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Effects of Zilmax on performance, carcass characteristics, and traveling ability of crossbred steers consuming rations with different concentrations of urea

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Introduction

Zilpaterol hydrochloride (Zilmax; Merck Animal Health, Summit, NJ) is a beta-adrenergic agonist commercially used to increase animal performance in the beef finishing industry. Studies in feedlot cattle (Avendaño-Reyes et al., 2006; Elam et al., 2009; Baxa et al., 2010) indicated that using Zilmax the last 20 to 40 days of the finishing period increased average daily gain, hot carcass weight, dressing percentage, and rib-eye area, and decreased 12th rib fat depth and marbling scores. These changes in carcass characteristics typically result in increased red meat yield, and minimal changes on consumer acceptability despite increased Warner-Bratzler shear force (Hilton et al., 2009).

Greater animal performance associated with use of repartitioning agents, such as Zilmax, could alter livestock nutrient requirements (Reeds and Meremann, 1991). Brake et al. (2011) demonstrated that urea entry rate and urea-nitrogen recycled to the gut (expressed as a percentage of total nitrogen intake) tended to be lower when Zilmax was included in corn-based diets fed to steers. These results suggest that Zilmax may repartition nitrogen into muscle protein synthesis, thus decreasing urea recycling. According to Titgemeyer et al. (2012), greater dietary nitrogen supply may be necessary to maintain rumen function when protein deposition is increased.

We hypothesized that a greater dietary supply of ruminally available nitrogen would improve performance of feedlot cattle fed Zilmax. The objective of this study was to evaluate the effects of Zilmax on performance and carcass characteristics of crossbred steers consuming rations with increasing concentrations of ruminally degradable protein supplied as urea. An additional objective of this study was to quantify the speed of movement of steers supplemented with Zilmax.

Experimental Procedures

Cattle and Facilities. All procedures were approved by the Institutional Animal Care and Use Committee at New Mexico State University. In October and November 2012, 450 crossbred steer calves (503 ± 39 lb body weight) were processed according to standard operating procedures at the Clayton Livestock Research Center. One load of cattle was obtained directly from the Corona Range and Livestock Research Center (Corona, NM) with known management practices, while four loads of cattle were obtained from Texas livestock auctions and had unknown management prior to arrival at the research feedlot. Each calf was individually weighed and processed in a tub and snake with a single-animal hydraulic squeeze chute (Silencer, Moly Mfg. Inc., Lorraine, KS). In addition to recording weights, steers were given an identification tag, vaccinated for respiratory diseases (Vista 5, Merck Animal Health, Summit, NJ) and clostridial organisms (Calvary 9, Merck Animal Health), treated for external parasites (Safe-Guard, Merck Animal Health), provided with one of two metaphylactic treatments (Draxxin, Zoetis Animal Health, Madison, NJ; or Zuprevo, Merck Animal Health), and given a growth implant (Revalor-IS, Merck Animal Health). Cattle were then utilized for an immunology study as outlined by Graves et al. (2013). Upon completion of the 56-day immunology study, cattle were fed an 85% concentrate feedlot ration containing monensin (Rumensin, Elanco Animal Health, Greenfield, IN) and tylosin (Tylan, Elanco Animal Health). At approximately 155 days on feed, 429 steers were weighed individually, re-implanted (Revalor-IS, Merck Animal Health), and sorted into 3 blocks based on body weight (average initial weight at the time of sorting was 857 ± 2.4, 933 ± 1.6, and 998 ± 2.4 lb for blocks 1, 2, and 3, respectively). Within each block, steers were assigned to pens so that the average body weight and standard error was similar among pens of each block. There were 36 soil-surfaced pens (40 ft. × 115 ft., with 36 ft. bunk line and a continuous flow water trough) in 3 blocks with 12 pens per block, and 11 to 12 steers per pen. Pens of cattle received a standard feedlot finishing ration containing 0.5% urea (and no Zilmax) until 27 days before harvest, at which time the finishing ration was replaced with 1 of 3 dietary treatments (Table 1). Before treatment application, 3 steers initially assigned to the study were removed; 1 steer was moved into the cull-pen while 2 other steers died from complications unrelated to this study.

Dietary Treatments. The experiment was a randomized complete block design. Within each block, pens were randomly assigned to 6 dietary treatments in a 2 × 3 factorial arrangement. Treatments were either no Zilmax or Zilmax supplemented to finishing rations containing 0%, 0.5%, or 1.0% urea (Table 1). Treatments were initiated after pens of cattle were weighed using a pen scale at 27 days before the scheduled harvest date. Due to body weight differences, both treatment initiation and harvest date were staggered in one-week increments among the 3 blocks. Treatments were fed for 24 days (due to beef processing plant availability) followed by a 3-day withdrawal period, during which cattle did not receive Zilmax. Cattle were fed twice daily, and Zilmax treatments were top-dressed onto the finishing ration in the feed bunk. Before top-dressing, the appropriate amount of Zilmax for a pen of cattle was mixed with 200 grams of wet corn gluten feed (Sweet Bran, Cargill Inc., Minneapolis, MN) to supply 75 mg zilpaterol hydrochloride per steer daily. Before Zilmax was mixed with wet corn gluten feed, granules of Zilmax were dyed using food coloring to ensure that the treatment was distributed evenly throughout the feed bunk. A rake was used in an attempt to thoroughly distribute the wet corn gluten feed and Zilmax evenly with the finishing ration. The ration of a pen of cattle receiving treatments with no Zilmax was top-dressed with 200 grams of wet corn gluten feed only.

Feeding Management and Collections. Feed bunks were evaluated visually two times per day to determine the quantity of feed to offer each pen utilizing a "slick bunk" approach. Feed was mixed in an overhead mixer (Butler Oswalt Model 1830, 5000-lb capacity, Garden City, KS) and delivered to pens by a 6-bin feed truck with individual dispensing augers. Daily feed offered was recorded and diet samples were collected on a weekly basis to calculate dietary dry matter and determine nutrient content. Feed refusals were collected as needed and analyzed for dry matter content (100°C overnight in a forced air oven) to calculate daily dry matter intake. The study was conducted during the summer of 2013 with mean daily temperatures ranging from 63°F to 83°F and intermittent rain and thunderstorms over the course of treatment application (Weather Underground, 2013).

Pens of steers were weighed to obtain final body weights before shipping to a commercial abattoir. An all-terrain vehicle was utilized to move cattle from their assigned pens to the scale platform, and a stopwatch was used to record the time for cattle to walk from their pens to the scale. The timer began once the pen gate was opened and stopped once all of the cattle had reached the pen scale platform. In addition to length of time required for each pen of cattle to reach the platform, the distance from each pen to the scale platform was recorded. Once pen weights were recorded, cattle were loaded onto a two decked trailer and transported approximately 141 miles to the processing plant (Tyson Fresh Meats, Amarillo, TX). Cattle were weighed and shipped before 9:30 AM to decrease exposure to heat stress. For the first experimental block, pen weights were recorded and cattle were moved into holding pens until shipping. For the second and third experimental blocks, pens of cattle were weighed and loaded directly onto the shipping trucks. Once cattle reached the processing plant they were housed in holding pens for a minimum of 2 hours prior to harvest.

Steers were humanely harvested and hot carcass weights and liver scores were recorded. All measurements for carcass characteristics and liver scores were collected by personnel from the Beef Carcass Research Center (West Texas A&M University, Canyon, TX). Liver condition was reported according to the Eli Lily liver check system (Brown et al., 2010). Carcasses were chilled for approximately 24 hours and individual carcass measurements included marbling score, USDA quality grade, 12^{th} rib fat depth, rib-eye area, and kidney-pelvic-heart fat. Kidney-pelvic-heart fat, rib-eye area, hot carcass weight, and 12^{th} rib fat depth were utilized to calculate USDA yield grade. Dressing percentage was calculated by dividing the average hot carcass weight of the steers in the pen by the final body weight of the pen.

Statistical Analysis. Performance data and carcass data with continuous variables (hot carcass weight, marbling score, 12^{th} rib fat depth, rib-eye area, kidney-pelvic-heart fat, and yield grade) were analyzed statistically using the MIXED procedure of SAS, and categorical data such as the distribution of liver scores and quality grades were analyzed using the GLIMMIX procedure of SAS. The model included UREA, ZILMAX, and the UREA × ZILMAX interaction in the model, and BLOCK was the random effect. Contrasts were used to test the linear and quadratic responses of increasing dietary concentration of urea. Initial and final body weights of steers were adjusted with a 4% shrink. For mobility data, a pen of cattle receiving the dietary treatment with 0% urea and top-dressed with Zilmax was excluded from statistical analysis because the pen contained a blind animal that was unrelated to treatments (the steer appeared to be blind before treatments were initiated).

Results

Interaction of Zilmax and Dietary Urea. No interactions ($P \geq 0.11$) between Zilmax and dietary urea were observed for all of the performance or carcass response variables (Table 2). Additionally, no Zilmax × urea interactions ($P \geq 0.35$) were observed for time to the scale or feet per second traveled (Table 3).

Effects of Dietary Urea. Initial and final body weights were not statistically different ($P \geq 0.21$) among cattle fed rations with different urea concentrations (Table 2). Increasing urea in the ration linearly decreased both dry matter intake ($P = 0.01$) and average daily gain ($P = 0.01$), and did not affect feed-to-gain ratio ($P \geq 0.17$). Hot carcass weights tended to decrease linearly ($P = 0.10$) with increasing urea concentrations in the ration. Dressing percentage, 12^{th} rib fat depth, rib-eye area, kidney-pelvic-heart fat, yield grade, percentage of carcasses grading Choice or better, and incidence of liver abscesses were not affected ($P \geq 0.16$) by increasing concentrations of urea in the ration. A tendency for a quadratic effect ($P = 0.07$) on marbling was observed as the concentration of urea increased in the ration. Mobility was not affected ($P \geq 0.24$) among cattle fed rations with different urea concentrations (Table 3).

Effects of Zilmax Application. Initial and final body weights were not statistically different ($P \geq 0.63$) for cattle fed Zilmax compared with no Zilmax (Table 2). Cattle fed diets with Zilmax had lower ($P = 0.01$) dry matter intake, greater ($P < 0.01$) average daily gain, and improved ($P < 0.01$) feed-to-gain ratio. Cattle receiving diets containing Zilmax exhibited greater hot carcass weights ($P < 0.01$), dressing percentage ($P < 0.01$), and rib-eye area ($P < 0.01$), as well as improved yield grade ($P = 0.02$) compared with cattle receiving diets with no Zilmax. Feeding Zilmax in the ration did not affect ($P \geq 0.28$) marbling score, 12^{th} rib fat depth, kidney-pelvic-heart fat, percentage of carcasses grading Choice or better, and incidence of liver abscesses. Animal mobility response variables were not affected ($P \geq 0.19$) by the addition of Zilmax to finishing rations (Table 3). Steer morbidity and mortality were 0% during the 27-day experimental period.

Discussion

Interaction of Zilmax and Dietary Urea. We hypothesized that a greater dietary supply of ruminally available nitrogen (i.e. urea) would improve performance of feedlot cattle receiving Zilmax. This hypothesis was based on evidence that greater tissue protein deposition (measured as nitrogen retention) in response to Zilmax could reduce urea recycling to the rumen as a result of decreased amino acid catabolism by the liver (Brake et al., 2011). If urea recycling is reduced by growth promoting technologies such as beta-adrenergic agonists, an increase in the dietary supply of ruminally available nitrogen may be necessary to support optimal rumen fermentation (Titgemeyer et al., 2012).

In this study, the finishing diets contained 0%, 0.5%, and 1.0% urea (dry matter basis) to supply an estimated 7.3%, 8.4%, and 9.7% rumen degradable protein, respectively (Table 1). According to Cooper et al. (2002), 8.3% ruminally degradable protein is considered adequate in typical feedlot diets containing no beta-adrenergic agonists. Therefore, it was assumed that the finishing diet containing 0.5% urea supplied adequate rumen available nitrogen, whereas rumen available nitrogen was potentially deficient in the diet containing 0% urea, and in excess in the diet containing 1.0% urea. Lack of interaction between Zilmax and dietary urea for performance and carcass traits suggests that feeding Zilmax did not require a greater dietary supply of ruminally available nitrogen. Despite evidence that Zilmax could reduce urea recycling (Brake et al., 2011), alterations in nitrogen metabolism were not large enough to increase the dietary requirements of ruminally degradable protein above the 8.4%.

Effects of Dietary Urea. Increasing urea concentration in the diet decreased animal performance regardless of Zilmax application. The decrease in average daily gain is likely due to lower dietary energy intake as a result of decreased dry matter intake in response to increasing dietary urea. The greatest numerical decreases in both dry matter intake and average daily gain occurred when urea was increased from 0.5% to 1.0% of the diet. The decrease in dry matter intake in response to increasing dietary urea concentrations is in contrast to Shain et al. (1998) and Gleghorn et al. (2004), but consistent with responses observed by Milton et al. (1997). In the current study, all pens of cattle were fed the finishing ration containing 0.5% urea (and no Zilmax) until 27 days before harvest, at which time the finishing diet was replaced with treatment diets containing either lower (0%), similar (0.5%), or greater (1.0%) concentrations of urea (Table 1). It is possible that an abrupt change from the diet containing 0.5% urea to the diet containing 1.0% urea negatively affected dry matter intake of steers during the final 27 days of finishing. In a review, Kertz (2010) discusses that when urea is provided in excess, dry matter intake will decrease. However, Kertz (2010) referenced studies with dietary urea concentrations larger than those in the present study. In the studies by Milton et al. (1997), Shain et al. (1998), and Gleghorn et al. (2004), urea concentrations in the dietary treatments remained constant throughout the finishing period. Furthermore, diets with the greatest urea concentrations reported previously (Milton et al., 1997; Shain et al., 1998; Gleghorn et al., 2004) had dietary crude protein (and perhaps ruminanlly degradable protein) concentrations similar or lower than the intermediate diet (0.5% urea) in this study. Therefore, decreases in both dry matter intake and average daily gain when urea was increased from 0.5% to 1.0% of the diet is perhaps due to an excess supply of ammonia. Additional research investigating urea kinetics and amino acid utilization of cattle receiving varying levels of ruminally available nitrogen may allow for further explanation of the results observed in this study.

A tendency for hot carcass weights to decrease in response to increasing concentrations of dietary urea is likely due to decreased performance. These results contrast those reported by Milton et al. (1997), Shain et al. (1998), and Gleghorn et al. (2004), who observed either no difference or increased hot carcass weights associated with increasing dietary urea concentration. However, in the aforementioned studies, the feeding protocol remained uniform throughout treatment application, perhaps resulting in more favorable performance and thus improved hot carcass weights. In the current study, other carcass measurements were not affected by dietary urea concentrations, and are in agreement with the results of Shain et al. (1998) and Gleghorn et al. (2004).

Effects of Zilmax Application. Final body weights were not statistically different, but steers fed Zilmax for 24 days followed by a 3-day withdrawal period had 6% lower dry matter intakes, 16% greater daily gains, and 19% lower (improvement) feed-to-gain ratios when compared with steers receiving no Zilmax. These results agree with most previous studies (Vasconcelos et al., 2008; Holland et al., 2010), although some studies (Scramlin et al., 2010) also reported greater final body weight for cattle fed Zilmax. In a review, Mersmann (1998) explains that synthetic beta-agonists may traverse the blood-brain barrier and influence central nervous system-mediated responses such as satiety and hunger signals, which may explain decreases in dry matter intake of cattle fed Zilmax.

Feeding Zilmax to steers increased hot carcass weights by approximately 32 pounds, which is slightly greater than the 28-pound heavier hot carcass weights observed by Montgomery et al. (2009) and Scramlin et al. (2010). Dressing percentage was 3.7% greater for cattle fed Zilmax, perhaps a result of increased carcass tissue accretion relative to visceral mass. The increase in dressing percentage observed in this study is greater than the 1.4% increase observed by Elam et al. (2009) for cattle fed Zilmax for 20 days. Differences in dressing percentage could be due to differences in final body weights, ration composition, or feeding management decisions. In this study, no differences in marbling score, 12^{th} rib fat depth, or kidney-pelvic-heart fat suggest that Zilmax did not affect carcass fat distribution. Results observed for both 12^{th} rib fat depth and kidney-pelvic-heart fat are consistent with the findings of Montgomery et al. (2009) and Holland et al. (2010). Vasconcelos et al. (2008) indicated that decreases in marbling are observed when fat deposition is decreased as a result of feeding Zilmax. However, this study reported greater average daily gain than the present study, which may have affected body composition. Larger rib-eye area in response to feeding Zilmax is indicative of increased protein deposition and muscle yield, and is consistent with the findings of Avendaño-Reyes et al. (2006). Additionally, Zilmax improved (decreased) yield grade, which agrees with the results reported by Holland et al. (2010), suggesting that Zilmax more directly affected protein deposition, as carcass fat composition was not altered by the inclusion of Zilmax in the diet. Because body fat composition was similar between cattle fed Zilmax and those not fed Zilmax, there was no difference in quality grade. In contrast, Montgomery et al. (2009) and Vasconcelos et al. (2008) observed an increase in the number of select carcasses. This change in quality grade can be explained by a decrease in marbling score when Zilmax was utilized, a response that was not reported in the present study. Zilmax did not increase the presence of condemned livers, which agrees with Holland et al. (2010). However, tylosin was provided in the diet in each of these studies, which may have affected the number of liver abscesses observed.

Utilizing Zilmax as a supplement in feedlot finishing rations did not significantly influence the steers' speed of movement from their pens to the scale platform prior to shipment to the commercial abattoir. However, additional research that utilizes multiple objective measurements is needed to evaluate the effects of Zilmax on finishing cattle mobility.

Conclusion

The results of this study indicate that cattle supplemented with the beta-agonist, Zilmax, during the last 24 days (excludes a 3-day withdrawal period) of the finishing period do not require additional ruminally degradable intake protein to maximize performance. Additionally, results of this study suggest that providing excess ruminally available nitrogen (as urea) may decrease performance of feedlot cattle during the last 27 days of the finishing period, regardless of whether Zilmax was included in the ration. These findings contrast our hypothesis that a greater dietary supply of ruminally available nitrogen would improve performance of feedlot cattle fed Zilmax. Regardless of dietary urea concentrations, feeding Zilmax during the last 24 days of the feeding period improved performance, hot carcass weight, dressing percentage, and rib-eye area, and did not decrease carcass fat deposition to the same extent that has been reported previously. Providing Zilmax in the diet did not alter speed at which steers walked from their feedlot pens to a scale platform before shipment to a commercial beef processing plant.

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Table 1. Ingredient and nutrient concentrations of dietary treatments

	Dietary Treatments[1]		
Item	**0%Urea**	**0.5%Urea**	**1.0%Urea**
Ingredient, % of DM			
Corn grain, flaked	60.99	61.01	60.95
Wet corn gluten feed[2]	18.66	18.67	18.65
Corn stover	8.12	8.12	8.11
Corn distiller's grains with solubles	9.35	9.82	8.91
Urea, 45% nitrogen	-	0.49	0.98
Limestone	2.05	2.05	2.05
Beefmax 510[3]	0.062	0.050	0.062
Salt	0.25	0.25	0.25
Vitamin supplement[4]	0.002	0.002	0.002
Medicated supplement[5]	0.021	0.021	0.021
Nutrient Analysis[6]			
CP, % DM	13.7	14.4	15.8
RDP, % DM[7]	7.3	8.4	9.7
RUP, % DM[7]	6.3	6.0	6.1
ADF, % DM	9.5	9.2	9.8
Ca, % DM	0.81	0.73	0.76
P, % DM	0.46	0.42	0.47
NEm, Mcal/kg DM[8]	2.12	2.21	2.21
NEg, Mcal/kg DM[8]	1.50	1.52	1.51

[1]Treatments were in a 2 × 3 factorial arrangement with two levels of Zilmax and three concentrations of ruminally degradable protein supplied as urea. For the Zilmax treatments, finishing rations in the feed bunk were top-dressed with 200 grams per pen wet corn gluten feed that contained either no Zilmax or Zilmax to supply 75 mg of zilpaterol hydrochloride per steer daily.
[2]Sweet Bran (Cargill Inc., Mineapolis, MN)
[3]Contained 1.8% Cu, 9.0% Zn, and 360 ppm Se (Cargill Inc.).
[4]Supplied 1694 IU vitamin A, 339 IU vitamin D, 12 IU vitamin E per pound of DM.
[5]Supplied 31 g of monensin and 8 g of tylosin per ton of dietary DM. (Elanco Animal Health, Indianapolis, IN)
[6]Nutrient concentrations are based on proximate analysis (Servi-Tech Labs, Amarillo, TX).
[7]Calculated based on tabular values (NRC, 1996).
[8]Calculated by Servi-Tech Labs.

Table 2. Effects of Zilmax and urea concentrations in finishing rations on performance and carcass characteristics of crossbred steers

	Treatments[1]							P-value[2]			
	No Zilmax			Zilmax				Urea	Urea		Urea
	0%Urea	0.5%Urea	1.0%Urea	0%Urea	0.5%Urea	1.0%Urea	SEM	Lin.	Quad.	ZIL	× ZIL
Pens[3]	6	6	6	6	6	6					
Performance											
Initial body weight, lb[4]	1197	1185	1201	1196	1199	1177	40.8	0.53	0.93	0.71	0.31
Final body weight, lb	1252	1239	1250	1262	1263	1231	41.0	0.21	0.83	0.63	0.24
Dry matter intake, lb/day	19.7	19.5	18.5	18.6	18.6	16.7	0.86	0.01	0.15	0.01	0.75
Gain, lb/day	2.03	2.00	1.83	2.44	2.40	1.98	0.13	0.01	0.22	<0.01	0.43
Feed-to-gain ratio	9.74	10.07	10.14	7.70	7.88	8.56	0.74	0.17	0.88	<0.01	0.78
Carcass Characteristics											
Hot carcass weight, lb	812	803	798	839	841	831	29.0	0.10	0.72	<0.01	0.71
Dressing %	64.8	64.8	63.8	66.4	66.5	67.7	0.60	0.82	0.95	<0.01	0.11
Marbling score	42.1	45.1	44.2	44.0	45.3	43.3	1.78	0.53	0.07	0.66	0.44
12th rib fat depth, in.	0.45	0.53	0.49	0.50	0.48	0.48	0.04	0.73	0.30	0.98	0.20
Rib-eye area, sq. in.	13.9	13.6	13.6	14.8	14.6	14.8	0.84	0.32	0.35	<0.01	0.71
KPH fat, %	1.86	1.81	1.82	1.82	1.87	1.77	0.03	0.16	0.47	0.76	0.19
Yield grade	2.64	2.86	2.78	2.56	2.61	2.49	0.17	0.75	0.18	0.02	0.52
Choice or better, %	56.0	66.0	58.0	63.4	59.2	57.2	9.07	0.72	0.45	0.98	0.50
Liver abscesses, %	20.4	17.3	13.0	10.4	9.92	19.6	5.41	0.77	0.57	0.28	0.14

[1] Treatments (2 × 3 factorial arrangement) were 2 levels of Zilmax (no Zilmax versus Zilmax to supply 75 mg zilpaterol hydrochloride per steer daily) and 3 concentrations of urea (0, 0.5, or 1.0% urea) in finishing rations (Table 1). Treatments were fed for 24 days followed by a 3-day withdrawal period.

[2] Urea Lin. = *P*-value for the linear effect of urea; Urea Quad. = *P*-value for the quadratic effect of urea; ZIL = *P*-value for the main effect of Zilmax; Urea × ZIL = *P*-value for the interaction of urea and Zilmax.

[3] Pens contained 11 to 12 steers.

[4] Initial body weight = body weight at the initiation of treatments (27 days before harvest).

Table 3. Effects of Zilmax and urea concentrations in finishing rations on traveling ability of crossbred steers

	Treatments[1]							P-value[2]			
	No Zilmax			Zilmax				Urea	Urea		Urea
	0%Urea	0.5%Urea	1.0%Urea	0%Urea	0.5%Urea	1.0%Urea	SEM	Lin.	Quad.	ZIL	× ZIL
Pens[3]	6	6	6	5	6	6					
Distance, ft[4]	469	467	469	466	463	459	94.4	0.53	0.83	0.19	0.72
Total time, min[4]	2.28	2.26	2.30	2.20	2.58	2.73	0.36	0.24	0.84	0.25	0.53
Feet per sec traveled	3.46	3.43	3.53	3.68	2.97	3.00	0.45	0.29	0.36	0.26	0.35

[1] Treatments (2 × 3 factorial arrangement) were 2 levels of Zilmax (no Zilmax versus Zilmax to supply 75 mg zilpaterol hydrochloride per steer daily) and 3 concentrations of urea (0, 0.5, or 1.0% urea) in finishing rations (Table 1). Treatments were fed for 24 days followed by a 3-day withdrawal period.

[2] Urea Lin. = *P*-value for the linear effect of urea; Urea Quad. = *P*-value for the quadratic effect of urea; ZIL = *P*-value for the main effect of Zilmax; Urea × ZIL = *P*-value for the interaction of urea and Zilmax.

[3] Pens contained 11 to 12 steers. A pen of cattle receiving Zilmax and 0% urea was removed from statistical analysis because it contained a blind steer.

[4] Distance = total distance from the cattle pens to the platform scale; Total time = total length of time for cattle to walk from their pens to the scale.