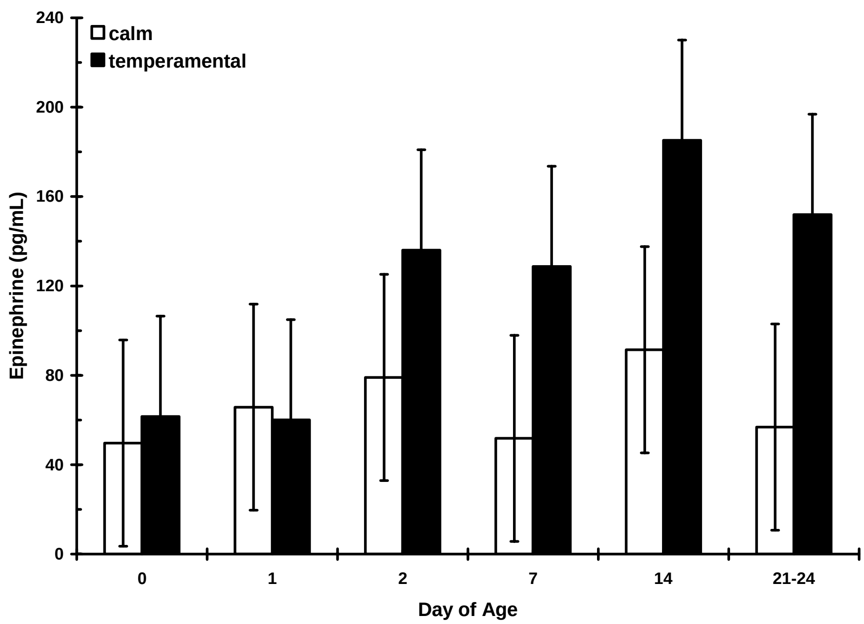


Figure 5. Effect of calf temperament on plasma concentrations of epinephrine (EPI). Plasma EPI was not affected by time, sex, or temperament ($P > 0.05$). However, temperamental calves had numerically greater EPI concentrations.

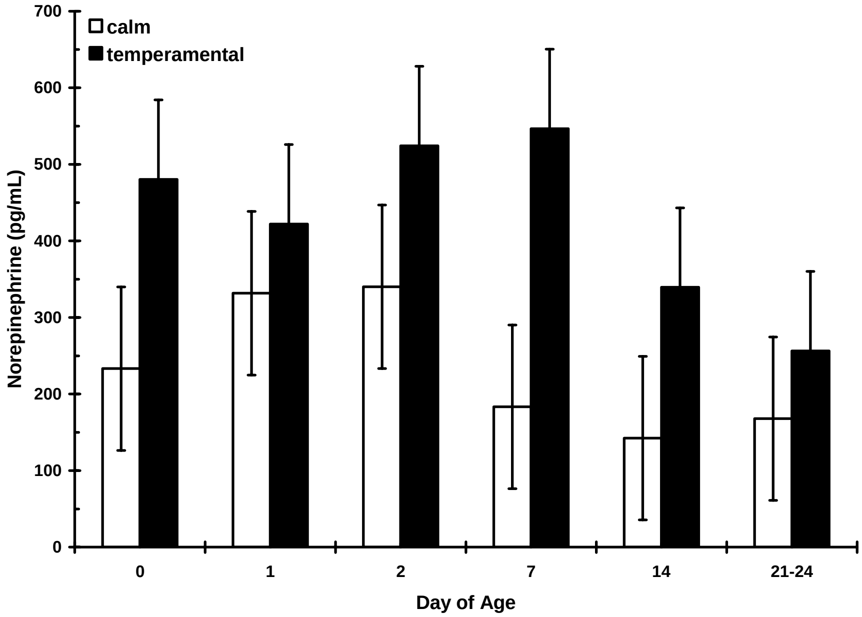


Figure 6. Effect of calf temperament on plasma concentrations of norepinephrine (NE). Plasma concentrations of NE were not affected by sex (P > 0.05), yet they were affected by time, with concentrations decreasing after 1 week of age (P < 0.05). There was a tendency (P < 0.09) for temperamental calves to have greater concentrations of NE when compared with calm calves.

# STEER TEMPERAMENT ASSESSED VIA EXIT VELOCITY UPON FEEDLOT ARRIVAL IS NOT INDICATIVE OF PERFORMANCE

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## Summary

Poor temperament has negative impacts on beef cattle production and may be an important trait to consider for certain segments of the beef industry. Exit velocity is a simple, effective measure of temperament and was used to classify steers as calm or temperamental upon feedlot processing. The calmer cattle arrived to the feedyard heavier, spent less time on feed and had less cost associated with their medical treatment. The temperamental steers spent more time on feed in order to reach appropriate fat thickness and required greater feed costs. However, as hot carcass weights, yield grade, and carcass quality was similar across temperament groups there was no difference in the net income generated from either set of steers. Therefore, based on this study, exit velocity measured upon arrival to the feedlot was not a predictor of steer performance or economic endpoints.

## Introduction

Temperament in cattle is commonly associated with a fear response to handling. Animals with a poor temperament are easily excited and exhibit a greater biological stress response to typical management scenarios (Curley et al., 2006b). This exaggerated stress response can negatively impact multiple facets of cattle production. Temperamental cattle exhibit lower weight gains (Burrow and Dillon, 1997), produce tougher meat (Voisinet et al., 1997), yield increased amounts of bruise trim (Fordyce et al., 1988), and have a compromised immune system (Fell et al., 1999). These linkages between animal behavior and economic endpoints within the beef industry may warrant producers' consideration of temperament within breeding programs and during management practices. Exit velocity (EV) may be useful to beef producers as it is a quick and labor friendly measure of cattle temperament. The objective of this study was to identify any relationship between EV measures obtained at entry to the feedlot with subsequent growth performance and carcass quality.

## Experimental Procedures

During the processing of 161 steers at a south Texas feedlot, temperament was assessed by measuring EV, which is the rate at which the steers exited the squeeze chute and traversed a fixed distance (6.0 feet), as described by Burrow et al. (1988). Infrared sensors were used to remotely trigger the start and stop of the timing apparatus, (FarmTek Inc., North Wylie, TX). This measurement was the basis for categorizing the steers as calm (C; those slower than 0.5 SD below the mean EV; n = 55) and temperamental (T; those faster than 0.5 SD above the mean EV; n = 49). At this time the cattle were also weighed, tagged, implanted and vaccinated. Implant (and reimplant) was Synovex S (or equivalent). Vaccinations were with Cattlemaster® 4 and Vision 7. All cattle were dewormed with Ivomec injectable. In order to measure endocrine parameters (i.e. cortisol) associated with individual animal stress status, blood samples were obtained via tail-vena puncture. Serum concentrations of cortisol were determined by RIA (Carroll et al., 2006). Also during processing, the steers were evaluated for USDA frame and muscle score and assigned an initial value. Cattle were then sorted by weight (100 lb increments) into lots for feeding. Following the feeding period, cattle were harvested based on fat thickness. Steers were weighed and sold to Sam Kane Beef Processor and graded 48 hr later by trained meat scientists.

All animals were participants in the Texas A&M Ranch to Rail Program and were thus from various ranches (n = 6) and of variable breed types. Both ranch of origin and Brahman influence (identified as greater than 1/8) were considered during data analyses. The GLM procedure of SAS (Version 9, SAS Inst., Inc., Cary, NC), was utilized for ANOVA of performance indices across the two temperament groups.

## Results and Discussion

From the blood samples obtained during feedlot processing, the linkage between temperament and stress physiology was confirmed as serum cortisol concentrations differed ($P < 0.01$; C = 6.40 ± 1.59, T = 11.77 ± 1.59 ng/ml) with temperament. The increased cortisol concentrations observed in the temperamental steers echoes previous findings (Curley et al., 2006a; Fell et al., 1999) and may be attributed to either a greater stress response to the shipping procedures, to the handling during feedlot processing, or most likely a combination thereof. Additionally, as cortisol and temperament have both been associated with reduced immune system function these measures obtained upon feedlot entry may be predictive of animal health throughout feeding. While there was no difference in the number of animals from each temperament group that received medical treatment (C = 7, T = 8) the mean cost of treatment was higher in those temperamental steers that were treated ($P < 0.03$; C = $21.46 ± 4.91, T =

$43.12 ± 6.89). This suggests that the severity of the medical issues that arose during the feeding period was greater in the temperamental versus the calm steers. Unfortunately specific data regarding medical treatment was not available.

Initial BW differed ($P < 0.01$) with temperament as the calm steers were heavier upon arrival to the feed yard (C = 683 ± 37, T = 564 ± 37 lbs). This corroborates past observations of our laboratory (unpublished data) of temperament influencing post-weaning growth performance with the calmer animals being the beneficiary. When muscle and frame score was incorporated with BW measures, an initial steer value was established. At the onset of the feeding period the mean value for the calm steers was greater than for the temperamental cattle ($P < 0.02$; C = $576.65 ± 27.30, T = $508.11 ± 27.30). As all steers were fed to a back fat thickness of 0.4 inches, the length of the feeding period varied. On average, the temperamental steers spent a slightly longer time on feed than the calm steers ($P < 0.05$; C = 207.0 ± 2.0, T = 214.0 ± 2.0 d). This increased time on feed translated to a greater feed cost for the temperamental steers (P < 0.01; C = $396.43 ± 10.50, T = $439.42 ± 10.50).

A final BW measure was recorded prior to the steers being sold for slaughter. Final BW did not differ ($P = 0.53$) with temperament. Therefore, while being fed out, the temperamental steers gained more weight ($P < 0.01$; C = 617 ± 33, T = 714 ± 33 lbs), and caught up to the calm steers that were heavier upon arrival to the feedlot. These observations contradict recent findings of temperament having a negative impact on gain in the feedlot (Vann et al., 2006). However, during that study the cattle were grouped by temperament while in the feedlot and it is quite possible that keeping the temperamental steers penned together produced a more stressful environment that hindered these animals' performance.

Following harvest, hot carcass weight did not differ ($P = 0.37$) between calm and temperamental animals. Additionally, temperament had no impact on carcass characteristics as mean rib eye area, USDA yield grade, marbling or USDA quality grade did not differ between carcasses from calm or temperamental steers. When considering the initial steer value, final carcass value and cost to feed the steers there was no fiscal impact of temperament as there was no difference ($P = 0.94$) in the mean net income received from each of the temperament groups.

## Implications

As animal temperament is linked with stress physiology, the benefits from decreasing numbers of temperamental animals within a herd may extend beyond behavior. Although temperament appraisals at weaning have been identified as a possible indicator of post-weaning growth, these data demonstrate that exit velocity measured upon arrival to the feedlot was not a predictor of steer performance during the feeding period. Therefore, based on this study, when feeding steers of differing breed types with possible dissimilar backgrounds, evaluating animal temperament may not be economically beneficial to feedlots.

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# Range and Pasture

# PREDICTING RANGE CATTLE PASTURE-USE WITH TRADITIONAL METHODS ENHANCED BY GPS/GIS-BASED INFORMATION

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## Summary

Since 1999, several studies have been conducted using GPS collars and GIS technology to determine cattle pasture-use in different ecological regions of Texas. Objectives of these studies were to 1) develop photographic evidence of grazing patterns, 2) determine reasons for these patterns, and 3) develop best management recommendations. Assuming adequate water distribution, measurements that have proven most useful in establishing reasons for use include rock cover, brush density scores, and herbaceous plant species composition.

Because of GPS collar expense and GIS technology complexity, we tested transferring what has been learned from GSP/GIS studies to landowner-friendly techniques that can be used to predict grazing patterns. A three-step procedure was developed to test the feasibility of transferring this information. Pasture-use estimates from aerial maps and from ground-level measurements were correct 82 and 95 percent of the time, respectively.

## Introduction

Previous work using GPS collars and GIS technology to monitor range cattle pasture-use in conjunction with field measurements has identified thresholds for landscape features which appear to have potential for predicting pasture-use. For example, previous work has shown that mature cows avoid areas with more than 30 percent rock cover, areas with brush density scores greater than 4, and areas dominated by unpalatable grasses. In addition, in a previous trial, 95% of GPS cow-locations were on slope of 11% or less. It is generally accepted that cattle avoid slopes above 10%.

This project was conducted to test the feasibility of transferring what has been learned from this GPS/GIS work to landowner-friendly techniques that could be used to predict range cattle pasture use. Specifically, we decided to test how well pasture-use could be predicted from aerial photographs and ground-level observations.

## Experimental Procedures

A three-step procedure was developed to test prediction techniques. Four trials were conducted, one on an Edwards Plateau ranch and three on South Texas Plains ranches.

In step-one, digital aerial photographs of the study ranch or pasture were obtained. Ecological sites were mapped on aerial photos using Arc Map 9 GIS software. Locations within ecological sites were selected and designated as grazed or ungrazed. Grazed/ungrazed designations from aerial photos were based on brush cover, potential rock cover, potential slope, and access to locations.

In step-two, designated sites from aerial photos were visited. Pasture-use criteria from previous work were used to adjust grazing designations from aerial photos if necessary. Use-criteria including percent rock cover, brush density scores, and herbaceous species composition were collected along 300-foot lines. Rock cover was estimated using PVC frames. Brush density was scored on a scale of 0 to 5, with 0 having no brush and 5 having brush so dense that it would be difficult to crawl through it.

In step-three, GPS cow-locations were plotted using Arc Map 9. Actual cow-locations were compared with grazing designations in step-one and step-two to determine their accuracy.

## Results and Discussion

*Grazing Designations*

For the Edwards Plateau ranch, Ecological Site Descriptions were obtained (Table 1). Deep Redland and Redland sites are identical in terms of percent surface rock and percent slope, both of which are below thresholds that would be expected to prevent cattle-use, 30% and 10%, respectively.

When step-one map estimates of cattle-use were made for the Edwards Plateau ranch, ecological sites were ranked according to expected use (Table 2). Deep Redland, Gravelly Redland, & Redland sites were separated from Low Stony Hill and Steep Rocky sites based on surface rock and slope shown in Table 1. Rankings of Deep Redland, Redland, and Gravelly Redland sites were based, to some degree, on previous experience.

Low Stony Hill surface rock is equal to or less than 50% which indicates that areas within this site could be above and below the 30% rock cover threshold. In addition, this site has slopes up to 15% which indicates that some areas within the site would be above the generally accepted 10% slope threshold for cattle.

Steep Rocky surface rock would be expected to exceed the 30% rock cover threshold. Furthermore, slopes within this site are expected to start at 15%. Therefore, based on potential rock cover and slope, the Steep Rocky site was ranked last among the five sites on this ranch.

When GPS points were plotted, only the rankings of the Deep Redland and Gravelly Redland sites changed (Table 2). Deep Redland, Gravelly Redland, and Redland sites which made up 12% of the land area on the Edwards Plateau ranch contained 41% of the total GPS points.

Ecological sites on South Texas Plains ranches had no surface rock and no significant slope (Table 3). Therefore, these sites could not be ranked using these characteristics. Cattle-use designations for step-one map estimates for these ranches were based on brush cover. However, brush cover dose not necessarily mean that brush density is great enough to prevent cattle-use.

On one South Texas Plains ranch, we ranked ecological sites as was done for the Edwards Plateau ranch. Rankings were Sandy Loam, Clay Loam, and Gray Sandy Loam. Rankings varied by pasture. For example in two of three pastures, Sandy Loam was first and second to Clay Loam in one pasture. Clay Loam ranked ahead of Gray Sandy Loam in one pasture but below it in the other two pastures. We believe these variations were due to differences in brush density and herbaceous species composition within pastures.
Average percent correct map estimates of cattle-use was above 80% for all trials except the South Texas Plains 1 ranch (Table 4). This ranch had the least brush cover which made grazing designations from the aerial map more difficult. There was also no ground estimate of cattle-use for this ranch because the 3-step procedure had not been fully developed by the time ground data was collected. In general, cattle-use estimates were improved with ground estimates compared to map estimates (Table 4).

*Use-Criteria Measurements*
*Edwards Plateau Ranch.* On the Edwards Plateau ranch, ground-level data were collected for six areas for which grazing designations had been made. Three of these areas were used by cattle and three areas were not used. Table 5 shows a comparison for grazed versus ungrazed areas for five of the variables measured within these areas.

Brush density scores and percent rock cover were greater for ungrazed than grazed areas. However, only one area had an average brush score of 4 and average rock cover of 29%, which are about the thresholds seen for nonuse by cattle in previous trials.

King Ranch bluestem frequency and number of herbaceous species did not differ between grazed and ungrazed areas. Although average King Ranch bluestem was numerically greater within grazed than ungrazed areas, these differences were not statistically different because of variation within these groups. It is not surprising that King Ranch bluestem frequency could be greater in grazed areas which are accessible and have a history of heavy grazing. Areas with heavy rock cover often contain palatable native grasses that have survived heavy grazing because cattle have avoided these areas.

An access score was also assigned to the six areas where measurements were taken. Access was scored on a scale of 1 (easy) to 5 (extremely difficult). Access scores differed between grazed (0=1) and ungrazed (0=4) areas.

*South Texas Plains Ranches.* On South Texas Plains ranches, herbaceous species frequency and brush density scores were estimated for grazed and ungrazed areas. For these three trials, no dominant grasses emerged as attractants or deterrents to grazed or ungrazed areas. However, average number of herbaceous species was greater in grazed areas for two of these ranches (STX2 and STX3, Figure 1). Kleberg bluestem, a relatively unpalatable introduced grass, dominated both grazed and ungrazed areas on one of these ranches (Figure 2). However, grazed areas had a lower frequency of this grass than ungrazed areas, possibly indicating that cattle avoid this grass when possible.

Brush density scores were greater for ungrazed than grazed areas for all three South Texas Plains ranches (Figure 3). The differences on STX1 were slight, but statistically significant. This difference may indicate that cattle took a path of least resistance. Differences for the other two ranches were more pronounced. In addition, brush density scores for ungrazed areas on these two ranches were 4 or greater, thresholds encountered in earlier trials.

## Implications

On the Edwards Plateau ranch, ranking of ecological sites according to cattle-use was fairly accurate because of the detail available from aerial photos and Ecological Site Descriptions. Rankings on South Texas Plains ranches were not as obvious because cattle-use was affected by brush density and herbaceous species composition which are not available from site descriptions. Use of 3-D views in Arc Map or topographic maps where sites have potential slope may improve map estimates. For example, in a 3-D view of the Edwards Plateau ranch, steep slopes where there was no cattle-use were easily visible on the Steep Rocky site.

Table 1. Ecological sites and their rock and slope characteristics available from Ecological Site Descriptions for an Edwards Plateau Ranch where the 3-step evaluation method was tested.

| Ecological Site | Surface Rock, % | Slope, % |
|---|---|---|
| Deep Redland | 7 | 0-5 |
| Redland | 7 | 0-5 |
| Gravelly Redland | ≤36 | 1-12 |
| Low Stony Hill | ≤50 | 0-15 |
| Steep Rocky | 35-65 | 15-45 (some 20-60) |

Table 2. Edwards Plateau ranch ecological site rankings from map estimates and GPS validation.

| Ecological Site | Map Estimate | GPS Validation |
|---|---|---|
| Deep Redland | 1 | 2 |
| Gravelly Redland | 2 | 1 |
| Redland | 3 | 3 |
| Low Stony Hill | 4 | 4 |
| Steep Rocky | 5 | 5 |

Table 3. Rock and slope characteristics for the South Texas Plains ranches.

| Ecological Site | Surface Rock, % | Slope, % |
|---|---|---|
| Clay loam | 0 | <3 |
| Claypan prairie | 0 | 0 |
| Gray sandy loam | 0 | <2 |
| Lakebed | 0 | <1 |
| Sandy loam | 0 | 0-5 |
| Tight sandy loam | 0 | 0-3 |

Table 4. A comparison of accuracy of cattle-use for map and ground estimates based on GPS validation.

| Region/Trial | Map Estimates, % Correct | Ground Estimates, % Correct |
|---|---|---|
| Edwards Plateau | 80 | 93 |
| South Texas Plains 1 | 67 | - |
| South Texas Plains 2 | 92 | 92 |
| South Texas Plains 3 | 88 | 100 |
| Average | 82 | 95 |

Table 5. Edwards Plateau ranch ground-level measurements.

| Measurement | Grazed | Ungrazed | P-value |
|---|---|---|---|
| Brush density score (0-5) | 1 | 1.7 | 0.0053 |
| Rock cover, % | 5 | 9 | 0.0880 |
| King Ranch bluestem, % | 77 | 44 | 0.3721 |
| Number of herbaceous species | 7 | 5 | 0.7866 |
| Access Score (1-5) | 1 | 4 | 0.0065 |

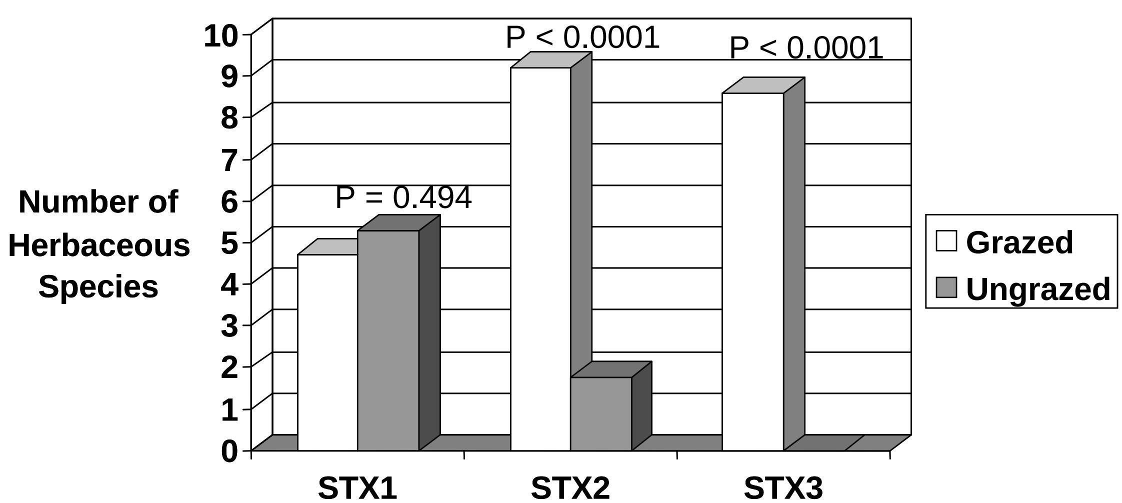


Figure 1. The number of herbaceous species was generally greater along grazed than ungrazed transects for the South Texas locations.

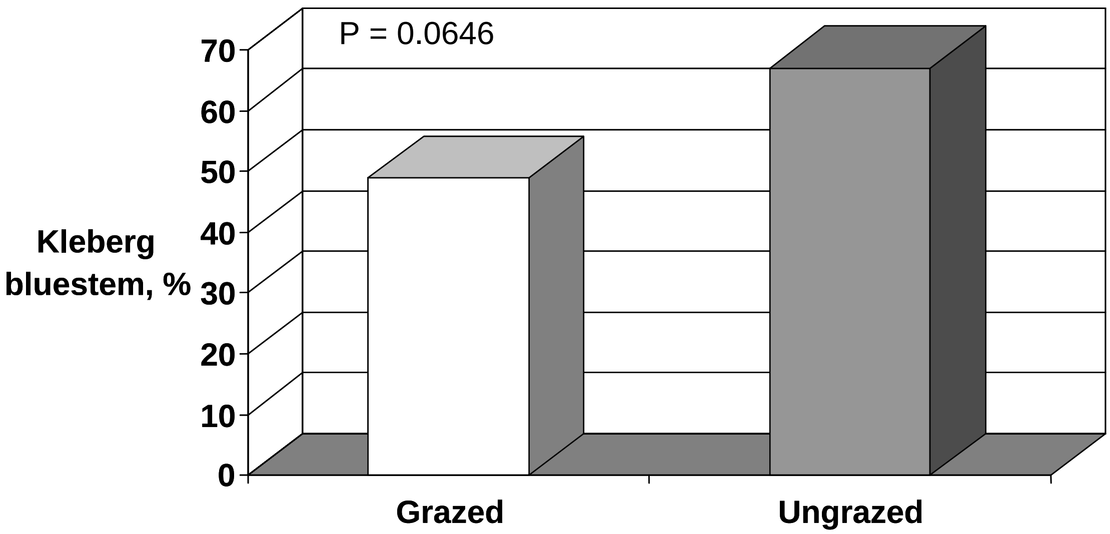


Figure 2. Although there was no difference in number of herbaceous species between grazed and ungrazed transects at the South Texas #1 ranch, ungrazed transects had a higher frequency of Kleberg bluestem, suggesting that cows avoided this grass.

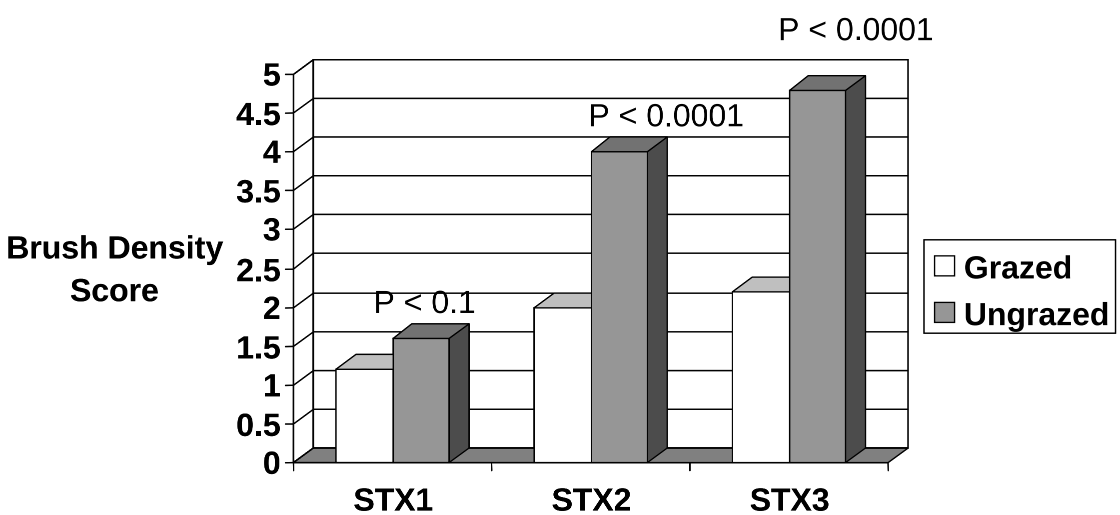


Figure 3. Comparison of brush density scores for the 3 South Texas data collections.

# PERFORMANCE OF STOCKER CATTLE GRAZING TWO SORGHUM-SUDANGRASS HYBRIDS UNDER VARIOUS STOCKING RATES

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## Summary

A three year study was conducted during the summers of 2004, 2005 and 2006 to compare the performance of steers grazing two different varieties of sorghum-sudangrass (SS) hybrids at different stocking rates. A brown midrib (BMR) and photoperiod sensitive (PS) SS hybrid were selected based on differences in nutritional value and yield. Twelve experimental pastures (6 per variety) were planted and grazed by steers (524 ± 45 lbs) for 84 days each summer at stocking rates ranging from 1.30 to 2.76 head/acre. Initial and final cattle weights were used to calculate ADG and gain/acre. A curvilinear model with stocking rate and forage variety best fit the data, accounting for 67 and 59% of the variation in ADG and gain/acre, respectively. At light to moderate stocking rates (< 1.85 head/acre), ADG and gain/acre were higher for the BMR, whereas, the PS maintained weight gain at higher stocking rates. Our results indicate that cattle grazing these forages were capable of gaining 2.4 lb head$^{-1}$ day$^{-1}$ and up to 397 lbs/acre over an 84 day grazing season, but response was dependent on stocking rate.

## Introduction

Summer annual forages are highly productive and permit high stocking rates, making them a practical forage source for stocker cattle operations. Several different types of sorghum-sudangrass (SS) hybrids that possess different agronomic characteristics are commercially available. The two SS types used in this study contained either the brown midrib (BMR) or the photoperiod sensitive (PS) trait. The incorporation of the BMR trait improves digestibility (Porter et al., 1978), whereas the PS trait improves yield potential (Bean et al., 2002). Cattle stocked at conservative rates have produced similar gains/acre on these forages (McCollum et al., 2005), with the BMR through higher average daily gains (ADG) and the PS through a higher carrying capacity. However, it is difficult to extrapolate performance and production per acre at higher stocking rates. Consequently, a three year study was conducted to develop regression equations that better describe the relationship between weight gain and stocking rate for two different types of SS.

## Experimental Procedures

Research was conducted at the Texas A&M University Bush Research Farm, Bushland, Texas during the summers of 2004, 2005, and 2006. A BMR (SS BMR 200) and PS (Megagreen) SS variety were planted on twelve 5.5 acre pastures (6 pastures/variety). Varieties were seeded at a rate of 20 lb/acre on June 1, 2004, May 16, 2005 and May 17, 2006. Prior to planting, pastures were fertilized based on soil tests and furrow irrigated with 3.75 in/acre in 2004 and 5.68 in/acre in 2006. No pre-irrigation was applied in 2005 due to adequate soil moisture. No irrigation water was applied after planting. Mean precipitation during the study period is presented in Table 1.

Forage samples were taken at the initiation of the study to characterize forage availability and nutritive value. Forage was clipped at ground level from twelve stratified locations across each pasture. Clipped forage was dried at 55°C for 7 days and weighed to determine dry matter. Forage samples from each pasture were composited, and a sub-sample was sent to the Dairy One Laboratory (Ithaca, NY) for crude protein (CP) and in vitro true digestibility (IVTD) analysis.

The grazing season was set at 84 days each year. Each pasture was assigned a different stocking rate which provided a continuum of data points that were used to develop linear relationships between stocking rate and cattle performance. Stocking rates ranged from 1.30 to 2.76 head/acre. Previous research indicated that the PS hybrid could maintain a higher carrying capacity compared to the BMR hybrid; consequently, higher stocking rates were assigned to the PS hybrid. Grazing was initiated on July 19, 2004, July 12, 2005, and July 11, 2006 when forage had reached a minimum of 24 inches in height. Steers had access to water and free-choice mineral supplement during the grazing season.

Preconditioned crossbred steer calves (n = 132, 132, and 134 for 2004, 2005, and 2006, respectively) were implanted in 2004 and 2006. The 2005 steers did not receive an implant. Individual steer weights were used to allocate calves into treatment groups of similar mean weight (556 ± 11 lb in 2004; 462 ± 8 lb in 2005; 553 ± 8 lb in 2006). Individual steer weights were obtained at the initiation and termination of the grazing trial. Individual steer weights were adjusted with a three-percent pencil shrink for use in weight change calculations.

Initial forage characteristics were analyzed using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC) with pasture as the experimental unit and forage type as a treatment. Prior to grazing, all pastures had been treated similarly; consequently, an analysis of variance was used to distinguish differences in availability and quality of forage due to variety. Weight response to stocking rate was analyzed using linear regression analysis (SAS Inst. Inc., Cary, NC) with pasture as the experimental unit. Dependent variables were weight gain/head (ADG) and gain/acre. Independent variables were forage variety and stocking rate. Average daily gain was calculated based on individual steer weight change over the 84 day grazing season. Gain/acre was calculated as the product of ADG and the number of steers per acre.

## Results and Discussion

*Growing season climate*

Although little precipitation fell in May 2004, the soil moisture provided by pre-plant irrigation and the above average rainfall in June allowed for an excellent stand to be established prior to grazing (Table 1). Rainfall during the winter of 2004 and spring of 2005 maintained adequate soil moisture and prevented the need for irrigation prior to planting in 2005. Droughty conditions during the fall of 2005 through the late spring of 2006 resulted in a less favorable production environment early in the grazing season for 2006.

*Forage characteristics*

The BMR variety tended to have a higher forage availability at the start of grazing compared to the PS variety ($P \leq 0.10$; Table 2). Based on visual observations since 2002, when PS varieties first started being used in grazing trials at Bushland, the PS variety appears to grow at a slower rate early in the season when compared to other types although initial forage availability was not different (McCuistion et al., 2005).

At the time grazing commenced, both forages were highly digestible due to their immature stage of production. The BMR variety was more digestible than the PS variety ($P < 0.01$). Because BMR varieties contain less lignin, they are generally more digestible than those varieties that do not contain this trait. The higher availability of forage combined with a more digestible plant allowed the BMR to have more available digestible DM (IVTD, lbs/ac) than the PS at the onset of grazing ($P < 0.07$). Initial CP levels were 19.6 and 22.3% for the BMR and PS forage, respectively. The PS had a significantly higher amount of CP compared to the BMR ($P \leq 0.01$). The difference possibly reflects a dilution effect. The BMR had accumulated a greater amount of biomass compared to the PS. The similar amounts of available CP (lb/ac) would support this proposal ($P = 0.57$).

*Cattle Performance*

After 84 days of grazing, stocking rate and forage variety explained 67% of the variation in ADG. The BMR variety had a maximum ADG of 2.41 lb at 1.84 head/acre. At stocking rates exceeding 1.85 head/acre, ADG on the BMR forage declined. The lowest ADG observed was 1.41 lb at the highest stocking rate of 2.38 head/acre. Gain on the PS variety was less sensitive to stocking rate than observed with the BMR (Figure 1). As stocking rate increased, ADG declined less severely on the PS relative to the BMR. The maximum observed ADG was 2.12 lb for the PS variety at 2.01 head/acre. Based on the regression models, at a stocking rate of 1.80 head/acre, estimated ADG was 2.20 lb for BMR and 1.91 lb for PS and at a stocking rate of 2.40 head/acre, ADG was 1.55 lb for the BMR and 1.64 lb for the PS.

The relationship between total gain/acre and stocking rate was curvilinear (Figure 2), with the model containing stocking rate and variety explaining 59% of the variation in gain. The observed weight gain of 397 lb/acre was achieved at 2.15 head/acre on the BMR. The maximum observed gain/acre for the PS was reached at 2.35 head/acre at 375 total lb of gain. Based on the model to predict gain/acre, the highest estimated gain/acre was 366 lb at 2.05 head/acre for the BMR and 326 lb at 2.30 head/acre for the PS. Gain/acre on the BMR reached a maximum at lighter stocking rates than the PS and declined more severely as stocking rate increased.

McCartor and Rouquette (1977) found that stocking rate affected both ADG and gain/acre of calves grazing pearl millet. Average daily gain increased as stocking rate decreased from 4.60 to 1.51 head/acre. A maximum ADG of 2.23 lb/day was observed at the lowest stocking rate of 1.51 head/acre over a 56 day grazing period. Increasing stocking rate above that point reduced ADG. At higher stocking rates, the quantity and quality of available forage was reduced. Both ADG and forage digestibility declined as the grazing season progressed (McCartor and Rouquette, 1977). When forage availability was not limited, as seen with lower stocking rates, the nutritional value of the forage was the driving force behind ADG. This suggests that the BMR forage was of higher quality than the PS as indicated by higher ADG in our study.

In a two-year grazing study conducted by Banta (2002), average gains of 2.94 lb/day and 337 lb/acre could be achieved when grazing a BMR SS hybrid at stocking rates of 2.69 and 2.04 head/acre for 41 and 58 days, respectively. In a two-year study that grazed SS hybrids for 86 days, cattle gained 2.70 and 2.12 lb/acre for the BMR and PS varieties, respectively (McCuistion et al., 2005). The BMR variety was grazed with 1.65 head/acre and produced gains of 385 lb/acre. The PS variety was stocked heavier (1.94 head/acre) because of additional forage availability and subsequently, produced gains of 356 lb/acre. At these stocking rates, gains/acre would fall into the data range reported for the current study.

Because this study was conducted over multiple years, additional variation due to environmental conditions, plant factors, and sets of cattle can be observed. In Figure 1 and 2, at lighter stocking rates, data points are more closely fit to the estimated regression line; however, as stocking rate increases, data points are more scattered, suggesting that the predictability of animal performance is less reliable at heavier stocking rates. A lighter stocking rate may not maximize ADG or gain/acre, but the predictability of gain will be more consistent from year to year than stocking at heavier rates. Likewise, the type of forage can also be used to mitigate risk. Although the BMR variety produced more weight gain than the PS at lighter stocking rates, the PS variety can maintain ADG and gain/acre at higher stocking rates than the BMR.

The curvilinear nature of the ADG and gain/ha response to stocking rate is more practical than a linear response surface and can be used to generate an optimum stocking rate based on desired goals of ADG or gain/acre. Plant quantity and quality are not uniformly distributed in the pasture or consumed similarly by cattle. Reduced forage availability exacerbated by high stocking rates forces cattle to be less selective and consume a lower quality diet as the grazing season progresses. Also, energy expenditure would possibly change as stocking rate increased. Additional time spent foraging would use energy that could otherwise go into weight gain production. The lower digestibility of available forage combined with reduced CP content (data not presented) suggest that cattle consuming forage at the end of the growing season may have growth limited as a result of protein and/or energy deficiency. Ultimately, a continued increase in stocking rate above a critical stocking rate point will result in an accelerated decline in cattle performance (Riewe, 1961; Conrad et al., 1981); however, a supplementation program that provides an additional source of protein and/or energy could be used late in the grazing season to alleviate nutrient restriction.

## Implications

The regression models developed from this three-year study using two different SS hybrids allow for an optimum stocking rate to be determined at which point the cattle producer/manager can achieve their desired objectives for ADG or gain/acre and economic returns. Although stocking rate and variety explain much of the variation in cattle weight change, additional factors, such as precipitation, impact forage production and ultimately cattle weight gain. Decisions concerning stocking rate and forage variety made early in the grazing season can be used to mitigate risk associated with stocker cattle production and profitability over time.

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Table 1. Precipitation amounts recorded during 2004, 2005, and 2006 at Bushland, Texas

| | 2004 | 2005 | 2006 |
|---|---|---|---|
| | Precipitation, inches | | |
| January | 0.51 | 1.97 | 0.09 |
| February | 0.63 | 0.63 | 0.02 |
| March | 1.77 | 1.18 | 0.88 |
| April | 2.56 | 1.06 | 0.24 |
| May | 0.28 | 1.61 | 0.70 |
| June | 4.13 | 3.11 | 1.17 |
| July | 1.61 | 1.18 | 2.45 |
| August | 2.32 | 3.19 | 3.89 |
| September | 3.74 | 0.12 | 1.26 |
| October | 1.65 | 0.67 | 1.72 |
| November | 3.54 | 0.35 | 0.00 |
| December | 0.47 | 0.04 | 1.53 |

Table 2. Forage characteristics prior to the initiation of grazing for each grazing season (2004, 2005 and 2006) and all three years combined

| Forage characteristic | BMR[a] | PS | SEM | P-value |
|---|---|---|---|---|
| 2004 | | | | |
| Available forage, lb/ac | 2760 | 2452 | 102 | 0.059 |
| IVTD, %DM | 88.0 | 85.3 | 0.39 | < 0.001 |
| CP, %DM | 19.9 | 22.0 | 0.59 | 0.029 |
| 2005 | | | | |
| Available forage, lb/ac | 2071 | 1833 | 95 | 0.106 |
| IVTD, %DM | 86.5 | 85.0 | 0.65 | 0.135 |
| CP, %DM | 17.2 | 19.5 | 0.49 | 0.008 |
| 2006 | | | | |
| Available forage, lb/ac | 1428 | 991 | 100 | 0.012 |
| IVTD, %DM | 87.0 | 85.8 | 0.38 | 0.057 |
| CP, %DM | 21.9 | 25.3 | 0.50 | < 0.001 |
| Combined | | | | |
| Available forage, lb/ac | 2022 | 1702 | 132 | 0.097 |
| IVTD, %DM | 87.2 | 85.4 | 0.29 | < 0.001 |
| Available IVTD, lb/ac | 1765 | 1452 | 116 | 0.065 |
| CP, %DM | 19.6 | 22.3 | 0.60 | 0.004 |
| Available CP, lb/ac | 392 | 370 | 26.8 | 0.566 |

[a]BMR = Brown midrib forage. PS = Photoperiod sensitive forage. SEM = Standard error mean; n = 6 for single years, n = 18 for combined years.

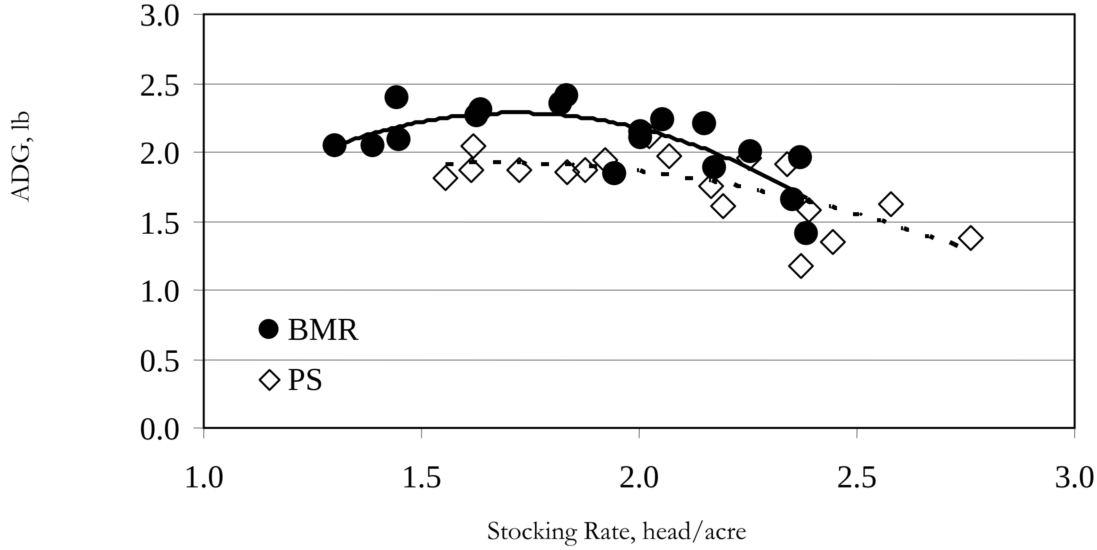


Figure 1. Average daily gain (ADG) as affected by stocking rate and variety for the entire 84 day grazing season. BMR = brown midrib forage; PS = photoperiod sensitive forage. The model generated the following regression equations that can be used to predict ADG: BMR ($y = -1.9 + 4.8x – 1.4x^2$); PS ($y = 0.4 + 1.8x – 0.6x^2$).

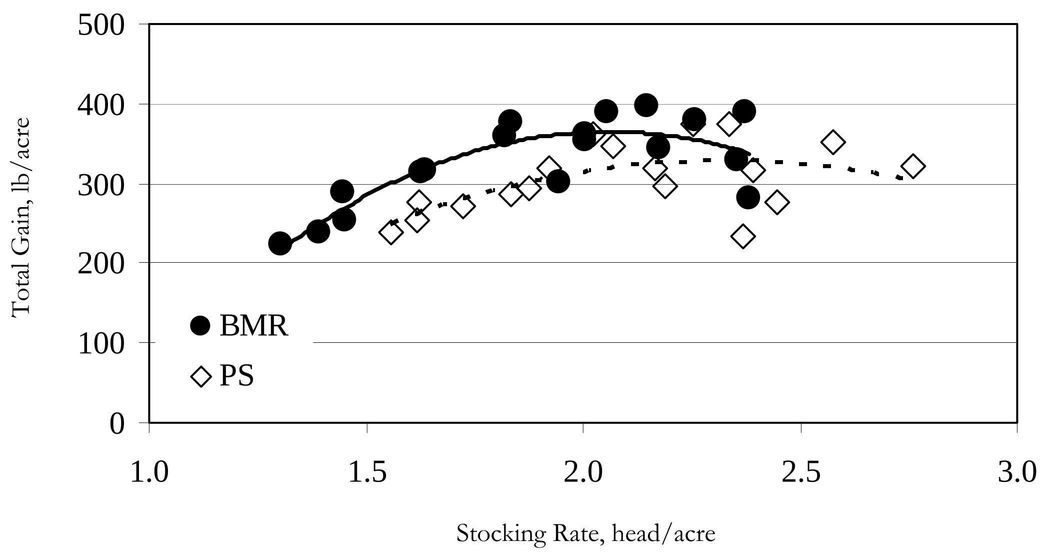


Figure 2. Total gain/acre as affected by stocking rate and variety for the entire 84 day grazing season. BMR = brown midrib forage; PS = photoperiod sensitive forage. The model generated the following regression equations that can be used to predict weight gain/acre: BMR ($y = -727 + 1060x – 257x^2$); PS ($y = -390 + 617x – 133x^2$).

# ECONOMIC PERSPECTIVE OF STOCKING RATES AND SUPPLEMENTATION FOR STOCKER STEERS AND HEIFERS GRAZING RYE AND RYEGRASS PASTURES

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## Summary

Stocker steer and heifer performance on rye and ryegrass pastures stocked at three rates of 1.5, 2.1 and 3.0 hd/ac and receiving a corn-based daily supplement of 0, 0.4%, and 0.8% BW provided the database for economic assessments. Increasing fertilizer nitrogen costs from $340/ton ($0.50/lb N) to $476/ton ($0.70/lb N) showed only a gradual decline in returns per acre. Increasing supplement costs from $125/ton to $400/ton had a more dramatic impact on return/ac. The supplement cost effects were more profound at high stocking rates and at the 0.8% BW level. These assumptions include efficiencies of supplement:extra gain; however, numerous commercially-available supplements are less efficient than the corn-based ration used in our experiment. As overall value of cattle declined from more than $1.15/lb to $0.85/lb, the opportunities for positive returns declined on most all stocking rate x supplement scenarios. The magnitude of negative margin had the most effect on positive returns/ac; thus purchase-sale price structures usually require more management attention compared to rising commodity prices.

## Introduction

With a majority of the cattle industry having fall-weaned calves, the use of cool-season annual pastures such as rye, wheat, oats, and/or ryegrass has long been a method of choice for backgrounding-developing cattle for the feedlot. Winter pasture costs have increased dramatically in direct proportion to energy-related costs associated with fuel, fertilizer, and feed grains. Depending upon fertilizer input, costs of small grain-ryegrass pastures planted on low to moderate-fertile soils of East Texas, may range from $100 to more than $225/ac. With moderate to high-priced cattle and low to moderate feed costs, use of supplementation to intentionally substitute for high-value forage offers management options to increase stocking rates and gain per acre. The objectives of this economic evaluation were to assess costs and returns per animal and per acre from rye and ryegrass pastures stocked at three rates with steers and heifers that received three levels of a corn-based supplement. Budgeting objectives were to assess the impact of increasing costs of fertilizer and supplement as well as changes in value of cattle and purchase-sell margins.

## Experimental Procedures

Performance of steers and heifers on 'Maton' rye (Secale cereale L) and 'TAM-90' annual ryegrass (<u>Lolium multiflorum</u> L) stocked at three rates (1.5, 2.1 and 3.0 hd/ac) and receiving three daily corn-based supplements containing Rumensin (0, 0.4% and 0.8% BW) was quantified at the Texas A&M University Agricultural Research and Extension Center at Overton (Rouquette et al., 2007). An array of economic budget scenarios were prepared, to evaluate potential profit-loss statements using variable input costs for fertilizer, supplements, and purchase-sell prices and margins. Some of the animal input costs included supplement, hay that was offered during initial grazing period, 8-way vaccine, implant (Revelor-G), vaccine for VAC-45 program, two separate injectable dewormer applications, salt and minerals, and interest cost at 10%. Some of the pasture input costs included 'Maton' rye seed at 100 lbs/ac, 'TAM-90' annual ryegrass seed at 25 lbs/ac, ammonium nitrate fertilizer (34-0-0) split applied for a total of 450 lbs/ac (153 lbs N/ac), 21-8-17 fertilizer at 250 lbs/ac, and interest at 10%. Purchase price of approximate 575-lb steers and heifers was set initially at $1.26/lb for steers and $1.15/lb for heifers. Some variations in both purchase price and margin were used to illustrate both positive and negative returns.

Selected budget scenarios based on purchase price were prepared with all items fixed in price except for fertilizer or for supplement. These two input items are uniquely associated with energy costs, and they also present the most questioned pre-grazing management options. Purchase-sale negative margins traditional with the stocker industry were used to project returns (Table 1). In addition, zero margins were explored in the case of substantially reduced purchase prices of cattle. Gross revenues and gross operating expenses allowed for estimates of net returns per head and per acre, as well as value of gain, costs, and returns per pound of gain.

## Results and Discussion

Based on costs of ammonium nitrate at $340/ton ($0.50/lb N), 21-8-17 at $380/ton, supplement at $125/ton ($0.625/lb), and hay at $80/ton, cost-returns were estimated using purchase price of $1.26/lb for steers and $1.15 for heifers. The sale prices were weight and calf sex dependent, and are shown in Table 1 as Sale Price I.

A base-line budget summary of animal performance, costs, and returns from stockers grazing rye-ryegrass pastures at three stocking rates and three levels of supplement is presented in Table 2. Costs per head included purchase price and all animal input costs. Costs per acre included cost per head x stocking rate, and all pasture input costs. For cool-season, annual grass pastures grown on relatively low fertile soils in East Texas, seasonal fertilizer nitrogen requirements may be 200 lbs/ac N, or nearly 600 lbs/ac of 34-0-0 or equivalent. Thus, pasture input costs, exclusive of animal costs, may vary from $150 to more than $225/ac depending upon fertilizer rate, ratio, and costs. Returns ranged from a loss of $80/ac when stocked at 3.0 hd/ac and non-supplementation to a positive $215/ac from pastures stocked at 2.2 hd/ac and cattle receiving 0.8% BW supplement. Thus, using these budget assumptions, the 0.8% BW supplement level that acted as a substitution for forage returned the most per acre. Responsible for those returns was the relatively low cost of supplement, moderate to high priced cattle, and ADG of more than 3 lbs/da. The cost per pound of gain from high stocked (3 hd/ac) pastures, non-supplemented cattle at $0.69/lb gain was nearly twice that of pastures stocked at 1.5 hd/ac. A comparison among stocking rates x supplementation showed the differential returns per acre for all treatments (Table 3). In this comparison, the influence of increasing stocking rate from 1.5 hd/ac to 3.0 hd/ac without supplementation resulted in a $215/ac reduction in returns per acre. In contrast, an additional $294/ac return was possible by reducing the stocking rate from 3.0 to 2.2 hd/ac and daily supplementing with 0.8% BW of corn ration.

Cool-season annual forages often contain excess nutritive value parameters for young, growing stocker cattle requirements; thus, these rye-ryegrass, wheat, and/or oats pastures have long-been used for backgrounding and developing cattle prior to feedlot residence. Management decisions pertaining to fertilizers and supplements have been re-assessed due to increasing energy costs. From 2003 to 2007, price of N fertilizer more than doubled from about $0.25/lb N to $0.50/lb N or more. Table 4 shows ranges in costs for both 34-0-0 and corn. In an effort to portray the effect of increasing nitrogen costs on returns per acre from these treatments, N costs were varied from $340/ton ($0.50/lb N) to $476/ton ($0.70/lb N) with all other costs fixed. The assumptions used showed that all stocking rate x supplement levels had decreasing, but positive returns/ac with increasing N cost except at the high stocked (3 hd/ac), non-supplemented treatment (Table 5). Thus, with these levels of animal performance, increasing costs of N was not destructive to management. Utilization of forage is a major factor that influences returns with increasing N costs. With supplement cost held constant at $125/ton ($0.625/lb), maximum return/ac was projected for the medium-stocking rate plus 0.8% BW daily supplementation.

With ammonium nitrate cost fixed at $340/ton and varying supplement costs from $125/ton to $400/ton, the projected return/ac showed several stocking rate x supplementation scenarios with negative returns/ac (Table 6). Assuming the same conversion of supplement:extra gain achieved in this experiment, it was interesting to note that all returns/ac were positive with 0.4% BW supplementation when using either low (1.5) or medium (2.1) stocking rates. Use of 0.8% BW supplementation did not yield positive returns/ac at any stocking rate with supplement costs of $400/ton. These two scenarios of variable N costs (Table 5) and variable supplement costs (Table 6) would reveal more negative returns/ac if both commodities were increasing concurrently.

The impact of increasing input costs is magnified with associated declining value of cattle. Using negative margin scenarios incorporated in the previous budgets, and reducing value of cattle to either $.90 and $.95 or $0.80 and $0.85, respectively, for heifers and steers, there were only four profitable scenarios with initial $.90 and $.95 cattle and no positive return scenarios with $.80 and $.85 cattle (Table 7). It is therefore prudent to remember that profitable stocking rate x supplementation strategies become more difficult and often impossible with declining cattle prices. As successful, and some opportunistic, managers know, the degree and extent of negative margin between purchase price and sale price is usually the most important factor contributing to profit or loss in a cattle venture. For example, regardless of value of cattle at time of purchase, with a zero margin (sale price/lb = purchase price/lb), all stocking rate x supplementation strategies yielded substantial, profitable returns/acre (Table 7).

Budget projections should be considered as a guideline due to variations in climatic conditions, forage growth rate, animal performance, and marketing uncertainties. As a base-line budget projection for short-term future considerations, prices for fertilizer ammonium nitrate at $374/ton ($0.55/lb N), $200/ton supplement, initial purchase prices of $1.10/lb for heifers and $1.15/lb for steers, and negative margins presented in Table 1 (Sale Price II), budget summaries and returns/hd and per acre are shown in Table 8. Returns per acre were optimized at low (1.5 hd/ac) and medium (2.1 hd/ac) stocking rates under both supplemented and non-supplementation levels. The high stocking rate of 3 hd/ac was not a profitable venture for the pasture phase using these budget assumptions. The differential returns/ac further illustrated these stocking rate x supplementation comparisons (Table 9). High stocking rates in which there is a lack of forage available for *ad libitum* consumption creates reduced ADG potential, which affects profitable returns. These reduced gains and potential economic losses on pasture may mandate that stocker operators maintain ownership of cattle through the feedlot phase.

## Implications

Baseline comparative data provide the structure for forage-animal management decisions and budget projections of cost-returns. The animal and pasture performance data of this grazing experiment, the input costs, and purchase-sell prices suggested that neither increasing fertilizer prices or supplement prices would be financially-devastating under moderate stocking rates. Reduced fertilizer applications are common and expected management reactions to increasing costs. However, management concerns should be directed equally toward forage utilization by using an appropriate stocking rate. Price of supplement has similar effects on management decisions as that of fertilizer costs. However, supplements are not all created equal with respect to enhanced animal performance pertaining to efficient supplement:extra gain ratios. One of the most profound impacts on extent of profit or loss is directly related to the magnitude of purchase-sell margin. Some of the budget scenarios presented confirm the philosophy that making money in the stocker business is heavily dependent on the art, skill, and good fortune of buying and selling cattle.

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Table 1. Purchase and sale price assumptions based on final weight and sex of calf from stocking rate (SR) and supplementation (SUP) experimentation

| Treatments SR | SUP | Final Steer Weight (lbs) | Sale[1] Price I ($/lb) | Sale[2] Price II ($/lb) | Sale[3] Price III ($/lb) | Sale[3] Price IV ($/lb) | Sale[4] Price V ($/lb) |
|---|---|---|---|---|---|---|---|
| 3.0 | 0 | 755 | 1.06 | 1.05 | .85 | .95 | .85 |
| 3.1 | 0.4 | 904 | .99 | 0.95 | .75 | .95 | .85 |
| 2.1 | 0 | 914 | .99 | 0.95 | .75 | .95 | .85 |
| 3.0 | 0.8 | 945 | .99 | 0.95 | .75 | .95 | .85 |
| 1.5 | 0.4 | 1018 | .95 | 0.93 | .73 | .95 | .85 |
| 1.5 | 0 | 1046 | .95 | 0.93 | .73 | .95 | .85 |
| 2.1 | 0.4 | 1051 | .95 | 0.93 | .73 | .95 | .85 |
| 2.2 | 0.8 | 1103 | .95 | 0.93 | .73 | .95 | .85 |
| 1.5 | 0.8 | 1119 | .95 | 0.93 | .73 | .95 | .85 |
| **Treatments SR** | **SUP** | **Final Heifer Weight (lbs)** | **Sale[1] Price I ($/lb)** | **Sale[2] Price II ($/lb)** | **Sale[3] Price III ($/lb)** | **Sale[3] Price IV ($/lb)** | **Sale[4] Price V ($/lb)** |
| 3.0 | 0 | 726 | 1.05 | 1.00 | .80 | .90 | .80 |
| 3.0 | 0.8 | 836 | .99 | .94 | .74 | .90 | .80 |
| 3.1 | 0.4 | 845 | .99 | .94 | .74 | .90 | .80 |
| 2.1 | 0 | 871 | .96 | .91 | .71 | .90 | .80 |
| 1.5 | 0 | 937 | .93 | .88 | .68 | .90 | .80 |
| 2.1 | 0.4 | 961 | .93 | .88 | .68 | .90 | .80 |
| 2.2 | 0.8 | 981 | .93 | .88 | .68 | .90 | .80 |
| 1.5 | 0.8 | 1008 | .93 | .88 | .68 | .90 | .80 |
| 1.5 | 0.4 | 1039 | .93 | .88 | .68 | .90 | .80 |

[1]Purchase price of steers = $1.26 and heifers = $1.15/lb.
[2]Purchase price of steers = $1.15 and heifers = $1.10/lb.
[3]Purchase price of steers = $.95 and heifers = $.90/lb.
[4]Purchase price of steers = $.85 and heifers = $.80/lb.

Table 2. Budget summaries of performance, costs, and returns from steers and heifers grazing rye-ryegrass at three stocking rates (SR) and three levels of supplemental corn ration (SUP)

| SR (hd/ac) | 1.5 | 2.1 | 3.0 | 1.5 | 2.1 | 3.1 | 1.5 | 2.2 | 3.0 |
|---|---|---|---|---|---|---|---|---|---|
| SUP (% BW) | 0 | 0 | 0 | 0.4 | 0.4 | 0.4 | 0.8 | 0.8 | 0.8 |
| Item | | | | | | | | | |
| Days on Pasture | 148.00 | 148.00 | 148.00 | 148.00 | 148.00 | 148.00 | 148.00 | 148.00 | 148.00 |
| Avg. Initial Wt (lbs) | 577.00 | 565.00 | 574.00 | 566.00 | 587.00 | 589.00 | 584.00 | 582.00 | 579.00 |
| Avg. Daily SUP (lbs/hd) | 0.00 | 0.00 | 0.00 | 2.82 | 2.80 | 2.70 | 5.90 | 5.94 | 5.40 |
| Avg. Daily Gain (lb/da) | 2.80 | 2.21 | 1.12 | 3.13 | 2.85 | 1.93 | 3.24 | 3.11 | 2.10 |
| Revenue / Head ($)[1] | 934.00 | 874.00 | 781.00 | 967.00 | 946.00 | 866.00 | 1,004.00 | 980.00 | 879.00 |
| Revenue / Acre ($) | 1,401.00 | 1,834.00 | 2,389.00 | 1,450.00 | 1,987.00 | 2,685.00 | 1,507.00 | 2,156.00 | 2,636.00 |
| Value of Gain ($/lb) | 0.57 | 0.58 | 0.53 | 0.61 | 0.57 | 0.55 | 0.61 | 0.60 | 0.59 |
| Cost / Head ($)[2,3,4] | 844.00 | 814.00 | 807.00 | 857.00 | 857.00 | 848.00 | 914.00 | 882.00 | 857.00 |
| Cost / Acre ($)[5] | 1,266.00 | 1,710.00 | 2,468.00 | 1,286.00 | 1,799.00 | 2,630.00 | 1,372.00 | 1,941.00 | 2,571.00 |
| Cost / lb gain ($/lb) | 0.36 | 0.40 | 0.69 | 0.38 | 0.36 | 0.48 | 0.43 | 0.39 | 0.52 |
| Return / Head ($) | 90.00 | 59.00 | -26.00 | 110.00 | 89.00 | 18.00 | 90.00 | 98.00 | 22.00 |
| Return / Acre ($) | 135.00 | 124.00 | -80.00 | 164.00 | 187.00 | 55.00 | 135.00 | 215.00 | 65.00 |
| Breakeven Wt (lb/hd) | 896.00 | 834.00 | 765.00 | 911.00 | 911.00 | 856.00 | 972.00 | 938.00 | 865.00 |
| Breakeven Price ($/lb) | 0.85 | 0.91 | 1.09 | 0.83 | 0.85 | 0.97 | 0.86 | 0.85 | 0.97 |
| Return / lb Gain ($) | 0.22 | 0.18 | -0.16 | 0.24 | 0.21 | 0.06 | 0.19 | 0.21 | 0.07 |

[1]Sales price varied according to weight and sex of calf (Table 1, Sale Price I).
[2]Supplement cost used was $125/ton ($0.625/lb).
[3]Hay was priced at $80/ton.
[4]Purchase price used for 575 lb calves was $1.26/lb for steers and $1.15/lb for heifers.
[5]Fertilizer prices used were: Ammonium nitrate, 34-0-0, at $340/ton ($0.50/lb N), and 21-8-17 at $380/ton.

Table 3. Differential returns per acre among stocking rate (SR) x supplement treatments (SUP)[3]

| SR | SUP | 0-1.5 | 0-2.1 | 0-3.0 | .4-1.5 | .4-2.1 | .4-3.1 | .8-1.5 | .8-2.2 | .8-3.0 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ---$/Ac--- | | | | | | | | |
| 1.5 | 0 | 0 | | | | | | | | |
| 2.1 | 0 | - 111 | 0.00 | | | | | | | |
| 3.0 | 0 | -215 | -204 | 0.00 | | | | | | |
| 1.5 | 0.4 | 30 | 41 | 245 | 0.00 | | | | | |
| 2.1 | 0.4 | 53 | 63 | 267 | 23 | 0.00 | | | | |
| 3.1 | 0.4 | -79 | -69 | 135 | -109 | -132 | 0.00 | | | |
| 1.5 | 0.8 | 0 | 11 | 215 | -30 | -52 | 80 | 0.00 | | |
| 2.2 | 0.8 | 80 | 91 | 2942 | 50 | 27 | 159 | 80 | 0.00 | |
| 3.0 | 0.8 | -70 | -59 | 145 | -100 | -122 | 10 | -70 | -150 | 0.00 |

[1]If 0-2.1 is compared with 0-1.5; $11/ac was lost due to increasing stocking rate from 1.5 to 2.1 hd/ac.
[2]An additional $294/ac was obtained by decreasing stocking rate from 3.0 to 2.2 hd/ac, and supplementing with .8% BW.
[3]Return/ac are summarized from Table 2, and uses same input cost assumptions.

Table 4. Commodity prices for ammonium nitrate and corn

| Ammonium Nitrate (34-0-0) | | | Corn | | |
|---|---|---|---|---|---|
| Price/ton ($) | Price/lb ($) | Price/lb N ($) | Price/ton ($) | Price/lb ($) | Price/bu[1] ($) |
| 272 | .136 | .40 | 100 | .05 | 2.80 |
| 306 | .153 | .45 | 120 | .06 | 3.36 |
| 340 | .170 | .50 | 140 | .07 | 3.92 |
| 374 | .187 | .55 | 160 | .08 | 4.48 |
| 408 | .204 | .60 | 180 | .09 | 5.04 |
| 442 | .221 | .65 | 200 | .10 | 5.60 |
| 476 | .238 | .70 | 240 | .12 | 6.72 |

[1]Bushel of corn weight = 56 lbs.

Table 5. Projected returns per acre for three stocking rates and three levels of supplementation with variable fertilizer nitrogen (N) costs

| Ammonium Nitrate Costs[1] | | Variable Fertilizer Nitrogen Costs | | | | |
|---|---|---|---|---|---|---|
| Cost/ton ($/T) | | 340 | 374 | 408 | 442 | 476 |
| Cost/lb N ($/lb) | | .50 | .55 | .60 | .65 | .70 |
| SR[2] | SUP[3] | Returns[4] /ac ($/ac) | | | | |
| 1.5 | 0 | 135 | 128 | 121 | 114 | 107 |
| 2.1 | 0 | 124 | 117 | 110 | 103 | 96 |
| 3.0 | 0 | -84 | -91 | -98 | -105 | -112 |
| 1.5 | .4 | 164 | 158 | 151 | 144 | 137 |
| 2.1 | .4 | 187 | 181 | 174 | 167 | 160 |
| 3.1 | .4 | 55 | 48 | 41 | 34 | 27 |
| 1.5 | .8 | 135 | 128 | 121 | 114 | 107 |
| 2.2 | .8 | 215 | 209 | 202 | 194 | 187 |
| 3.0 | .8 | 65 | 58 | 51 | 44 | 37 |

[1]Ammonium nitrate (34-0-0) cost/ton and cost/lb Nitrogen.
[2]Initial stocking rates based on 550 lb calf = 1 hd.
[3]Supplementation rates of 0, .4% BW, and .8% BW/hd/da.
[4]Returns per acre assuming purchase price of $1.15/lb for heifers and $1.26 for steers with sales prices based on sex and weight of calf (Refer to Table 1; Sales Price I).

Table 6. Projected returns per acre for three stocking rates and three levels of supplementation with variable supplement costs

| Supplement | | Variable Supplement[1] Costs | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Cost/ton ($/T) | | 125 | 150 | 180 | 210 | 240 | 300 | 400 |
| Cost/lb ($/lb) | | .0625 | .075 | .090 | 105 | .120 | .15 | .20 |
| SR[2] | SUP[3] | Returns /ac ($/ac)[4] | | | | | | |
| 1.5 | 0 | 135 | 135 | 135 | 135 | 135 | 135 | 135 |
| 2.1 | 0 | 124 | 124 | 124 | 124 | 124 | 124 | 124 |
| 3.0 | 0 | -84 | -84 | -84 | -84 | -84 | -84 | -84 |
| 1.5 | .4 | 164 | 157 | 147 | 137 | 128 | 108 | 76 |
| 2.1 | .4 | 187 | 177 | 163 | 150 | 136 | 109 | 64 |
| 3.1 | .4 | 55 | 39 | 20 | 1 | -19 | -57 | -122 |
| 1.5 | .8 | 135 | 118 | 98 | 77 | 57 | 16 | -52 |
| 2.2 | .8 | 215 | 190 | 160 | 130 | 100 | 39 | -61 |
| 3.0 | .8 | 65 | 34 | -4 | -41 | -78 | -153 | -278 |

[1]Supplement costs per ton and per pound.
[2]Initial stocking rates based on 550 lb calf = 1 hd.
[3]Supplementation rates of 0, 0.4% BW, and 0.8% BW/hd/da.
[4]Returns per acre assuming purchase prices of $1.15/lb for heifers and $1.26 for steers with sales prices based on sex and weight of calf (Refer to Table 1; Sales Price I).

Table 7. Purchase prices with negative and zero margin sale prices for stocking rate (SR) x supplementation (SUP)

| | | Purchase at $0.90 and $0.95 | | Purchase at $0.80 and $0.85 | |
|---|---|---|---|---|---|
| SR | SUP | Negative[1] Margin Sales | Zero[2] Margin Sales | Negative[3] Margin Sales | Zero[4] Margin Sales |
| | | Returns/ac ($/ac)[5] | | | |
| 1.5 | 0 | 51 | 376 | -8 | 317 |
| 2.1 | 0 | 24 | 390 | -40 | 326 |
| 3.0 | 0 | -76 | 152 | -119 | 108 |
| 1.5 | .4 | 39 | 378 | -27 | 312 |
| 2.1 | .4 | 28 | 493 | -55 | 409 |
| 3.1 | .4 | -113 | 377 | -194 | 295 |
| 1.5 | .8 | -19 | 333 | -88 | 264 |
| 2.2 | .8 | -11 | 493 | -107 | 397 |
| 3.0 | .8 | -166 | 313 | -251 | 227 |

[1]Purchase price = .90 for heifers; .95 for steers, sale price = .68 to .75 based on weight and sex.
[2]Purchase price = .90 heifers; .95 steers, sale price = .90 to .95 (0 margin).
[3]Purchase price = .80 heifers; .85 steers, sale price = .58 to .65 based on weight and sex.
[4]Purchase price = .80 heifers; .85 steers, sale price = .80 to .85 (0 margin).
[5]N price @ $374/ton, ($.55/lb N) and supplementation = $200/ton ($0.10/lb).

Table 8. Budget summaries of performance, costs, and returns based on $374/ton ammonium nitrate, $200/ton corn and purchase price of $1.15 for steers and $1.10 for heifers

| SR (hd/ac) | 1.5 | 2.1 | 3.0 | 1.5 | 2.1 | 3.1 | 1.5 | 2.2 | 3.0 |
|---|---|---|---|---|---|---|---|---|---|
| SUP (% BW) | 0 | 0 | 0 | 0.4 | 0.4 | 0.4 | 0.8 | 0.8 | 0.8 |
| Item | | | | | | | | | |
| Days on Pasture | 148 | 148 | 148 | 148 | 148 | 148 | 148 | 148 | 148 |
| Avg. Initial Wt (lbs) | 577 | 565 | 574 | 566 | 587 | 589 | 584 | 582 | 579 |
| Avg. Daily SUP (lbs/hd) | 0 | 0 | 0 | 2.82 | 2.80 | 2.70 | 5.90 | 5.94 | 5.40 |
| Avg. Daily Gain (lb/da) | 2.80 | 2.21 | 1.12 | 3.13 | 2.85 | 1.93 | 3.24 | 3.11 | 2.10 |
| Revenue / Head ($)[1] | 900 | 833 | 759 | 932 | 912 | 827 | 969 | 944 | 839 |
| Revenue / Acre ($) | 1350 | 1750 | 2322 | 1398 | 1914 | 2562 | 1453 | 2078 | 2516 |
| Value of Gain ($/lb) | 0.61 | 0.60 | 0.68 | 0.64 | 0.60 | 0.57 | 0.61 | 0.63 | 0.61 |
| Cost / Head ($)[2,3,4] | 788 | 761 | 755 | 818 | 818 | 810 | 890 | 862 | 837 |
| Cost / Acre ($)[5] | 1181 | 1597 | 2310 | 1227 | 1718 | 2512 | 1335 | 1897 | 2510 |
| Cost / lb gain ($/lb) | 0.33 | 0.38 | 0.66 | 0.39 | 0.38 | 0.52 | 0.48 | 0.45 | 0.60 |
| Return / Head ($) | 112 | 73 | 4 | 114 | 93 | 16 | 79 | 82 | 2 |
| Return / Acre ($) | 168 | 152 | 12 | 171 | 196 | 50 | 118 | 0.81 | 6 |
| Breakeven Wt (lb/hd) | 867 | 816 | 737 | 902 | 903 | 857 | 980 | 951 | 885 |
| Breakeven Price ($/lb) | 0.79 | 0.85 | 1.02 | 0.80 | 0.81 | 0.93 | 0.93 | 0.83 | 0.94 |
| Return / lb Gain ($) | 0.27 | 0.22 | 0.02 | 0.25 | 0.22 | 0.06 | 0.16 | 0.18 | 0.01 |

[1]Sales price varied according to weight and sex of calf (Table 1, Sale Price II).
[2]Supplement cost used was $200/ton ($0.10/lb).
[3]Hay was priced at $80/ton.
[4]Purchase price used for 575 lb calves was $1.15/lb for steers and $1.10/lb for heifers.
[5]Fertilizer prices used were: Ammonium nitrate, 34-0-0, at $374/ton ($0.55/lb N), and 21-8-17 at $380/ton.

Table 9. Differential returns per acre based on $374/ton of ammonium nitrate and $200/ton supplement

| SR | SUP | 0-1.5 | 0-2.1 | 0-3.0 | .4-1.5 | .4-2.1 | .4-3.1 | .8-1.5 | .8-2.2 | .8-3.0 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $/Ac[1] | | | | | | | | |
| 1.5 | 0 | 0.00 | | | | | | | | |
| 2.1 | 0 | -16 | 0.00 | | | | | | | |
| 3.0 | 0 | -156 | -141 | 0.00 | | | | | | |
| 1.5 | 0.4 | 22 | 18 | 159 | 0.00 | | | | | |
| 2.1 | 0.4 | 28 | 43 | 1843 | 25 | 0.00 | | | | |
| 3.1 | 0.4 | -118 | -103 | 38 | -121 | -146 | 0.00 | | | |
| 1.5 | 0.8 | -50 | -34 | 106 | -53 | -78 | 68 | 0.00 | | |
| 2.2 | 0.8 | 13 | 29 | 169 | 10 | -15 | 131 | 63 | 0.00 | |
| 3.0 | 0.8 | -163 | -147 | -6 | -165 | -190 | -44 | -113 | -175 | 0.00 |

[1]Assumptions for purchase and sales from Table 8.
[2]If stocking rates of 1.5 hd/ac without supplementation is compared with stocking rates of 1.5 hd/ac with .4% BW, a $2/ac increase was realized.
[3]An additional $184/ac was realized by changing stocking rate from 3.0 hd/ac without supplementation to 2.1 hd/ac and 0.4% BW daily supplement.

# INFLUENCE OF CONTINUOUS VS ROTATIONAL STOCKED RYE-RYEGRASS PASTURES AT DIFFERENT STOCKING RATES ON STEER PERFORMANCE

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## Summary

During 155 days of stocker steers grazing rye-ryegrass pastures from mid-December to mid-May, ADG was maximum in both years of a two-year study with initial, fixed stocking rates of about 1.5 hd/ac (900 lb body weight/ac). Steer ADG of about 2.9, 2.5, and 1.7 lb/d were different for each respective stocking rate of 1.7, 2.3, and 2.9 hd/ac in the first year. Stocking method of continuous vs rotational did not influence ADG in year one; however, in year two, both stocking method and stocking rate affected ADG. Rotational stocking increased ADG on both medium (2.1 hd/ac) and high stocked (2.9 hd/ac) pastures, but did not affect steer gains on the low stocked (1.5 hd/ac) pastures. Maximum ADG in both years occurred when forage dry matter (DM) available for consumption was about 1500 lb DM/ac. Steer gains ranged from 700 to 950 lb/ac across stocking rates in year one; however, reduced forage growth attributable to climatic conditions in year two resulted in gains of 170 lb/ac on high stocked pastures to 700 lb on all low stocked pastures and medium rotational stocked pastures. Steers weighing 600 lb at initiation of grazing weighed 1000 lb or more by mid-May on low stocked pastures. Stocker management should consider sale or feedlot options for the heavy weight steers off pasture.

## Introduction

Backgrounding stocker cattle on cool-season annual grass pastures has long been used to increase body weight of cattle entering the feedlot. Stocker grazing ventures and activities often fluctuate with pasture costs and availability, corn prices, and cost of gain for feedlot cattle. Stocker operators have direct control of initial stocking rates, and they often influence method of stocking such as continuous vs a multi-paddock rotational system. In an effort to provide a comparative stocker-forage database for winter pastures, the primary objective for this grazing experiment was to assess steer performance at three fixed stocking rates with each stocking rate incorporating two stocking methods of continuous vs an 8-paddock rotational stocking system.

## Experimental Procedures

A two-year stocking rate x stocking method (continuous vs rotational) experiment was conducted at the Texas A&M University Agricultural Research and Extension Center at Overton. Bermudagrass pastures were overseeded via drill planter with 'Maton' rye at 100 lb/ac and 'TAM-90' annual ryegrass at 25 lb/ac in late-September to early October. Pastures were fertilized with 300 lb/ac 21-8-17 in late-October to early-November each year, and with 200 lb/ac 34-0-0 at three separate application dates (mid-December, late January-early February, and late-March) for a total fertilization of 267-24-51 lb/ac of N-$P_2O_5$-$K_2O$. Simmental-sired steers from Angus x Brahman (AxB) and Brahman x Hereford (BxH) dams, and AxB (F-1) steers grazed pastures from early December to mid-May in both years. All steers received an implant for growth enhancement, and received an injectable dewormer pre-stocking and again mid-experiment. Two replicate pastures of all treatments with six steers each were stocked either continuous (CONT) or rotationally (ROTN) at three stocking rates. Fixed stocking rates (1 steer = 600 lb at initiation) for Year 1 were 1.7, 2.3, and 2.9 hd/ac, whereas, in Year 2 stocking rates were 1.5, 2.1, and 2.7 hd/ac, respectively, for low, medium, and high stocked pastures.

An 8-paddock system was used for rotational stocking at each stocking rate. Residence time in any one paddock varied from 2 to 3 days, and steers on all stocking rate treatments were moved on the same day. Forage mass and stubble height on the high stocked paddocks were the determining parameters for duration of stocking residence on a paddock. A two-day stocking residence per paddock, for example, provided for a 14-day deferment from grazing on the 8-paddock system. All stocking rates remained intact for the 156 to 159-day stocking period in both years, regardless of forage mass. All CONT stocked pastures were sampled for nutritive value on 14-d intervals and for forage mass at 28-d intervals. For the ROTN stocked pastures, a "test" paddock was identified for each replicate x stocking rate treatment from which samples for nutritive value and forage mass were taken. Forage samples were taken from "test" paddocks both pre- and post-stocking to provide estimates of forage nutritive value as well as growth and disappearance (consumption, trampling) on 14-to-16-day intervals. Cattle were weighed at approximate 28-day intervals throughout the stocking study. At termination of stocking in mid-May, all cattle were transported to a commercial feedlot in Hereford, TX.

## Results and Discussion

During both years of this experiment, ADG was negatively related to increases in stocking rate. Climatic conditions were substantially different for the two years such that forage dry matter (DM) production differed significantly under grazing defoliation at the medium and high stocking rates for each year. Stocker ADG on low stocked CONT or ROTN pastures for both years was similar at about 3 lb/hd/day. In Year 1, only stocking rates caused differences in ADG (P < .001); whereas, in Year 2, stocking rate (P < .001), stocking method (P < .005), and breed type (P < .04) were responsible for differences in ADG. Results will be presented and discussed by year.

*Year 1.* In the first year of this experiment, climatic conditions were conducive to average to slightly above-average forage production for the Pineywoods region of Texas. There was no difference in steer ADG between CONT and ROTN stocked pastures. However, each stocking rate was different (P < .01) from each other (Table 1). Averaged among stocking methods, the ADG for low, medium, and high stocked pastures, respectively, were 2.86, 2.53, and 1.66 lb/d. In the first year, when monthly ADG and corresponding forage DM available for consumption were examined for CONT stocked pastures, maximum ADG occurred at about 1600 lb/ac forage DM. Thus, forage availability in excess of 1600 lb/ac DM did not enhance additional gain. However, with the dynamic growth processes of cool-season annual grasses, this level of forage available is a difficult management target to maintain for periods more than 4 weeks or so due to the physiological and chronological maturity processes of rye and ryegrass. Off-pasture weights averaged 1012, 953, and 821 lb, respectively, for low, medium, and high stocking rates. There was no difference in ADG due to breed type. Live weight gain per acre was about 750 to 775 lb/ac for both low and high stocking rates, and was about 925 lb/ac for medium stocking rate (Table 2). The near-identical gains per acre from both low and high stocking rates resulted from steer ADG of about 2.9 lb/d from stocking rates of 1.7 hd/ac, and ADG of about 1.7 lb/d from stocking rates of 2.9 hd/ac. Thus, for the first year of this study, gain/ac data resulted in a typical bell-shaped response (Figure 1). There was a predicated, negative relationship between ADG and stocking rate.

*Year 2.* Climatic conditions during the winter months of the second year of this stocking study were not as favorable for forage growth compared to Year 1. Although fixed stocking rates were similar in both years, reduced forage mass in Year 2 resulted in more profound effects from the medium and high stocking rate pastures on resultant steer ADG. In Year 2, there was a difference (P < .01) between ROTN and CONT stocked pastures at both the medium and high stocking rates (Table 3). At the low stocking rate, more than adequate forage mass was available for selective grazing throughout the December to May period with resultant ADG of 3.0 lb/d for both CONT and ROTN stocked pastures. In Year 2, maximum stocker ADG occurred when forage DM available for consumption exceeded 1200 lb/ac. These forage mass values for Year 1 (1600 lb/ac) and Year 2 (1200 lb/ac) are in agreement with earlier grazing research with perennial ryegrass. At medium stocking rates, steers on ROTN stocked pastures had higher ADG (P < .01) at 2.15 lb/d than steers on CONT stocked pastures with ADG of 1.75 lb/d. The same trend held for high stocking rate with steers on ROTN stocked pastures with ADG of about 1 lb/d, and steers on CONT stocked pastures with ADG of 0.37 lb/d (P < .01). The 14-day deferment period allowed for more forage DM production on ROTN compared to CONT stocked pastures at both medium and high stocking rates. This additional forage DM provided for season-long ADG of nearly triple that of CONT stocked at 2.9 hd/ac. In Year 2, AxB steers had higher (P < .05) ADG than the Simmental-sired steers (1.67 vs 1.43) across all stocking treatments. Final body condition scores were different (P < .05) for all stocking rates at 6.7, 5.7, and 4.7, respectively, for low, medium, and high stocked pastures. Steers on CONT, high stocking rate, gained only 58 lb each during the 159-day period for a total of 168 lb/ac (Table 4). Gain per acre was similar for both CONT and ROTN low stocked pastures and for medium stocked ROTN pastures at 700 lb/ac (Figure 2). The reduced growth rate of steers from December through January was indicative of reduced forage mass available for consumption. Both years data show the potentially devastating economic situations from high stocked pastures.

## Implications

Small grain plus ryegrass pastures have a bimodal growth rate with a minor forage dry matter peak in the fall and a major forage dry matter peak in the spring months. The low stocking rate pastures produced the most forage during the winter months due to reduced severity of defoliation, and with the on-set of warmer temperatures and longer day length, the forage DM production from the low stocking rate pastures exceeded stocker consumption in the spring months. In contrast, on the medium and high CONT stocked pastures, forage consumption on these pastures exceeded forage growth rates. The constant and severity of defoliation and subsequent reduced leaf area diminished forage growth rate and subsequent ADG. The ROTN stocked pastures in Year 2 provided a deferment period for additional forage DM compared to CONT stocked pastures. The apparent contrasting implications from Year 1 vs Year 2 was due to differences in climatic conditions. Hence, during unfavorable conditions for forage DM production, deferment periods such as the ROTN stocked pastures may result in additional forage mass compared to CONT stocked systems, and especially at high stocking rates. With respect to stocking rate, there is no “correct” fixed stocking rate, but rather, management practices should be implemented that have flexibility in initiating grazing with a low stocking rate and then increasing the stocking rate during the rapid forage DM production periods of spring.

Table 1. Influence of stocking rate and stocking method on steer average daily gain (ADG) in Year 1

| Stocking rate[1] | | Stocking method | Steer ADG | | |
|---|---|---|---|---|---|
| | | | Simx[2] | AxB[3] | All |
| | (hd/ac) | | --------------------lb/d-------------------- | | |
| LO | 1.7 | CONT | 3.11 | 2.75 | 2.93 a[4] |
| LO | 1.7 | ROTN | 2.81 | 2.76 | 2.79 a |
| ME | 2.3 | CONT | 2.32 | 2.62 | 2.47 b |
| ME | 2.3 | ROTN | 2.56 | 2.60 | 2.58 b |
| HI | 2.9 | CONT | 1.49 | 1.62 | 1.56 c |
| HI | 2.9 | ROTN | 1.79 | 1.70 | 1.75 c |

[1]Stocking rate based on initial stocking of steers weighing 600 lb.
[2]Simmental-sired steers with Hereford x Brahman and Angus x Brahman dams.
[3]Angus x Brahman (F-1) steers.
[4]Numers in a column and followed by a different letter, differ ($P < .01$).

Table 2. Steer average daily gain (ADG), gains per animal and per acre from different stocking methods and stocking rates (SR) in Year 1

| | Year 1 | | | |
|---|---|---|---|---|
| Stocking method | SR | ADG | Gain/hd | Gain/ac |
| CONT | 1.7 | 2.93 | 466 | 792 |
| ROTN | 1.7 | 2.79 | 444 | 755 |
| CONT | 2.3 | 2.47 | 393 | 904 |
| ROTN | 2.3 | 2.58 | 410 | 943 |
| CONT | 2.9 | 1.56 | 248 | 719 |
| ROTN | 2.9 | 1.75 | 278 | 806 |

Table 3. Effect of stocking rate and stocking method on steer average daily gain (ADG) in Year 2

| Stocking rate[1] | | Stocker method | Steer ADG | | |
|---|---|---|---|---|---|
| | | | Simx[2] | AxB[3] | All |
| | lb/ac | | -------------------lb/d------------------- | | |
| LO | 1.5 | CONT | 2.88 | 3.12 | 2.96 [a4] |
| LO | 1.5 | ROTN | 3.04 | 3.04 | 3.04 [a] |
| ME | 2.1 | CONT | 1.64 | 2.01 | 1.76 [c] |
| ME | 2.1 | ROTN | 2.02 | 2.29 | 2.15 [b] |
| HI | 2.9 | CONT | 0.41 | 0.31 | 0.37 [e] |
| HI | 2.9 | ROTN | 1.05 | 0.86 | 0.99 [d] |

[1]Stocking rate based on initial stocking of steers weighing 600 lb.
[2]Simmental-sired steers with Hereford x Brahman and Angus x Brahman dams.
[3]Angus x Brahman (F-1) steers.
[4]Numers in a column and followed by a different letter differ (P<.01).

Table 4. Steer average daily gain (ADG) per animal and per acre from different stocking methods and stocking rates (SR) in Year 1

| | Year 1 | | | |
|---|---|---|---|---|
| Stocking method | SR | ADG | Gain/hd | Gain/ac |
| CONT | 1.7 | 2.93 | 466 | 792 |
| ROTN | 1.7 | 2.79 | 444 | 755 |
| CONT | 2.3 | 2.47 | 393 | 904 |
| ROTN | 2.3 | 2.58 | 410 | 943 |
| CONT | 2.9 | 1.56 | 248 | 719 |
| ROTN | 2.9 | 1.75 | 278 | 806 |

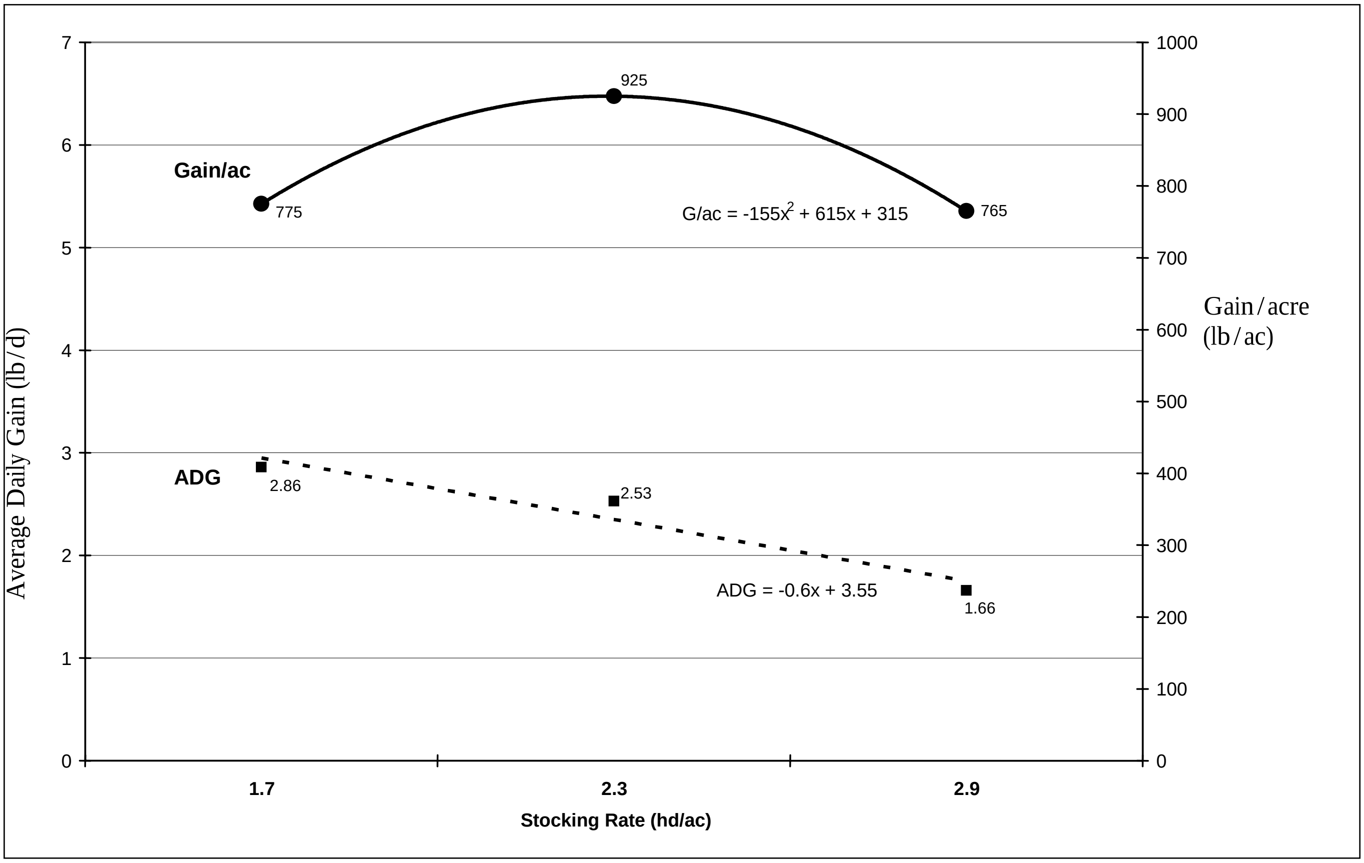


Figure 1. Average daily gain (ADG) and liveweight gain per acre for steers grazing rye-ryegrass pastures at three stocking rates in Year 1.

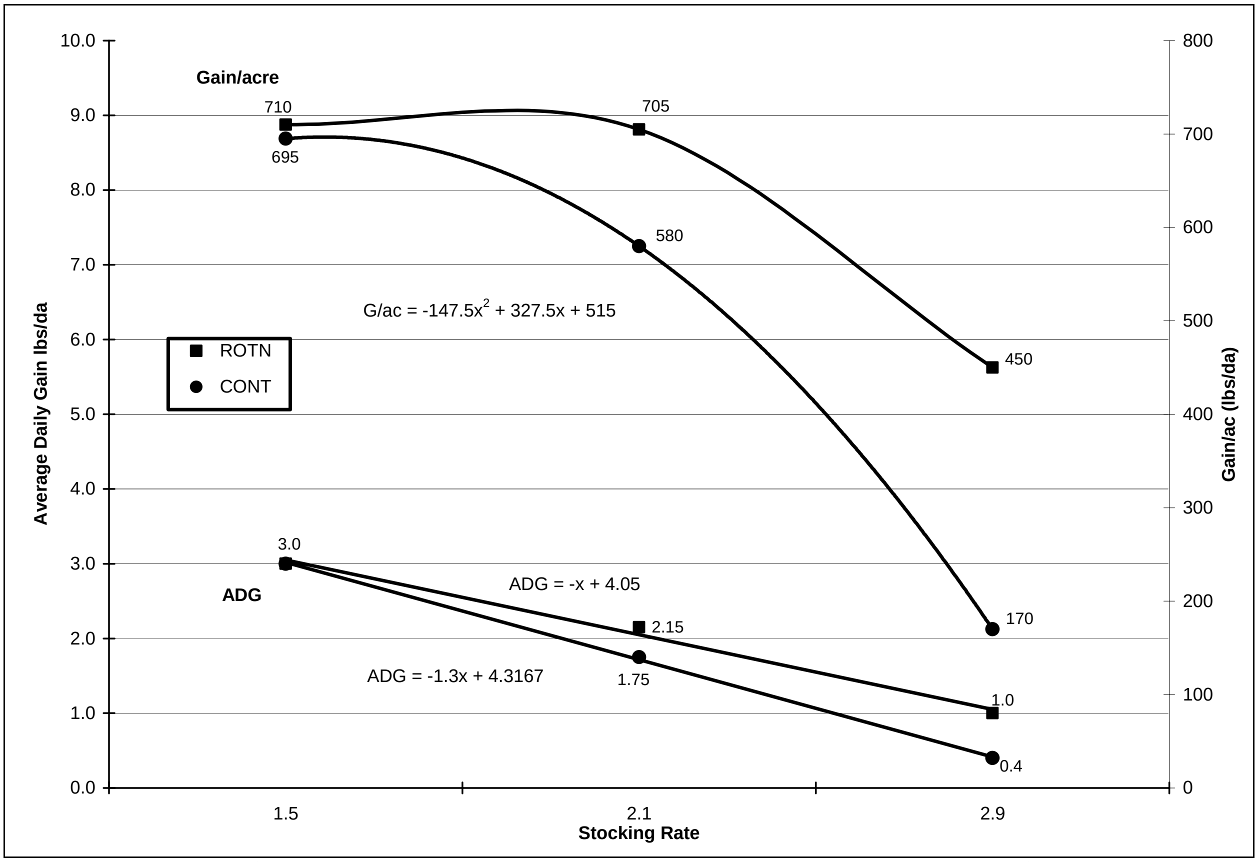

Figure 2. Comparison of continuous (CONT) vs rotational (ROTN) stocked rye-ryegrass pastures for average daily gain (ADG) and gain per acre at three stocking rates in Year 2.

# STOCKING RATE AND SUPPLEMENT LEVEL EFFECTS ON STOCKERS GRAZING RYE-RYEGRASS PASTURES

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## Summary

Increasing stocking rates from 1.5 hd/ac to 2.1 hd/ac to 3.0 hd/ac on 'Maton' rye and 'TAM-90' annual ryegrass pastures caused the greatest impact on ADG at 2.80, 2.21, and 1.13 lb/d, respectively, for non-supplemented stockers. The use of 0.4% body weight (BW) and 0.8% BW daily supplementation with a corn-based ration was similar in affecting ADG over non-supplemented cattle. At the 3 hd/ac stocking rate, supplementation produced a near doubling of ADG from 1.13 lb/d (non-supplemented) to about 2 lb/d for both 0.4% and 0.8% BW. At the low stocking rate of 1.5 hd/ac (550 lb stockers), ADG from non-supplementation was 2.8 lb/d, and supplementation with either 0.4% BW or 0.8% BW increased ADG to more than 3 lb/d. Gain per acre ranged from 900 to 1000 lb with supplementation and stocking rates of medium (2.1 hd/ac) or high stocking rates (3 hd/ac). Gain per acre from non-supplemented cattle at 3 hd/ac was reduced to 500 lb/ac. The efficiency of supplement:extra gain ratio was best for 0.4% BW compared to 0.8% BW, and supplement:extra gain ratio had dramatic improvements with increasing stocking rate.

## Introduction

Economic incentives for stocker cattle grazing winter pastures are uniquely associated with increased stocking rates to optimize gain per animal and gain per acre. In situations in which corn or other supplements are low-to moderate-priced along with moderate-to high-priced cattle, the use of supplements to enhance gain and substitute for high value forage presents management alternatives to increase returns per acre. The objective of this experiment was to ascertain gain per animal and gain per acre relationships between stocking rates and level of supplementation on stocker steers and heifers grazing rye-ryegrass-bermudagrass pastures.

## Experimental Procedures

On stocking research pastures at the Texas A&M University Agricultural Research and Extension Center at Overton, 'Maton' rye (Secale cereale L) and 'TAM-90' annual ryegrass (Lolium multiflorum L.) were sod-seeded into bermudagrass. Using a conventional grain drill with 7-inch spacings, rye was planted at 100 lb/ac and ryegrass at 25 lb/ac in late September to early October. Initial fertilization of 250 lb/ac of 21-8-17 was applied in early November, and 150 lb/ac of 34-0-0 was applied at each of three times in early December, early to mid-February, and late March. Pastures were stocked from December 20, 2004 to May 17, 2005 with 550-lb initial weight, Simmental x (Angus x Brahman dams) steers and heifers (n = 108 hd). Cattle on three fixed stocking rates of 1.5, 2.1, and 3 hd/ac were provided three daily levels of a cracked corn ration of 0, 0.4%, and 0.8% BW. Two replicate pastures were used for each treatment (total = 18 pastures) with three steers and three heifers per pasture (n = 6 hd/replicate). The daily, hand-fed supplement ration consisted of 95.6% cracked corn, 2.5% dried molasses, 1.25% salt, 0.65% dicalcium phosphate, and Rumensin 80 (at 0.0625% for 0.4% BW and at 0.031% at 0.8% BW) to supply 150 mg/hd/da. Cattle were weighed monthly, and rations were adjusted (increased) for total body weight per pasture (% BW) after each weigh period. Salt and dicalcium phosphate were used in the ration to prevent supplement gorging by dominant cattle. Initial and final body condition scores were taken on all animals to quantify treatment effects on weight gain and fatness.

Round bales of Coastal bermudagrass [Cynodon doctylon (L.) Pers] were offered ad libitum in each pasture from time of initial stocking on December 20 until March 23 to buffer impact of stocking rate during the winter months. Each hay bale was weighed and sampled for nutrient analyses prior to placement in hay rings of each pasture. At termination of hay feeding, visual estimates and weighing of hay refusals were made. Previous winter pasture experimentation has provided data on cool-season annual grass DM growth and production responses to temperature and short day length during the December-February period. The use of hay during the winter period buffered the severity of grass defoliation, allowed for more rapid rye-ryegrass regrowth, and also aided animal adaptation from an exclusive hay-deferred forage diet to the high nutritive value-high moisture containing small grain-ryegrass diet. All pastures were sampled monthly for forage mass and at 2-week intervals for forage nutritive value. Performance data were analyzed by PROC GLM of SAS using stocking rate, supplementation level, and stocking rate x supplementation interaction to assess treatment differences. Separations among treatments were made using LSD. Monthly comparisons were made using repeated measures.

## Results and Discussion

Forage mass for stocking rate treatments were uniform at initiation of grazing and through the most severe winter conditions of January (Fig 1). Access to ad libitum hay served as a partial buffer until late winter-early spring (March 23) at which time hay was removed from pastures to allow full expression of stocking rate on forage mass and animal performance. The quantity of hay offered for each pasture, estimated disappearance attributed to consumption, and refusal-waste of hay are shown in Table 1. Averaged across replicate pastures, estimated hay consumption per animal showed relative similarities on all low stocking rate pastures at about 250 to 275 lb/hd. These consumptions were likely attributed to a normal animal behavior of seeking both DM and an alternative diet component. Hay intake increased with stocking rate as was predicted. The use of both 0.4% and 0.8% BW supplement caused slight reductions in hay consumption with increased stocking rates compared to non-supplemented cattle. From February through termination of stocking in mid-May, more forage was available for consumption on the low stocked pastures compared to medium and high stocked pastures (Fig. 1). During the last 60-75 days of the experiment, high stocked pastures averaged about 1000 lb/ac which restricted stocker ADG. The 0.4% BW level of supplement was chosen based on previous experimentation that showed biological efficiencies of supplementation on winter pastures ranged from 0.25 to 0.4% BW on a daily, hand-fed basis.

The biological efficiency parameter was based primarily on the supplement:extra gain ratio. In general, the higher the level of supplement offered to grazing cattle, the greater the potential for substitution of supplement for forage intake. The intent and management objective of limited daily supplementation of 0.25 % to 0.4% BW were to enhance forage intake and digestion (associative or additive effects) with reduced effects of substitution of supplement for forage intake. The increased level of daily supplementation at 0.8% BW was intended to substitute the low- to moderate-priced corn rations for the moderate- to high-valued winter pasture. Additionally, increased levels of supplementation that substitutes for forage consumption allows for increased stocking rates without adverse, negative effects on animal performance.

Stocker steer and heifer ADG decreased with increasing stocking rate ($P < .05$). For each stocking rate, ADG was improved with 0.8% BW supplementation (Table 2). At the low stocking rate, the 0.4% BW supplement level did not enhance ADG over non-supplemented cattle. Averaged across supplementation treatments, the effects of stocking rate on monthly ADG and stocker body weight are shown in Figure 2. Final body condition scores decreased with each increase in stocking rate ($P < .05$). Stocking rates of 1.5, 2.1, and 3.0 caused final body condition scores of 6.20, 5.90, and 4.77, respectively. There was an interaction between stocking rate and supplementation ($P = .09$) that is worthy of management consideration. On non-supplemented pastures, stocker ADG was different ($P < .05$) for all stocking rates at 2.80, 2.21, and 1.13 lb/d, respectively, for 1.5, 2.1, and 3.0 hd/ac stocking rates (Table 3). For both 0.4% and 0.8% BW supplemented stockers, ADG was more than 3.0 lb/d on low and medium stocked pastures, and about 2 lb/d on high stocked pastures. Although ADG of stockers was similar for both 0.4% and 0.8% BW supplementation, forage DM available for consumption was greater on pastures at the 0.8% BW level. Thus, substitution effects were present for the pasture as expected, and under flexible stocking rate management options, this would allow for increased stocking rates from March to May without adverse affects on ADG.

Stocker gains per animal, gain per acre, and supplement:extra gain ratio are shown in Table 4. Gain per acre was maximized at 900 to 1000 lb/ac with supplementation and stocking rates of 2.1 to 3.0 hd/ac. Pastures stocked at 1.5 hd/ac produced 630 lb/ac without supplementation, and about 700 lb/ac with supplementation. The non-supplemented and high stocked (3 hd/ac) pastures produced only 500 lb/ac. The influence of stocking rate and level of supplementation on efficiency of stocking rate increased with stocking rate from 1.5 to 3.0 hd/ac. The supplement:extra gain ratios were greatly improved with increased stocking rates from 11:1 to 4:1 with 0.4% BW supplement and 17:1 to 7:1 with 0.8% BW supplement. The biological efficiencies dramatically affect economy of production using supplements. Using the 0.4% BW level, for example, the 11 lb requirement for an extra pound of gain vs 4 lb of supplement for an extra pound of gain has major economic impacts on management decisions.

## Implications

Use of low to moderately low stocking rates at initiation of grazing in late fall usually provides maximum ADG and reduced risks associated with restricted forage DM during the winter. Use of hay during the first 45 to 90 days of stocking on winter annual pastures can successfully buffer reduced forage mass due to winter climatic conditions. The major dilemmas for management that are associated with use of supplementation are the lack of knowledge and comparative information on the enhanced gain and supplement:extra gain ratios for supplements. Biological and economic efficiencies associated with supplementation favor daily levels of 0.25 to 0.4% BW in contrast to 0.8% to 1% BW or higher. Increasing the level of low to moderate-priced supplement for use with moderate- to high-priced cattle can have positive, economic implications as well as management options to increase stocking rates. Optimum forage utilization of small grain + ryegrass pastures and animal performance attributes may be best achieved using a variable stocking rate strategy in which an initial low stocking rate may be increased by two-fold or more at the onset of spring-like conditions in late-February to early-March. Finally, off-pasture body weights of 950 to

1150 lb for cattle on low stocked and/or supplemented pastures requires management consideration for sale off-pasture vs feedlot options. The heavy weight cattle off-pasture may be a targeted objective only when excessive, negative margins are avoided, and/or if retained ownership through the feedlot can be implemented.

Table 1. Total hay consumed on stocking rate and supplementation pastures

| Stocking rates[1] (hd/ac) | Supplementation (% BW) | Hay consumed[2] per head (lb) |
|---|---|---|
| 1.5 | 0 | 251 |
| 2.1 | 0 | 566 |
| 3.0 | 0 | 713 |
| | | |
| 1.5 | .4 | 248 |
| 2.1 | .4 | 460 |
| 3.1 | .4 | 661 |
| | | |
| 1.5 | .8 | 276 |
| 2.2 | .8 | 421 |
| 3.0 | .8 | 550 |

[1]Stocking rate based on 550 lb = 1 stocker at initiation of grazing on 12-20-04.
[2]Hay consumed is an estimate of hay disappearance minus refusal-residue in hay ring feeding area from 12-20-04 to 3-23-05.

Table 2. Effect of stocking rate on average daily gain (ADG) on rye-ryegrass pastures

| Supplement (% BW) | Stocking Rates[1] (hd/ac) | | |
|---|---|---|---|
| | 1.5 | 2.1 | 3.0 |
| | ADG (lb/d) | | |
| 0 | 2.80 [b] | 2.21 [b] | 1.13 [b] |
| 0.4% | 3.13 [ab] | 2.86 [a] | 1.94 [a] |
| 0.8% | 3.24 [a] | 3.11 [a] | 2.10 [a] |

[1]Stocking rates based on 550lbs = 1 stocker at initiation of grazing on 12-20-04.
[2]ADG followed by a different letter in a stocking rate column, differ at P < .05.

Table 3. Effect of supplement level on average daily gain (ADG) on rye-ryegrass pastures

| Stocking Rate[1] hd/ac | Supplementation (% BW) | | |
|---|---|---|---|
| | 0 | 0.4% | 0.8% |
| | ADG (lb/d) | | |
| 1.5 | 2.80 [a] | 3.13 [a] | 3.24 [a] |
| 2.1 | 2.21 [b] | 2.86 [a] | 3.11 [a] |
| 3.0 | 1.13 [c] | 1.94 [b] | 2.10 [b] |

[1]Stocking rates based on 550 lbs = 1 stocker at initiation of grazing on 12-20-04.
[2]ADG followed by a different letter within a supplement column, differ at $P < .05$

Table 4. Gains per animal, per acre, supplement (SUP) gains, and supplement to extra gain ratioson rye-ryegrass pastures

| SUP | STK rate[1] | ADG | Gain/ animal | Gain/ acre | Extra gain due to SUP | SUP fed | SUP: extra gain ratio |
|---|---|---|---|---|---|---|---|
| % BW | hd/ac | lb/d | lb/hd | lb/ac | lb/hd/d | lb/hd/d | lb:lb |
| 0 | 1.5 | 2.80 | 414 | 630 | - | - | - |
| 0 | 2.1 | 2.21 | 327 | 697 | - | - | - |
| 0 | 3.0 | 1.13 | 167 | 502 | - | - | - |
| 0.4% | 1.5 | 3.13 | 463 | 681 | 0.33 | 3.64 | 11.0:1 |
| 0.4% | 2.1 | 2.86 | 423 | 876 | 0.65 | 3.53 | 5.4:1 |
| 0.4% | 3.1 | 1.94 | 287 | 890 | 0.81 | 3.17 | 3.9:1 |
| 0.8% | 1.5 | 3.24 | 480 | 725 | 0.44 | 7.44 | 16.9:1 |
| 0.8% | 2.2 | 3.11 | 460 | 1008 | 0.90 | 7.52 | 8.4:1 |
| 0.8% | 3.0 | 2.10 | 311 | 936 | 0.97 | 6.47 | 6.7:1 |

[1]Stocking rates based on 550 lb = 1 stocker.

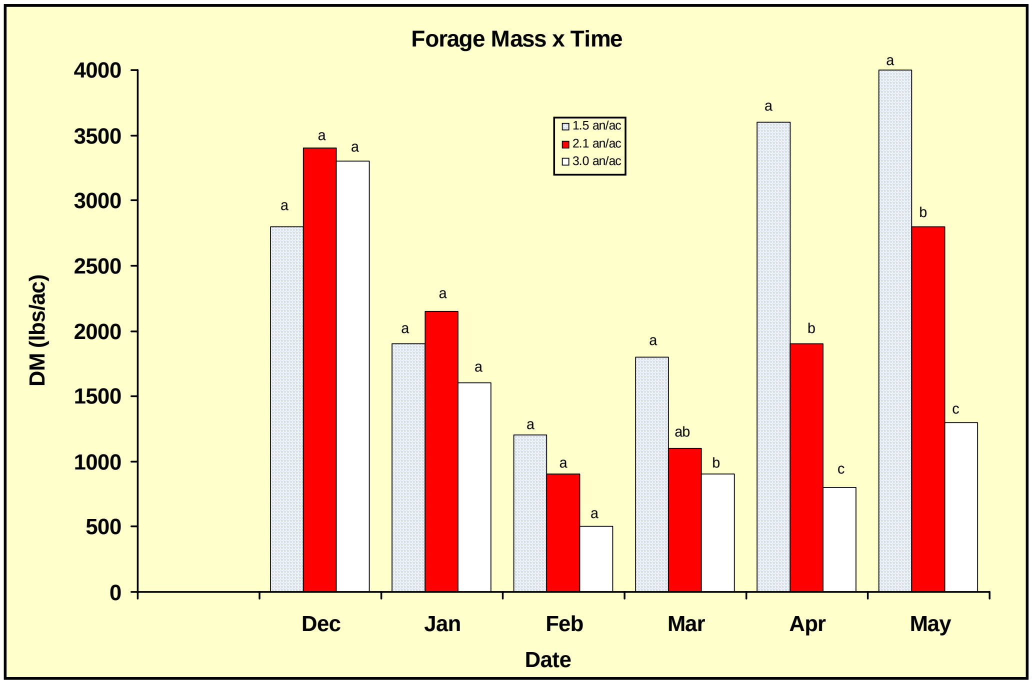


Figure 1. Forage mass on different stocking rate pastures from initiation to termination of stocking. Different letters in forage mass bar graph are different within a date.

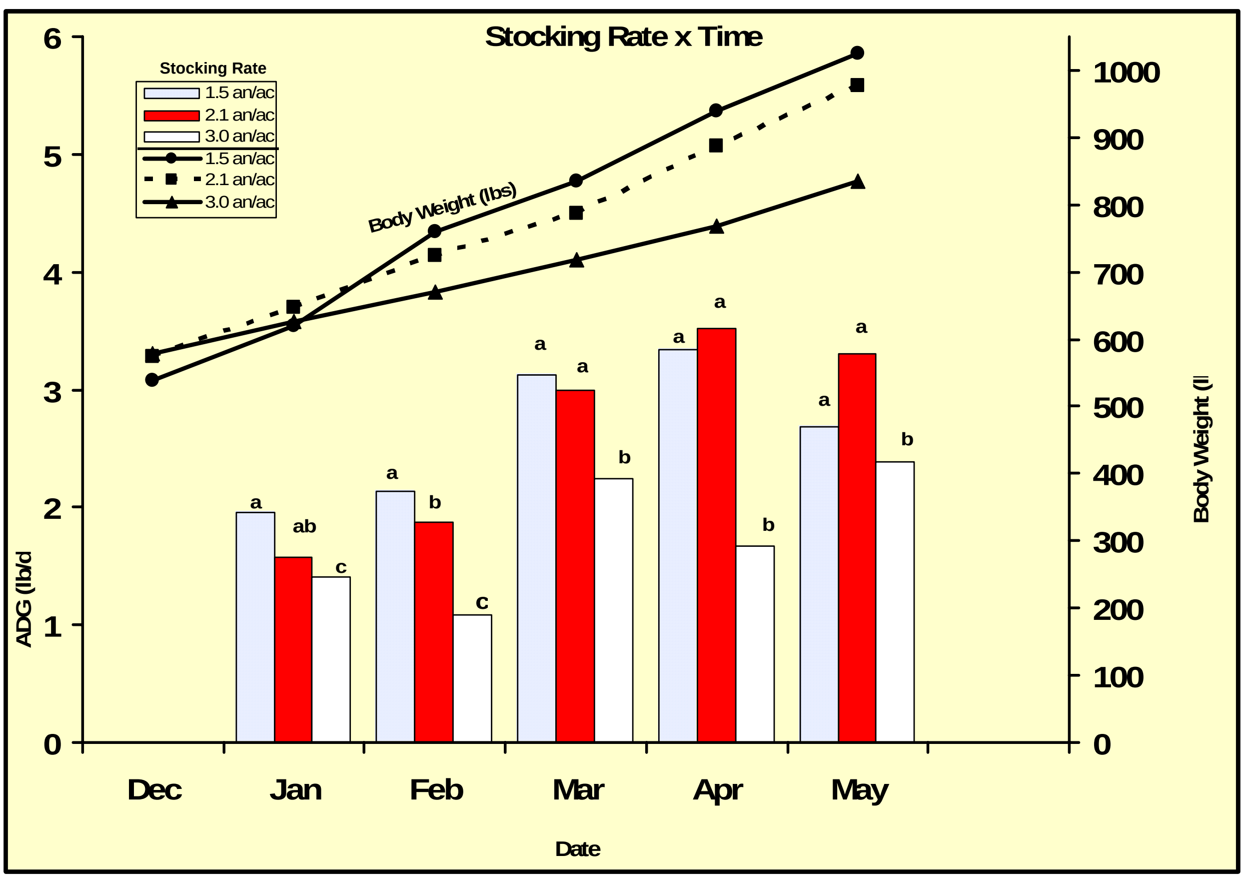


Figure 2. Average daily gain (ADG) and change in body weight (BW) during stocking of rye-ryegrass pastures at three stocking rates. Different letters in ADG bar graph are different within a date.

# WINTER PASTURE STOCKING RATE EFFECTS ON CARCASS COMPOSITION AND MEAT TENDERNESS OF TWO BREEDTYPES

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## Summary

Winter pasture stocking rates (SR) of 1.5, 2.1, and 2.9 calves per acre were employed to create graded levels of pre-feedlot animal gain and growth rate. Angus x Brahman (AxB) steers and Simmental-sired (Simx) steers and heifers (n = 125 d) from AxB and Hereford x Brahman dams were fed in pens according to pasture SR. Cattle were harvested at similar, visual backfat of about 0.4-inch backfat, with carcass evaluations on physical, chemical, and sensory traits. Feedlot period was 131days for both low and medium SR cattle, and 175 days for high SR cattle. Average feedlot pay weights were similar at about 1250 lbs. Minor differences among breedtype and sex were detected for physical carcass traits except for marbling and subsequent USDA quality grade in that all cattle graded USDA Select with AxB higher ($P < .05$) than Simx heifers which, in turn, were higher ($P < .05$) than Simx steers. Low SR calves had lower ($P < .001$) percent soluble collagen (6.34 vs 8.48 and 8.47%), respectively, than calves from medium or high SR. Calpastatin activity was different ($P < .001$) for each SR (1.69, 2.19, 3.04 ± .16 activity/g), respectively, for low, medium, and high SR. Warner-Bratzler shear force values and sensory panel attributes of samples after 14 and 35 days aging were not affected by SR. A trained sensory panel rated AxB steers with a slight advantage ($P < .001$) over Simx steers and heifers for muscle fiber tenderness, connective tissue, and overall tenderness, at both 14-and 35-days aging. When cattle were fed to a common backfat endpoint, SR did not affect tenderness nor flavor attributes, but influenced calpastatin and collagen solubility.

## Introduction

The cattle industry functions in segments or components in which the cow-calf, stocker, and feeder operations are usually independent from each other. However, for the past several years there has been an increasing percentage of vertically integrated operations. But, to date, most of this integration continues to separate the cow-calf phase from the stocker-feeder phase. Gain and growth targets for stocker cattle are often compromised between optimum gain per animal vs optimum gain per acre. Pasture productivity which is dependent upon climatic conditions and management can often provide less than *ad libitum* forage for consumption. As a consequence, it is not uncommon for stocker cattle to have restricted ADG. The objectives of this experiment were to create graded levels of animal gain and growth rate using pasture stocking rates and quantify effects of pre-feedlot performance on carcass composition and meat tenderness. In addition, we wanted to ascertain differences in breed types of cattle including 50% and 25% Brahman as well as 50% Continental-sired calves.

## Experimental Procedures

'Maton' rye (Secale cereale L) and 'TAM-90' ryegrass (Lolium multiflorum L) pastures were stocked at three rates (1.5, 2.1, and 2.9 hd/ac) under both continuous and rotationally stocked systems at the Texas A&M University Agricultural Research and Extension Center at Overton. Angus x Brahman steers and Simmental-sired steers and heifers from Angus x Brahman and Hereford x Brahman dams (total = 125 hd at 600-lb initial weight) grazed pasture treatments from mid-December to mid-May. At termination of experiment, all cattle were transported to a commercial feedlot in Hereford, TX and fed in pens according to stocking rate. Cattle in each pen (n = 3) were fed to a visually estimated .4-inch backfat, and harvested at Excel Corp, Friona, TX. At 24 hr postmortem, about 100g of the longissimus muscle was excised at the 5th and 6th rib interface from the right side of the carcass for calpastatin activity (Koohmaraie et al., 1995) and sarcomere length determination (Cross et al., 1980). At approximately 48 hours postmortem, all USDA quality and yield characteristics were evaluated by trained personnel from West Texas A&M University. Carcass data collected included fat thickness, longissimus muscle area, percent kidney, heart, and pelvic fat (KPH), preliminary yield grade, marbling score, and visible defects. Final yield grades were calculated according to USDA Beef Grading Standards (USDA, 1995).

At time of grading, rib sections, including the 9-10-11 ribs, were removed from the right side of each carcass, and transported to the Rosenthal Meat Science and Technology Center in the Department of Animal Science at Texas A&M University, College Station. Two one-inch steaks were removed from the 12th rib interface for Warner-Bratzler (WB) shear force measurement and sensory panel evaluations. Steaks were individually vacuum-packaged and aged for 14 days at 4°C. Rib sections were weighed and dissected into muscle, lean, fat, connective tissue and bone. Soft tissues from each 9-10-11 rib section were combined, ground, vacuum-packaged and frozen at -23°C for future moisture, fat, and protein determinations (AOAC, 1995). At 48 hrs postmortem, beef ribs from the left side of the carcass were vacuum-packaged and aged for 35 days. Three one-inch steaks were removed from the posterior end of the 112A rib sections at the 12th rib interface, frozen, and designated for WB shear force, percent soluble collagen, or trained sensory panel evaluation. After thawing, day 14 and 35 steaks were broiled to an internal temperature of 70°C and cooled to room temperature for at least four hours. Six cores, one-inch each, were removed from each steak and assessed for WB shear. One 14-day and 35-day steak from each animal were evaluated by a 5-to-7 member, trained, meat descriptive attribute sensory panel (AMSA, 1995). Data were analyzed by PROC GLM procedures of SAS (1991). The full model included main effects of breed and sex, stocking rate, stocking method, and the 2-and 3-way interactions. Hot carcass weight was defined as a covariate for all analyses. Mean separations were performed using standard pdiff procedures, and simple correlations were calculated using SAS (1991).

## Results and Discussion

*Pasture Performance*

During the winter pasture phase, ADG varied ($P < .01$) from 2.78 lb/d, 1.81 lb/d, and 0.75 lb/d, respectively, for low, medium, and high stocking rate. Angus x Brahman (AxB) steers had higher ($P < .01$) ADG than Simmental-sired (Simx) steers and heifers. During the feedlot phase, cattle were fed in pens according to stocking rate (n = 3), and were harvested when cattle within a pen had visually estimated 0.4-inch backfat. Thus, days on feed was 131 for both low and medium stocking rates, and 175 days for high stocked cattle. Pen average liveweight at time of harvest was 1252, 1213, and 1253 lb, respectively for low, medium, and high stocked cattle. Feedlot ADG of 3.56, 2.98, and 2.62 lb/d respectively, for high, medium, and low stocking rates on pasture exhibited compensating growth.

*Carcass Characteristics and Composition*

Simmental-sired steers had heavier ($P < .03$) hot carcass weight than Simx heifers, but were similar to AxB steers (Table 1). In addition, Simx steers had less ($P < .001$) fat thickness (.30 in) compared to both AxB steers (.43 in) and Simx heifers (.39 in). Ribeye area and KPH were similar across breedtypes and sex. Simmental-sired steers had lower (better) yield grade and decreased marbling, and USDA quality grade compared to both AxB and Simx heifers (Table 2).

Since cattle were fed to visually similar backfat and high stocked cattle were on feed 44 days longer (175 days) than low and medium stocked cattle, stocking rate effects had minimal effects on carcass physical traits. However, high stocked cattle had higher backfat, KPH, and yield grade; low stocked cattle had larger ribeye area; and medium stocked cattle had less marbling and lower USDA yield grade (Table 1 and 2). Rotationally stocked cattle had heavier hot carcass weight and subsequent larger ribeye area.

Simmental-sired steers carcass had higher percent water, protein, lean, and bone, but lower percent lipid, subcutaneous fat, and seam fat compared to both AxB steers and Simx heifers (Tables 3 and 4). Stocking rate had minimal effect on chemical characteristics with the exception that high stocked cattle had lower percent bone compared to both low and medium stocked cattle (Tables 3 and 4). Stocking method did not influence any of the chemical traits measured. Restricting ADG on pasture followed by feedlot periods to similar backfat showed only modest affects on carcass composition. Meyer et al. (1965) found little difference in carcass composition of steers that received high and low-energy dense diets prior to feedlot period. The pre-feedlot cattle ADG of .77, 1.7, and 2.31 lbs/da of Meyer et al. (1965) were similar to the winter pasture ADG in our experiment, and both studies were in close agreement with respect to pre-feedlot gains on carcass attributes. With respect to physical and chemical measurements of tenderness, Simx heifers had lower total collagen, low stocked cattle had lower soluble collagen, and all three stocking rates had different calpastatin activity (high > medium > low) (Table 5).

Trained sensory panel assessments of juiciness, muscle fiber tenderness, connective tissue amount, overall tenderness, and overall flavor tenderness detected no effects due to stocking method, and only an increase ($P < .04$) in connective tissue amount of high stocked cattle at 14-day aging but none at 35-day aging (Tables 6 and 7). The AxB steers had higher ($P < .01$) muscle fiber tenderness and overall tenderness ($P < .01$) at both 14 and 35-day aged meat. However, AxB steers had higher ($P < .01$) connective tissue amount for both 14 and 35-day aged steaks.

## Implications

Tenderness as measured by both Warner-Bratzler shear force and trained sensory panel was not affected by pre-feedlot, pasture ADG. Some detectable, but minor, differences in carcass composition were influenced by breedtype and sex of calf. Calpastatin activity, however, showed clear differences between each stocking rate. For these cattle, the increased calpastatin levels were not responsible for any tenderness-acceptance measurements. However, there was a direct relationship with calpastatin activity and connective tissue amount. There was no advantage in tenderness measurements between a 14-day and 35-day aging period. For this age class of cattle, 19 to 20 months at harvest, and modest to above-average growth rate, pre-feedlot restrictions of growth had minimal influence on carcass characteristics when cattle were harvested at similar backfat of about 0.4 inch. Data from this one-year study also implied that feedlot performance and carcass traits were relatively similar for 50% Brahman vs 50% Continental x 25% Brahman breed types.

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Table 1. Least squares means for carcass quality and yield grade characteristics of hot carcass weight (HCW), backfat thickness, and kidney heart and pelvic fat (KPH)

| Item | HCW (lb) | Fat thickness (in) | Ribeyearea (in$^2$) | KPH |
|---|---|---|---|---|
| *Breed and sex* | .0292[d] | .0001[d] | .1261[d] | .2367[d] |
| Angus x Brahman steers | 784[ac] ± 18 | 0.43[b] ± .022 | 13.2 ± 0.20 | 1.7 ± .05 |
| Sim x steers | 830[bc] ± 16 | 0.30[a] ± .020 | 13.7 ± 0.19 | 1.6 ± .05 |
| Sim x heifers | 768[a] ± 18 | 0.39[b] ± .022 | 13.4 ± 0.21 | 1.7 ± .06 |
| *Stocking rate* | .0973[d] | .0500[d] | .0142[d] | .0011[d] |
| Low | 801 ± 22 | 0.37[ab] ± .028 | 14.0[b] ± 0.24 | 1.7[a] ± .06 |
| Medium | 787 ± 15 | 0.34[a] ± .020 | 13.3[a] ± 0.17 | 1.6[a] ± .05 |
| High | 801 ± 18 | 0.41[b] ± .020 | 13.0[a] ± 0.19 | 1.9[b] ± .05 |
| *Grazing method* | .0162[d] | .7500[d] | .0104[d] | .3966 |
| Rotational | 819[a] ± 15 | 0.37 ± .020 | 13.7[a] ± 0.17 | 1.7 ± .05 |
| Continuous | 769[b] ± 14 | 0.36 ± .020 | 13.1[b] ± 0.25 | 1.7 ± .04 |

[abc]Mean values within a column and followed by a different letter are not significantly different ($P < .05$).
[d]P-value from analysis of variance.

Table 2. Least squares means for carcass quality and yield grade characteristics of preliminary yield grade (PYG), yield grade (YG), marbling, and USDA quality grade (QG).

| Item | PYG | YG | Marbling[e] | USDA QG[f] |
|---|---|---|---|---|
| *Breed and sex* | .0001[d] | .0035[d] | .0001[d] | .0001[d] |
| Angus x Brahman steers | 3.1b ± .06 | 2.70[b] ± .09 | 378[c] ± 8.5 | 666[c] ± 6.4 |
| Sim x steers | 2.7[a] ± .05 | 2.20[a] ± .08 | 319[a] ± 7.9 | 622[a] ± 5.8 |
| Sim x heifers | 2.8[b] ± .06 | 2.50[b] ± .09 | 344[b] ± 8.6 | 643[b] ± 6.5 |
| *Stocking rate* | .0537[d] | .0001[d] | .0010[d] | .0010[d] |
| Low | 2.9 ± .10 | 2.30[a] ± .10 | 358[b] ± 9.8 | 654[b] ± 7.3 |
| Medium | 2.8 ± .07 | 2.40[a] ± .07 | 323[a] ± 7.2 | 626[a] ± 5.4 |
| High | 3.0 ± .08 | 2.70b ± .08 | 361[b] ± 8.2 | 652[b] ± 6.0 |
| *Grazing method* | .7526[d] | .0712[d] | .8300[d] | .3657[d] |
| Rotational | 2.9 ± .08 | 2.40 ± .08 | 347 ± 7.1 | 641 ± 5.3 |
| Continuous | 2.9 ± .08 | 2.55 ± .08 | 345 ± 7.1 | 647 ± 5.0 |

abcMean values within a column and followed by a different letter are not significantly different ($P$ < .05).
[d]P - value from analysis of variance.
[e]300 = Slight[00]; 400 = Small[00]
[f]600 - 649 = sel$^-$; 650 - 699 = el$^+$

Table 3. Least squares means for 9-10-11 rib chemical moisture, fat, and protein composition

| Item | Water % | Lipid % | Protein % |
|---|---|---|---|
| *Breed and sex* | .0028[d] | .0001[d] | .0001[d] |
| Angus x Brahman steers | 54.1[a] ± .74 | 29.12[b] ± .69 | 18.71[a] ± .29 |
| Sim x steers | 57.4[b] ± .67 | 24.23[a] ± .63 | 20.71[b] ± .26 |
| Sim x heifers | 54.7[a] ± .74 | 28.72[b] ± .70 | 19.10[a] ± .29 |
| *Stocking rate* | .4035[d] | .0684[d] | .0425[d] |
| Low | 54.8 ± .75 | 28.00 ± .57 | 19.58[ab] ± .34 |
| Medium | 55.0 ± .93 | 26.06 ± .60 | 19.92[b] ± .24 |
| High | 56.2 ± .64 | 28.57 ± .71 | 19.00[a] ± .27 |
| *Stocking method* | .7629[d] | .8831[d] | .0600[d] |
| Rotational | 55.4 ± .64 | 27.46 ± .61 | 19.19 ± .25 |
| Continuous | 55.3 ± .64 | 27.61 ± .59 | 19.81 ± .22 |

[ab]Mean values within a column and followed by a different letter are significantly different ($P$ < .05).
[d]P - value from analysis of variance.

Table 4. Least squares means for 9-10-11 rib characteristics of subcutaneous fat, intermuscular fat, lean, and bone

| Item | Subcutaneous fat % | Seam fat % | Lean % | Bone % |
|---|---|---|---|---|
| *Breed and sex* | .0002[d] | .0146[d] | .0001[d] | .0413[d] |
| Angus x Brahman steers | 13.42[b] ± .69 | 14.25[b] ± .77 | 52.92[a] ± .63 | 17.61[ab] ± .37 |
| Sim x steers | 09.42[a]±.63 | 11.83[a] ± .70 | 58.25[c] ± .59 | 18.51[b] ± .34 |
| Sim x heifers | 11.58[ab] ± .71 | 14.64[b] ± .78 | 55.41[b] ± .64 | 17.26[a] ± .38 |
| *Stocking rate* | .1025[d] | .3861[d] | .0569[d] | .0013[d] |
| Low | 11.21 ± .80 | 12.93 ± .88 | 55.51 ± .73 | 18.70[b] ± .43 |
| Medium | 10.67 ± .58 | 13.38 ± .65 | 56.50 ± .53 | 17.99[b] ± .32 |
| High | 12.53 ± .66 | 14.40 ± .73 | 54.58 ± .60 | 16.70[a] ± .36 |
| *Stocking method* | .1617[d] | .4475[d] | .0509[d] | .9151[d] |
| Rotational | 12.03 ± .53 | 13.90 ± .64 | 54.82 ± .49 | 17.77 ± .31 |
| Continuous | 10.92 ± .58 | 13.24 ± .60 | 56.24 ± .53 | 17.82 ± .29 |

[abc]Mean values within a column and followed by a different letter are significantly different ($P < .05$).
[d]P - value from analysis of variance.

Table 5. Least squares means for tenderness characteristics as represented by sarcomere length, calpastatin, total collagen, soluble collagen, 14-d and 35-d Warner-Bratzler shear force

| Item | Sarcomere length (μm) | Calpastatin (activity/g) | Total collagen (mg/g) | Soluble collagen (%) | 14 d shear force (lb) | 35 d shear force (lb) |
|---|---|---|---|---|---|---|
| *Breed and sex* | .4098[d] | .7138[d] | .0109[d] | .9220[d] | .5478[d] | .0716[d] |
| Angus x Brahman steers | 2.20 ± .05 | 2.27 ± .16 | 3.03[b] ± .121 | 7.89 ± .41 | 6.8 ± .46 | 5.5 ± .02 |
| Sim x steers | 2.25 ± .05 | 2.41 ± .15 | 2.97[b] ± .110 | 7.76 ± .37 | 7.0 ± .40 | 6.2 ± .20 |
| Sim x heifers | 2.16 ± .05 | 2.24 ± .17 | 2.54[a] ± .125 | 7.65 ± .42 | 7.5 ± .42 | 6.2 ± .20 |
| *Stocking rate* | .4363[d] | .0001[d] | .1416[d] | .0005[d] | .3870[d] | .1794[d] |
| Low | 2.19 ± .06 | 1.69[a] ± .19 | 2.66 ± .135 | 6.34[a] ± .46 | 7.0 ± .48 | 6.4 ± .24 |
| Medium | 2.25 ± .04 | 2.20[b] ± .14 | 3.00 ± .102 | 8.49[b] ± .35 | 7.5 ± .35 | 5.9 ± .18 |
| High | 2.17 ± .05 | 3.04[c] ± .16 | 2.88 ± .120 | 8.47[b] ± .41 | 6.8 ± .40 | 5.7 ± .20 |
| *Stocking method* | .2514[d] | .2583[d] | .1393[d] | .0484[d] | .3543[d] | .9187[d] |
| Rotational | 2.24 ± .04 | 2.20 ± .14 | 2.95 ± .09 | 8.23 ± .34 | 6.8 ± .35 | 5.9 ± .18 |
| Continuous | 2.17 ± .04 | 2.41 ± .13 | 2.75 ± .09 | 7.30 ± .32 | 7.1 ± .35 | 5.9 ± .15 |

[abc]Mean values within a column and followed by the a different are significantly different ($P < .05$).
[d]P - value from analysis of variance.

Table 6. Least squares means for sensory panel attributes of juiciness, muscle fiber tenderness, connective tissue amount, overall tenderness and overall flavor intensity

| Item | Juiciness$^{e}$ 14-d | Juiciness$^{e}$ 35-d | Muscle fiber tenderness$^{f}$ 14-d | Muscle fiber tenderness$^{f}$ 35-d | Connective tissue amount$^{g}$ 14-d | Connective tissue amount$^{g}$ 35-d |
|---|---|---|---|---|---|---|
| *Breed and sex* | .2131$^{d}$ | .3181d | .0001d | .0086d | .0004d | .0175d |
| Angus x | 5.0 ± .07 | 5.1 ± .08 | $6.8^{b}$ ± .10 | $6.9^{b}$ ± .09 | $7.3^{b}$ ± .08 | $7.4^{b}$ ± .07 |
| Sim x steers | 4.9 ± .07 | 4.9 ± .07 | $6.3^{a}$ ± .10 | $6.6^{a}$ ± .08 | $7.0^{a}$ ± .07 | $7.2^{a}$ ± .06 |
| Sim x heifers | 4.9 ± .07 | 5.1 ± .08 | $6.1^{a}$ ± .11 | $6.6^{a}$ ± .09 | $6.9^{a}$ ± .08 | $7.2^{a}$ ± .07 |
| *Stocking rate* | .3680$^{d}$ | .7739$^{d}$ | .1614$^{d}$ | .3017$^{d}$ | .0431$^{d}$ | .4529$^{d}$ |
| Low | 5.0 ± .08 | 5.1 ± .09 | 6.3 ± .12 | 6.8 ± .10 | $6.9^{a}$ ± .09 | 7.3 ± .08 |
| Medium | 5.0 ± .06 | 5.0 ± .07 | 6.3 ± .09 | 6.6 ± .07 | $7.0^{a}$ ± .07 | 7.2 ± .06 |
| High | 5.0 ± .07 | 5.0 ± .08 | 6.6 ± .10 | 6.7 ± .08 | $7.2^{b}$ ± .08 | 7.2 ± .07 |
| *Stocking method* | .6216$^{d}$ | .7498$^{d}$ | .0634$^{d}$ | .4484$^{d}$ | .1063$^{d}$ | .3753$^{d}$ |
| Rotational | 4.9 ± .06 | 5.0 ± .07 | 6.5 ± .09 | 6.7 ± .07 | 7.0 ± .07 | 7.3 ± .06 |
| Continuous | 4.9 ± .06 | 5.0 ± .06 | 6.3 ± .08 | 6.7 ± .07 | 7.0 ± .06 | 7.2 ± .05 |

$^{ab}$Mean values within a column and followed by a different letter are significantly different ($P < .05$).
$^{d}$P - value from analysis of variance.
$^{efghi}$Sample evaluated on an 8-point scale for juiciness (8 = extremely juicy, 1 = extremely dry), muscle fiber tenderness (8 = extremely tender, 1 = extremely tough), connective tissue (8 = none, 1 = abundant), overall tenderness (8 = extremely tender, 1 = extremely tough) and overall flavor (8 = extremely intense, 1 = extremely bland).

Table 7. Least squares means for sensory panel attributes of juiciness, muscle fiber tenderness, connective tissue amount, overall tenderness and overall flavor intensity

| Item | Overall tenderness$^{e}$ 14-d | Overall tenderness$^{e}$ 35-d | Overall flavor intensity$^{f}$ 14-d | Overall flavor intensity$^{f}$ 35-d |
|---|---|---|---|---|
| *Breed and sex* | .0001$^{d}$ | .0086d | .8691d | .3736$^{d}$ |
| Angus x Brahman steers | $6.8^{b}$ ± .10 | $6.9^{b}$ ± .09 | 4.8 ± .06 | 4.9 ± .05 |
| Sim x steers | $6.3^{a}$ ± .10 | $6.6^{a}$ ± .08 | 4.8 ± .05 | 4.8 ± .04 |
| Sim x heifers | $6.1^{a}$ ± .10 | $6.6^{a}$ ± .08 | 4.8 ± .06 | 4.8 ± .05 |
| *Stocking rate* | .1381$^{d}$ | .2901$^{d}$ | .3542$^{d}$ | .0656$^{d}$ |
| Low | 6.3 ± .11 | 6.8 ± .10 | 4.7 ± .06 | 4.8 ± .06 |
| Medium | 6.3 ± .08 | 6.6 ± .07 | 4.8 ± .05 | 4.8 ± .04 |
| High | 6.6 ± .10 | 6.7 ± .08 | 4.9 ± .06 | 4.9 ± .05 |
| *Stocking method* | .0591$^{d}$ | .3629 | .5737$^{d}$ | .0702$^{d}$ |
| Rotational | 6.5 ± .08 | 6.8 ± .07 | 4.8 ± .05 | 4.9 ± .04 |
| Continuous | 6.3 ± .08 | 6.7 ± .07 | 4.8 ± .04 | 4.8 ± .04 |

$^{ab}$Mean values within a column and followed by the same letter are not significantly different ($P>.05$).
$^{d}$P - value from analysis of variance table.
$^{ef}$Sample evaluated on an 8-point scale for tenderness (8 = extremely tender, 1 = extremely tough), and overall flavor (8 = extremely intense, 1 = extremely bland).

# Reproduction

# REPRODUCTIVE RATE OF RANGE BEEF COWS IN CONVENTIONAL OR LOW BULL TO FEMALE RATIO BREEDING GROUPS

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## Summary

The objectives of this study were to: (1) quantify the relationship of bull to female ratio (BFR) with reproductive performance in extensively-managed herds; (2) confirm that breeding pressure does not skew the calf gender; (3) determine relationships between BFR and change in sperm morphology and bull weight loss during the breeding season; (4) evaluate the repeatability of semen traits and social dominance measurements taken pre- and post-breeding season; and (5) determine the difference in reproductive performance between bull groups with uniform versus extreme variation in social dominance rank in pastures with a conventional BFR. Bonsmara bulls (n = 19; 20-24 mo of age) were joined with multiparous, crossbred females (n = 586) for 90 d in 2003 and 2004. Bulls were allotted by selected physical traits, seminal traits, social rank, and serving capacity to one of two BFR treatments: Conventional (1:21-1:29; n = 6 pastures) or Low (1:47-1:52; n = 2 pastures) BFR. Pregnancy rate ($P = 0.33$), calving rate ($P = 0.26$), and calving date ($P = 0.22$) did not differ between Conventional and Low BFR treatments. Bull to female ratio treatments did not affect the gender ratio of progeny. Post-breeding evaluation of bulls in 2002 (n = 16) indicated that social rank, but not seminal traits, was significantly correlated with pre-breeding values ($P < 0.05$). Changes in sperm morphology or bull weight during the breeding season did not differ between BFR treatment groups. Variation in social dominance rank among bulls within Conventional BFR pastures did not affect reproductive rate. The current study demonstrates that Low BFR can be utilized in single- and multi- sire, pastures of up to 2,090 ha during a 90-d breeding season without adversely affecting reproductive performance.

## Introduction

Bull cost per pound of calf produced influences profitability of commercial cattle operations. Bull expense, fertility level, serving capacity and social dominance rank are factors that ultimately dictate bull cost per calf in multi-sire herds. Employment of a bull to female ratio (BFR) of approximately 1:25 is a conventional practice. However, calf output distribution per bull has generally been demonstrated to be inefficient in multiple-sire herds at conventional BFR levels (Neville et al., 1989; Holroyd et al., 2002; Whitworth, 2002). Reducing the BFR could lead to increased efficiency of bull use in multiple-sire herds, but the potential adverse affects on reproductive performance must be investigated to validate this management practice. We tested the hypothesis that the BFR in single- and multiple-sire breeding groups can be stretched beyond the traditional level of 1:25 without adversely impacting the reproductive performance of the herd.

## Experimental Procedures

This study was conducted at the Texas A&M Agricultural Research and Extension Center in Uvalde, TX. Range conditions at the ranch (6,780 ha) are extensive, and the environment is semi-arid. The current study involved three 90-d breeding seasons (April to July from 2002 to 2004 and the information on the resulting calf crops. Bonsmara bulls (n = 16 for 2002; n = 11 for 2003; n = 14 for 2004; 20-24 mo of age) were obtained at least 2 wk prior to the beginning of each breeding season. Breeding soundness evaluations (BSE) were performed and social dominance rankings were determined both pre- and post-breeding season. Serving capacity tests were conducted before the breeding season. Pre-breeding evaluations were performed the day before the start of the season, and post-breeding evaluations were performed from 2 to 4 wk after the conclusion of the season. Bulls were allotted by physical, reproductive, and behavioral traits to multiple-sire pastures (with the exception of one single-sire pasture) with BFR ranging from 1:16 to 1:53. Sixty to 75 days following conclusion of the breeding season, females were palpated per rectum to determine pregnancy status. Three measures of reproductive performance were evaluated for each breeding group: pregnancy rate, calving rate, and calving date.

*Bull Allotment.* During the three breeding seasons, Bonsmara bulls (n = 41) were assigned to fourteen different breeding pastures. Bulls were joined with crossbred females of varying percentages of Bonsmara, Tuli, Angus, Brahman, and Hereford. In 2002, three mature cow breeding groups (n = 203; 2-12 yr of age) and one heifer group (n = 110; 11-14 mo of age) were utilized at BFR that ranged from 1:16 to 1:22. In 2003, four mature female breeding groups (n = 308; 2-12 yr of age) and one heifer group (n = 106; 11 to 14 mo of age) were utilized at BFR that ranged from 1:24 to 1:53. In 2004, four mature female breeding groups (n = 278; 3-12 yr of age) and one heifer group (n = 193; 11-26 mo of age) were utilized at BFR that ranged from 1:21 to 1:48. The composition of females in each pasture was similar across years. Bulls were assigned to each breeding pasture based on the average motility, serving capacity (number of ejaculates), and social dominance of the group.

*BSE.* Standards employed to determine if a bull was a satisfactory potential breeder followed the Society for Theriogenology's guidelines (Hopkins and Spitzer, 1997). Physical traits measured included body weight (BW), scrotal circumference (SC), body condition score (BCS) and frame score (FS). Body condition score and frame score were based on a scale of one to nine (BIF, 2002). Semen samples were collected by electroejaculation (Electrojac II, Chicago, IL), and the percentage of progressively motile spermatozoa was estimated. Percentage of sperm with normal morphology, percentage of primary abnormalities and percentage of secondary sperm abnormalities were classified according to the standards set by Barth and Oko (1989).

*Social Dominance.* Bulls were randomly allotted into groups (n = 5 to 8 bulls) and allowed to compete for a feed source. Each encounter between bulls was recorded as a win, loss, or tie (Carpenter et al., 1990). Final social rank was based upon the social dominance hierarchy within the entire group of bulls. Post-breeding season social dominance ranking was only available in 2002.

*Serving Capacity.* Bulls were placed with estrus-synchronized females at a ratio of .75-1.4 for 30 min. Copulatory behavior was then assessed by recording the number of mounts (M), intromissions (I), and ejaculations (E). Serving capacity scores were based on total number of E, and classified as low (2 of fewer E), medium (3E), and high (4 or more E). Serving efficiency (SE) was calculated ((M+I+E)/E).

*Conventional vs. Low Bull to Female Ratio.* Breeding groups were allotted to either a Conventional BFR (ranged from 1:21 to 1:29) or a Low BFR (ranged from 1:47 to 1:52). A total of six conventional and two low BFR groups in 2003 and 2004 were compared for differences in pregnancy rate, calving rate, and calving date. Only mature female groups were analyzed statistically. Heifer groups from all three years were also reported (one Conventional and two Low BFR groups). Progeny sex ratios were recorded per pasture, and totaled within Conventional and Low BFR groups. Mean values for BW, BCS, FS, SC, spermatozoa motility, normal sperm morphology, serving capacity, serving efficiency, and social rank did not differ ($P > 0.05$) between Conventional and Low groups (Table 1). To account for variability in number of bulls each year, social dominance rankings were converted into percentages and reported on a scale of one to ten.

*Repeatability of and Relationships among Physical and Reproductive Traits of Bulls.* The repeatability of BW, BCS, FS, SC, percentage of motile spermatozoa, percentage of normal spermatozoal morphology, percentage of primary sperm abnormalities, percentage of secondary sperm abnormalities, and social rank was determined from pre- to post-breeding season in 2002 (n = 16). Bulls from 2002 and 2003 were analyzed for relationships between change in percentage of normal spermatozoal morphology and changes in bull weight and BCS from pre- to post-breeding season (n = 27). Bulls from all three years were evaluated for relationships between breeding pressure (Conventional vs. Low BFR group) and change in percentage of normal morphology (n = 41).

*Uniform vs. Extreme variation in Social Arrangement in Conventional BFR Groups.* Conventional BFR breeding groups comprised of mature cows from 2002, 2003, and 2004 were utilized to determine differences in pregnancy rates among pastures assigned bulls with uniform (n = 5) versus extreme variation (n = 4) in social rank. If a dominant bull was paired with a submissive bull in the same breeding pasture then the group was classified as extreme. If there were no dominant and submissive bulls paired together in the same pasture then the group was classified as uniform.

*Statistical Analysis.* The SAS program (SAS Inst. Inc., Cary, NC) was utilized to analyze all data. Least square (LS) means by BFR group were derived by the GLM procedure to determine treatment differences for pregnancy rate, calving rate, and calving date. Data expressed as a percentage were adjusted to fit a normal, independent distribution by an arcsine transformation. Progeny gender ratio by BFR group was analyzed using chi-square distribution frequency analyses. The GLM procedure was used to compare LS means for physical, reproductive, and behavioral traits of bulls allotted to either Conventional or Low BFR groups. Differences in pregnancy rates between uniform and extreme social rank groups were determined by LS means. Pearson correlation coefficients were utilized to determine the repeatability between pre- and post-breeding season bull traits and the relationship between change in sperm morphology and change in bull weight or BCS. Changes in percentage of normal sperm morphology, bull weight or BCS between Conventional and Low BFR groups were analyzed by LS mean differences using the GLM procedure.

## Results and Discussion

*Conventional vs. Low Bull to Female Ratio.* Pregnancy rate, calving rate, and mean calving date of mature cows did not differ ($P > 0.20$) between BFR treatments (Table 2). In the heifer groups (yearling and first-calf heifers), the average pregnancy rate in two Low BFR groups (82.8%) was similar to the pregnancy rate in the Conventional BFR group (82.0%). The ratio of male to female progeny did not differ ($P > 0.10$) from the expected 50:50 ratio in either the Conventional or Low BFR groups.

In single-sire mating groups, Neville et al. (1979) demonstrated that lowering the BFR from 1:25 to 1:40 had no adverse affects on pregnancy rates, and Rupp et al. (1977) reported a similar conclusion when BFR was lowered to 1:44 or 1:60. In extensive, multiple-sire pastures, the BFR can be reduced to 2.5% (1:40) without detrimental effects upon calf output (Fordyce et al., 2002). The findings in our study are in agreement with previous results for both single- and multiple-sire breeding groups. However, the criteria that are necessary to achieve success with a reduced BFR must be defined. Bull groups used in the current study were in moderate body condition, classified as satisfactory by a BSE, and averaged a moderate serving capacity classification.

There are numerous variables, which could potentially impact the success or failure of reducing BFR below conventional levels. It is possible, that in this study and in the Australian study (Fordyce et al., 2002), that not all females were cycling at the beginning of the breeding season and thus estrus frequency and mating demand would have been diluted over a longer span of time. Investigations into optimal BFR for estrus-synchronized females exposed to multiple-sires lend insight into possible limitations of a reduced BFR if all females are cycling at the beginning of the breeding season. Healy et al. (1993) determined that the optimal BFR level is 1:25 with estrus synchronized females (83% pregnancy rate during the 28-d breeding season). The authors reported a 6% decrease in pregnancy rate when BFR was increased to 1:50. Although pregnancy rates were comparable for females subjected to a BFR of 1:16, the females calved three days sooner than females in the BFR treatment of 1:25, but an economic analysis indicated that the BFR group of 1:25 yielded the highest return (Healy et al., 1993). It is likely that strict serving capacity standards must be employed for bull candidates utilized in low BFR groups. In the current study, all bulls used in Low BFR treatments had serving capacity scores of ≥ 2.

The ability of bulls to detect all females in estrus is a potential concern of low BFR groups. Beerwinkle (1974) indicated that estrus detection rate was 95% at a BFR of 1:30, but only 64% at a BFR of 1:60. In contrast, Rupp et al. (1977) reported that estrus detection accuracy was adequate at BFR up to 1:60. The attraction of estrus females to sexually active groups helps negate the inability of bulls to seek out all females in estrus. In fact, bulls with the least range of movement sire the greatest proportion of calves (Fordyce et al., 2002). These results suggest that sexually active groups of females attract bulls, and the social behavior of bulls that have limited range of movement facilitates their ability to sire more calves. However, a potential obstacle to the formation of these sexually active groups could be pastures with high herd dispersion due to extensive stocking rates. The current study involved two Low BFR pastures of 2,090 ha and 1,049 ha, respectively. The Australian study utilized low BFR paddocks up to 6,000 ha size (Fordyce et al., 2002). Neither study found adverse effects of low BFR in extensive pastures on calf output.

Fordyce et al. (2002) concluded that herd dispersion is a critical variable in the effectiveness of potentially reducing the BFR. Dispersion differences could be attributed to the size of the pasture, the number and location of watering points, the topography, tree or brush density, forage quality, and weather extremes. The analysis of range use with GPS technology in the Edwards Plateau and Rio Grande Plains region in Texas indicated that all ranches had uneven grazing distribution problems (Lyons et al., 2005). Collectively, variation in herd dispersion and breeding pressure may create challenges for bulls to mate at an optimal time. It has been suggested that the timing of insemination relative to ovulation may influence the gender ratio of progeny (Baublits et al., 2003). However, the gender ratio of progeny did not differ between Low and Conventional BFR groups in the current study. Although differences between treatments were not found for average calving date, Low BFR groups calved an average of 8 d later than Conventional BFR groups. Future studies should investigate the possibility of delayed conception with reduced BFR.

*Repeatability of and Relationships among Physical and Reproductive Traits of Bulls.* The repeatability of bull traits before and after the 90-d breeding season was analyzed ($n = 16$). Only pre-breeding bull weight ($r = 0.66$), scrotal circumference ($r = 0.81$), and social rank ($r = 0.55$) were significantly correlated with the post-breeding measurement (Table 3).

The current study failed to find a relationship between BFR treatment and change in sperm morphology. In addition, sperm morphology was not correlated to a change in BW or BCS. Furthermore, there were no significant relationships between BFR treatment and changes in BW or BCS during the breeding season. These data are in agreement with results from an Australian study (Fordyce et al., 2002). The authors determined that the "harder working" bulls (bulls that sired the greatest proportion of calves) had no relationship with body condition loss. Additionally, the bulls in low BFR pastures (1:40) maintained body condition, while bull attrition occurred in conventional BFR pastures. The authors attributed the attrition to heightened agonistic behavior between bulls with a higher ratio of bulls to females. Multiple grazing-time studies have concluded that breeding pressure does not affect daily grazing length (Raadsma et al., 1983; Boyd et al., 1989). Collectively, these results support the theory that weight and body condition losses during the breeding season are not limiting factors in the decision to reduce the BFR below conventional levels.

There is limited information regarding the repeatability of social dominance tests amongst bulls. The current study indicates that social ranking is repeatable before and after a 90-d breeding season (r = .55). Sperm motility has been shown to be moderately repeatable on an annual basis (r = .44) (Fitzpatrick et al., 2002), and unchanged during 4-d intervals (Coulter and Kozub, 1989). Sperm motility can be higher after mating activity (Chacón et al., 2002) and may explain, in part, the low correlation between pre- and post- breeding spermatozoal motility. Pre- and post-breeding spermatozoal morphology, primary abnormalities, and secondary abnormalities were not significantly correlated. Seasonal effects could have accounted for the lack of correlation between a late spring, pre-mating seminal evaluation and a mid-summer post-evaluation. Environmental effects can cause fluctuations in sperm morphology (Johnson, 1997).

*Uniform vs. Extreme Variation in Social Arrangement in Conventional BFR Groups.* Each multiple-sire breeding group was classified as either Uniform or Extreme in their social arrangement. Only the Conventional BFR groups comprised of mature cows from 2002, 2003, and 2004 were analyzed (n = 9). Social arrangement had no affect on pregnancy rate (P = 0.72), calving rate (P = 0.72), or calving date (P = 0.84).

Although it has been demonstrated that social dominance is highly related to the proportion of calves sired per individual bull in multiple-sire groups (Coulter and Kozub, 1989; Fordyce et al., 2002; Whitworth et al., 2002), the effect of variations in social arrangement between groups on total pregnancy rate has not been reported. In the current study, uniform versus extreme variation in social behavior groupings yielded no difference in pregnancy rate when comparing Conventional BFR groups. Likewise, variation in social behavior between bulls in the multiple-sire Low BFR group was uniform and high pregnancy rates were obtained (98.06%). Social variations among bulls within the same breeding group are of less significance with regard to pregnancy rate when BFR is lowered (Carpenter et al., 1990).

## Implications

The results from the current study demonstrate that the BFR can be reduced to unconventional levels (1:47 to 1:52) in extensive pasture with a 90-d breeding season without adversely affecting pregnancy and calving rates. Selection pressure for bulls with adequate fertility must be utilized to ensure a high reproductive rate. Inclusion of socially submissive with socially dominant bulls in multi-sire groups at a Conventional BFR does not appear to reduce overall pregnancy or calving rates. Increasing breeding pressure on bulls was not associated with a greater decrease in body weight, BCS, or percentage normal sperm, which further supports the reduction in BFR to less conventional levels. However, caution should be exercised in the application of unconventional BFR in herds where estrus synchronization protocols are used to maximize the number of females that are cycling at the beginning of the breeding season.

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Table 1. Means for physical, reproductive, and behavioral traits of bulls allotted to either Conventional or Low bull to female ratio (BFR) groups

| | BFR | | Pooled | |
|---|---|---|---|---|
| | Conventional | Low | SEM | P-Value |
| Weight (kg) | 595.4 | 586.3 | 13.28 | 0.793 |
| Body condition score | 5.5 | 5.5 | 0.13 | 0.967 |
| Frame score | 5.9 | 6.5 | 0.13 | 0.962 |
| Scrotal circumference (cm) | 37.8 | 37.8 | 0.73 | 0.968 |
| Spermatozoal motility (%) | 67.2 | 75.0 | 4.34 | 0.500 |
| Normal morphology (%) | 77.3 | 90.0 | 2.08 | 0.051 |
| Serving capacity | 2.3 | 2.5 | 0.20 | 0.684 |
| Serving efficiency | 5.11 | 3.99 | 0.34 | 0.235 |
| Social rank[a] | 5.7 | 5.1 | 0.60 | 0.527 |

[a] Adjusted to a scale of 1 to 10

Table 2. Reproductive performance of mature female groups assigned to Conventional or Low bull to female ratio (BFR) groups

| | BFR | | Pooled | |
|---|---|---|---|---|
| | Conventional | Low | SEM | P-Value |
| Pregnancy rate (%) | 90.68 | 94.78 | 0.56 | 0.33 |
| Calving rate (%) | 90.39 | 94.78 | 0.56 | 0.26 |
| Calving date[a] (d) | 308 | 316 | 3.41 | 0.22 |

[a] Interval from start of breeding until calving

Table 3. Repeatability of physical and reproductive traits of bulls pre- and post-breeding season

| | Body Weight | BCS[a] | SC[b] | Spermatozoa % Motile | Spermatozoa % Normal | % Primary Abnorm. | % Secondary Abnorm. | Social Rank |
|---|---|---|---|---|---|---|---|---|
| r | 0.66** | 0.18 | 0.81*** | 0.12 | 0.35 | 0.36 | 0.25 | 0.55* |

*** P < 0.001
** P < 0.01
* P < 0.05
[a] Body condition score
[b] Scrotal circumference

# RELATIONSHIP OF REPRODUCTIVE TRACT SCORES IN HEIFERS WITH TWO-YEAR REPRODUCTIVE PERFORMANCE

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## Summary

The objectives of this study were to: (1) determine the influence of age, dam parity, frame score, weaning weight, post-weaning weight gain, and yearling weight on reproductive tract scores (RTS); (2) determine the relationship between RTS and two-year reproductive performance of heifers placed in natural service, multiple-sire breeding groups in an extensively managed environment; and (3) establish whether RTS assigned at the start of the breeding season can be used to identify heifers that should be culled. Yearling, one-half or three-quarter Bonsmara heifers (n = 106; 11-14 mo of age) were palpated per rectum and assigned a reproductive tract score (RTS) immediately prior to the beginning of the breeding season. Reproductive performance was measured in their two subsequent breeding years in order to estimate the value of the RTS system in extensively-managed, natural mating, 90-d breeding season programs. RTS was positively correlated ($P < 0.01$) with frame score ($r = 0.25$), age ($r = 0.31$), weaning weight ($r = 0.47$), and the weight of the heifer on the day of RTS exam ($r = 0.56$). The RTS means by dam parity also differed ($P < 0.03$). A lower ($P < 0.01$) percentage of females conceived during each of their first two breeding seasons for heifers of RTS 1 and 2 (65%) than for heifers of RTS 3, 4, and 5 (91.2%). Females with a RTS of 1 had a lower pregnancy rate over each of their first two breeding seasons ($P < 0.05$), conceived later during their first breeding season ($P = 0.06$), weaned lighter first calves ($P < 0.05$), and remained lighter each year for fall body weight and body condition score than did heifers with RTS of 2 to 5 ($P < 0.05$). The results indicate that heifers with a RTS of 1 immediately prior to a 90-d breeding season should be culled. Consideration should also be given to eliminating RTS 2 heifers, but further studies will be needed to confirm the potential economic advantage of this practice.

## Introduction

It is imperative that replacement heifers reach puberty early and conceive early in the breeding season, as these females will be more likely to remain in the breeding herd and will produce more pounds of calf in their lifetime than heifers calving later (Lesmeister et al., 1973). The reproductive tract scoring system is a classification system which assesses the development of the uterus and ovarian activity of heifers prior to their virgin breeding season. The five-point scale was designed by researchers at Colorado State University to aid producers in management decisions regarding the selection of replacement heifers (Lefever and Odde, 1986). However, application has been minimal as only 1% of beef cattle operations in the United States utilize RTS (Field and Taylor, 2003), and its value has not been quantified in 90-d, natural mating programs. We tested the hypothesis that RTS are effective in estimating subsequent two-year reproductive performance in 90-d, natural mating breeding systems.

## Experimental Procedures

This study was conducted at the Texas A&M Agricultural Research and Extension Center in Uvalde, TX. Range conditions at the ranch (6,780 ha) are extensive and the environment is semi-arid. The current study involved the development of replacement heifers (n = 106) and the information on their resulting reproductive performance through 3.5 yr of age. The Bonsmara-sired heifers were born at the ranch between January 21 and May 2, 2002. A portion of the heifer calves (n = 26) were produced from first-calf heifer dams, and their breed composition was three-quarter Bonsmara and one-quarter Brahman, Tuli, or Angus or crosses thereof. The remaining heifer calves (n = 80) were produced from mature cow dams and their breed composition was one-half Bonsmara and one-half Brahman, Tuli, or Angus or crosses thereof. After weaning at approximately 7 mo of age, the heifers were retained in a dry lot for 30 d and fed 8 lb per day of an 11% CP concentrate and *ad libitum* access to sorghum hay. At the beginning of the 30-d dry lot period, an anthelmintic pour-on was administered, and calves were immunized with an injection of a 7-way clostridial and of CattleMaster® GOLD™ (BVD type 1 & 2, IBR, BRSV, $PI_3$). After the 30-d dry lot period, the heifer calves were grazed on native range pasture until December 10, 2002 at which time they were placed on oat pasture until June, 2003. During both the native range and oat grazing periods, the heifers were supplemented with 12 lb of 20% CP cottonseed cake $hd^{-1}$ $wk^{-1}$.

Heifer age, dam parity, frame score (FS), weaning weight (WW), weight on the first day of the virgin breeding season (RTSwt), and weight gain from weaning until the first day of the breeding season (PostWW) were recorded. Heifers were palpated per rectum on the first day of their virgin breeding season (11 – 14 mo of age), and assigned a RTS according to the description (Table 1) outlined by LeFever and Odde (1986).

Heifers were managed as a group during 90-d breeding seasons both years within a 973.9 ha multiple-sire pasture. They were placed with Bonsmara bulls, (20-24 mo of age), at a BFR of 1:53 during year 1 and 1:48 during year 2. Sixty days following the conclusion of the breeding season females were palpated per rectum to determine pregnancy state. At this time, BCS and weights were assessed and measured on the females during both years. At calving, birth weight (BW) and a subjective calving ease score (1 to 4) was recorded during year one. Estimated conception dates were determined by subtracting 282 days from each female's calving date. Actual calf weaning weights were recorded during year one and kgs of calf weaned per exposed female was calculated.

*Statistical Analysis.* The SAS program (SAS Inst. Ins., Cary, NC) was utilized to analyze all data. Pearson correlation coefficients were used to assess the relationships of RTS with the traits measured prior to the beginning of the virgin breeding season (Age, Dam, FS, WW, PostWW, and RTSwt) by using the Corr procedure of SAS. Least squares means or each trait within each RTS classification were derived by the GLM procedure and differences were determined by ANOVA. The independent variables with the lowest F-values were sequentially deleted from a regression model until a model which best predicted the dependent variable (RTS) was derived. RTS was then used as the independent variable. To assess the predictive value of RTS, GLM procedures were used to compare differences between two-year pregnancy status relative to RTS. Two RTS groups (RTS group) were also analyzed by combining RTS 1 and 2, and comparing them against RTS 3, 4, and 5 for two-year pregnancy status. Both RTS and RTS group were treated as main effects in GLM procedures to determine differences in conception date, calf weaning weight, calf birth weight, calving score, BCS, fall cow weight, and kg of calf weaned per exposed female. Pearson's Chi-Square test was used to determine differences in the percentage of heifers that conceived during each 30-d interval of the breeding season. A regression analysis was conducted with the independent variables (Age, RTSwt, and RTS) in an attempt to fit a model that could predict pregnancy status over both years.

## Results and Discussion

Frame score ($r = 0.25$), age ($r = 0.31$), WW ($r = 0.47$), and RTSwt ($r = 0.56$) were positively correlated ($P < 0.008$) with RTS. No correlation was found between RTS and postWW. More specifically, heifers that received an RTS of 1 were lighter at weaning ($P = 0.03$) and on the day of the RTS exam ($P < 0.01$) than heifers in all other RTS scores (Table 2). Age only differed between RTS 1 and RTS 3, thus RTS 1 heifers were younger ($P < 0.01$) than RTS 3 heifers. Frame score was smaller ($P < 0.01$) for RTS 1 versus RTS 2 and 3 heifers.

The RTS means differed ($P = 0.03$) between heifers by first-calf heifer dams and heifers by mature cow dams. However, when either the WW of the heifers or the RTS weight of the heifers was included in the ANOVA model, dam parity was not predictive of RTS. A full model predicting RTS with the independent variables (dam parity, age, WW, post WW gain, RTS weight, and FS) was analyzed ($R^2 = 0.25$). Analysis of the full model indicated that age ($P = 0.01$) and RTS weight ($P < 0.01$) were the two variables most predictive of RTS. These two variables were combined to yield the reduced model, RTS = -8.12 + .0116 Age + .0174 RTS weight ($R^2 = 0.35$).

This study is among the first to evaluate the relationship between various pre-breeding measurements of heifers and RTS. If RTS is accepted as being a valuable selection tool for replacement heifers, as demonstrated in the current study, then it is helpful to understand which traits ultimately affect the outcome of the RTS exam. From a management perspective, these traits could be more critically monitored to facilitate an early decision on which females to retain and develop as replacements after weaning. The data suggest that the weaning weight of the heifers moderately affected the eventual RTS outcome. Weaning weight had higher predictive value than did age, although both were linked to RTS. Interestingly, FS also affected RTS but to a lesser degree. It is understood that smaller-framed cattle are earlier maturing, and thus should generally attain puberty at a younger age. However, our results show a positive correlation between RTS and FS, rather than a negative correlation. This apparent discrepancy could be due to the fact that in this study the heifers were subjectively assessed for FS by an evaluator instead of by hip height and age (BIF, 2002). The evaluator did not know ages during the evaluation, and thus it is likely that there was a tendency to evaluate all cattle as though they were equal in age. Furthermore, it is likely that plane of nutrition under these extensive conditions could have limited both growth (weight and height) and pubertal development, thus explaining the relationships found in this study.

The final ANOVA model encompassing pre-breeding traits only explained a modest percentage of the variation in RTS ($R^2 = 0.35$). This model included age and RTSwt. To reduce the error term we could have measured other environmental and genetic factors. For example, there is a known relationship between the sire's scrotal circumference and the age at which puberty is obtained in his daughters (Smith et al., 1989). In the current study sire information was unavailable because the heifers were produced in multiple-sire pastures.

Table 3 displays pregnancy rate by RTS for the female's virgin breeding season (Year 1), and their second breeding season (Year 2). Although pregnancy rate did not differ ($P > 0.10$) by RTS, the pregnancy rate distribution across RTS classification was consistent between years. When comparing RTS to the female's pregnancy status over their first two years (Table 4), it is interesting to note the downward pattern in the percentage of females that were deemed pregnant both years. All RTS 4 and 5 females, 87.5% of the RTS 3 females, 65.2% of the RTS 2 females, and only 61.2% of the RTS 1 females were pregnant both years. However, only RTS 1 heifers differed from RTS 3 ($P < 0.01$), RTS 4 ($P < 0.04$) and RTS 5 ($P < 0.09$) heifers among females that were pregnant in both years 1 and 2.

First-year pregnancy rate tended to be lower ($P < 0.10$) for RTS group 1 (81.9%, RTS 1 and 2 females) than for RTS group 2 (94.1%, RTS 3, 4, and 5 females). There was a difference ($P < 0.05$) between RTS group 1 (75.0%) and RTS group 2 (91.2%) for year two pregnancy status. Additionally, RTS group 1 (62.5%) excelled ($P < 0.01$) RTS group 2 (91.2%) in the percentage diagnosed pregnant both years as opposed to being non-pregnant either year or both years.

Date of conception was inversely associated with RTS during year 1 ($P = 0.07$), but not during year 2 (data not shown). Heifers with a RTS of 1 conceived later in the first breeding season than RTS 4 heifers ($P = 0.06$). Using a simple linear regression model, RTS did predict date of conception ($P = 0.004$), however only 9% of the variation was explained ($R^2 = 0.09$). Logically, RTS was also predictive of the conception date when grouped by 30 d intervals during the breeding season ($P = 0.02$; Table 5). Heifers classified as an RTS of 1 were less likely to conceive within the first 30 d of the breeding season compared to RTS 3, 4, and 5 heifers ($P < 0.05$).

Calf weaning weight during year 1 tended to increase ($P = 0.12$) in association with increased RTS. RTS did not significantly affect kg of calf weaned per exposed female. There were no significant relationships for RTS with either calf birthweight or calving ease score. Heifer body weight at pregnancy determination in the fall differed by RTS in both year 1 ($P < 0.02$), and year 2 ($P < 0.05$, data not shown). The BCS of the females at pregnancy determination also differed by RTS for both year 1 ($P < 0.02$) and year 2 ($P < 0.02$, data not shown).

Researchers have quantified the link between RTS and subsequent pregnancy status during the first breeding season for synchronization/AI programs, followed by a 60-d single-sire natural service system (LeFever and Odde, 1986; Pense and BreDahl, 1999; Williams, 2001). However, we are not aware of any literature regarding extensively-managed replacement heifers which are allotted to natural service, multiple-sire breeding pastures, for 90-d breeding seasons. Likewise, we were unable to locate any reports that investigated the utility of implementing the RTS system as a selection tool at the beginning of the breeding season, instead of 30 to 60 d before the start of breeding. Furthermore, the relationship between RTS and dystocia, calf weaning weight, second-year pregnancy status, or cow weight and BCS patterns during subsequent years has not been previously reported. This study validates the value of the RTS system as a selection tool when making management decisions regarding replacement heifers immediately before the start of a natural service, 90-d breeding season. However, future studies encompassing additional variables will be necessary in order to more accurately explain lifetime reproductive performance based upon replacement heifer traits. Lesmeister et al. (1973) presented data which indicated that heifers calving earlier in their initial calving season produce more pounds of calf in their lifetime than heifers calving later. Furthermore, the authors concluded that most of the difference in average annual lifetime production was associated with increased production at the first calving.

It has been recommended that more than 50% of the heifers should be cycling (RTS 4 and 5) 30 d prior to the beginning of a synchronization program to ensure that a large portion of females will be detected in estrus (Torrel et al., 1996). In the current study, only 9.4% of the heifers were deemed pubertal and thus cycling on the first day of the breeding season, yet 85.5% of the entire group of heifers became pregnant during their virgin, 90-d breeding season. This illustrates that, in fact, reasonable pregnancy results can be achieved in a natural mating, 90-d breeding season even if the majority of the heifers are not cycling at the start of breeding. At the end of the breeding season, females ranged from 14 to 17 mo of age. However, a closer look at the individual RTS scores reveals that RTS 1 heifers were less likely to become pregnant both as heifers and as first-calf heifers. The RTS 1 heifers conceived later in the breeding season and had lighter calves at weaning. Additionally, RTS 1 heifers had lighter body weight at 2 yr of age and a lower body condition score at the time of pregnancy determination during each fall than heifers with RTS > 1 which further jeopardized the ability of these females to rebreed in subsequent years. Consequently, the evidence supports the recommendation that heifers with a RTS of 1 should be culled from the breeding herd. If sold as a short-yearling, these immature heifers would likely be treated as other feeder cattle and should not receive price discounts versus retention of a heifer that fails to reproduce and is later culled. Additionally, this would spare the owner additional expenses associated with heifer development and breeding.

When data for RTS 1 and 2 heifers were pooled, lower pregnancy rates were found during year 1 (81.9%), year 2 (75.0%), and both years combined (62.5%) when compared with RTS 3, 4, and 5 heifers. If traditional culling standards were practiced, (e.g., any non-pregnant female after the breeding season would be culled) these culling rates would clearly not be acceptable. However, in the current study pregnancy rate, breeding date, and calf weaning weight for RTS 2 heifers were not significantly lower than for RTS 3, 4, and 5 heifers. Future studies are needed to ascertain the potential value of retaining or culling heifers with an RTS of 2 under these conditions.

## Implications

The value of the RTS system in estimating two-year reproductive performance for replacement heifers utilized in a 90-d, natural mating breeding season has been validated in the current study. The weight of the heifers on the date of RTS assignment, weaning weight, age, frame score, and dam parity affected the ultimate RTS outcome of yearling heifers. RTS 1 heifers were less likely to conceive in both years, they conceived later in the first year, and they weaned lighter calves their first year. Furthermore, the RTS 1 females had lighter body weight as 2-yr-olds and lower BCS after each of the first two breeding season which would further jeopardize their long term rebreeding potential. These results indicate that heifers that receive a RTS of 1 on the first day of a 90-d, natural mating breeding season should be culled from the breeding herd. Consideration should also be given to eliminating RTS 2 heifers, but further studies will be needed to confirm the potential economic advantage of this practice.

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Table 1. Description of reproductive tract scores (RTS)

| RTS | Uterine Horns | Ovaries: Approximate Size Length (mm) | Height (mm) | Width (mm) | Follicle Diameter |
|---|---|---|---|---|---|
| 1 | Immature <20mm diameter – no tone | 15 | 10 | 8 | <8 |
| 2 | 20 – 25 mm diameter – no tone | 18 | 12 | 10 | 8 mm |
| 3 | 25 – 30 mm diameter – good tone | 22 | 15 | 10 | 8 – 10 mm |
| 4 | 30 mm diameter – good tone – erect | 30 | 16 | 12 | >10 mm CL[a] possible |
| 5 | >30mm diameter – good tone - erect | >30 | 16 | 12 | >10 mm CL[a] present |

[a] corpus luteum

Table 2. Least square (LS) mean age, weight, and frame score measurements of heifers by reproductive tract score (RTS)

| RTS | Number of heifers (%) | LS means WW[a] (kg) | Post WW[b] (kg) | RTS wt[c] (kg) | Age[d] (d) | Frame score |
|---|---|---|---|---|---|---|
| 1 | 49 (46.2%) | 217.7[e] | 65.80 | 282.9[g] | 406.00[g] | 5.06[g] |
| 2 | 23 (21.7%) | 251.8[f] | 67.40 | 319.2[h] | 414.00 | 5.82[h] |
| 3 | 24 (22.6%) | 261.6[f] | 66.80 | 328.3[h] | 421.00[h] | 5.83[h] |
| 4 | 6 (5.7%) | 276.1[f] | 59.40 | 335.6[h] | 421.00 | 5.50 |
| 5 | 4 (3.8%) | 258.0[f] | 62.50 | 320.5[h] | 418.00 | 5.75 |
| Pooled SEM | | 7.79 | 6.31 | 5.67 | 4.17 | 0.22 |

[a] Weaning weight
[b] Post weaning weight gain until the date the RTS exam was administered
[c] Weight the day the RTS exam was administered
[d] Age when the RTS exam was administered
[e, f] Means with unlike superscripts within column differ ($P = 0.03$)
[g, h] Mean with unlike superscripts within column differ ($P < 0.01$)

Table 3. Pregnancy rate during year 1 and year 2 by reproductive tract score (RTS) (n =106)

| RTS | Pregnancy rate (%) Year 1 | Year 2 |
|---|---|---|
| 1 | 79.5 | 73.5 |
| 2 | 87.0 | 78.3 |
| 3 | 91.7 | 87.5 |
| 4 | 100.0 | 100.0 |
| 5 | 100.0 | 100.0 |

Table 4. Two-year pregnancy outcomes by reproductive tract score (RTS)

| | Two-year pregnancy status totals (%) | | | | |
|---|---|---|---|---|---|
| RTS | PP[a] | PN[b] | NP[c] | NN[d] | Total |
| 1 | 30 (61.2%)c | 9 (18.4%) | 6 (12.2%) | 4 (8.2%) | 49 |
| 2 | 15 (65.2%) | 5 (21.7%) | 3 (13.0%) | 0 (0.0%) | 23 |
| 3 | 21(87.5%)f | 1 (4.2%) | 0 (0.0%) | 2 (8.3%) | 24 |
| 4 | 6 (100.0%)f | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) | 6 |
| 5 | 4 (100.0%)g | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) | 4 |
| Total | 76 | 15 | 9 | 6 | 106 |

[a-d] Pregnant both year 1 and year 2, Pregnant year 1, but non-pregnant year 2, Non-pregnant year 1, but pregnant year 2, Non-pregnant both year 1 and year 2, respectively
[e, f] Values with unlike superscripts differ ($P < 0.05$)
[e, g] Values with unlike superscripts differ ($P < 0.10$)

Table 5. Percentage of heifers that conceived within 30-d intervals during the virgin breeding season by reproductive tract score (RTS)

| | | Heifers that conceived By 30-d intervals (%) | | | Heifers that failed to conceive |
|---|---|---|---|---|---|
| RTS | n | Day 0-30 | Day 31-60 | Day 61-90 | (%) |
| 1 | 49 | 26.5[a] | 34.7 | 16.3 | 20.4 |
| 2 | 23 | 30.4 | 52.2 | 4.3 | 13.0 |
| 3 | 24 | 50.0[b] | 41.7 | 0.0 | 8.3 |
| 4 | 6 | 83.3[c] | 16.7 | 0.0 | 0.0 |
| 5 | 4 | 75.0[b] | 25.0 | 0.0 | 0.0 |

[a, b] Values with unlike superscripts within column differ ($P < 0.05$)
[a, c] Values with unlike superscripts within column differ ($P < 0.01$)

# SYNCHRONIZATION OF FOLLICULAR WAVE EMERGENCE, LUTEAL REGRESSION, AND OVULATION FOR FIXED-TIME ARTIFICIAL INSEMINATION OF BRAHMAN COWS

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## Summary

This study was designed to compare the use of a controlled internal drug release (CIDR) insert and prostaglandin $F_{2}\alpha$ (PGF) in combination with either estradiol 17β and progesterone or gonadotropin releasing hormone (GnRH) on pregnancy rate to fixed-time artificial insemination (FTAI) in Brahman cows. A protocol that incorporated estradiol 17β and progesterone with a CIDR insert resulted in a higher pregnancy rate to FTAI in lactating and non-lactating Brahman cows than a CIDR plus GnRH protocol. Results indicate that acceptable pregnancy rates can be attained in lactating and non-lactating Brahman cows after timed-insemination. Results of this study also verify the utility of CIDR inserts in estrous synchronization protocols for FTAI in Brahman cows. The more efficacious protocol was also more cost effective.

## Introduction

*Bos indicus* cattle have made significant contributions and are an integral part of beef cattle industries in tropical and subtropical parts of the world. The use of AI represents the most economical and viable tool to advance genetic progress in cattle in these environments. AI is most efficient when used in combination with estrous synchronization; however, the challenge of effective estrus detection limits the success of AI in *Bos indicus* cattle.

Duration of estrus in *Bos indicus* cattle has been reported to be shorter than in *Bos taurus* cattle with an average duration of about 10 h (Galina and Arthur, 1990). *Bos indicus* cattle also have a particular behavior and temperament that makes estrus detection even more difficult. A greater incidence of "Silent" estrus and a lower number of mounts during estrus have been reported in Brahman crossbred cows compared to Charolais cows (Galina et al., 1982). Social hierarchy also appears to play a role in the expression of estrus as the interval from PGF treatment to behavioral estrus was longer in dominant Brahman cows compared to subordinates (Landaeta-Hernandez et al., 2002). Complicating the situation is the fact that *Bos indicus* cattle tend to display signs of estrus during the night. Pinheiro et al. (1998) reported that 54% of Nelore cows initiated estrus at night and 30% started and finished behavioral estrus during the night. All these factors help to explain the poor estrus detection rates in AI programs of *Bos indicus* cattle.

Another factor that limits the efficiency of AI programs in not only *Bos indicus* cattle, but all cattle, is the number of cyclic animals at the start of the breeding season. Only 30 to 50% of cows may be estrous cycling at the start of breeding in many herds (Yelich et al., 1995). Recent research suggests that the addition of progesterone to estrous synchronization protocols can induce cyclicity in postpartum cows. Lucy et al. (2001) reported that CIDR inserts increased the percentage of cattle in estrus and pregnant during the initial days of the breeding season while using a protocol that included a 7-d CIDR treatment with PGF injected on d 6 of the CIDR treatment. This treatment was effective in both cyclic and acyclic females and pubertal and prepubertal heifers.

In order to address the problems of non-cycling females at the initiation of the breeding season and the low rate of estrus detection in *Bos indicus* cattle, it appears that the addition of progesterone to an estrous synchronization protocol that also controls the time of ovulation and allows for fixed-time insemination is necessary. It has been proposed that ovulation can be synchronized by inducing synchronous emergence of a new follicular wave in concert with control of the luteal phase (Martinez et al., 2000). Synchronous follicle growth should result in synchronous ovulation when the suppressive effect of progesterone is removed.

Progesterone has been included in synchronization systems to suppress estradiol-induced LH release (Bo et al., 1994). In progestogen-treated heifers that received 5 mg of estradiol 17β, a new follicular wave emerged in an average of 4.3 d regardless of the stage of development of the dominant follicle at the time of treatment. Gonadotropin-releasing hormone (GnRH) or its analogs have also been used in several studies to synchronize follicular wave emergence and ovulation. GnRH induces ovulation of large antral follicles with a new follicular wave emerging approximately 2 d later (Martinez et al., 2002). However, synchronous emergence of a new follicular wave occurs only when treatment causes ovulation.

The objectives of this study utilizing Brahman cows were to: (1) compare the effects of E17 or GnRH in combination with a CIDR insert on pregnancy rate to fixed-time AI, (2) determine the retention rate of the CIDR insert, and (3) compare the cost per pregnancy between synchronization protocols that combined either E17+P4 or GnRH with a CIDR insert and PGF.

## Experimental Procedures

Multiparous, lactating and non-lactating Brahman cows (n = 138) maintained on coastal bermudagrass pasture were used in this study. Calves at side ranged in age from 1 to 5 mo. Calving records were not available, so cows were allotted into two postpartum groups by visual appraisal of the age of the calf. Body condition scores of cows were recorded at the time of treatment.

Cows were randomly allotted within postpartum group to one of two treatments. The treatment groups consisted of one synchronization protocol incorporating estradiol 17β (E17), progesterone (P4, Med-Shop Pharmacy, Longview, TX), prostaglandin $F_2\alpha$ (PGF; ProstaMate, RXVeterinary Products, Grapevine, TX), and controlled internal drug release (CIDR; Pharmacia & Upjohn, Kalamazoo, MI) inserts. The second synchronization protocol utilized gonadotropin-releasing hormone (GnRH; OvaCyst, Phoenix Scientific, St. Joseph, MO), PGF, and CIDR inserts. The first treatment group (E17) received a CIDR insert in addition to an injection (i.m.) of E17 (2.5 mg) and P4 (50 mg) at the initiation of treatment (d 0). CIDR inserts were removed, and an injection (i.m.) of PGF (25 mg) was administered on d 7. A second injection (i.m.) of E17 (1 mg) was administered on d 8, and cows were inseminated 30 hr later on d 9. Cows in the second treatment group (GnRH) received a CIDR insert in addition to an injection (i.m.) of GnRH (100 μg) at the initiation of treatment (d 0). An injection (i.m.) of PGF (25 mg) was administered on d 6, and CIDR inserts were removed on d 7. Cows received a second injection (i.m.) of GnRH (100 μg) at the time of insemination 48 hr after CIDR removal on d 9.

All cows were inseminated with two 0.5 mL units of frozen-thawed semen from a single sire by a single technician. Detection of estrus was conducted by application of paint to the tail head using a paint stick at the time CIDR inserts were removed. Absence of the paint at the time of insemination indicated the cow had been mounted associated with estrus.

Cows remained in their respective treatment groups and were placed with fertile bulls in pasture for the purpose of natural mating for 75 d beginning 14 d after insemination. The bull to cow ratio was approximately 1:17 for both groups. Transrectal ultrasonography was utilized to determine pregnancy 30 d after bull removal.

Data were analyzed using the Statistical Analysis System (SAS Inst. Inc., Cary, NC). Synchronized estrus rate, pregnancy rates, percentage of non-pregnant estrous cycling cows, body condition, days postpartum, and percentage of non-lactating cows were analyzed by chi-square analysis using the frequency procedure of SAS. Pregnancy rate to FTAI was calculated by dividing the number of cows pregnant to AI by the number of cows inseminated. Pregnancy rate to natural service was calculated by dividing the number of cows pregnant to natural service by the number of cows inseminated that did not conceive to AI. Final pregnancy rate was calculated by dividing the number of cows pregnant to AI and natural service combined by the number of cows inseminated.

Estrous cyclicity of cows that were not pregnant at the pregnancy examination was determined by ovarian examination using transrectal ultrasonography. Cost per pregnancy to AI was calculated by multiplying the cost of the products used in each estrous synchronization protocol by the number of cows treated with that protocol and dividing the product by the number of cows pregnant to the single, timed insemination. Values used to determine cost of each synchronization protocol were: $8 per CIDR insert, $2.50 per 100 μg dose of GnRH, $3.00 per 2.5 mg dose of E17 + 50 mg dose of P4, $1.00 per 1 mg dose of E17, and $1.70 per 25 mg dose of PGF. CIDR retention rate was calculated by dividing the number of CIDR inserts manually removed at the end of treatment by the number inserted at the initiation of treatment.

## Results and Discussion

Overall pregnancy rate to fixed-time insemination (FTAI) was 35.51%. Pregnancy and estrus rates are presented in Table 1. Pregnancy rate to FTAI was higher ($P < 0.01$) for cows treated with E17 (47.22%) than for cows treated with GnRH (22.73%). Percentage of cows detected in estrus prior to insemination did not differ between groups (80.56% E17 vs 69.70% GnRH).

The synchronization protocols used in this trial were designed to facilitate the use of a single fixed-time insemination of all cows. Estradiol and GnRH have been used successfully in many trials to control follicular wave emergence at the initiation of treatment and to induce ovulation following the removal of the suppressive effects of progesterone (Colazo et al., 2003; Martinez et al., 2002; Colazo et al., 2004). A source of exogenous progesterone (CIDR) was used in this study to facilitate induction of cyclicity in postpartum cows (Day, 2004). Estrous synchronization protocols incorporating GnRH or estradiol with CIDR inserts resulted in pregnancy rates to FTAI of approximately 50 to 60% in *Bos taurus* cows (Bo et al., 1994; Lamb et al., 2001); however, limited information is available in cattle with *Bos indicus* influence.

In this study, an acceptable pregnancy rate of FTAI was achieved in Brahman cows treated with E17 (47.22%);

however, pregnancy rate to FTAI in the GnRH-treated group was significantly lower (22.73%). Final pregnancy rate was also much lower in the GnRH-treated cows, but this was a function of a low pregnancy rate to natural service in this group (13.73%). Pregnancy rate to natural service was lower for both groups compared to previous reports. Riley et al. (2001) reported a pregnancy rate to natural service during a 75-d breeding season over 14 yr of 96.4% for Brahman x Hereford cows, and Molina et al. (2003) reported a pregnancy rate of 88.67% in Zebu cows subjected to a 9-wk rotational breeding season.

The pregnancy rate to FTAI was lower than expected for the GnRH-treated cows, but similar to previous results for the E17-treated cows. Yelich et al. (2001) conducted a FTAI study in lactating cows containing some *Bos indicus* breeding. Cows were subjected to an estrous synchronization protocol similar to the E17 group in this study except that E17 was replaced with estradiol benzoate (EB) and no progesterone was included with the initial injection of EB. Cows were FTAI at 48 h after CIDR removal and this resulted in a pregnancy rate to FTAI of 50.6%, which was slightly higher than the results in this study. A recent review reported an overall pregnancy rate to FTAI of 51.3% when cows or heifers were treated with estradiol in combination with a CIDR insert (Bo et al., 2003). Lamb et al. (2001) reported a higher pregnancy rate to FTAI of 58% in *Bos taurus* cows using the same synchronization protocol utilized in the GnRH treatment group. This protocol was also effective in non-cycling cows resulting in a pregnancy rate of 59%. Williams et al. (2002) conducted a study on Brahman-influenced cows and heifers and reported a higher pregnancy rate to FTAI (42.4%) using the Ovsynch protocol alone without a source of exogenous progesterone. Another study using Brahman-influenced cows reported a pregnancy rate of 31.0% when cows were subjected to the Cosynch regimen (Lemaster et al., 2001).

Generally, the addition of progesterone to the Ovsynch or Cosynch protocols has resulted in similar or moderately higher pregnancy rates in beef cows. Hiers et al. (2003) conducted a study with melengestrol acetate in non-lactating *Bos indicus* x *Bos taurus* cows using a modified Cosynch protocol. Melengesterol acetate was fed for 6 d between the first injection of GnRH and PGF beginning 1 d after administration of GnRH and FTAI occurred 72-80 h after administration of PGF. Pregnancy rate to the timed insemination was 39%.

In a recent review by Bo et al. (2003), it was stated that pregnancy rates to FTAI reported in *Bos indicus* cattle were not different from those reported in *Bos taurus* cattle when treated with the Ovsynch protocol, with pregnancy rates ranging from 42 to 48%. As expected, pregnancy rates in anestrous cows were significantly lower than in estrous-cycling cows.

In the current study, pregnancy rate to natural service was 32.58%. Pregnancy rate to natural service was higher ($P < 0.01$) for the group treated with E17 (57.89%) than for the group treated with GnRH (13.73%). Final pregnancy rate to FTAI and natural service for both treatments combined was 56.52%. Again, final pregnancy rate was higher ($P < 0.01$) for the E17 group (77.78%) than for the GnRH group (33.33%). Of the cows that were not pregnant after the breeding season, the percentage that was estrous cycling did not differ between the E17 (56.25%) and GnRH (77.27%) treatments.

The most likely explanation for the difference in pregnancy rates to natural service between the two groups is that the treatment with E17+P4 was more effective at initiating cyclicity compared to the GnRH treatment. If this was the case, the cows in the E17 group had a greater chance of conceiving to FTAI and a greater chance of conceiving to natural service with induction of cyclicity earlier in the breeding season. Both treatment groups were similar in body condition, number of cows < 60 d postpartum, number of cows > 60 d postpartum, and number of non-lactating cows at the initiation of treatment. With these factors held constant between the two groups, another possible explanation for the difference in conception rate to natural service is a difference in fertility of the bulls used for each group as the cows remained in their respective treatment groups during the natural mating period. This study took place during the summer months in central Texas, and heat stress may have resulted in subfertility of the bulls used for natural mating (bulls associated with the GnRH group may have been affected more than bulls associated with the E17 group). A decreased libido during this season of the year could have contributed as well. In addition, among cows that were not pregnant at the end of the breeding season, a greater percentage of cows in the GnRH group were estrous cycling compared to cows in the E17 group at the time of pregnancy determination.

Production status and body condition score were recorded for each cow at the initiation of treatment and are presented in Table 2. Mean body condition score did not differ between E17 (5.44) and GnRH (5.20) treatment groups. In addition, between the E17 group and the GnRH group, the percentages of cows < 60 d postpartum (15.28% vs 12.12%), > 60 d postpartum (41.67% vs 46.97%), and non-lactating cows (37.50% vs 36.36%) were similar. Pregnancy rate to FTAI tended ($P < 0.17$) to be higher for the E17 group for cows < 60 d postpartum, but there were no significant differences between treatments within any of the aforementioned categories.

There was no difference ($P = 0.28$) in pregnancy rate to FTAI between lactating (32.2%) and non-lactating cows (41.2%). Of the cows pregnant to FTAI, 57.1% were lactating and 42.9% were not lactating. Within treatment groups, 55.9% of the cows pregnant to FTAI in the E17 group were lactating and 60.0% of the cows pregnant to FTAI in the GnRH group were lactating at the time of treatment.

Estrous cyclicity was not evaluated prior to initiation of treatment in the present study; however, it is likely that a large percentage of cows in this study were anestrous at the initiation of treatment, and this may have led to the low pregnancy rate to FTAI in the cows treated with GnRH. Cows in this study were in average body condition, most were lactating, some were early in the postpartum period, and they were grazing low quality native pasture.

CIDR retention rate across both treatments was 96%. Cost to implement each treatment and cost per pregnancy to FTAI were calculated for both groups. Cost to implement the synchronization protocol used in the GnRH group was $14.70/cow, and cost per pregnancy to FTAI in this study was $64.68. Cost to implement the synchronization protocol in the E17 group was lower at $13.70/cow, and cost per pregnancy to FTAI in this study was much lower at $29.01. The economic advantage in cost per pregnancy in the E17 group was primarily due to the increased FTAI pregnancy rate since there was only a difference of $1.00 in the estimated cost per cow between the two treatment protocols.

## Implications

Results of this study indicate that acceptable pregnancy rates to FTAI can be achieved in postpartum, suckled and non-lactating Brahman cows using CIDR inserts in combination with E17. In addition to higher pregnancy rates, the E17/CIDR protocol was also the most cost effective based on pregnancy rate to FTAI. Pregnancy rate to FTAI may be reduced when injections of GnRH are used in combination with a CIDR insert to synchronize estrus in postpartum, Brahman cows. Retention rate of CIDR inserts was high, and the inserts proved to be an effective method of delivering progesterone in an estrous synchronization protocol for FTAI.

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Table 1. Fixed-time AI, natural service, and final pregnancy rate and synchronized estrus rate for cows by treatment

| Item | E17 | GnRH |
|---|---|---|
| Number of cows | 72 | 66 |
| Pregnancy rate to FTAI (%) | 47.22$^a$ | 22.73$^b$ |
| Detected in estrus (%) | 80.56 | 69.70 |
| Pregnancy rate to natural service (%) | 57.89$^a$ | 13.73$^b$ |
| Final pregnancy rate (%) | 77.78$^a$ | 33.33$^b$ |
| Non-pregnant cows, % estrous cycling | 56.25 | 77.27 |

$^{a, b}$ Percentages within a row without a common superscript differ ($P < 0.05$)

Table 2. Days postpartum and average body condition score of cows at initiation of estrous synchronization by treatment

| Item | E17 | GnRH |
|---|---|---|
| Number of cows | 72 | 66 |
| Average body condition score | 5.44 | 5.20 |
| Cows > 60 d postpartum (%) | 44.12 | 49.21 |
| Cows < 60 d postpartum (%) | 16.18 | 12.70 |
| Non-lactating cows (%) | 39.70 | 38.09 |

# PERFORMANCE OF STEAM-STERILIZED, PREVIOUSLY-USED CIDR INSERTS FOR SYNCHRONIZATION OF OVULATION IN BEEF COWS

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## Summary

Serum concentrations of progesterone were determined in ovariectomized cows receiving 1) New, 2) re-used disinfected (DIS), and 3) re-used autoclaved (AC) controlled internal drug release (CIDR) inserts. Six ovariectomized (OVX) beef cows were used in a replicated 3 x 3 Latin square design. Each experimental period was 7 d. Once-used CIDR inserts were either washed and soaked in a disinfectant for 2 h (DIS) or washed and steam sterilized at 250 ºF and 724 mm Hg for 20 min. Overall serum concentrations of progesterone were greater ($P < 0.03$) for New and AC than for DIS CIDR. These effects occurred primarily during the first 8 h after CIDR insertion ($P < 0.05$) when values for AC were markedly greater than both New and DIS. Autoclaving may be the best option when re-using CIDR inserts because it creates greater concentrations of progesterone immediately after insertion and minimizes disease risks.

## Introduction

Intravaginal devices containing progesterone and progestogens have been used for more than 40 yr with the aim of controlling estrous cycles of cattle and sheep (Carrick and Shelton, 1967; Mauer et al., 1975). The only currently-available, and most recently introduced, device to the United States is the controlled internal drug releasing device (CIDR) for use in cattle (CIDR-B; Macmillan and Peterson, 1993; Rathbone et al., 1997). The CIDR is a vaginal insert containing 1.9 (Canada, Mexico, Japan, Australia, New Zealand) or 1.38 g (United States) of progesterone (Rathbone et al., 2002; Mapletoft et al., 2003). The residual progesterone load after a 7-d insertion period of the 1.38-g CIDR is 0.72 g (Rathbone et al., 2002), thus having the potential for additional utilization. Although a single use is recommended by the manufacturer, re-utilization of CIDR inserts has been widely reported (Martinez et al., 2003; Stevenson et al., 2003; Colazo et al., 2004), and no differences in performance have been observe between new or once-used CIDR inserts (Colazo et al., 2004). Objectives herein were to compare the performance of new, re-used disinfected and re-used autoclaved CIDR inserts.

## Experimental Procedures

The Institutional Agricultural Animal Care and Use Committee of the Texas A&M University approved in advance all procedures used in this study.

### *Animals*

Six non-lactating, bilaterally ovariectomized (OVX) cows (Brahman x Hereford, F1; n = 5) and one OVX Hereford cow were used in a replicated 3 x 3 Latin square study. Each experimental period was determined to 7 d, with at least 48 h between different periods to minimize any carry-over effects from the preceding treatment. Mean (± SEM) age and BW were 7.8 ± 0.9 yr and 1328 ± 19.8 lb, respectively. Cows were housed in pens (dry-lot) measuring 25.6 x 9.6 m; and were fed a forage-based (Coastal Bermuda hay) diet ad libitum.

### *Procedures*

Insert treatments for this experiment were: 1) New, 2) Re-used disinfected (DIS), and 3) Re-used autoclaved (AC) CIDR. All CIDR inserts to be re-used had been used initially in beef cows for 7 days. Immediately after removal, they were placed in an empty bucket, washed thoroughly with soap and water, with emphasis on trying to remove mucus and debris that had accumulated in empty spaces between the silicon layer and the T-shaped body. Inserts for the DIS treatment were soaked in a Chlorhexidine Gluconate solution (0.03%) for 2 h, rinsed thoroughly with water, allowed to air-dry and placed in zip-lock bags for storage. For the AC treatment, CIDR inserts were not soaked in disinfectant but were autoclaved at 250 ºF and 724 mm Hg for 20 min, allowed to cool and placed in zip-lock bags for storage before use.

### *Blood sampling and assay*

Blood samples were collected via puncture of a tail vessel using evacuated 10-ml tubes and 20-guage bleeding needles at 0, 10, 30, 60, 180, 480 min relative to time of insertion of CIDRs, daily until day 7. Blood samples were placed on ice immediately after collection and remained on ice until transported to the laboratory. Samples were allowed to clot at room temperature for approximately 1 h before centrifugation at 3000 x g for 30 min. Serum was collected and stored at -20°C until hormone analysis using a commercial radioimmunoassay kit for progesterone (Coat-a-Count; Diagnostic Products Corporation, Los Angeles, CA). Samples were assayed in duplicate. Intra- and interassay CV were 8.01 and 10.4%, respectively, and sensitivity was 0.05 ng/mL.

*Statistical Analysis*

All data were subjected to ANOVA using the GLM procedure (SAS Inst. Inc., Cary, NC) as for a Latin square design.

## Results

The majority (61 %) of maximum peak values occurred between 10 and 180 min after insertion of CIDR inserts. Although mean (± SEM) serum concentrations (ng/mL) of progesterone during the 7-d period of insertion (Fig. 1) were greater ($P < 0.03$) for New (3.7 ± 0.2) and AC (3.4 ± 0.3) than for DIS CIDR (2.8 ± 0.2), these effects were created primarily by differences occurring during the first 8 h after CIDR insertion (Fig. 2). Within the first 8 h, mean concentrations (ng/mL) differed ($P < 0.05$) among all treatments, with AC > New > DIS. During both the first 0 to 3 and 0 to 8h, mean concentrations of progesterone in AC were nearly double those of DIS and 1.3 to 1.4-fold greater than New (Fig. 3).

Discussion

Serum concentrations of progesterone obtained during the 7-d insertion period of a new CIDR in the current study were comparable to those in a previous report using the 1.38-g CIDR (Rathbone et al., 2002). Concentrations of progesterone obtained with the DIS CIDR were also similar to those reported by Martinez et al. (2006) using a re-used insert originally containing 1.9 g progesterone in ovariectomized cows. Progesterone concentrations in the 3 treatments used in the current experiments peaked within the first 3 h after insertion and reached plateaus that were sustained for about 8 h. This was followed by a constant decrease until removal on d 7. Macmillan et al. (1991) reported that following CIDR (1.9 g) insertion in ovariectomized heifers, plasma progesterone concentrations increased to a maximum of approximately 8.7 ng/mL by 6 h and then decreased to 6.8 ng/mL and 2.5 ng/mL on d 1 and 12 after insertion, respectively. Furthermore, Cerri et al. (2005) compared plasma progesterone concentrations after insertion of a new or a 7-d used, autoclaved CIDR. In both treatments, concentrations of progesterone increased immediately after insertion, reached a plateau at 90 min and followed the same pattern during the remainder of the insertion period.

While it is possible that lower progesterone concentrations observed with the DIS CIDRs compared to the AC inserts were caused by an extended exposure to the disinfectant solution, it is more likely that steam sterilization of the CIDR in the AC group increased the rate of elution during the first few h after insertion compared to DIS. Such an effect indicates that the autoclaving process modifies in some way the structure of the implant or the disposition of the progesterone within the insert. Plasma profiles of progesterone resulting from re-used, gas-sterilized PRID devices were lower compared to autoclaved PRID devices where steady-state plasma concentrations following re-insertion were observed to be very similar to an unused insert (McPhee et al., 1983). Results were attributed to formation of a large quantity of crystalline progesterone on the surface of the autoclaved PRID (McPhee et al., 1983). Structural and functional similarities exist between the PRID and CIDR inserts. Both inserts are made using micronized progesterone in a silicon rubber skin which is molded into a nylon (CIDR) or stainless steel structure (PRID; Rathbone et al., 1998). Due to this similarity, it is possible that the heat-sterilization process used in the current study may have resulted in the same effect observed previously in autoclaved PRID inserts.

Different approaches have been used to clean, disinfect or sterilize inserts in studies reporting CIDR reuse. Colazo et al. (2004) soaked used CIDRs in a povidone iodine-based detergent solution for approximately 2 h, followed by scrubbing, rinsing with water, air-drying, and steam sterilization in an autoclave. Others have used schemes restricted only to chemical disinfection (Van Cleeff et al., 1992; Martinez et al., 2006), gas sterilization (Schmitt et al., 1996) or autoclaving (Cerri et al., 2005). The efficacy of any of these methods in terms of preventing disease transmission has not been proven. Padula and Macmillan (2006) demonstrated that changes in uterine and vaginal microflora in early postpartum beef cows occur after the insertion of a CIDR for 14 days. Microbial culture of swabs of CIDR inserts after removal yielded intense growth of bacteria. The predominant species isolated were *Pseudomonas aeruginosa* and *Actinomyces pyogenes* (Padula and Macmillan, 2006). Furthermore, progesterone has an immunosuppressive effect on the uterus (Hansen, 1998). Therefore, reutilization of CIDR inserts has the potential to transmit pathogens and spread disease. Nonetheless, there are apparently no reports of disease transmission related to the re-use of CIDR inserts.

Finally, some studies support the contention that the magnitude of the acute rise in serum progesterone at the onset of synchronization protocols involving an estrogen is important for reducing variance associated with new follicular wave emergence (Moreno et al., 2001; Bo et al., 2003). As a result, supplemental progesterone is often injected at the time of CIDR insertion with a goal of maximizing the acute increase in progesterone. Given the differences observed in the current study between AC and DIS, and to some extent between AC and New, it is possible that high-pressure steam sterilization of CIDR could contribute to that goal and eliminate the need for supplemental progesterone.

## Implications

High-pressure steam sterilization (autoclaving) may be the best option when re-using CIDR inserts for synchronization. This process results in greater concentrations of progesterone immediately after insertion and reduces maximally the risk of disease transmission.

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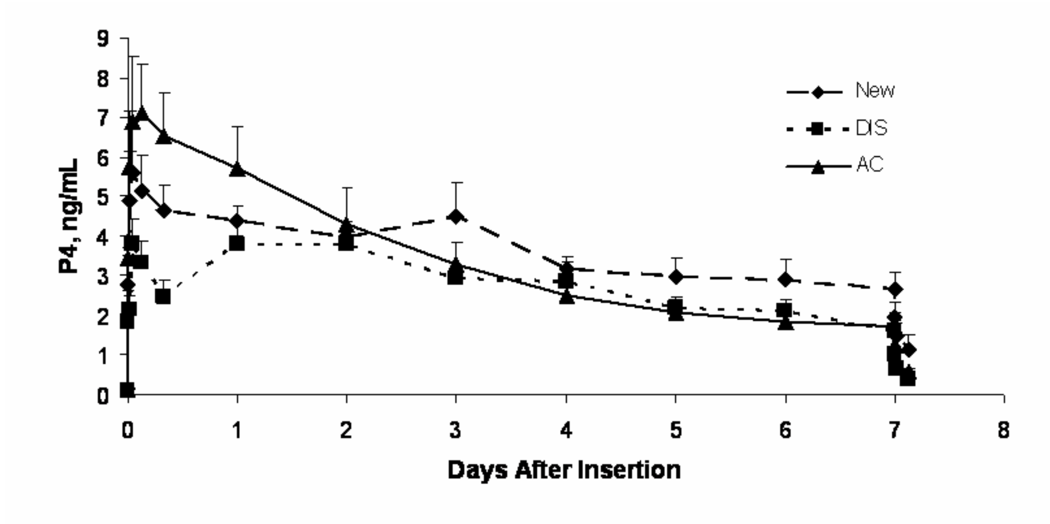


Figure 1. Mean (± SEM) serum concentrations of progesterone (P4, ng/mL) in ovariectomized cows bearing New, re-used disinfected (DIS) or re-used autoclaved (AC) CIDR inserts during a 7-d insertion period. Mean concentrations of progesterone during the 7-d period of insertion were greater ($P$ < 0.03) for New and AC than for DIS CIDR (2.8 ± 0.2)

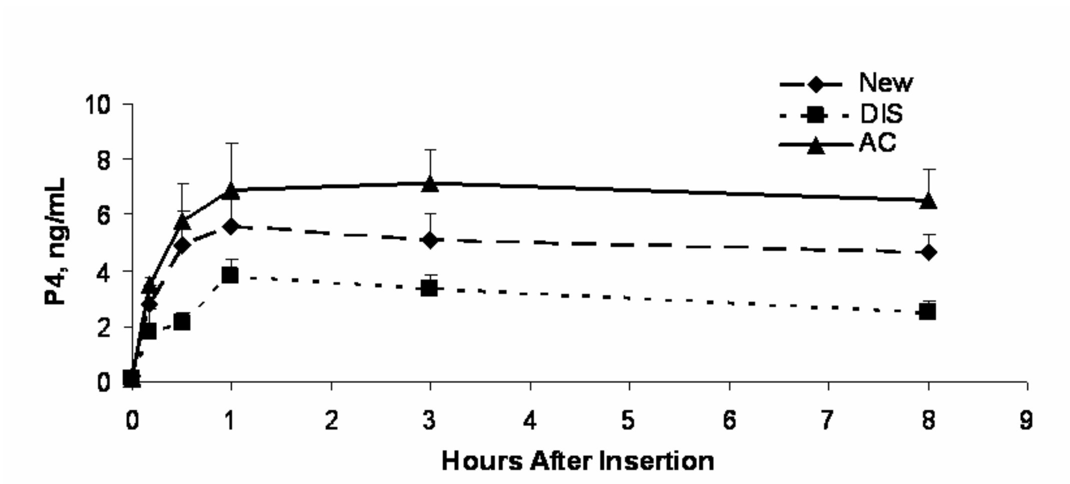


Figure 2. Mean (± SEM) serum concentrations of progesterone (P4, ng/mL) in ovariectomized cows bearing New, re-used disinfected (DIS) or re-used autoclaved (AC) CIDR inserts during the first 8 h after insertion. Mean serum concentrations were greater (P < 0.03) for the AC and New CIDR treatments than for the DIS treatment.

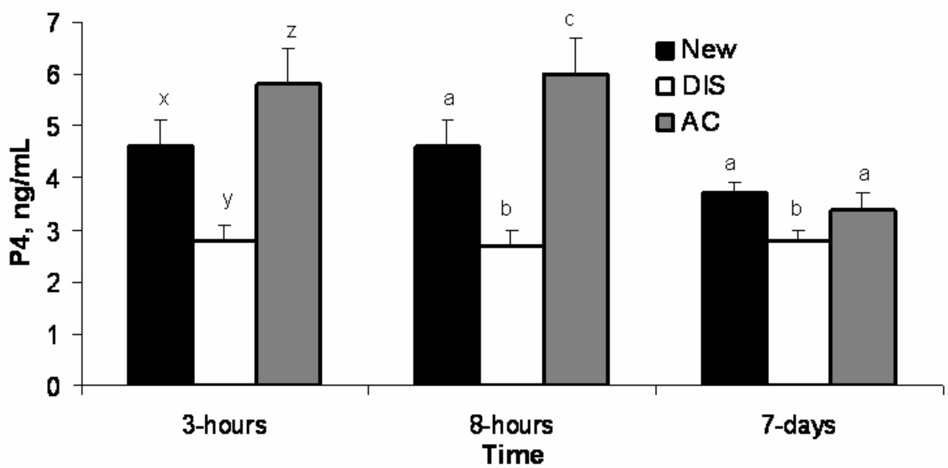


Figure 3. Mean (± SEM) serum concentrations of progesterone (P4, ng/mL) in ovariectomized cows bearing New, re-used disinfected (DIS) or re-used autoclaved (AC) CIDR inserts during the first 0 to 3 or 0 to 8 h relative to insertion and the entire 7-day insertion period. Different letters within time differ ($^{x,y,z}$ $P < 0.01$; $^{a,b,c}$ $P < 0.05$).

# VAGINAL ELECTRICAL RESISTANCE AS A CHUTE-SIDE INDICATOR OF SUITABILITY FOR TIMED ARTIFICIAL INSEMINATION FOLLOWING SYNCHRONIZATION OF OVULATION IN BEEF COWS

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## Summary

Objectives were to determine whether vaginal electrical resistance (VER) could be used to identify cows without a large follicle at timed AI (TAI) following a synchronization of ovulation protocol. Brahman x Hereford (F1) females (n = 233) were synchronized with the CO-Synch + CIDR protocol. Vaginal electrical resistance was determined on d 0, 7, and 10 (66 h post-CIDR removal). Mean VER (ohms) was greatest on d 0 and declined ($P < 0.01$) through d 10. Mean VER on d 7 and 10 and VER difference (VER on d 10 minus VER on d 7) did not differ between females with the largest follicle < 10 mm or ≥ 10 mm on d 7. However, TAI pregnancy rate was greater ($P < 0.01$) for females identified by ultrasound as having follicles ≥ 10 vs < 10 mm. Measurement of VER did not permit identification of females unsuitable for TAI after synchronization.

## Introduction

Reports on the use of the CO-Synch + CIDR protocol in *Bos taurus* beef cows for synchronization of ovulation and TAI have indicated TAI pregnancy rates that consistently exceed 50% (Bremer et al., 2004; Schaefer and Patterson, 2006). However, studies in our laboratory have demonstrated that this protocol yields TAI pregnancy rates in *Bos indicus* influenced females that are consistently lower (< 40%) than those reported for straight *Bos taurus* (Saldarriaga et al., 2006). Efforts to understand the basis of the lower results in *Bos indicus*-influenced cattle continue. However, alternative approaches for improving efficiency of these systems might include the ability to identify at chute-side females that failed to synchronize optimally and thus should not be inseminated. Herein, we tested the measurement of vaginal electrical resistance (VER) as a method (Schams et al., 1977; Foote et al., 1979) for predicting ovarian status of females at targeted TIA after the CO-Synch + CIDR protocol.

## Experimental Procedures

*Study locations and animal protocols*

This experiment was conducted at the Texas Agricultural Experiment Station, Beeville, Texas. The Institutional Agricultural Animal Care and Use Committee of the Texas A&M University approved in advance all procedures used in these studies.

*Cattle and synchronization procedure*

Two hundred and thirty three Brahman x Hereford (F1) females (nulli-, primi- and multi-parous) were utilized. Cattle were maintained in Coastal Bermuda and Kleingrass pastures and were required to have a minimum BCS of 5 (1 - 9 scale, 1 = emaciated, and 9 = obese), and if suckled be at least 50 d post-calving at TAI. All females received the CO-Synch + CIDR treatment for synchronization of ovulation (Fig. 1). The regimen included a CIDR insert (1.38 g of P4; Pfizer Animal Health, New York, NY) plus a GnRH (100 μg; Cystorelin) injection on d 0, removal of the CIDR 7 d later (d 7) coincident with an injection of PGF (25 mg; Lutalyse; Pharmacia & Upjohn Co., Kalamazoo, MI). Sixty-six h following CIDR removal and PGF injection (d 10), all females were artificially inseminated and received a second injection of GnRH (100 μg; Cystorelin). All females were turned with bulls 5 d after TAI for a 90-d breeding season. Pregnancy status to TAI were determined by transrectal ultrasonography (Dynamic Imaging, Concept/MCV, equipped with a 5-7.5 MHz linear array probe; Livingston, UK) 30 d after TAI.

*Vaginal electrial resistance (VER) measurements*

A commercially-available device (Ovascan; Animark Inc., Aurora, CO) was used to determine VER on d 0, 7, and 10 of the synchronization protocol (Fig. 1). The portable battery-driven device consists of a main unit with a digital screen to display readings and a stainless steel detachable probe. The probe was disinfected daily before each use and tested in a sodium chloride solution for calibration as recommended by the manufacturer's manual. The vulvar area of each female was cleaned with a paper towel, and the probe was introduced in the vagina by spreading the vulva to avoid contamination. The probe was rotated and moved back and forth 2 to 3 times and then held in place during 10 to 15 sec or until the readings on the display stabilized. After each use VER determination, the probe was wiped with a clean paper towel to remove contamination and placed into Chlorhexidine solution (0.03%) until the next cow or heifer was in place for examination. Before each subsequent measurement, the probe was thoroughly rinsed with water and shaken to remove any excess water. Vaginal electrical resistant readings were taken by the same operator.

*Ultrasonography*
Transrectal ultrasonography of ovaries to evaluate follicular and luteal structures was performed at TAI on d 10 in all cattle and in a subset (n = 98) on d 0, 7, and 10 (Fig. 1). Ultrasound examinations were performed by the same operator. Follicle structures were measured and an image of the dorsal and lateral view of each ovary was then obtained.

*Statistical analysis*
Effects of animal, time and pregnancy outcome and its interaction on VER and follicular sizes and effects of pregnancy outcome on follicular size difference (follicle size at d 10 minus follicle size at d 7) and VER difference (VER on d 10 minus VER on d 7) were evaluated using the GLM procedure (SAS Inst. Inc., Cary, NC). When a significant F-value was identified the LSD test was used to contrast means. After accounting for significant sources of variation, appropriate comparisons of pregnancy rates were made using chi-square analysis (PROC FREQ of SAS). Pearson correlation coefficient was applied to determine any linear correlation between variables of physiological interest.

## Results

Average (± SEM) age, BCS, BW, and d post-calving of all the females used in the study were 7.2 ± 0.3 yr, 5.2 ± 0.1, 538 ± 5.3 kg and 77 ± 1.1 d, respectively. Average VER for the 233 females was greatest (101.4 ± 0.8) on d 0 and declined ($P < 0.01$) to 95.2 ± 0.8 and 82 ± 0.8 ohms, respectively, on d 7 and 10 (Fig. 2). Average VER for the subset of 98 females examined with ultrasound on d 0, 7 and 10 decreased ($P < 0.01$) from 103.8 ± 1.2 to 95.5 ± 1.2 and 85.1 ± 1.2 ohms, respectively. Follicle sizes in these females on d 0, 7 and 10 were 10.1 ± 0.23, 10.2 ± 0.23, and 12.3 ± 0.25 mm, respectively. We observed a low negative but highly significant relationship ($r = -0.38$; $P < 0.001$) between VER and follicle size on d 0, 7, and 10. Follicle diameter and VER for the subset of 98 females in which both ultrasonography and VER measurements were made are illustrated in Fig. 3.

Time and follicle size had an effect ($P = 0.05$) on pregnancy outcome (pregnant or not pregnant after TAI; Fig. 4) and VER ($P = 0.05$; Fig. 5). Average follicle sizes on d 0, 7, and 10 for females that conceived were 10 ± 0.38, 10.4 ± 0.38, and 13 ± 0.4 mm, respectively. For females that did not conceive after TAI, follicle sizes were 10.2 ± 0.26 mm, 10 ± 0.26 mm, and 11.5 ± 0.27 mm respectively. Average VER values on d 0, 7 and 10 were 100 ± 1.2, 96 ± 1.2, and 80.4 ± 1.2 ohms, respectively, in females conceiving after TAI and 102.9 ± 1, 94.4 ± 1, and 83.6 ± 1 ohms, respectively, in those that did not conceive to TAI. Furthermore, the follicular size difference (follicle size at d 10 minus follicle size at d 7) and VER difference (VER on d 10 minus VER on d 7) differed ($P < 0.05$ and $P < 0.01$) between females that conceived (2.6 ± 1.6 mm and -15.6 ± 1.3 ohms, respectively) and those that did not conceive (1.5 ± 2.3 mm and -10.8 ± 1 ohms, respectively). Timed-AI pregnancy rate was positively correlated with follicular size on d 10 ($r = 0.16$; $P < 0.05$) and follicular size difference ($r = 0.24$; $P < 0.05$), and negatively correlated with VER on d 10 (-0.15; $P < 0.05$) and VER difference (-0.18; $P < 0.01$). Relationships are summarized in Table 1.

Stratification of females into those in which the largest follicle was < 10 mm or ≥ 10 mm at TAI (d 10) revealed a greater ($P < 0.01$) ovulation rate for those with large (≥ 10 mm) compared to those with smaller (< 10 mm) follicles. Average VER on d 7 and 10 were not different in animals with smaller (95.6 ± 1.8 and 83.7 ± 1.6) or larger (95.6 ± 1.8 and 82 ± 1.6) follicles at TAI. Similarly, VER difference (VER diff.; ohms) did not differ between females with smaller (-11.9 ± 2) and larger (-13.5 ± 2) follicles at TAI (Fig. 6). Timed-AI pregnancy rate was greater ($P < 0.01$) for females with large follicles than those with small follicles (Fig. 7). To contrast this information with the VER difference, we transformed the VER difference readings into two categories: negative (< 0 ohms) or neutral/positive (≥ 0 ohms). Pregnancy rates did not differ (39.4 ± 3.5 vs 29.4 ± 7.9%) between females represented in the negative and neutral/positive categories, respectively (Fig. 7). A total of 11.4% (10/88) of females that became pregnant after TAI had a neutral/positive VER difference.

## Discussion

Using a commercially-available device, the current study examined the efficacy of VER readings to identify cows without a mature preovulatory follicle at TAI. Overall, VER values observed in the current study were relatively greater than those presented in previous reports (Wehner et al., 1997; Scipioni and Foote, 1999). These differences may be the result of changes in commercial intravaginal probe designs over time. Other factors such as depth of probe insertion in the vagina (McCaughey and Patterson, 1981; Kitwood et al., 1993), position of the probe within the vagina (dorsal or ventral; Foote et al., 1979), pressure against the mucous membrane (Leidl and Stolla, 1976), pathological conditions of the reproductive tract (Leidl and Stolla, 1976) and technician (Foote et al., 1979) can influence the results. Changes in VER at different times during the synchronization protocol were comparable to changes reported during the estrous cycle (Aboul-Ela et al., 1983). Similar to previous studies in buffaloes (Markandeya et al., 1993; Gupta and Purohit, 2001), VER and developmental stage of the largest follicle were correlated in cattle in the current study. This is the first experiment reporting a correlation between follicular size assessed via ultrasonography and VER in cattle. However, electrical resistance of vaginal tissue has been correlated with circulating levels of progesterone and estradiol in cattle (Lewis et al., 1989) and sheep (Bartlewski et al., 1999), and the lowest values have been reported to be near estrus and coincident with the time of the luteinizing hormone (LH) peak (Schams et al., 1977; Aboul-Ela et al., 1983). Changes in estradiol and progesterone concentrations regulate the degree of hydration of vaginal tissue and electrolyte content of reproductive tract secretions (Lewis et al., 1989). Although VER seems to be controlled primarily by circulating concentrations of P4, it also changes in response to shifts in the estradiol:progesterone ratio when progesterone concentrations are decreasing (Bartlewski et al., 1999). In the current study, mean follicular size was similar on d 0 and d 7, but progesterone was greater on d 7 compared to d 0 due to the presence of the CIDR. Thus, VER values should have been the same or slightly greater on d 7 compared to values on d 0. We hypothesize that presence of a CIDR during a 7-day period might generate inflammation of the vaginal mucosa, increasing the amount of extracellular fluid (edema) that eventually will reduce the tissue electrical resistance (Lewis et al., 1989).

Follicle size is an indicator of ovulatory capacity (Sartori et al., 2001), and it has been associated with fertility. Thus, in the current study, females that conceived to TAI had larger follicles compared to those that did not conceive. This is in agreement with previous reports in which follicle size at the time of ovulation was associated with an increase in fertility (Vasconcelos et al., 2001; Perry et al., 2005). Furthermore, we observed that TAI pregnancy rate was positively correlated with follicle size and negatively correlated with VER. The difference in VER at TAI between females that conceived or did not conceive might be explained by a greater rate of follicle growth and larger follicles in females conceiving to TAI. Follicle size is associated with estradiol production (Ireland and Roche, 1982) and a defining characteristic of the dominant follicle is a greater capacity for estradiol production (Fortune et al., 2001). Bartlewski et al. (1999) suggested that VER is controlled by the progesterone:estradiol ratio when progetsterone is low, such as during the follicular phase of the estrous cycle, or in the case of this study, after the induced luteolysis and removal of the external source of progesterone.

Marked variations among and within animals make single VER observations unreliable (Feldman et al., 1978; Rorie et al., 2002). Single measurements of VER every second (Gartland et al., 1976) or third (Foote et al., 1979) day was demonstrated to be too infrequent and unreliable in distinguishing physiological states in cattle. Accurate identification of estrus requires measurements at least every 12 h (Canfield and Butler, 1989) or more often (Aboul-Ela et al., 1983) to identify the changes in resistance over a period of time. Given that a single measurement allows only a limited evaluation, repetitive measurements are required in order to establish individual female baselines and associated declines in VER. We used VER on d 7 in the present study as a baseline to determine its decline over the 66- to 72- h pattern of decline after CIDR removal to day 10. We detected a small (4.8 ohms) but statistically significant difference in VER between d 7 and 10 in females that conceived (-15.6 ohms) vs those that did not (-10.8 ohms).

Stratification of females in which the largest follicle was <10 or ≥10 mm was made based on the ability of follicles to reach ovulatory competence around 10 mm in diameter (Sartori et al., 2001). As expected, a greater ovulation rate was observed in females with follicles ≥10 compared to <10 and is in agreement with previous reports (Sartori et al., 2001). Additionally, an association between follicle size and fertility was observe in this study. Based on the follicle categories defined above, a greater proportion of females with follicles ≥10 mm at TAI become pregnant compared to those with follicles <10 mm. To the contrary, the VER difference was not significant (1.6 ohms) between females with large or small follicles, making this an unreliable measure to estimate follicle size. Furthermore, arrangement of VER difference values into categories demonstrated that pregnancy rates did not differ between females with negative and neutral/positive readings. Surprisingly, some females that became pregnant had a neutral/positive difference.

## Implications

These results are interpreted to mean that VER, as applied in this study, does not permit consistent estimation of degree of follicle maturity in synchronized females. However, assessment of follicle size via ultrasonography is a very good methodology for detecting cows and heifers that have failed to respond optimally to synchronization and thus are less likely to conceive to the fixed TAI. Alternatively, more frequent VER measurements could possibly result in more accurate identification of cows suitable for insemination. However, the financial costs associated with extra handling during synchronization would likely not be cost-effective and the added stress of the extra handling would also negatively impact reproductive performance.

## Acknowledgements

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Table 1. Relationships (Pearson correlation coefficient) of follicle size at timed AI (TAI), follicular size difference (follicle size at day 10 minus follicle size at d 7), vaginal electrical resistance (VER) at TAI and VER difference (VER on d 10 minus VER on day 7) to TAI pregnancy rate

| Variable | r | P - Value |
|---|---|---|
| Follicular Size at TAI | 0.16 | < 0.05 |
| VER on TAI | -0.15 | < 0.05 |
| Follicular Size Difference | 0.24 | < 0.05 |
| VER Difference | -0.18 | < 0.01 |

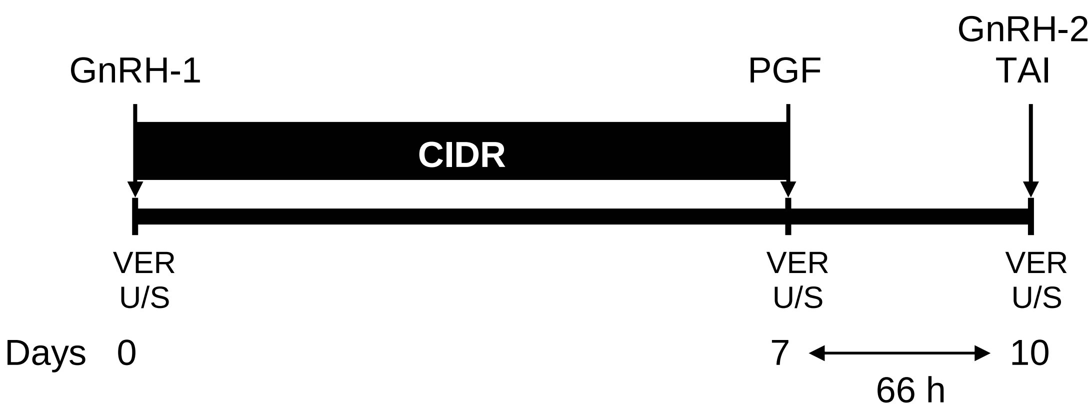


Fig. 1. Experimental protocol for synchronization of ovulation and timeline of events. All cattle received the CO-Synch + CIDR treatment for synchronization of ovulation. The regimen included a CIDR insert plus a GnRH injection on d 0 (GnRH-1), removal of the CIDR 7 d later coincident with an injection of Prostaglandin F2α (PGF). On d 10 (66 h after CIDR removal and PGF injection), all cattle were timed AI (TAI) and received a second injection of GnRH (GnRH-2). Vaginal electrical resistance (VER) measurements and ultrasound (U/S) examinations were performed on days 0, 7 and 10

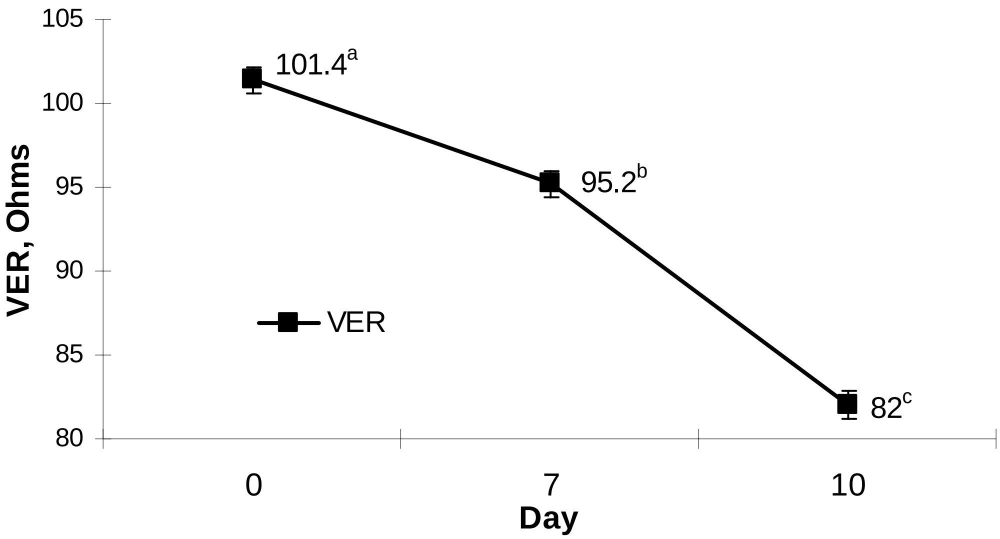


Fig. 2. Vaginal electrical resistance (VER) at different times during the synchronization protocol in all females in the study (n = 233). Means with different superscripts (a,b,c) differ ($P < 0.01$).

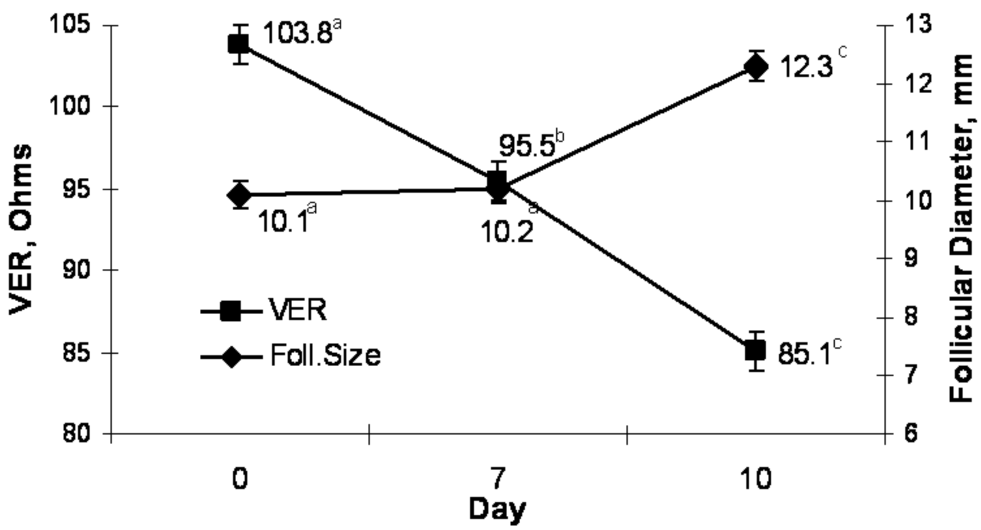


Fig. 3. Follicle diameter and vaginal electrical resistance (VER) in a subset of females in which both measurement were made at all three time points (n = 98). Means within measurements with different superscripts (a,b,c) differ ($P < 0.01$).

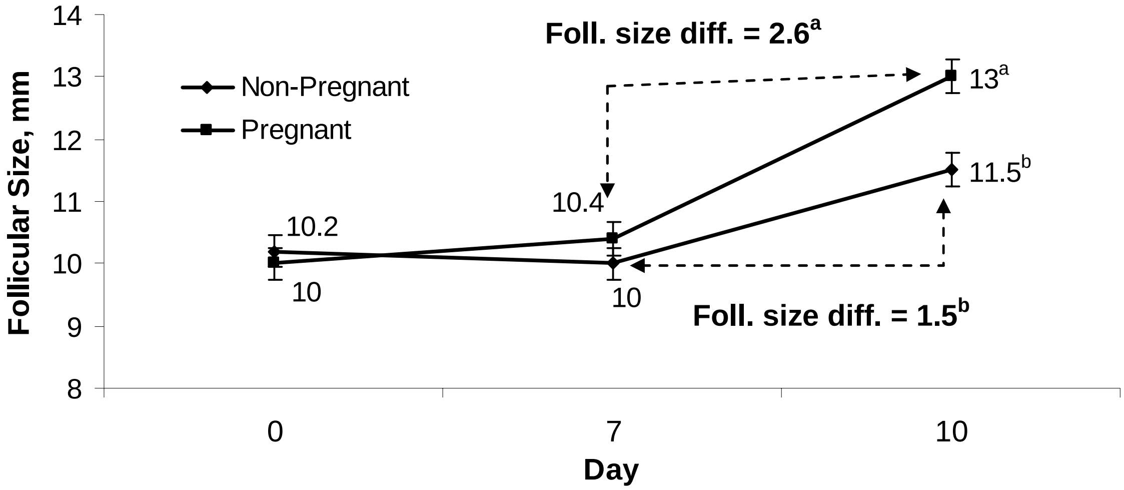


Fig. 4. Follicle diameter at three times during synchronization in females that either conceived or did not conceive to timed AI (TAI). Follicle size difference (Foll. Size Diff.) refers to: follicle size at d 10 minus follicle size at d 7. Females that became pregnant had a greater Foll. Size Diff than those that did not become pregnant ([a,b]$P < 0.05$).

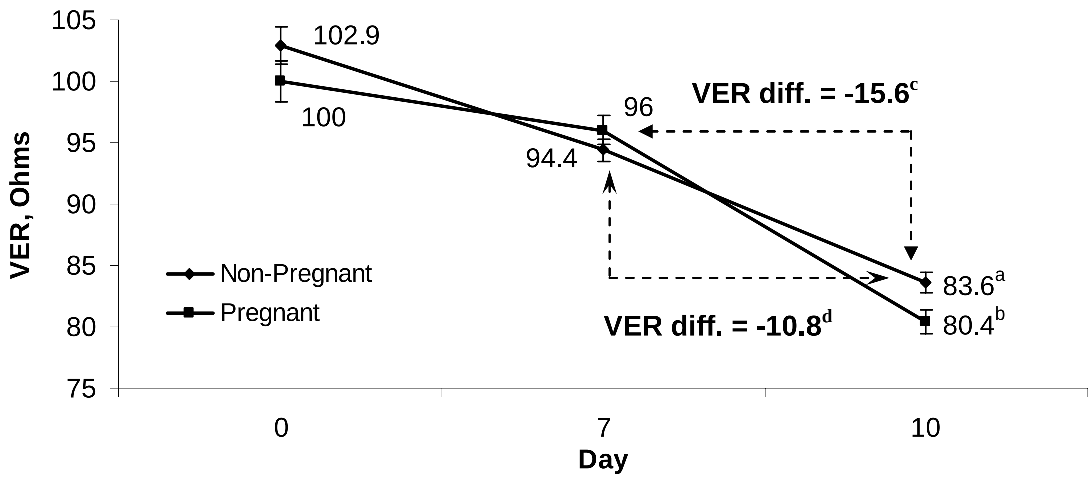


Fig. 5. Vaginal electrical resistance (VER) at three times during synchronization in females that either conceived or did not conceive to timed AI (TAI). VER difference (VER diff.) refers to: VER on d 10 minus VER on d 7. Females that became pregnant had a lower VER Diff on average than those that did not become pregnant. Means at each time point with different superscripts (a,b or c,d ) differ at $P < 0.05$ and $P < 0.01$, respectively.

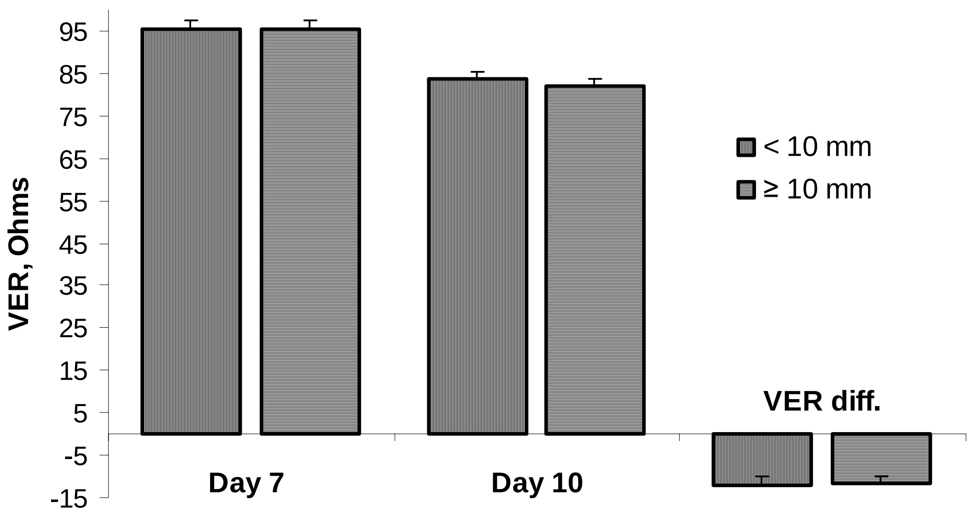


Fig. 6. Vaginal electrical resistance (VER) and VER difference (VER diff.; VER on d 10 minus VER on 7) in relation to size of the largest follicle at TAI (d 10). VER averages did not differ by follicle class.

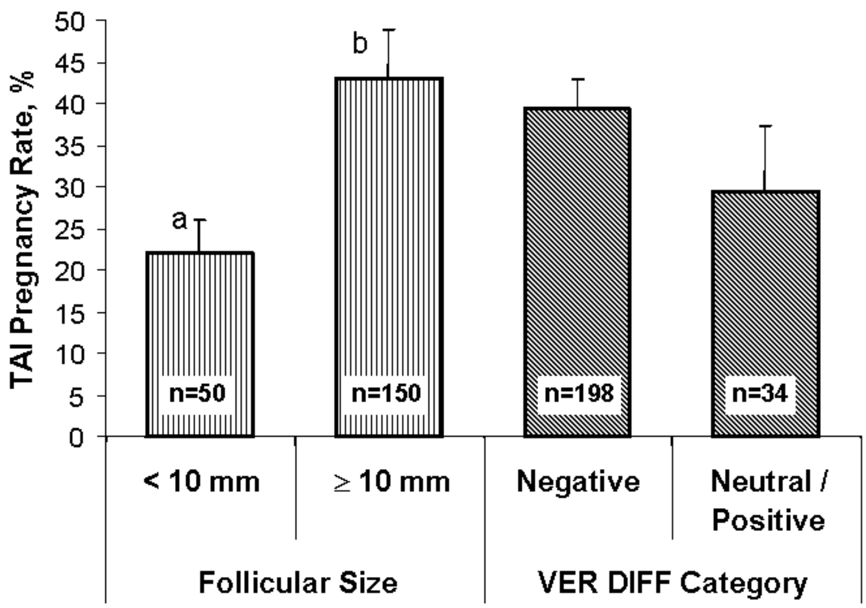


Fig. 7. Timed AI (TAI) pregnancy rate in relation to follicle diameter on d 10 and VER difference categories (Negative or Neutral / Positive). TAI pregnancy rate was greater ([a,b] $P < 0.01$) for females in which the largest follicle was ≥ 10 mm than in those in which the largest follicle was < 10 mm. There was no difference in pregnancy rate between females in the two VER Diff categories.

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