Iowa State Beef Checkoff Research Program

Project title: Optimizing Beef Production: Reducing Nitrogen Excretion and Improving Cattle Growth with Growth Promoting Technologies

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I. Nontechnical Summary:

Growth promoting technologies such as implants and beta agonists are valuable tools that provide opportunities to increase cattle growth and producer profitability. Anabolic implants are used in the beef industry to enhance lean muscle growth and improve feed efficiency. Beta adrenergic agonists are feed additives that activate specific receptors in the animal's body, which stimulate increased muscle growth and feed efficiency. These technologies also improve producer environmental responsibility by promoting nitrogen (N) accretion on the carcass as protein, which reduces N excretion. This 172-day study aimed to help producers see the differences in technology and how they may benefit from different programs, economically and environmentally. Angus-cross steers (n = 216; BW = 617 ± 38 lb) originating from a single ranch in western South Dakota were randomly assigned to 1 of 4 treatments: 1) a control treatment receiving no anabolic implant or β-agonist **(CON)**, 2) a treatment receiving just anabolic implants (Synovex Choice and Synovex Plus; Zoetis) **(IMP)**, 3) a treatment receiving implants plus the β3-agonist Experior (lubabegron fumarate; Elanco), for 56 days prior to harvest followed by a 4 day withdrawal **(EXP)**, 4) a treatment receiving implants plus the β1-agonist, Optaflexx (ractopamine hydrochloride; Elanco), for 31 days prior to harvest **(RAC)**. Dietary treatments were delivered by total mixed ration (TMR). Increased growth performance was seen in all treatments that received growth promoting technologies (**TECH**). Final BW in TECH were ~11% greater than CON. There were also increases in DMI, ADG, and G:F in TECH over CON at amounts of 9%, 20%, and 13% respectively. The increases in growth performance resulted in lower levels of urinary N excretion per unit of ADG in TECH treatments compared to CON, leading to lesser emissions and increased sustainability. Cattle belonging to the TECH treatments had better levels of insulin sensitivity compared to CON cattle, allowing them to partition more nutrients towards increased growth and an overall heavier carcass. Increased growth was observed in carcass characteristics as well, with a greater HCW; EXP excelled over other TECH treatments. Greater HCW in TECH treatments followed with a larger REA. Marbling was not affected by use of steroidal implants alone or with RAC, however, EXP did decrease marbling compared to CON and IMP. Cattle receiving EXP had higher dressing percentages compared to all other treatments. Yield grades did not differ between treatments. Overall, the use of growth promoting technologies tended to result in greater net return for producers. Cattle in the TECH treatments demonstrated greater feed efficiency, increased live BW, and had higher HCW and REA, leading to improved net returns when COG and cattle prices were averaged over 14 years. In this study, with CON artificially set at $0 return, the use of Experior resulted in a $39 net return/head, with the use of steroidal implants resulting in $29 net return/head, and Optaflexx resulting in $10 net return/head.

Photo on the left:
CON pen 21 days following the start of EXP
Photo on the right:
EXP pen 21 days following the start of EXP

II. Technical Report:

a. Impacts

Using anabolic implants and a beta agonist improved net returns due to increased efficiency of production and greater production of saleable product. Further, these technologies resulted in lesser overall urinary N excretion into the environment, when expressed on a unit of gain. Providing cattle with growth promoting technologies increased producer profitability over controls while also lessening N excretion in urine per unit of daily gain.

b. Methods and Results

Animals and Experimental Design

Angus-cross steers (n = 216; BW = 617 ± 38 lbs) originating from a single ranch near Rapid City, SD were used in a study conducted at the Beef Nutrition Farm located in Ames, IA from late November 2023 to early June 2024. All steers were enrolled in a receiving study until November 30, at which point they were randomized within previous treatment to the current experiment.

Steers were blocked by weight to heavy and light blocks, and within block stratified to pens of 6 steers. The heavy block contained 96 steers (16 pens; 4 pens per treatment). The light block contained 120 steers (20 pens; 5 pens per treatment). There were four treatments: 1) a control treatment receiving no anabolic implant or β-agonist (CON), 2) a treatment receiving just anabolic implants (IMP), 3) a treatment receiving implants plus the β3-agonist lubabegron fumarate at 36 mg/steer/day(Experior; Elanco, Greenfield, IN), for 57 days prior to harvest including a 4 day withdrawal (EXP), 4) a treatment receiving implants plus the β1-agonist, ractopamine hydrochloride at 300 mg/steer/day (Optaflexx; Elanco), for 31 days prior to harvest (RAC). On day 0, steers in treatments 2-4 received a Synovex Choice implant (100 mg trenbolone acetate; 14 mg estradiol benzoate; Zoetis). Cattle were managed as one block prior to day 69 of the trial. Beginning on day 69, there was a 14-day stagger between the two blocks, where the heavy block received terminal implant on d 69 and the light block continued on the finishing diet for 14-d prior to receiving their terminal implant. All study activities were kept the same relative to the day of harvest for both blocks. For appropriate treatments, the terminal implant was given 104 d prior to harvest (Synovex Plus; 200 mg trenbolone acetate; 28 mg estradiol benzoate; Zoetis). Individual steer BW was recorded prior to feeding at study initiation (day -1, 0) prior to placement in final study pen, as well as days 42, 69, 98, 116, 141, and 172. A 4% pencil shrink was applied to all BW. Body weights and days for each period were used to calculate ADG. Dry matter intake was calculated on a pen bases for each period and divided by the number of animals in that pen. Feed efficiency was calculated by dividing ADG by DMI for a respective period. **Table 1** provides an experimental sampling schedule.

Diet composition and analysis is shown in **Table 2**. Steers were fed the growing diet from days 0 to 56, then transitioned to a high concentrate diet over the course of two weeks. On day 69, steers began a high concentrate finishing diet. CON and IMP treatments received the same TMR throughout the duration of the project. EXP (n = 9 pens) and RAC (n = 9 pens) dietary treatments started 57 and 32 days prior to harvest, respectively. Feed bunks were read at 0630 hours and cattle were fed at approximately 0800 hours daily. Bunks were managed using a modified slick bunk protocol, with the target of crumbs at time of reading.

Supplementation of lubabegron fumarate was targeted at 36 mg per steer daily. Calculations using dry matter intake (DMI) and premix inclusion percentage revealed the intake of lubabegron fumerate was 39 ± 1.7 mg per steer daily. Supplementation of ractopamine hydrochloride was targeted at 300 mg per steer daily. Calculations using DMI and premix inclusion percentages revealed an intake of 307 ± 19 mg per steer daily.

On study days 173 and 187 steers in the heavy and light block, respectively, were harvested at a commercial abattoir (National Beef, Tama, IA) via industry-accepted practices (104 d post terminal implant). Trained personnel collected hot carcass weight (HCW) data on the day of harvest. Ribeye area (REA), 12th rib back fat (RF), USDA yield grade (as called by the plant) and marbling score were collected after a 48-h chill.

Sample Collection and Analytical Procedures

Total mixed ration (TMR) samples were collected weekly. Samples were dried in a forced-air oven at 70 °C for 48 h for determination of dry matter (DM). Pen DMI was calculated from as-fed delivery and corrected for the DM (%) of weekly TMR samples. Samples of the CON, EXP, and RAC TMR were dried, ground, and composited for analysis of nitrogen, neutral detergent fiber and ether extract by a commercial laboratory (Dairyland Laboratories, Inc., Arcadia, WI).

Jugular blood samples were collected from 1 steer per pen (n = 36) into vacuum tubes (serum, potassium EDTA, sodium heparin) on days 0, 69, 98, 116, 141, and 172 prior to feeding. Whole blood samples were centrifuged at 1,000 x g for 20 minutes at 4 °C. Serum was aliquoted and stored at -80 °C prior to sample analysis. Plasma was aliquoted and stored at - 20 °C prior to sample analysis.

Analysis of circulating metabolites was completed on 1 steer per pen (n = 36). Serum glucose (FUJIFILM Wako Diagnostics; intra-assay CV = 5.07%, inter-assay CV = 5.15%), insulin (Bovine Insulin ELISA assay; Mercodia, INC., Winston Salem, NC; intra-assay CV = 3.99%, inter-assay CV = 2.54%), non-esterified fatty acids (NEFA) (Wako Pure Chemical Industries Ltd., Chuo-Ku Oska, Japan; intra-assay CV = 2.62%, inter-assay CV = 5.17%), and urea-N (Teco Diagnostics, Anaheim, CA; intra-assay CV = 1.49%, inter-assay CV = 6.85%) were determined on study days 0, 69, 98, 116, 141, and 172. Samples were assayed in duplicate.

Insulin sensitivity was measured from 1 steer per pen (n = 36) using the RQUICK-I index and concentrations of glucose, insulin, and NEFA. RQUICK-I = 1/[log(Glucose) + log(Insulin) + log(NEFA)] (De Sousa et al. 2022). Urinary N excretion levels were estimated from 1 steer per pen (n = 6) using the equation of (Kohn et al. 2005) CR × SUN × BW where CR = clearance rate (1.3L of blood cleared of urea per day in cattle, SUN = serum urea N (g/L), and BW = body weight (kg).

Analysis of proinflammatory cytokine secretion was completed on 1 steer per pen (n = 36). Whole blood was stimulated in the presence of PAM3CSK4 (PAM), lipopolysaccharide (LPS), and Poly I:C (POLY) to mimic an infection using methods described by Mahmoud et al. (2020) and McDonald et al. (2021). Stimulated interleukin (IL)-1β (Bovine IL-1β Uncoated ELISA assay; Thermo Fisher Scientific, INC., Waltham, MA; intra-assay CV = 8.17%, inter-assay CV = 11.04%) and IL-6 (Bovine IL-6 Uncoated ELISA assay; Thermo Fisher Scientific, INC., Waltham, MA; intra-assay CV = 7.23%, inter-assay CV = 13.32%) were measured in cell culture supernatants.

Economic Analysis

An economic analysis using a partial budget (CON cattle held to $0 in net return) was completed to estimate net return for each treatment. Feeder cattle prices, dressed delivered cattle prices, and cost of gain prices were found and held constant for each treatment using a fourteen year average for each of those variables, and a different purchase price for the heavy and light block. Net return was calculated and reported within the carcass characteristics. Cost assumptions are listed in **Table 3**.

Statistical Analysis

Growth performance, carcass characteristics, and blood metabolites were analyzed as a randomized complete block design using Proc MIXED of SAS 9.4 (SAS Institute Inc., Cary, NC). Pen served as the experimental unit for all analyses (36; n = 9 per treatment). The model included fixed effects of treatment and block and the random effect of pen. Blood metabolites were analyzed as repeated measures using the repeated effect of day, with day 0 being used as a covariate. Outliers were evaluated on a pen basis. The following covariance structures were used based on lowest Akaike's information criterion: TOEPH (insulin), AR(1) (glucose, BUN), CS (NEFA), VC (RQUICK-I). For BW, ADG, carcass characteristics, and blood metabolites, data points for a pen were removed if more than three standard deviations from the treatment's mean. IL-1β and IL-6 data were log transformed to fit the assumption of normality and then back transformed. One steer (CON) was removed from the trial approximately 14 days following initiation. The BW for that animal was used to estimate DMI, and BW, ADG, DMI, and G:F was removed from the data set. Prior to receiving a terminal implant and at the end of the growing period, three sick animals (3 IMP), and three animals with horns (2 EXP, 1 CON) were removed from the trial. For the three sick animals, BW was used to calculate an estimated DMI, and their BW, DMI, ADG, and G:F were removed from the data for the growing period. The BW, DMI, ADG, and G:F were included for the growing period for the three animals with horns that were removed prior to terminal implant. During the finishing period, one animal was removed (CON) prior to the beginning of EXP dietary treatments. The data for that animal is included until removal. The least-squares means and SEM are reported. Statistical significance was determined at $P \leq 0.05$, and a statistical tendency was determined at $0.05 < P \leq 0.1$.

Results

Growth Performance

Performance results through the growing period are shown in **Table 4**. In this period, IMP, EXP and RAC treatments are identical, having received an initial implant, but are not yet receiving any beta agonists. Body weight at study initiation at the beginning of the growing period was not different across treatments ($P = 0.59$). At the end of the growing period, BW, ADG, DMI, and G:F through the growing period were greater in implanted treatments (IMP, EXP, and RAC; $P \leq 0.05$) than CON.

Performance results through the finishing period, overall performance, and carcass adjusted (CA) performance are shown in **Table 5**. Body weights at the time of re-implant and start of EXP and RAC dietary treatments, were greater in IMP, EXP, and RAC compared to CON ($P < 0.01$). Final BW was greater in IMP, EXP, and RAC compared to CON ($P < 0.01$), with a tendency for EXP to be greater than IMP (*P* = 0.09). Finishing period ADG, DMI, and G:F was greater in IMP, EXP, and RAC compared to CON (*P* < 0.01).

Overall DMI was greater in IMP, EXP and RAC compared to CON (*P* < 0.01). Overall ADG and G:F was greater in IMP, EXP, and RAC compared to CON (*P* < 0.01), with a tendency for EXP to be greater than IMP (*P* = 0.07).

Carcass adjusted (CA) final BW and ADG were greater in IMP, EXP, and RAC compared to CON (*P* < 0.01), with a tendency for EXP to be greater than IMP (*P* = 0.08). Carcass adjusted DMI was greater in IMP, EXP, and RAC compared to CON (*P* < 0.01). Carcass adjusted G:F was greater in EXP and lowest in CON, with IMP and RAC being greater than CON but less than EXP (*P* < 0.01).

Carcass Characteristics

Carcass characteristics can be found in **Table 6**. Hot carcass weight was greater in EXP and lowest in CON, with IMP and RAC being greater than CON but less than EXP (*P* < 0.01). Ribeye area was greater in IMP, EXP and RAC compared to CON (*P* < 0.01). Marbling was greatest in CON and IMP, with EXP being the lowest and RAC being not different from CON, IMP, and EXP (*P* < 0.01). Back fat was greater (*P* = 0.04) in RAC compared to CON and EXP, with IMP being not different than RAC or CON and a tendency for IMP to be greater than EXP (*P* = 0.08). Dressing percentage (DP) was greater in EXP compared to CON, IMP, and RAC (*P* = 0.01). Yield grade was not different across treatments (*P* = 0.24). Empty body fat (EBF) percentage was greater in IMP and RAC compared to EXP, with IMP being no different than CON or RAC, and CON being no different than EXP or IMP (*P* = 0.05) Net return tended to be greater (*P* = 0.07) for EXP and IMP compared to CON and RAC, with IMP and RAC being similar.

Blood Metabolites

Results for blood metabolites will be represented in days prior to harvest, with day 179 representing a common day between both blocks for the beginning of the trial. Study events in the form of days prior to harvest are shown in **Table 2**. Blood collected at the beginning of the trial served as a covariate in repeated measures analysis of blood metabolites for the remaining collection dates.

Values for RQUICK-I index are shown in **Figure 1A**. There was a treatment by day effect for RQUICK-I (*P* < 0.01). During the growing period, EXP and RAC values decreased while CON and IMP values remained constant (during this period IMP, EXP and RAC are all just implanted steers). From d 104 to d 75, IMP, EXP, and RAC values held constant while CON values decreased. Values for IMP and EXP decreased from d 75 to d 57 while CON and RAC held constant. EXP and RAC dietary treatments began 57 and 32 days prior to harvest, respectively. From d 32 to 1, RQUICK-I for CON, IMP, and RAC remained constant, and decreased in EXP. Within the day prior to harvest (d 1), there was an effect for RAC to be greater compared to CON, and a tendency for EXP to be greater than CON, and RAC to be greater than IMP with RAC being no different from EXP and IMP being no different from CON.

Insulin values are shown in **Figure 1B**. There was a treatment by day effect for insulin ($P <$ 0.01). Insulin values on d 179 were similar across all treatments. From d 179 to d 104, insulin increased for all treatments. On d 104, there was a tendency for EXP to be greater compared to CON. CON increased from d 104 to d 75, while all other treatments remained statistically no different. There was an effect for IMP, EXP, and RAC to be less than CON. From d 75 to d 57, EXP increased while all other treatments remained constant. On d 57, there was an effect for CON to be greater compared to IMP and a tendency for CON to be greater than RAC. A decrease in insulin values for EXP was seen from d 57 to d 32. EXP values were statistically less than RAC and IMP, with a tendency for EXP to be less than CON on d 32. From d 32 to d 1 all treatments, other than RAC, had a numerical increase, while not significant.

Figure 2A shows SUN values. There was a treatment by day effect for SUN ($P < 0.01$). On d 179, SUN values were similar for all treatments. During the growing period, SUN values for IMP, EXP, and RAC remained constant while CON increased. This effect continued throughout the finishing until harvest, where SUN values for CON dropped below all other treatments. SUN values for EXP dropped below all other treatments 32 days prior to harvest (approximately 21 days into the EXP feeding period).

The area under the curve (AUC) for urinary N excretion for each sampler steer was calculated across the entire trial, then this value was divided by the CA ADG for that steer (**Figure 2B**). Performance adjusted urinary N output for all treatments receiving technology (IMP, EXP, RAC) was less than CON ($P < 0.01$).

There was a day effect for glucose ($P < 0.01$). Glucose values are shown in **Figure 1D**. Serum glucose generally decreased across days on feed ($P < 0.01$).

NEFA values are shown in **Figure 1C**. There was no treatment by day, treatment, or day effect ($P = 0.9$). While no treatment by day effect exists, there are several strong numerical trends at the midpoint of EXP dietary treatments, where NEFA is lesser in the EXP treatment.

The results for IL-1β production can be found in **Table 7**. For the IL-1β production after stimulation for 48 hours was not different due to treatment 30 days following terminal implant (75 days prior to harvest) for MOCK or control stimulation, LPS, PAM, and POLY ($P \geq 0.31$). Thirty days following the start of EXP dietary treatments (57 days prior to harvest), IL-1β production after stimulation was not different due to treatment for MOCK, LPS, or POLY ($P \geq 0.24$). There was an effect for PAM 30 days after EXP dietary treatments where EXP was greater compared to CON and IMP. The capacity for IL-1β production was not different due to treatment 30 days following the start of RAC dietary treatments for MOCK, LPS, PAM, or POLY ($P \geq 0.24$).

Table 8 expresses the IL-6 production results. No effects were seen for MOCK or control stimulation, LPS, PAM, or POLY ($P \geq 0.13$) in samples collected thirty days following terminal implant administration or 30 days following the start of EXP dietary treatments. An effect for RAC to be greater compared to IMP and EXP, where CON is not different than

EXP or RAC 30 days following RAC dietary treatment initiation ($P = 0.01$). There was a tendency for RAC to be greater compared to CON, IMP, and EXP 30 days following RAC dietary treatment initiation ($P = 0.09$). There was no effect on treatment for MOCK or PAM 30 days following the initiation of RAC dietary treatments ($P \geq 0.26$).

c. Discussion

Beef producers are under pressure to produce more pounds of beef products at a faster rate, while safeguarding product quality and the environment. Growth promoting technologies have had a positive impact on the industry, leading to increased production, while maintaining product quality. Improving the efficiency of animal production is an effective mitigation strategy against ammonia and methane emissions (Boadi et al., 2004). The primary objective of this study was to determine the effects of growth promoting technologies on nitrogen retention in the animal and sustainability of feedlot cattle in Iowa to maximize producer profits.

Nitrogen Excretion and Live Performance

Urinary N (UN) concentrations per unit of ADG were decreased in all treatments receiving growth promoting technologies (IMP, EXP, RAC - **TECH**) in the current study. This is a result of increased BW, ADG, feed efficiency, and lower circulating serum urea nitrogen (SUN). As demonstrated by others (Bryant et al., 2010; Parr et al., 2014; Smith et al., 2018), the use of anabolic implants decreased SUN concentrations in this study. Throughout the duration of the finishing period, SUN levels in the CON treatment were higher than TECH treatments. Walter et al. (2016) found that UN excretion was lower in zilpaterol hydrochloride treated cattle compared to control without β-agonist supplementation by approximately 7 grams per day. With the use of β-agonists (zilpaterol hydrochloride), Cowley et al. (2019) found ammonia emissions from Angus production systems in California were decreased by about 6%. β-agonists increase muscle mass and decrease fat mass when fed to growing animals (cattle, sheep, poultry, and swine), most likely in the expected form of an increase in muscle protein synthesis and a decrease in muscle protein degradation (Mersmann, 1996). This promotes retention of N on the carcass in support of muscle accretion, while decreasing N output into the environment.

An analysis of performance and carcass variables indicated the treatments elicited differences in line with those typically documented in the literature. Treatment-specific dressing percentages were applied when calculating CA measures. In the present study, there was an expectation of increased performance due to growth promoting technologies. At the time of re-implant, TECH treatments were outperforming the CON treatment. This performance difference continued throughout the remainder of the study. An increase in final BW of 11% at the time of harvest was seen in TECH treatments compared to CON. Stackhouse-Lawson et al. (2013) also saw in an increase in final BW for their treatments receiving implants and β-agonists compared to their control treatments. Average daily gain and feed efficiency increased in TECH treatments by 20% and 13%, respectively. A meta-analysis done by Wileman et al. (2009) supports the results of the current study. They identified a17% improvement in ADG and a 9% improvement in feed efficiency when comparing cattle receiving single implant vs. non-implanted cattle. When only comparing β-agonist technologies, McAtee et al. (2024) noted a 3.67% decrease in DMI for cattle fed Experior (36 mg/hd/d) for 53 days compared to cattle fed Optaflexx (300 mg/hd/d) for 28 days, which was not seen in the current study with nearly identical β-agonist treatments. While all TECH treatments expressed increased BW, ADG, DMI, and G:F over controls, steers did not reach ad libitum feed intake, and thus complete DMI for each individual treatment is likely not expressed. A 9% improvement in DMI was seen in the present study with the use of growth promoting technologies, with no differences between the various technologies (IMP, EXP, RAC). The use of anabolic implants was shown to increase DMI (Parr et al., 2011).

Carcass Performance

The use of growth promoting technologies increased HCW, with the use of EXP increasing HCW the most by 13% over CON, and 3% over IMP. This response is due largely to the differences in final BW between CON and TECH treatments, and an increased DP for EXP. Implants consistently result in heavier carcass weights and often dressing percentage, over non implanted controls (Johnson et al., 1996; Bryant et al., 2010; Parr et al., 2014). Dressing percentage has been shown to increase with the use of β-agonists compared to implanted and non-implanted cattle (Maxwell et al., 2015). In the present study, EXP cattle had a 3% increase in HCW over IMP with only a 1.5% increase in final BW over IMP. Holland et al. (2010) noted that in most experiments feeding a now not used in the U.S. β-agonist (zilpaterol hydrochloride) the increase in HCW was greater than the live BW response. It has been hypothesized (Montgomery et al., 2009b) that the increase in HCW and dressing percentage that is observed in cattle fed zilpaterol hydrochloride is due to a shift in mass from non-carcass tissues, to carcass tissues. They further hypothesize that the reductions in the mass of visceral organs, such as mesenteric and omental fat, could account for the greater increase in HCW compared to final BW when fed zilpaterol. In the present study, calculated EBF in EXP and CON lesser than RAC or IMP. This provides evidence that because cattle fed EXP had higher HCW and lower EBF, they may be experiencing a similar phenomenon as described my Montgomery et al. (2009b).

In the present study, when cattle were on a terminal implant for 104 days, marbling was not affected in implanted treatments, EXP decreased marbling compared to CON, IMP, and RAC. While implanting cattle can negatively affect marbling, this can be avoided through management techniques such as ensuring cattle are consuming adequate dietary energy when implanted, and targeting ~100 days on terminal aggressive implants. McAtee et al. (2024) saw similar responses between β-agonist treatments as that observed in the present study, with a slight drop in marbling from RAC to EXP treatments. Ribeye area was greater in TECH cattle compared to CON cattle. Growth promoting technologies have been known to increase ribeye area, which eventually leads to a heavier HCW (Holland et al., 2010; Maxwell et al., 2015; Vogel et al., 2004). Back fat for cattle in the current study was highest in RAC and lowest in EXP, with IMP being not different than EXP or RAC. CON cattle were similar to EXP cattle. Vogel et al. (2004) saw decreased RF in Holstein cattle who were fed 300 mg/d of Optaflexx 45 for the final 28 to 38 days of finishing. The comparison to CON and EXP cattle is similar to that of several others when comparing CON cattle to cattle fed a β-agonist (Montgomery et al., 2009a; Maxwell et al., 2015). The increase in REA and decrease in RF is one of the major benefits of growth promoting technologies, helping producers limit risk of discounts due to overly fat cattle (high YG). In this study, YG did not differ between treatments. Maxwell et al. (2014) found that calculated yield grades were lower for conventional (implanted) steers compared to natural (non-implanted) steers. They saw a 19.9% unit increase in YG 2 and a 16.04% unit decrease in YG 4 and 5 for conventional steers compared to natural steers.

An increase in HCW lead to a tendency for greater net return for producers using growth promoting technology, with cattle belonging to EXP producing the largest net return at roughly $39 over CON cattle and $10 over IMP cattle when using historical pricing. McAtee et al. (2024) noted a larger net return difference between their EXP and RAC fed cattle. However, they found that the increase in net return was largely due to less feed consumed, increased BW and HCW between the two treatments. The difference in these variables leads to a positive impact on estimated emissions and producer profitability.

Insulin Sensitivity, Inflammation, and Serum Metabolites

Insulin sensitivity was measured using the RQUICK-I index. As cattle increase in their body fat percentage, they also tend to become less insulin sensitive. Smerchek et al. 2024a noted increased levels of insulin sensitivity with the use of implants, with the sensitivity decreasing over time. In the current study TECH treatments remained more insulin sensitive for a longer period of time, allowing them to optimize their energy metabolism, encouraging greater levels of growth performance compared to CON treatments. Experior was originally developed by Lilly as an anti-obesity/diabetic drug. It is known to work partially through improved insulin sensitivity of tissues such as muscle. EXP cattle had improved insulin sensitivity during the EXP feeding period, suggesting more nutrient uptake and a greater final BW and HCW, showcasing the value of improving insulin sensitivity in late stage finishing cattle.

Insulin levels in CON cattle are higher roughly 30 days into the finishing period compared to TECH treatments as they attempt to maintain glucose sensitivity. TECH treatments have a better insulin sensitivity response and therefore need less insulin to respond to the amount of glucose in the bloodstream that increased with the finishing period diet. Smerchek et al. (2024b) also noted that implanted cattle had lower serum insulin levels compared to control cattle. Serum glucose levels decreased over time in the present study. While there was more a drastic drop around the time of terminal implant, levels decreased as cattle got closer to harvest. Smerchek et al. (2024a) also saw a decrease in serum glucose over time, however, in that study, the decrease was not as drastic as was seen in the present study.

Proinflammatory cytokine production is a crucial aspect of innate immune system function (Mahmoud et al., 2020). Stimulation of cytokines IL-1β and IL-6 was completed 30 days following terminal implant administration, and 30 days after the dietary treatment initiation of EXP and RAC. Stimulation with lipopolysaccharide (LPS) and PAM3CSK (PAM) will mimic responses to bacterial infections. Stimulation under POLY I:C (POLY) will show responses to viral infections. In this study, for IL-1β, cells isolated from steers fed EXP showed a greater response to bacterial infection stimulation compared to IMP and CON cattle. For IL-6, RAC cattle showed the greatest response to LPS stimulation 30 days following the start of RAC dietary treatments. For IL-6 under POLY stimulation, RAC tended to be higher than all other treatments 30 days following the commencement of RAC dietary treatments. In this study, the stimulation of various bacterial and viral agents provided evidence that the use of TECH did not decrease the animal's ability to respond to infectious challenges.

No changes in serum NEFA concentrations were seen in steers given IMP or RAC. Bryant et al. (2010) also noted that there was not a change in serum NEFA concentrations when feeding RAC. Similarly, Parr et al. (2014) did not note any differences in serum NEFA concentrations when using various types of implants. For the EXP treatment, there was a decline in serum NEFA concentrations approximately 30 days into the EXP feeding period, where it was lesser than CON and tended to be less than IMP. Hwang et al. (2021) used in vitro stimulation of adipocytes with several β-agonists and found EXP did not induce lipolysis, unlike RAC. Further, NEFA may be depressed in part because of muscle growth in these animals, which could be increasing NEFA demand by the muscle to use for energy production.

This and other research indicate the importance of using growth promoting technologies as they provide a beneficial outcome, both environmentally and economically. Growth promoting technologies increased final BW and HCW, while decreasing urinary N excretion per unit of CA ADG. Growth promoting technologies also increased insulin sensitivity, allowing those animals to have increased nutrition utilization when compared to CON animals. With the use of implants and β-agonists, producers are able to effectively produce more beef using less resources while being strong environmental stewards.

d. Tables and Figures

Table 1: Experimental sampling schedule

Activity	Day of Study	
BW	-1	
BW, blood, growth implant	0	
Prior to this point, all cattle were managed as one block. The light block was on the finishing diet two weeks longer. All study activities were kept the same relative to the day of harvest.		
Activity	**Day of Study**	**Days Prior to Harvest**
BW, blood, terminal implant	69	- 104
BW, blood	98	- 75
BW, blood, EXP dietary treatments started	116	- 57
BW, blood, RAC dietary treatments started	141	- 32
EXP dietary treatments ended	169	- 4
BW, blood, ship to abattoir	172	- 1
Harvest	173	0

Table 2: Composition of diets fed

	Growing	Finishing CON[7]	EXP[8]	RAC[9]
Ingredient, %DM Basis				
Dry rolled corn	25	52	52	52
Sweet Bran [1]	32	20	20	20
Corn silage	38	15	15	15
Dried distillers grains	3.03	11.03	11.03	11.03
Limestone	1.5	1.5	1.5	1.5
Vitamin A & E premix [2]	0.1	0.1	0.1	0.1
Salt	0.31	0.31	0.31	0.31
Rumensin	0.0135	0.0135	0.0135	0.0135
Trace mineral premix [3]	0.0159	0.0159	0.0159	0.0159
Analyzed composition, %DM [5]				
Crude protein	14.22	13.47	13.64	13.95
Neutral detergent fiber	25.78	18.10	18.03	20.35
Ether extract	4.79	4.65	4.51	4.75
NEm, Mcal/lb [5]	0.87	0.94	0.94	0.94
NEg, Mcal/lb [6]	0.58	0.64	0.64	0.64

[1] Branded wet corn gluten feed (Cargill Corn Milling, Blair, NE).
[2] Provided 2,200 IU vitamin A and 25 IU of vitamin E per kg diet DM.
[3] Provided per kg of diet DM: 10 mg of Cu, 100 mg of Zn, 20 mg of Mn, 0.5 mg of I, 0.1 mg of Se, and 0.15 mg of Co, all from inorganic sources.
[4] Based on TMR wet chemistry analysis from Dairyland, INC., Arcadia, WI.
[5] Based on NASEM (2016) reported NEm values of feedstuffs.
[6] Based on NASEM (2016) reported NEg values of feedstuffs.
[7] CON and IMP treatments both received the CON finishing diet.
[8] Lubabegron fumarate (Experior 10) was delivered using dried distillers grains as the carrier.
[9] Ractopamine hydrochloride (Optaflexx 45) was delivered using dried distillers grains as the carrier.

Table 3: Cost assumptions over a fourteen-year average

		Cost Assumption
Purchase price, cwt[1]		
Light (550-600 lbs)	$	179.13
Heavy (600-700 lbs)	$	173.99
Cost of gain (COG) price, cwt[2]	$	188.63
Technology cost, head		
Synovex choice & plus implant	$	7.70
Experior 10	$	20.00
Optaflexx 45	$	15.00
Dressed, delivered price, cwt[3]	$	215.98
Premiums and discounts, head		
Certified Angus beef (CAB)	$	4.00
Prime	$	16.00
Select	$	(14.00)
Below 700 lbs	$	(10.00)
Yield grade 2	$	4.00
Yield grade 4	$	(12.00)
Yield grade 5	$	(25.00)

[1] Data pulled from USDA "Iowa Weekly Cattle Auction Summary" Report
[2] Data pulled from KSU Focus on Feedlots Monthly Reports
[3] Data pulled from USDA "IA/MN Weekly Weighted Average Direct Slaughter Cattle - Negotiated" Report

Table 4: Effect of growth promoting technologies on growing period (d 0 to d 69) performance of feedlot beef steers

	Treatment				*P*-value	
	CON	**IMP**	**EXP**[1]	**RAC**[1]	**SEM**[2]	**TRT P-Value**
Initial BW, lbs	620	620	619	620	1.0	0.59
End Growing BW, lbs	847^{b}	901^{a}	904^{a}	907^{a}	5.1	<0.01
ADG, lbs	3.29^{b}	4.06^{a}	4.13^{a}	4.15^{a}	0.069	<0.01
DMI, lbs	17.93^{b}	19.26^{a}	19.13^{a}	19.03^{a}	0.358	0.05
G:F	0.184^{b}	0.212^{a}	0.217^{a}	0.218^{a}	0.0034	<0.01

[abc] Within a row, means with different superscripts differ ($P < 0.05$).
[xyz] Within a row, means with different superscripts tend to differ ($0.05 < P \leq 0.1$).
[1] During this time (d 0 to 69), IMP, EXP and RAC were all on the same treatment (growing implant).
[2] Highest SEM of any treatment is reported.

Table 5: Effect of growth promoting technologies on finishing period (d 70 to d 172) performance, overall performance, and carcass adjusted (CA) performance of feedlot beef steers

	Treatment				*P*-value	
	CON	**IMP**	**EXP**	**RAC**	**SEM[1]**	**TRT P-Value**
Finishing performance						
Re-implant BW, lbs	879^{b}	936^{a}	938^{a}	940^{a}	4.8	<0.01
EXP period starting BW, lbs	1045^{b}	1144^{a}	1150^{a}	1152^{a}	9.1	<0.01
RAC period starting BW, lbs	1126^{b}	1250^{a}	1271^{a}	1250^{a}	9.0	<0.01
Final BW, lbs	1230^{b}	1374^{ay}	1394^{ax}	1386^{a}	8.3	<0.01
ADG, lbs	3.48^{b}	4.30^{a}	4.45^{a}	4.37^{a}	0.064	<0.01
DMI, lbs	22.21^{b}	24.43^{a}	24.44^{a}	24.59^{a}	0.313	<0.01
G:F	0.157^{b}	0.176^{a}	0.182^{a}	0.177^{a}	0.0026	<0.01
Overall live performance						
Overall ADG, lbs	3.41^{b}	4.21^{ay}	4.33^{ax}	4.28^{a}	0.046	<0.01
Overall DMI, lbs	20.49^{b}	22.40^{a}	22.37^{a}	22.45^{a}	0.283	<0.01
Overall G:F	0.166^{b}	0.188^{ay}	0.194^{ax}	0.191^{a}	0.0019	<0.01
CA performance						
CA final BW, lbs	1230^{b}	1373^{ay}	1393^{ax}	1385^{a}	8.2	<0.01
HCW, lbs	777^{c}	867^{b}	893^{a}	877^{b}	5.2	<0.01
CA ADG, lbs	3.40^{b}	4.21^{ay}	4.33^{ax}	4.27^{a}	0.045	<0.01
CA DMI, lbs	20.52^{b}	22.44^{a}	22.42^{a}	22.48^{a}	0.284	<0.01
CA G:F	0.166^{c}	0.188^{b}	0.193^{a}	0.190^{b}	0.0018	<0.01

^{abc} Within a row, means with different superscripts differ ($P < 0.05$).

^{xyz} Within a row, means with different superscripts tend to differ ($0.05 < P \leq 0.1$).

[1] Highest SEM of any treatment is reported.

Table 6: Carcass Characteristics

	Treatment				*P*-value	
	CON	**IMP**	**EXP**	**RAC**	**SEM[1]**	**TRT P-Value**
HCW, lbs	777^{c}	867^{b}	893^{a}	877^{b}	5.2	<0.01
Marbling [2]	533^{a}	496^{a}	448^{b}	475^{ab}	15.5	<0.01
Yield grade	3.0	3.2	3.0	3.1	0.09	0.24
Ribeye area, in	13.0^{b}	13.7^{a}	13.9^{a}	13.9^{a}	0.11	<0.01
12^{th} rib back fat, in	0.57^{b}	0.62^{abx}	0.56^{by}	0.66^{a}	0.037	0.04
Dressing %	63.1^{b}	63.2^{b}	64.1^{a}	63.3^{b}	0.002	0.01
Empty body fat, %	31.0^{bc}	31.6^{ab}	30.7^{c}	31.8^{a}	0.3936	0.05
Net return, $	-0.28^{y}	29.66^{xy}	39.41^{x}	10.87^{y}	10.511	0.07

^{abc} Within a row, means with different superscripts differ ($P < 0.05$).
^{xyz} Within a row, means with different superscripts tend to differ ($0.05 < P \leq 0.1$).
[1] Highest SEM of any treatment is reported.
[2] Marbling scores: slight: 300, small: 400, modest: 500, moderate: 600, slightly abundant: 700.

Table 7: IL-1β, pg/mL

	Treatment				*P*-value	
	CON	**IMP**	**EXP**	**RAC**	**SEM[4]**	**TRT P-VALUE**
30 d post terminal implant [1]						
MOCK	24.7	28.6			5.45	0.58
LPS	56.5	43.9			11.87	0.31
PAM	37.9	33.4			6.48	0.53
POLY	598.2	597.8			101.87	1.00
30 d post EXP start [2]						
MOCK	14.1	14.9	16.1		2.11	0.81
LPS	31.7	20.9	24.7		6.43	0.24
PAM	13.7[b]	13.8[b]	22.6[a]		3.73	0.05
POLY	185.8	268.7	329.5		90.16	0.33
30 d post RAC start [3]						
MOCK	14.0	12.1	15.2	15.7	2.07	0.52
LPS	26.0	23.1	30.9	38.1	6.82	0.24
PAM	28.1	20.8	18.1	29.2	7.45	0.49
POLY	269.0	223.2	281.5	381.7	68.87	0.23

[abc] Within a row, means with different superscripts differ ($P < 0.05$).
[1] For CON, n = 9; for IMP, n = 27
[2] For CON, n = 9; for IMP, n = 18, for EXP, n = 9
[3] For all treatments, n = 9
[4] Highest SEM of any treatment is reported.

Table 8: IL-6, pg/mL

	Treatment					*P*-value
	CON	IMP	EXP	RAC	SEM[4]	TRT P-VALUE
30 d post terminal implant [1]						
MOCK	63.4	117.7			23.80	0.13
LPS	171.7	186.5			66.84	0.86
PAM	122.8	142.6			47.50	0.74
POLY	129.5	212.4			46.33	0.24
30 d post EXP start [2]						
MOCK	52.6	80.4	73.9		23.54	0.55
LPS	129.9	169.9	106.3		48.33	0.57
PAM	107.1	137.5	99.3		32.65	0.64
POLY	155.7	200.7	177.2		66.99	0.86
30 d post RAC start [3]						
MOCK	71.6	45.2	59.3	85.0	19.51	0.26
LPS	300.6^{ab}	128.6^{c}	176.6^{bc}	523.6^{a}	129.59	0.01
PAM	249.4	212.0	200.8	418.6	123.75	0.30
POLY	311.3^{y}	274.8^{y}	291.8^{y}	646.1^{x}	166.81	0.09

^{abc} Within a row, means with different superscripts differ ($P < 0.05$).

^{xyz} Within a row, means with different superscripts tend to differ ($0.05 < P \leq 0.1$).

[1] For CON, n = 9; for IMP, n = 27

[2] For CON, n = 9; for IMP, n = 18, for EXP, n = 9

[3] For all treatments, n = 9

[4] Highest SEM of any treatment is reported.

Figure 1A-C: Effect of treatment by day (index value, μeq/mL, mg/dL) based on repeated measures analysis of blood samples collected 179, 104, 75, 57, 32, and 1 day prior to harvest, using blood collected 179 days prior to harvest as a covariate. Days with a "*" differ $P \leq 0.05$ across sampling days and "‡" indicate a tendency ($0.05 < P \leq 0.10$). Figure 1A shows RQUICK-I index values, Figure 1B shows insulin (mg/dL), and Figure 1C shows NEFA values (μeq/mL).
Figure 1D: Effect of day on glucose ($P < 0.01$) values (mg/dL) based on repeated measures analysis using blood collected 179 days prior to harvest as a covariate. There was a day effect where glucose generally decreased across days on feed.

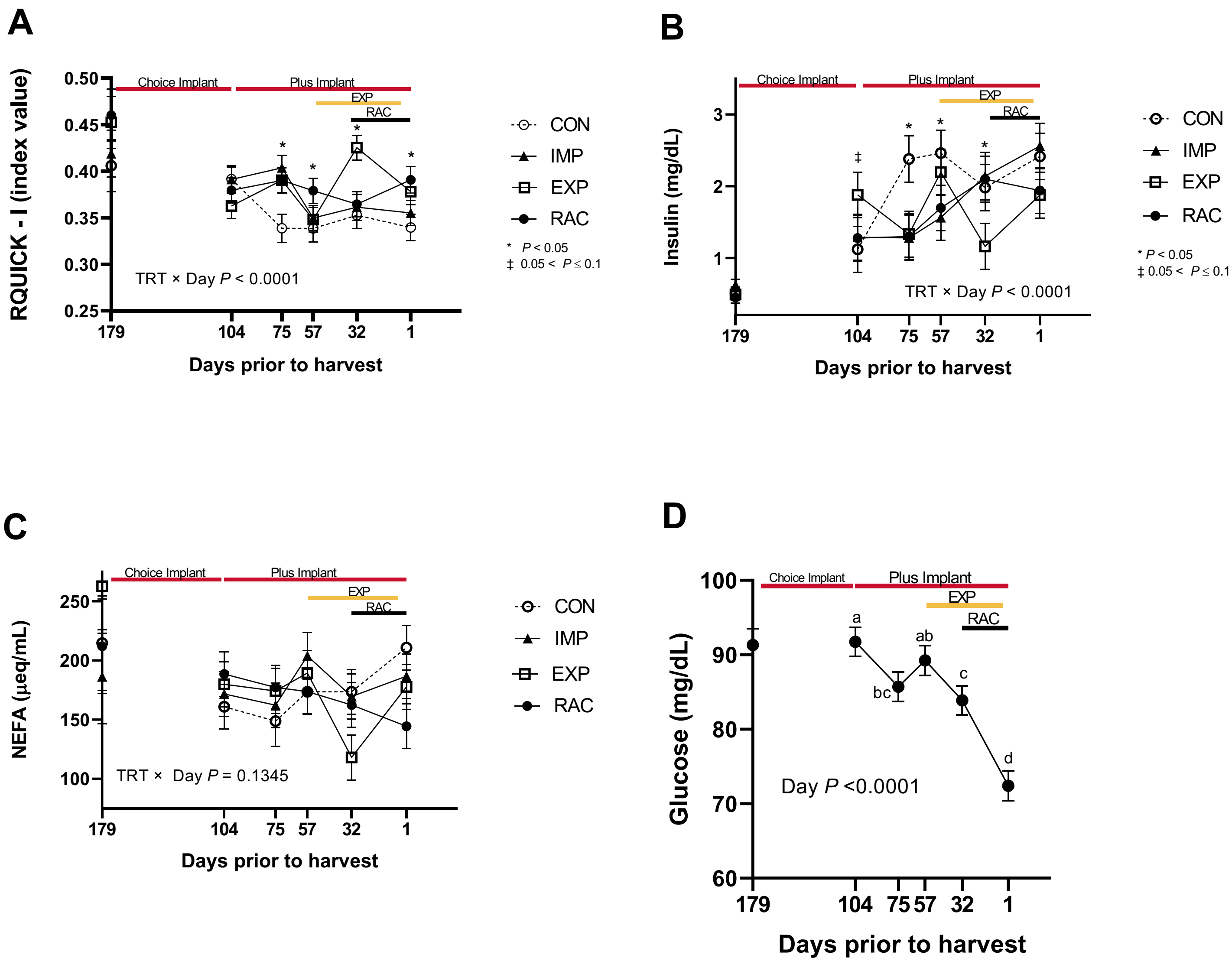
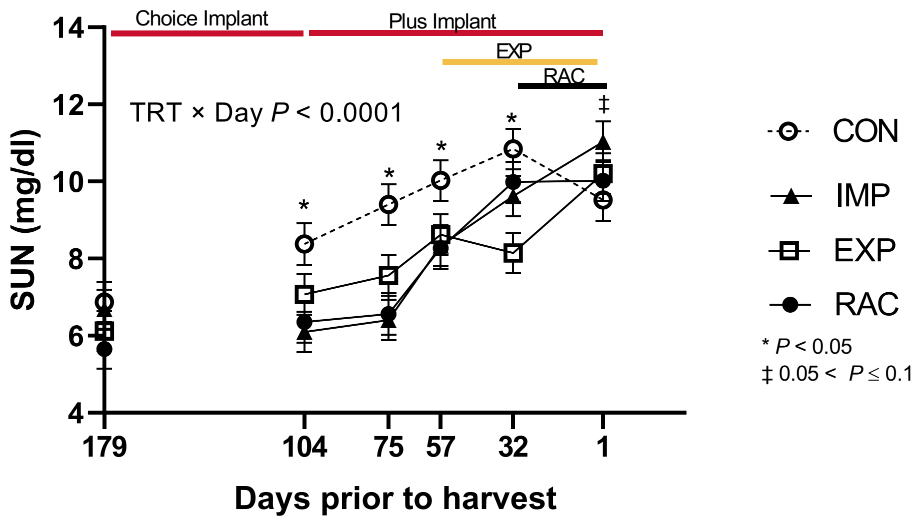
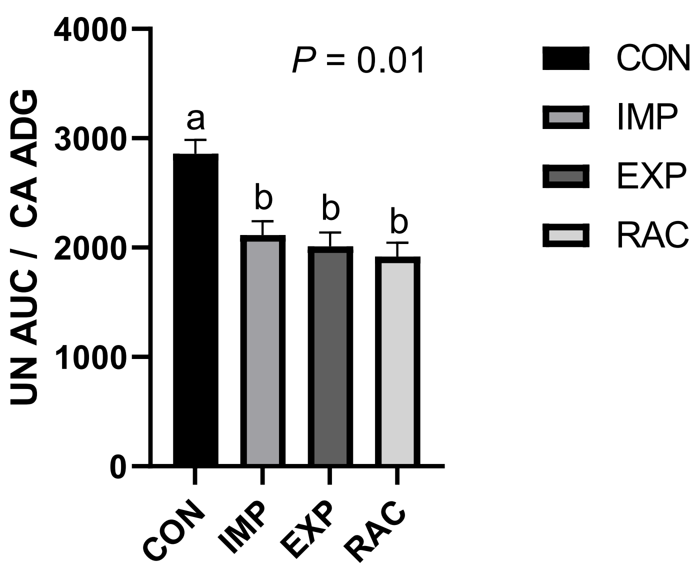

A
RQUICK - I (index value)
Choice Implant
Plus Implant
EXP
RAC
TRT × Day P < 0.0001
Days prior to harvest
CON
IMP
EXP
RAC
* P < 0.05
‡ 0.05 < P ≤ 0.1
B
Insulin (mg/dL)
TRT × Day P < 0.0001
C
NEFA (µeq/mL)
TRT × Day P = 0.1345
D
Glucose (mg/dL)
Day P <0.0001

Figure 2A: Effect of treatment by day on serum urea nitrogen (SUN - mg/dL) based on repeated measures analysis of blood samples collected 179, 104, 75, 57, 32, and 1 day prior to harvest, using blood collected 179 days prior to harvest as a covariate. Days with a "*" differ $P \leq 0.05$ across sampling days and "‡" indicate a tendency ($0.05 < P \leq 0.10$).
Figure 2B: Effect of treatment on urinary nitrogen AUC by carcass adjusted ADG. Values within the graph with unlike superscripts (a and b) differ ($P \leq 0.05$) across treatments.

A



B



e. **Conclusions**
   In order to meet the expected increased food demand for a growing global population, it will be imperative to utilize technologies to our advantage to better increase the efficiency, sustainability, and productivity of beef production. Cattle who received growth promoting technologies exhibited increased live and carcass performance, better insulin sensitivity, decreased urinary N excretion, and increased net return for producers compared to cattle who did not receive growth promoting technologies. It is critical that cattle producers have access to growth promoting technologies such as anabolic implants and β-adrenergic agonists to stay profitable while meeting consumer demands of a decreased environmental footprint. These are necessary factors to ensure the continuous availability of a nutritious, and safe, beef supply to the US and global populations that depend upon our industry.
f. **Unexpected Problem or Outcomes**
   None to report.
g. **Presentations and Publications**
   None as of time of final report submission, but we will submit a manuscript for review this fall, as well as an animal industry report and an abstract for Midwest Animal Science Meetings.

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