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The Effects of Feed Additives in Beef Finishing Systems and the Effect of Rumen Degradable Protein Supplementation in Corn Residue Grazing Systems with the Use of Distillers on Growth Performance

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THE EFFECT OF RUMEN DEGRADABLE PROTEIN SUPPLEMENTATION IN

CORN RESIDUE GRAZING SYSTEMS WITH THE USE OF DISTILLERS ON

GROWTH PERFORMANCE

by

Robert Michel Jones

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Galen E. Erickson and James C. MacDonald

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University of Nebraska, 2017

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One receiving trial evaluated the effect of the feed additive monensin (trade name: Rumensin) on steer growth performance in the receiving period while evaluating the effects of two receiving vaccinations on morbidity and mortality of newly received calves. No differences were observed in growth performance, morbidity rate or mortality rate between treatments for the first 28 d of receiving.

A finishing trial evaluated the effect of the feed additive ractopamine hydrochloride (trade name: Optaflexx) on feedlot growth performance and carcass characteristics of crossbred yearling steers fed to differing degrees of finish. Feeding ractopamine hydrochloride at 300 mg improved ADG, G:F, and HCW regardless of days on feed (i.e., degree of finish).

A growing trial evaluated the performance effects of grazing steers on corn residue supplemented with modified distillers grains plus solubles (MDGS; 1.4 or 2.3 kg/d) with or without urea (0 or 0.05 kg/d). No differences were observed in growth performance suggesting that supplemental urea is not necessary when supplementing at least 1.4 kg MDGS to steers grazing corn residue.

Acknowledgements

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CHAPTER I. LITERATURE REVIEW

Introduction

In the past decade, both economic and public considerations have greatly influenced the beef industry. Ruminant nutritionists are focused to optimize animal performance and efficiency through maximum utilization of microorganisms in the ruminant animal. Technological advances have provided nutritionists and producers alike with many tools that allow an animal to more efficiently utilize forage and concentrate sources to produce beef to meet consumer demand. With the world population ever increasing, total consumption of beef has increased. Over the past 50 years, total beef consumption has risen from 13.7 billion pounds to approximately 27 billion pounds in 2004 (Elam and Preston, 2004). The beef industry has relied on feed additives as a tool to promote growth and increase the efficiency of an animal at an affordable price. Since 1955, the average consumer cost per pound of beef has decreased 26% adjusting for inflation (Elam and Preston, 2004).

Ionophores

Ionophores have been widely used in cattle feeding operations since 1975 (Goodrich et al., 1984). In 2011, 91.5% of feedlot operations fed ionophores such as monensin (APHIS, 2011). Competition for the beef industry from other sources of protein such as swine and poultry is a driver in the promotion of feed additive utilization in feedlot diets. Competition pushes producers to find ways to reduce cost of production. Lawerence and Ibarburu (2007) reported that feeding an ionophore can reduce costs by approximately $12- 13 per head or 1.2%.

Pressure from both the media and consumers in the last decade regarding the use of antibiotics in meat production has caused the beef industry to evaluate alternatives. In January of 2006, the European Union banned the use of antibiotics in the feeding of livestock. The European Union represents 27 countries and over 450 million people (Directive 1831/2003/CEE, European Commission, 2003). The U. S. Food and Drug Administration (FDA) released the Veterinary Feed Directive (VFD) to implement policy on the more judicious use of medically important antimicrobial drugs in food-producing animals. Regulations went into effect starting January, 1 2017 where use of antimicrobials in the feed that are deemed medically important will require a written VFD from a licensed veterinarian and cannot be used for growth promotion. The feed additive monensin is a type A medicated article that is classified as a category one not requiring a withdrawal period and is not regulated under the VFD (VFD, 2017). Monensin is marketed under the trade name Rumensin (Elanco Animal Health, Greenfield IN). In 1975, monensin was approved for use in cattle fed in confinement for slaughter (Elam & Preston, 2004). Monensin is classified as an antimicrobial that manipulates the microbial population in the rumen and its label claims to improve feed efficiency and aid in the prevention and control of coccidiosis due to Eimeria bovis and Eimeria zuemii in feedlot cattle.

Mode of Action

Monensin is a carboxylic polyether ionophore compound that changes the volatile fatty acid (VFA) and fermentation profile in the rumen (Duffield et al., 2012). Monensin elicits several responses on both animal health and performance. In the liver mitochondria, monensin inhibits K^+ uptake and due to monensin's relationship

with K^+, a membrane carrier mechanism inhibits ATP hydrolysis and oxidation of selective substrates (Estrada-O and Lardy, 1967). Monensin inhibits Gram- positive bacteria in the rumen by inserting ion channels into the plasma membrane of the cell. As a result of the lack of a protective barrier, the ion concentration gradient is disrupted; monensin moves H^+ and Na^+ across the cell membrane into the cell that binds to a K^+ or H^+ ions inside the cell and moves them back across the cell membrane (Russell, 1987; Russell and Strobel, 1989; Hasenauer, 2014). There is a large abundance of K^+, H^+ and Na^+ ions in the rumen that are readily available (Russell and Strobel, 1989; Hasenauer, 2014). Potassium has 25 times greater the concentration gradient as compared to the gradient of Na^+ (Russell, 1987). Thus, the efflux of K^+ out of the cell via monensin is more exergonic than the Na^+ efflux (Russell, 1987). The efflux of K^+ out of the cell leads to an accumulation of H^+ in the cell causing a drop in intracellular pH (Russell, 1987). The pH drop drives the influx of Na^+ by the efflux of H^+ (Russell, 1987). This causes the bacteria to enter into a futile ion cycle leading to an eventual degradation of the cell and loss of viability or death (Russell and Strobel, 1989; Duffield et al., 2012; Hasenauer, 2014). The expulsion of H^+ from the cell requires the utilization of ATP, which could be a factor in growth inhibition of the bacteria due to the cell being de-energized (Russell, 1987). As a result, gram-negative bacteria out compete the gram positive, which positively impacts energy metabolism. Acetate producing bacteria are inhibited by the presence of monensin thus there is more propionate in relation to acetate being produced. Propionate is more efficient to the animal as propionate enters the tricarboxylic acid cycle (TCA cycle) as succinyl-CoA (4c), which is more efficient per mole of glucose

as no carbon is lost in the TCA cycle, whereas acetate enters the TCA as acetyl-CoA resulting in a loss of 2 carbons per mole of glucose. Thus, propionate is more efficient being gluconeogenic and is a primary source of glucose for the animal (Ellis et al., 2012). Protozoa in the rumen are not essential to feed digestion; however, they do play a role in reducing ruminal ammonia by defaunation and recycling of bacterial protein as protozoa in the rumen can account for up to 50% of the protein in the rumen (Russell and Strobel, 1989; Russell and Houlihan, 2003). Monensin inhibits protozoa in the rumen; this is beneficial to the ruminant animal as this causes less methane to be produced as protozoa produce hydrogen in the rumen, which is a primary substrate in methanogenesis (Russell and Strobel, 1989). Loss of methane is loss of energy from feed digestion, thus making the animal less efficient (Russell and Strobel, 1989).

Impact of Monensin on Cattle Growth Performance and Carcass Characteristics

Gill et al. (1976) conducted a study utilizing 96 steers fed a diet containing corn silage at 14, 30, or 75% of ration DM. Authors reported carcass adjusted feed efficiency increased ($P < 0.01$) by 6.0% for steers fed 300 mg of monensin/steer daily as compared to those fed none. Intake levels were also numerically lower ($P > 0.05$) for cattle fed monensin as compared to those fed none. However, no significant ($P > 0.05$) effect on DMI, ADG or carcass characteristics was observed (Gill et al., 1976).

Zinn et al. (1994) conducted a growing feedlot study utilizing yearling crossbred steers fed a steam flaked corn based diet with or without 28.0 mg/kg of monensin/steer daily. Authors reported that there were no differences ($P > 0.10$) in

ADG, DMI or feed efficiency between steers fed 28.0 mg/kg of monensin/steer daily and those fed no monensin (Zinn et al., 1994).

Goodrich et al. (1984) summarized performance of 16,000 head of feedlot cattle. Authors reported that cattle fed monensin on average increased ADG by 1.6% compared to cattle fed none. Additionally, cattle fed monensin consumed 6.4% less feed, which led to a 7.5% increase in feed efficiency compared to cattle fed diets containing no monensin. There was a large variation in monensin response across studies. In response to this, the author utilized models to account for 33.2, 35.2, and 55.0% of the variation in the alteration of average daily gain, feed intake, and feed efficiency, respectively. Monensin fed to cattle had a slight effect on carcass characteristics. Cattle fed monensin had a 0.61% increase in rib eye area; however, cattle fed monensin had a 0.38% lower dressing percentage, 0.39% lower marbling score, 0.24% decrease in fat depth, 0.69% decrease in quality grade, and a 0.31% reduction in yield grade as compared to cattle not fed monensin.

Potter et al. (1985) summarized 14 feedlot trials. The average days on feed of the trials was 132 d, ranging from 84 to 223 d. Primarily corn based diets were utilized and cattle were fed either 0 or 33 mg/kg of monensin/steer daily. Authors reported that steers fed 33 mg/kg of monensin/steers daily had improved ($P < 0.01$) feed efficiency of 8.6% as compared to steers fed none. Furthermore, DMI was reduced ($P < 0.01$) for steers fed monensin as compared those not fed monensin.

Similarly, in a meta-analysis by Duffield et al. (2012), over the 40 peer reviewed articles and 24 additional trials summarized, cattle fed a mean of 28.1

mg/kg of monensin/steer daily had reduced ($P < 0.01$) DMI by 6.4%, increased ($P < 0.01$) ADG by 2.5%, and improved ($P < 0.01$) feed efficiency by 1.3%.

Monensin used in Receiving Diets

Pritchard and Thomson (1992) conducted a receiving trial utilizing weaned steer calves fed a corn silage based diet for 85 d with 0, 11.0, 22.1, or 33.1 mg/kg of monensin included. Authors conducted interim weights at d 29 and 57 to determine interim growth performance. From days 1 to 29, steers fed monensin had greater ($P < 0.05$) BW as compared to steers fed none and BW increased ($P < 0.05$) linearly as monensin concentration increased. Furthermore, in the first 29 d steers fed monensin had lower ($P < 0.05$) DMI as compared to the control, DMI decreased ($P < 0.01$) linearly as monensin concentration increased and steers fed 11.0 mg/kg had greater ($P < 0.05$) DMI compared to steers fed 22.1 and 33.1 mg/kg of monensin/steer daily. Feed efficiency linearly ($P < 0.05$) improved as monensin concentration increased and steers fed 11.0 mg/kg had a lower ($P < 0.05$) G:F compared to steers fed 22.1 and 33.1 mg/kg of monensin/steer daily. There were no differences ($P > 0.05$) in d 30 to 57 interim performance or d 1 to 85 overall performance (Pritchard and Thomson, 1992).

Burrin et al. (1988) conducted a trial evaluating the performance effects of feeding steers 0, 11 or 33 mg/kg of monensin broke into segments of the first 28 d grain adaptation period, followed by the 119 d finishing period. For the first 28 d, DMI decreased ($P < 0.05$) linearly as monensin concentration increased from 0 to 33 mg/kg of monensin/steer daily. Furthermore, steers fed 11 mg/kg of tylosin/steer daily had lower ($P < 0.05$) ADG and feed efficiencies relative to other treatment

combinations. In the finishing phase, all steers were fed 33 mg/kg of monensin/steer daily until slaughter. Steers fed either 11 or 33 mg/kg of monensin/steer daily for the 28-d adaptation period had lower (linear, $P < 0.05$) DMI and ADG tended (linear, $P = 0.20$) to be lower with no difference in G:F or carcass characteristics as compared to steers fed no monensin. In a second trial by Burrin et al. (1988), crossbred heifers were fed 0, 11 or 33 mg/kg of monensin/heifer daily for the beginning 21 d of the finishing period, followed by all heifers being fed 33 mg/kg of monensin for the remainder of the finishing period. There was no significant difference ($P > 0.05$) in DMI between all monensin treatments (0, 11 or 33 mg/kg). Additionally, there was a tendency for heifers to have greater (quadratic, $P = 0.12$) ADG as concentration of monensin increased with heifers fed monensin having an improvement (linear, $P < 0.05$; quadratic, $P < 0.10$) in G:F as compared to heifers fed none. Estimates of variance in intake were divided into the step-up methods (slow and fast). Heifers in the slow step-up regimen experienced less ($P < 0.05$) variation in intake patterns when fed monensin from d 1-21. Likewise, the fast step-up group of heifers had reduced variation when fed monensin during d 11 to 21; however, overall from d 1-21 there was no difference in intake variation as compared to heifers not fed monensin. Similar to trial 1, in the finishing phase there was no difference ($P > 0.05$) in ADG and DMI between heifers fed monensin. In contrast, there was no difference in G:F between monensin treatments in the finishing phase (Burrin et al., 1988).

Intake Impact in Feedlot Cattle

Past research has shown that when monensin is added into the diet there is little effect on DMI. However, the response from monensin is more of a regulatory

function as it minimizes the fluctuation in rate of intake (Burrin et al., 1988; Cooper et al., 1997; Erickson et al., 2003). Cooper et al. (1997) conducted a study with 6 fistulated steers that were adapted onto a 92.5% concentrate diet and then fed three different levels of intake: ad libitum, intake variation of 0.91 kg/day and intake variation of 1.81 kg/d. Results from the adaptation period showed that cattle fed monensin had a more gradual and even transition onto feed as the steers experienced less acidosis. Steers fed monensin had numerically less ($P = 0.25$) time under a ruminal pH of 5.6 in the first 5 days of the finishing period and significantly less ($P = 0.08$) time for the second 5 days of the finishing period as compared to steers fed no monensin. The authors reported that steers fed monensin consumed less ($P < 0.05$) DMI over the 20-d adaptation period including 10 d at the beginning of the finishing phase as compared to steers not receiving monensin. Furthermore during the finishing period, intake amount was maintained at approximately 12.7 kg/d and did not differ ($P > 0.10$) between steers fed 0 and 27.6 mg/kg of monensin/steer daily. There are varying results on how monensin impacts DMI in feedlot cattle. Summary of Duffield et al. (2012), Gill et al. (1976), and Goodrich et al. (1984) research concludes that DMI ranges from a decrease of 3.1% to an increase of 14%. The level of intake varies between trials however; the number of meals per day increases and the fluctuation in rate of intake is minimized when feedlot cattle are fed monensin (Erickson et al., 2003; Cooper et al., 1997). Erickson et al. (2003) reported that steers fed 28.6 mg/kg of monensin/steer daily during the summer months (April to November) had greater ($P = 0.03$) live ADG, with a tendency for an increase in live final BW and G:F compared to steers fed 36.3 mg/kg of monensin/steer daily. There were no differences

($P \geq 0.34$) in carcass-adjusted performance in the summer between steers fed 28.6 and 36.3 mg/kg of monensin/steer daily. Steers fed 28.6 mg/kg of monensin/steer daily had a greater dressing percent ($P = 0.01$) and USDA yield grade 1 ($P = 0.02$) with no differences ($P \geq 0.16$) in other carcass characteristics compared to steers fed 36.3 mg/kg of monensin/steer daily. A follow-up study was conducted in the winter months (November to April) of the same year. Authors observed no difference ($P \geq 0.20$) in growth performance between steers fed 28.6 and 36.3 mg/kg of monensin/steer daily. Additionally, there were more ($P = 0.03$) cattle that graded USDA choice and less ($P = 0.05$) that received a USDA yield grade 3 when fed 28.6 mg/kg of monensin/steer daily compared to 36.3 mg/kg of monensin.

In clinical diagnosis of acidosis, a ruminal pH of 5.6 is the benchmark for subacute acidosis. Researchers monitor the time under a pH of 5.6 in minutes to determine the amount of time the animal was experiencing subacute acidosis (Owens et al., 1998). As discussed previously, Cooper et al. (1997) conducted a trial utilizing 6 fistulated steers in a 111 d metabolism trial. Authors reported that there was no difference ($P > 0.10$) in ruminal pH for the grain adaptation period and a tendency ($P = 0.11$) for a difference in the finishing period between steers fed 27.6 mg/kg of monensin and steers fed none. Furthermore, steers fed monensin did have less ($P < 0.10$) time under a ruminal pH of 5.6 as compared to steers not fed monesin in the finishing phase; but no significant differences ($P > 0.10$) were observed in the adaptation period. Conversely, Erickson et al. (2003) conducted a metabolism study utilizing 8 ruminally fistulated steers in a 2 × 4 factorial arrangement with two bunk management strategies and four monensin treatments. Monensin treatments included

0, 36.7 mg/kg, 36.7 mg/kg fed prechallenge changing to 48.9 mg/kg for the remaining duration, and 48.9 mg/kg fed continuous. Results showed that across all treatments there was no difference ($P > 0.15$) in average ruminal pH, pH change, and ruminal pH area below 5.6. In the pre-challenge phase, feeding monensin reduced ($P < 0.05$) ruminal pH variance, average meal size and average meal length compared to steers not fed monensin. In the challenge phase, there were no differences ($P \geq 0.10$) in consumption patterns and ruminal pH measurements between treatments. In the post-challenge phase, steers fed monensin consumed more ($P < 0.06$) meals per day compared to the control. There was a significant interaction ($P < 0.10$) between bunk management system and monensin supplementation strategy for average meal size, ruminal pH change and ruminal pH variance. Steers in the clean bunk management system fed monensin had a reduced average meal size ($P < 0.05$), ruminal pH change ($P < 0.10$) and ruminal pH variance ($P < 0.05$) compared to steers not fed monensin in the clean bunk system whereas, steers in the traditional bunk management system fed monensin were not different ($P > 0.10$) in these measurements compared to the control (Erickson et al., 2003). However, between Cooper et al. (1997) and Erickson et al. (2003) the monensin levels differ in each of the experiments. Thus, research suggests that an inclusion level of monensin over 36.7 mg/kg has little effect on average ruminal pH, pH change, or ruminal pH (Cooper et al., 1997; Erickson et al., 2003).

Energy Metabolism

Having a lower feed efficiency (G:F) suggests that there must be lower energy requirements or improved dietary energy values for the animal. When DM

digestibility and hydrogen retention in propionic acid is increased, the level of metabolizable energy (ME) of feeds is increased (Goodrich et al., 1984). This is correlated to ability of monensin to inhibit hydrogen-producing bacteria in the rumen whereas the succinate and propionate-producing bacteria flourish (Russell and Strobel, 1989). Rowe et al. (1981) reported that using estimated ruminal VFA production rates, sheep fed monensin had approximately 20% more ME available to the animal as compared to sheep fed none. The increased concentration of propionate by inclusion of monensin offers two main benefits to the animal. The first being that propionate compared to acetate is more energetically favorable and flexible to the animal as it can be utilized in gluconeogenesis as well as be oxidized for use in the citric acid cycle (Schelling et al., 1984). The second advantage of propionate, although controversial, is tissues more efficiently utilize propionate compared to acetate (Smith, 1971). Based on a summary of 8 trials by Goodrich et al. (1984), the apparent DM digestibility of the feedlot diet is increased from 71.6% to 72.8% for cattle fed monensin as compared to the control.

Protein Metabolism

Goodrich et al. (1984) concluded that in cattle fed monensin the CP requirement is reduced to 11.2%. Darrt et al. (1978) utilized 96 crossbred steers to test the effects of monensin and supplemental protein withdrawal on performance and carcass characteristics. Results suggested that when supplemental protein was taken out of the diet, cattle fed monensin had greater ($P < 0.05$) ADG and improved feed efficiency as compared to steers fed no monensin. Authors suggested that monensin has a protein sparing effect due to ADG being higher ($P < 0.05$) for steers fed

monensin when supplemental protein was removed (Dartt et al., 1978). Russell and Houlihan (2003) summarized feeding trials and in vitro incubations that showed that the addition of monensin to the diet could limit inefficient amino acid deamination by inhibiting ammonia producing bacteria, which leads to less ammonia and greater protein availability in the rumen. However, the reduction in ammonia producing bacteria by addition of monensin is somewhat diet specific. The authors reported that feeding alfalfa hay plus monensin decreased amino acid deamination but did not affect ammonia production in the rumen (Russell and Houlihan, 2003). This phenomenon of reduced deamination is known as the protein sparing effect (Darrt et al., 1978; Goodrich et al., 1984; Russell and Strobel, 1989; Russell and Houlihan, 2003). Protein sparing means that when amino acid (protein) deamination is reduced in the rumen, protein degradation is shifted to the small intestine in the form of rumen undegradable protein (RUP).

As noted earlier, monensin inhibits proteolytic bacteria from flourishing in the rumen. Considering this, research shows that ionophores have the ability to inhibit degradation of protein hydrolysates and protein, thereby supporting the assumption that ionophores have a greater affect on deamination than proteolysis (Russell and Strobel, 1989). Nitrogen passage is impacted when monensin is fed in the diet. There is an increased rate of passage for dietary N and constant or decreased rate of passage for bacterial N in the rumen (Goodrich et al., 1984).

VFA Profiles

Ionophores, such as monensin, alter the VFA ratio in the rumen (Russell and Strobel, 1989; Richardson et al., 1976). In the ruminant animal, the VFA propionate

is more energetically efficient compared to acetate or butyrate fermentation (Richardson et al., 1976). Propionate is more efficient due to the fact that propionate has a higher enthalpy compared to acetate; therefore, as propionate is oxidized more feed energy is available for productive purpose as propionate can be used as substrate for gluconeogenesis (Russell and Strobel, 1989; Ellis et al., 2012). Propionate is also more efficient as no carbon is lost in the TCA cycle converting pyruvate to oxaloacetate whereas, acetate and butyrate result in a net loss of carbon through methane and CO_2. The reduction of gram-positive bacteria and the resistance of gram-negative bacteria to monensin is a contributor to this efficiency response. The inhibition in hydrogen-producing bacteria by the presence of monensin leads to an increase in the proportion of propionate:acetate; as hydrogen-producing bacteria mainly contribute to acetate and butyrate production (Russell and Houlihan, 2003). In a study by Richardson et al. (1976), cattle on a high concentrate diet were fed varying inclusions of monensin to determine the effects of 0.1, 0.25, 0.5, 1.0, 5.0, and 25.0 mg/kg on production of VFA's. Richardson et al. (1976), observed monensin levels at or over 1.0 mg/kg reduced acetic acid, isovaleric acid and valeric acid production. Monensin fed at dosages of 0.5 mg/kg or greater reduced butyric acid production. All dosages of monensin increased propionic acid production. The conversion of butyric and acetic acid to greater molar percentages of propionic acid provides more energy to the animal, as it is more energetically favorable. This means in metabolism there will be more utilization of energy coming from the feed to the animal as propionate is more reduced allowing more energy capture, thus increasing the amount of glucose that is produced from gluconeogenesis. As the production of propionic acid increases

in the rumen, the hepatic gluconeogenic flux increases (Duffield et al., 2012). There

was a benefit to rumen pH as monensin reduced hydrogen sources by lowering ($P <$

0.01) levels of butyrate and acetate increasing the molar proportion of propionate

(Burrin and Britton, 1986; Ellis et al., 2012). Similarly, Raun et al. (1976) and

Richardson et al. (1976) reported that the addition of monensin caused a change in

molar proportion of VFA's where acetate and butyrate were reduced and propionate

remained the same but had a higher molar concentration in the rumen profile;

however, there was no change in the total concentration of VFA's in the rumen.

Whereas, Burrin and Britton (1986) observed a reduction ($P < 0.01$) in the total

concentration of VFA's in the rumen which authors attribute mainly to the reduction

of acetate and butyrate.

Methane Production

Methane production is reduced by the inclusion of monensin in the diet

(Goodrich et al., 1984; Russell and Houlihan, 2003). Odongo et al. (2007) reported

that monensin fed to dairy cows reduced ($P < 0.05$) methane (CH_4) emissions by 7%

or 9% expressed as grams per day and grams per kilogram of BW, respectively,

compared to cows not fed monensin. Van Nevel and Demeyer (1977) analyzed the

impact of monensin on fermentation patterns by conducting in vitro incubations of

rumen fluid and substrate. Authors reported that incubations utilizing formate or a

mixture of CO_2 and H_2 as specific methane bacteria substrates showed that monensin

did not affect methane production from CO_2 and H_2 substrates; however monensin did

have an impact on methane production in incubations utilizing formate as the

substrate. Authors suggested that monensin did not alter methanogenic flora in the

rumen, as no effect on methane production was observed in incubations with CO_2 and H_2 as the substrates, but that monensin inhibits organisms that decompose formate to CO_2 and H_2 which are primary substrates for methane producing bacteria (Van Nevel and Demeyer, 1977). Gram-positive bacteria that produce H_2 in the rumen are more apt to produce acetate and butyrate than produce succinate and propionate thus, inclusion of monensin limits substrate supply to methane producing bacteria and shifts fermentation profiles (Russell and Houlihan, 2003). Through indirect calorimetry measurements methane losses could account for approximately 2 to 12% of the gross energy intake (Johnson and Johnson, 1995). Thus, the reduction in methane emission is a conservation of lost energy, as methane gas is primarily belched, and lost into the atmosphere (Russell and Strobel, 1989).

Lactate Production

Bacteria in the rumen can be classified as either lactate utilizers or lactate producers. Predominately, lactate utilizers cannot survive in a rumen environment at a relatively low pH, whereas, lactate producers can survive in a low pH environment. Under normal conditions in the rumen, accumulation of lactate would not occur and ruminal lactate levels would maintain below 5μM (Owen et al., 1998). When an animal is in an anaerobic state, pyruvate is converted to lactate to regenerate NAD^+ to be used in glycolysis, thus lactate tends to accumulate in the rumen at levels above 40 mM, thus acidosis occurs (Owen et al., 1998). Consumption of large quantities of a high concentrate diet that contains readily fermentable carbohydrates in a short time frame can cause sub acute acidosis, acute acidosis or digestive upsets. There are several steps involved with acid production and acidosis in the rumen. One of the

most predominant causes of acidosis is rapid engorgement of rapidly fermentable

carbohydrates. When cattle are switching from a predominately forage diet to a

higher concentrate diet that has a large amount of fermentable starch, the animal's

mechanism of intake regulation changes from rumen fill to chemostatic regulation.

Grain processing, starch type, and grain source all cumulate to achieve the rate at

which starch can be cleaved to glucose (Owens et al., 1998). Meal frequency can play

a big role in onset of acidosis, it is important to consider not only how much is

consumed but also how much time it takes to consume the diet. Owens et al. (1998)

summarized that when levels of lactate accumulate and reach levels over 100 mM the

animal is experiencing D- lactic acidosis. Sub-acute acidosis is when there is a build

up of blood and ruminal lactate, which can reduce feed intake and ADG, however no

clinical signs will be prevalent. If acidosis occurs further and the ruminal pH drops

below the benchmark of 5.2, then the animal is experiencing acute acidosis (Owens et

al., 1998). Prevalent symptoms are reduced or no feed consumption, reduced

performance, damage to the rumen, and eventually death (Slyter, 1976). More

specifically when there are large numbers of lactate producing bacteria in the rumen

then more lactate is being produced (Slyter, 1976). This occurs from an increase in

glucose synthesis but a reduced utilization of glucose so lactic acid builds up and the

lactic acid microorganisms flourish (Slyter, 1976). Previous research suggests that

subacute acidosis is influenced more by the total organic acid concentrations whereas

in the rare instance of acute acidosis lactate levels have a greater influence (Nagaraja

et al., 1981; Burrin and Britton, 1986). In either case reducing levels of lactate

produced in the rumen can reduce acidosis incidences and increase feed efficiency of the animal.

Research demonstrates that monensin reduces the number of lactate producing bacteria in the rumen (Goodrich et al., 1984; Burrin and Britton, 1986). The reduction of lactate producing bacteria by the presence of monensin leads to less lactate, which results in a higher pH in the rumen (Russell and Houlihan, 2003). Research showed that addition of monensin in the diet also stabilizes the fluctuation of ruminal pH variance when cattle are fed a concentrate diet due to intake stabilization (Erickson et al., 2003). A steer metabolism study was conducted to determine what the impacts of abruptly switching cattle from forage to a high concentrate diet has on ruminal and blood components. In a 3×3 Latin-square design steers were fed one of three diets containing 0, 150 or 300 mg of monensin/steer daily. Steers were fed a forage diet for 14 d then abruptly switched to concentrate diet. Results suggested that when steers were fed monensin there was a decrease in ruminal lactate while maintaining a higher pH profile (Burrin and Britton, 1986).

In conclusion, monensin improves feed efficiency (Gill et al., 1976; Goodrich et al., 1984; Potter et al., 1985; Duffield et al., 2012) with no differences in ADG compared to steers fed no monensin (Gill et al., 1976; Zinn et al., 1994). The impact of monensin on DMI is variable within the literature. Steers fed increasing levels of monensin in the receiving period had lower DMI compared to steers fed no monensin (Pritchard and Thomson, 1992; Burrin et al., 1998). Although not as consistent as monensin reducing the variation in rate of intake and the number of meals per day

compared to steers fed none (Burrin et al., 1988; Cooper et al., 1997; Erickson et al., 2003).

RAMP Diets

As a result of the wet milling industry, wet corn gluten is a byproduct utilized in the feedlot industry. Sweet Bran is a branded wet corn gluten product developed by Cargill Corn Milling. RAMP (Cargill Corn Milling, Blair, NE) is a complete-feed starter ration that contains high levels of Sweet Bran, minerals, vitamins and a minimal amount of forage consisting of cottonseed hulls and/or alfalfa hay (Schneider et al., 2017). RAMP is utilized in grain adaptation period before the finishing phase as a replacement for traditional step up diets.

Of the reviewed literature, there are few studies evaluating the product RAMP; however the findings are fairly consistent. Schneider et al. (2017) conducted an experiment to determine the effects of feeding RAMP as compared to a traditional step-up program in the adaptation phase on steer growth performance and carcass characteristics. The two RAMP treatments included decreasing the amount of RAMP and increasing the amount of finishing ration and delivered separately in the two ration system or blending the rations together delivering once in the single ration system. There were no differences ($P > 0.05$) between the two RAMP treatments for growth performance or carcass characteristics. In the first 28 d, steers adapted with RAMP had lower ($P = 0.03$) DMI with no difference in G:F or ADG as compared to steers on the traditional step up program. Furthermore, during the overall finishing period, steers fed RAMP had an improvement ($P < 0.01$) in feed efficiency with an increase ($P = 0.03$) in ADG whereas there were no differences in DMI ($P = 0.39$) as

compared to the traditional step up program. There was a numerical increase ($P =$ 0.13) between steers fed RAMP and the traditional step up program in final BW of 14.1 kg for the one-ration system and 8.2 kg of the two-ration system. Hot carcass weight followed the same trend with a numerical increase of 8.6 kg for the one-ration system and 5.0 kg for the two-ration system as compared to the traditional step up program. There were no differences in any of the carcass characteristics recorded (Schneider et al., 2017). Buttrey et al. (2012) utilized 306 crossbred steers to determine the effect on growth performance and carcass characteristics of adapting cattle to a finishing diet using RAMP compared to a traditional step up program. Steers assigned to the traditional step-up treatment were fed an adaptation diet consisting primarily of steam flaked corn (SFC), Sweet Bran and alfalfa hay. As cattle transitioned through the step-ups the inclusion of Sweet Bran remained constant while the level of alfalfa hay decreased and the level of SFC increased. Steers fed RAMP were fed for 14, 18, 22, 26, or 30 d and as cattle transitioned through the step-ups the level of RAMP was decreased and replaced by the finishing diet. All steers were finished on the same finishing diet. Both 36 d and 84 d interim performance data showed that steers fed RAMP had greater ($P = 0.01$) ADG leading to heavier ($P =$ 0.01) BW with no difference ($P > 0.05$) in DMI or G:F as compared to steers on the traditional step-up program. Furthermore, there were no significant linear or quadratic effects on the number of days steers were fed RAMP (14-30 d; $P \geq 0.17$). Authors reported over the entire feeding period the use of RAMP increased ($P = 0.05$) carcass adjusted final BW by 13 kg with a tendency for an increase ($P = 0.06$) in ADG and no difference in G:F ($P = 0.25$) or DMI ($P = 0.07$) compared to steers on the traditional

step up program. Steers fed RAMP had an 8 kg increase ($P = 0.05$) in HCW while dressing percent tended to increase ($P = 0.07$) quadratically which is backed by a numeric linear increase ($P = 0.06$) in fat thickness and a significant linear increase in YG as days fed RAMP increased (Buttrey et al., 2012). Therefore, RAMP has been shown to be an effective method to adapt cattle onto a concentrate finishing diet.

Beta-adrenergic agonist

In 2003, the Food and Drug Administration (FDA) approved the β-andrenergic agonist (β-AA) ractopamine hydrochloride (RAC; Optaflexx, Elanco Animal Health, Greenfield, IN) for use in beef cattle to increase rate of weight gain and improve feed efficiency (FDA, NADA 141-221, 2003). Similarly, in 2006 the FDA approved the β-AA zilpaterol hydrochloride (Merck Animal Health; De Soto, KS) to be fed to cattle in the United States (FDA, NADA 141-258, 2006). However, in September of 2013 zilpaterol hydrochloride was removed from U.S. markets despite still being FDA approved. Even with the absence of zilpaterol hydrochloride in the U.S. market place, survey showed that 84.8% of producers are using beta adrenergic agonists (β-AA) with 95.5% of nutritionist indicating that RAC was the product being utilized (Samuelson et al., 2016). For the purpose of this literature review, the main focus will be on the use of ractopamine hydrochloride in beef cattle.

Mode of Action

Beta adrenergic agonists (β-AA) are phenethanolamines that bind to β-adrenergic receptors (β-AR) located in the cellular membrane (Mills, 2002a; Scramlin et al., 2010). Beta adrenergic receptors belong to the family of guanine nucleotide binding protein (G-protein) coupled receptors (Mills, 2002a). Beta adrenergic

agonists are similar in structure to catecholamines such as norepinephrine, epinephrine, and dopamine (Scramlin et al., 2010). Catecholamines are naturally occurring compounds in ruminants and other mammals that have an effect on the animals organs and tissues (Bell et al, 1998). Beta adrenergic receptors are present in nearly every cell type that are associated with growth, such as skeletal muscle and adipose tissue (Mersmann, 1998; Yang and McElligott, 1989). Beta adrenergic agonists are distinctive from other growth promoting technologies, as the effects in the animal transpire on a cellular level. Sillence and Matthews (1994) demonstrated that there are several β-adrenoreceptor sub-types (β 1-3) present in bovine tissue depending on tissue type. Most tissues contain several receptor types with varying concentrations of each (Moody et al., 2000). Based on literature utilizing ligand binding studies, the β_2– AR is the most abundant receptor subtype in bovine skeletal muscle and adipose tissue (Sillence and Matthews, 1994). Ractopamine hydrochloride preferentially binds to β_1– AR in tissues (Moody et al., 2000).

Conclusive research on the effect of β-AA in vitro on lipid metabolism has been conducted. Results showed that β-AA stimulate adipocyte triacylglycerol degradation, inhibition of fatty acid and triacyglycerol synthesis in vitro in cells of multiple species; however, data in vivo is much more ambiguous (Mersmann, 1998). Similarly, research on protein metabolism is somewhat unclear in vivo but also mixed results shown in vitro as well (Mersmann, 1998). When animals are fed β-AA orally, on the cell surface, β-AA binds to beta agonist receptors (β-AR) (Mersmann, 1998). However, evidence of whether the mechanism a β-AA has on adipose and skeletal tissue is direct, indirect or both is unclear (Mersmann 1998; Mills, 2002a).

The direct mechanism of action when a β-AA is fed is the β-AA binds to a β-AR in the plasma membrane and coupled with stimulatory G-proteins (G_s-proteins) signal the enzyme adenylate cyclase to synthesize cyclic adenosine monophosphate (cAMP) from ATP (Hausdorff, 1990; Mersmann, 2002). Cyclic adenosine monophosphate acts as an intracellular messenger for the β-AR and activates protein kinase A (Hausdorff, 1990; Mersmann, 2002). Protein kinase A triggers the phosphorylation of intracellular proteins such as hormore sensitive lipase (Mersmann, 1998). In lipid metabolism, the lipase acts to possibly inhibit fatty acid synthesis by decreasing regulatory enzymes and promoting triglyceride hydrolysis leading to less lipid accumulation (Mills, 2002a; Yang and McElligott, 1989). Whereas in protein synthesis, a β-AA binds directly to a β-AR in skeletal muscle and the cascade of events leads to protein accretion (Yang and McElligott, 1989). Indirect effects could be a multitude of factors where a β-AA binds to a β-AR or other receptors, in both muscle and non-muscle tissues, leading to production of hormones and stimulates protein accretion or in the case of fat a stimulation in lipolysis (Yang and McElligott, 1989). Regardless of the mechanism, β-AA has been shown to increase protein synthesis or decrease protein degradation, as well as decrease lipogenesis and increase lipolysis in cattle (Mersmann, 1998). The decrease in lipogenesis when animals consume RAC is debated throughout the literature. Mills (2002a) reported that when animals consume RAC, fat deposition is not altered; however, RAC caused an increase in protein accretion therefore the amount of fat compared to protein is diluted and reflects a reduction in carcass fat. The number of muscle fibers an animal has at birth is a fixed number for the life of the animal (Mills, 2002a). However, the

size of those muscle fibers can increase and decrease throughout the animal's life (Mills, 2002a). The increase in protein deposition has been directly linked to a β-AR ligands causing an increase in hypertrophy on muscle fibers and consequently having an impact on protein synthesis, degradation, or both (Bell et al., 1998; Mills, 2002a).

There are several factors that influence the response a β-AA may have in livestock when fed. External factors such as diet, dose, sex, age of animal, β-AA type, breed and many other factors can have significant impacts to the response of a β-AA (Mersmann, 2002). As an animal becomes older in age there are many changes in physiological responses. The response an animal has from receiving a β-AA can change and aspects such as the number of receptors or the specificity of those receptors may be different in a younger animal as compared to an animal more physiologically mature (Mersmann, 2002). As an animal matures the amount of muscle being deposited declines while the rate of fat deposition increases. Thus, a β-AA, such as RAC, is fed to reverse this effect late in the feeding period by increasing muscle accretion and decrease fat deposition (Mersmann 2002). Ractopamine hydrochloride (RAC) is a category one β-AA having no withdrawal period that is approved for feeding the last 28 to 42 d of the finishing period at a concentration of 10.0 to 30.0 mg of RAC/kg providing 70 to 430 mg of RAC/steer daily (FDA, NADA 141-221, 2003).

The desensitization of β-AR occurs when there is prolong exposure to a β-AA resulting in a down-regulation in receptor number due to degradation of receptors (Mills, 2002b). Desensitization means a reduction in response despite continued presence of the stimulus (Mills, 2002b). Desensitization has been attributed to acute

uncoupling responses and chronic down-regulation responses (Hausdorff, 1990; Mills, 2002b). The uncoupling responses can be described as the phosphorylation of the β-AR, thus not allowing coupling with the G-proteins (Hausdorff, 1990; Mills, 2002b). Whereas, down-regulation is the process of declining the total number of β-AR. Typically down-regulation is a slower process taking hours to days as compared to uncoupling which is rapid and reversible (Hausdorff, 1990; Mills, 2002b). Once a cell loses a significant number of β-AR it loses its ability respond to an agonist as it once did, leading to less tissue response (Hausdorff, 1990; Mills, 2002b). Spurlock et al. (1994) observed that prolonged exposure to β-AA caused β-AR to internalize and ultimately degrade. In swine adipose tissue β-AR density both in the middle and outer layers of subcutaneous tissue decreased ($P < 0.01$) linearly as d fed RAC increased with the greatest reduction (54%) occurring when steers were fed RAC for 24 d compared to steers not fed RAC (Spurlock et al., 1994). There was no difference ($P > 0.05$) in β-AR density in swine skeletal muscle tissue when RAC was fed compared to the control (Spurlock et al., 1994).

Impact of Ractopamine Hydrochloride on Cattle Growth Performance and Carcass Characteristics

Final Body Weight

Avendaño-Reyes et al. (2006) and Sudbeck et al. (2016) reported an increase in final BW of 19.5 and 23 kg when steers were fed 300 mg of RAC/steer daily. A large pen study conducted by Quinn et al. (2016) utilizing 2,083 steers evaluated the effects of feeding 300 mg of RAC/steer daily. The authors observed a significant increase ($P < 0.01$) in carcass-adjusted final BW of 2.0% or 12.6 kg for steers fed 300

mg of RAC/steer daily as compared to steers not fed RAC. Increasingly, Boler et al.

(2012) conducted a trial evaluating steers fed 0, 200, or 300 mg of RAC/steer daily.

Authors reported that steers fed 200 and 300 mg of RAC/steer daily had an increased

($P < 0.01$) final live BW with steers gaining 14.8 and 14.6 kg more live weight as

compared to steers fed no RAC. Conversely, Bohrer et al. (2014) conducted a study

evaluating the effects of feeding 300 mg of RAC/steer daily with or without

supplemental zinc and chromium propionate for 35 d and they reported no differences

($P = 0.15$) in final BW when comparing cattle fed 300 mg of RAC/steer alone and the

control. However, the authors did report a significant difference ($P < 0.01$) in total

weight gain during the last 35 d of 55 and 64 kg for steers fed 0 mg of RAC/steer

daily and steers fed 300 mg of RAC/steer daily, respectively. Similarly, Styrdom et

al. (2009) observed no difference ($P > 0.05$) in final live BW between treatments

when steers were fed 300 mg of RAC/steer daily compared to steers fed 0 mg of

RAC/steer daily. Furthermore, Hales et al. (2016) reported no difference ($P = 0.37$) in

live final BW over the whole feeding period when steers were fed 300 mg of

RAC/steer daily for 30 to 33 d at the end of the finishing period compared with steers

not fed RAC.

Average Daily Gain

Steers fed 300 mg of RAC/steer daily had an 18.9% improvement ($P < 0.01$)

in carcass-adjusted ADG compared to steer fed no RAC (Quinn et al., 2016).

Similarly, Arp et al. (2014) and Quinn et al. (2016) observed a 18.1% and 18.9%,

respectively, increase ($P < 0.05$) in carcass-adjusted ADG compared to steers fed 0

mg of RAC/steer daily. Boler et al. (2012) fed 0, 200, or 300 mg of RAC/steer daily

to 144 early weaned steers (70-80 d old) for the final 28 d of the finishing period.

Authors reported no difference ($P =0.92$) in ADG between steers fed 200 and 300 mg

of RAC/steer daily; however both treatments had a 35% increase ($P < 0.01$) in ADG

as compared to steers fed no RAC. Feeding steers 300 mg of RAC/steer daily for the

final 33 d of the finishing period improves ($P < 0.01$) ADG 24.0% compared to steers

fed no RAC; this is in agreement with subsequent data showing a 19.2% increase (P

< 0.05) in ADG for steers fed 300 mg of RAC/steer daily for 30 d (Avendaño-Reyes

et al., 2006; Strydom et al., 2009). Bohrer et al. (2014) fed steers 300 mg of

RAC/steer daily for 35 d and observed an increase ($P < 0.01$) of 14.2% in ADG

compared to steers fed no RAC. In the three previously discussed trials, cattle were

only on trial for the time period that RAC was administered. To a lesser extent,

Sudbeck et al. (2016) saw a 2.8% increase ($P = 0.02$) in carcass-adjusted ADG over

the entire feeding period when steers were fed 300 mg of RAC/steer daily compared

to steer fed no RAC. Hales et al. (2016) reported that ADG were inconsistent from

previous data; in that steers fed 300 mg of RAC/steer daily ADG was not different (P

$= 0.63$) from steers fed 0 mg of RAC over the finishing period.

Gain:Feed

Bohrer et al. (2014) reported a 16.8% improvement ($P < 0.01$) in feed

efficiency when steers were fed 300 mg of RAC/steer daily compared to steers fed no

RAC. Likewise, Quinn et al. (2016) and Arp et al. (2014) fed 300 mg of RAC/steer

daily and they observed a 20.1% and 18.8% improvement ($P < 0.01$) in carcass-

adjusted G:F compared to steers fed no RAC. To a greater extent, Avendaño-Reyes et

al. (2006) compared steers fed 300 mg of RAC/steer daily to steers fed 0 mg and

observed a 25.4% improvement ($P < 0.01$) in feed efficiency in steers fed 300 mg.

Hales et al. (2016) fed 300 mg of RAC/steer daily and reported a 3.6% increase ($P = 0.04$) in G:F compared to steers fed no RAC over the entire feeding period.

Dry Matter Intake

It has been well established in previous literature that steers fed 300 mg of RAC/steer daily at the end of the finishing period has slight to no ($P > 0.05$) impact on DMI compared to steers not receiving RAC (Boler et al. 2012; Bohrer et al., 2014; Hales et al., 2016; Sudbeck et al, 2016). Bohrer et al. (2014) and Sudbeck et al. (2016) fed 300 mg of RAC/steer daily and observed no differences in DMI as compared to the control. Similarly, Boler et al. (2012) fed steers in slatted floor feedlot pens with one Growsafe unit located in each pen. The Growsafe units measured and recorded each individual animal's daily feed intake, meal events, and bunk visits. Data were recorded each day for the final 28 d of the finishing period. Authors observed that DMI of steers fed 300 mg of RAC/steer daily was not statistically different ($P = 0.27$) compared to steers fed no RAC. Conversely, Avendaño-Reyes et al. (2006) fed 300 mg of RAC/steer daily to 424 kg steers in a randomized complete block design with 3 treatments and 6 blocks (18 pens with 3 steers per pen). Steers were fed RAC the last 33 d of the feeding period. Authors reported that steers fed 300 mg of RAC/steer daily consumed 1.7% less ($P = 0.03$) DM as compared to steers fed 0 mg of RAC/steer daily. Likewise, Quinn et al. (2016) fed steers 300 mg of RAC/steer daily and noted a 1.7% decrease ($P = 0.01$) in DMI compared to steers not fed RAC. Although not significant, steers fed 300 mg of RAC/steer daily had a tendency to consume 1.6% less ($P = 0.06$) DM compared to

steers not fed RAC (Arp et al., 2014).

Hot Carcass Weight

Winterholler et al. (2007) fed 200 mg of RAC/steer daily and Quinn et al. (2016) fed 300 mg of RAC/steer daily and authors reported a 8 kg increase ($P < 0.05$) in HCW compared to steers not fed RAC. Likewise, feeding steers 300 mg of RAC/steer daily for the final 35 d of the finishing period resulted in an increase ($P = 0.04$) of 1.87% or 6.6 kg of HCW as compared to steer fed no RAC (Bohrer et al., 2014). In agreement with Bohrer et al. (2014), Sudbeck et al. (2016) fed 300 mg of RAC/steer daily to crossbred steers and noted a 6.4 kg increase ($P < 0.01$) in HCW compared to steers fed no RAC. To a greater extent, Boler et al. (2012) and Avendaño-Reyes et al. (2006) observed an increase of 14.9 and 13.6 kg in HCW for steers fed 300 mg of RAC/steer daily compared to steers not fed RAC. Arp et al. (2014) fed increasing doses of RAC (0, 200, 300, and 400 mg) and observed an increase ($P < 0.05$) in HCW for steers fed 300 and 400 mg of RAC/steer daily of 3.9 and 6.3 kg, respectively, compared to steers not fed RAC. Hales et al. (2016) reported steers fed 300 mg of RAC/steer daily had numerically 6 kg heavier ($P = 0.36$) HCW compared to steers not fed RAC.

Dressing %

Arp et al. (2014) and Bohrer et al. (2014) fed steers 300 mg of RAC/steer daily and reported no statistical difference ($P > 0.05$) in dressing percentage compared to steers fed no RAC. Conversely, Boler et al. (2012) reported a higher ($P = 0.02$) dressing percentage (63.39%) for crossbred steers fed 300 mg of RAC/steer daily for the final 28 d of the finishing period compared to steer fed 0 mg of

RAC/steer daily (62.27%). Similarly, Avendaño-Reyes et al. (2006) fed 300 mg of RAC/steer daily and observed a 2.4% increase ($P = 0.02$) in dressing percent compared to steers not fed RAC. Furthermore, Quinn et al. (2016) and Hales et al. (2016) noted a 0.54% and 1.5% increase ($P = 0.02$) in dressing percent when steers were fed 300 mg of RAC/steer daily compared to steer fed no RAC.

Marbling Score, Fat Thickness, Calculated Yield Grade, Longissimus Muscle area

Steers fed 300 mg of RAC/steer daily had no difference ($P > 0.05$) in fat thickness or calculated yield grade (Arp et al., 2014; Bohrer et al., 2014; Boler et al., 2012; Quinn et al. 2016; Sudbeck et al., 2016; Hales et al., 2016). Impact of feeding RAC on LM area and marbling score is less consistent in the literature. Avendaño-Reyes et al. (2006) reported no difference ($P > 0.13$) in LM area and fat thickness between steers fed 0 and 300 mg of RAC/steer daily the final 33 d of the finishing period. Boler et al. (2012) observed an increase in LM area over the 28 d RAC feeding period when steers were fed 200 or 300 mg of RAC/steer daily compared to the control. Sudbeck et al. (2016) observed an increase ($P = 0.01$) in LM area for steers fed 300 mg of RAC/steer daily compared to steers fed 0 mg of RAC/steer daily over the entire feeding period. Furthermore, authors reported no difference ($P > 0.22$) in marbling score, fat thickness, or CYG. Quinn et al. (2016) noted a decrease ($P < 0.01$) in marbling score (small[39]) and a 2.4 cm^2 increase ($P < 0.01$) in LM area when steers were fed 300 mg of RAC/steer daily compared to steers not fed RAC (small[52]); with no difference ($P > 0.05$) in fat thickness or CYG. Results from Arp et al. (2014) are comparable to the reduced marbling score reported by Quinn et al. (2016); steers fed 300 mg of RAC/steer daily had a lower ($P = 0.04$) marbling score (small[12])

compared to steers not fed RAC (small[29]).

Yearling Steers

Winterholler et al. (2007) evaluated the effect of feeding yearling steers 200 mg of RAC/steer daily for the final 28 d of the finishing period. Serial slaughter dates were set at days 150, 171, and 192. No significant RAC × days on feed interactions were noted. Therefore, RAC inclusion in the diet had an improvement on steer performance regardless of days on feed. Steers fed 200 mg of RAC/steer daily had increased ($P < 0.05$) final BW, ADG, G:F, and HCW with a tendency for an increase ($P = 0.08$) in LM area compared to steers fed no RAC. Authors reported no difference ($P > 0.05$) in DMI, dressing percent, fat thickness, yield grade, or marbling score between steer fed 200 mg of RAC/steer daily and steers fed none. Conversely, Griffin et al. (2009) conducted a trial utilizing long yearling steers fed 200 mg of RAC/steer daily for the last 28 d. Authors reported no difference in final BW ($P = 0.86$), ADG ($P = 0.85$), DMI ($P = 0.75$), G:F ($P = 0.82$) or carcass characteristics such as HCW ($P = 0.83$), fat thickness ($P = 0.72$), LM area ($P = 0.95$), yield grade ($P = 0.77$), and marbling score ($P = 0.81$) between steers fed 200 mg of RAC/steer daily and steers fed no RAC.

Dose Amount

Bittner et al. (2017) fed crossbred yearling steers 0, 300, or 400 mg of RAC/steers daily for 14, 28 or 42 d before harvest. There were no significant ($P > 0.07$) RAC dose × duration interactions for carcass adjusted growth performance or carcass characteristics; however, the interaction was significant ($P < 0.05$) for some live growth performance variables. Carcass adjusted final BW was not different ($P >$

0.44) for steers fed 0, 300, or 400 mg of RAC/steer daily for 14 d. Steers fed 300 or
400 mg of RAC/steer daily for 28 and 42 d carcass adjusted final BW were not
statistically different ($P > 0.05$); however, both were significantly ($P < 0.01$) heavier
than steers not fed RAC. Between treatments, DMI was not different ($P > 0.59$). Hot
carcass weight was not different ($P = 0.33$) between steers fed 0, 300, or 400 mg of
RAC/steer daily for 14 d. Hot carcass weight was greater ($P < 0.01$) for steers fed 300
and 400 mg of RAC compared to cattle fed 0 mg for 28 and 42 d, with no difference
($P > 0.05$) between steers fed 300 and 400 mg of RAC/steer daily. There were no
differences ($P > 0.53$) between steers fed 0, 300, or 400 mg of RAC/steer daily in
dressing percent, marbling score, LM area, fat thickness, or calculated yield grade
(Bittner et al., 2017). Arp et al. (2014) conducted a commercial feedlot trial utilizing
approximately 4,000 crossbred steers fed 0, 200, 300, or 400 mg of RAC/steer daily
for the final 30 d of the finishing period plus one treatment receiving zilpaterol
hydrochloride fed at 7.5 mg/kg for the final 23 d of the finishing period. Authors
reported no differences ($P > 0.05$) in growth performance or carcass characteristics
between steers fed 300 and 400 mg of RAC/steer daily. However, steers fed 300 or
400 mg of RAC/steer daily had greater ($P < 0.05$) carcass adjusted ADG, carcass
adjusted feed efficiency and dressing percent as compared to steers fed 200 mg of
RAC/steer daily. Furthermore, steers fed 400 mg of RAC/steer daily had greater ($P <
0.05$) HCW as compared to steers fed 200 mg of RAC with steers fed 300 mg
intermediate as they were not statistically different ($P > 0.05$) than steers fed 200 and
400 mg of RAC/steer daily. Marbling score was reduced ($P < 0.05$) for steers fed 300
mg of RAC/steer daily as compared to steer fed no RAC. There were no differences

($P > 0.05$) in DMI, fat thickness and yield grade between all treatments of steers fed

RAC (Arp et al., 2014). Conversely, Boler et al. (2012) fed steers 0, 200, or 300 mg

of RAC/steer daily and found no differences in growth performance or carcass

characteristics between steers fed 200 and 300 mg of RAC/steer daily. As the

inclusion of RAC in the diet increased from 0 to 200 mg of RAC/steer daily, final

BW, ADG and G:F increased ($P < 0.01$) linearly with no difference ($P \geq 0.16$) in

DMI (Abney et al., 2007). A meta-analysis summarized by Pyatt et al. (2013)

reported a linear increase ($P < 0.01$) in dressing percent with no difference ($P > 0.05$)

in LM area as RAC dose increased. Quality and yield grade distributions were shifted

lower (linear; $P < 0.01$) for steers fed RAC compared to the control (Pyatt et al.,

2013).

In summary, increasing the inclusion of RAC in the diet increases HCW

(Abney et al., 2007; Bryant et al., 2010; Boler et al., 2012; Pyatt et al., 2013; Bittner

et al., 2017). Steers fed 300 mg of RAC/steer daily had improved ADG (Arp et al.,

2014; Quinn et al., 2016) and G:F (Arp et al., 2014; Bohrer et al., 2014; Quinn et al.,

2016) with no difference in DMI (Bohrer et al., 2014; Sudbeck et al., 2016).

Additionally, there were no differences in growth performance or carcass

characteristics between steers fed 300 or 400 mg of RAC/steer daily (Arp et al., 2014;

Bittner et al., 2017) Increasing the inclusion of RAC in the diet has no effect on

marbling score, fat thickness or CYG (Abney et al., 2007; Boler et al., 2012; Bryant

et al., 2012; Bittner et al., 2017). Conversely, Pyatt et al. (2013) reported a linear

decrease in marbling score ($P < 0.01$) and CYG ($P < 0.01$) as RAC dose increased.

Previous literature would support that RAC dose has no effect on quality grade

distribution (Boler et al., 2012; Bryant et al., 2012).

Impact of Length of Feeding on Cattle Performance and Carcass Characteristics

Winterholler et al. (2007) fed steers to 150, 171 and 192 days on feed.

Authors reported increasing days on feed (DOF) increased ($P < 0.01$) final BW 11

(0.52 kg/d) and 22 (1.05 kg/d) kg between d 150 to 171 and 171 to 192, respectively;

while HCW increased 15 (0.71 kg/d) and 18 (0.86 kg/d) kg between d 150 to 171 and

171 to 192, respectively. Gain and G:F decreased ($P < 0.01$) as DOF increased from

150 to 192 d. Furthermore, longer DOF increased ($P < 0.05$) dressing percentage,

ribeye area and marbling score. Similarly, Van Koevering et al. (1995) fed crossbred

yearling steers split into serial slaughter dates of 105, 119, 133, and 147 DOF.

Authors reported that carcass-adjusted final BW increased ($P = 0.01$) linearly as DOF

increased, carcass-adjusted ADG was not different ($P > 0.05$) between steers fed to

119, 133 and 147 DOF; however all had a greater ($P < 0.05$) ADG than steers fed to

105 d, and carcass-adjusted G:F had a significant ($P = 0.01$) cubic response as DOF

increased. Additionally, HCW, fat thickness, and USDA yield grade increased ($P =$

0.01) linearly as DOF increased with no difference ($P > 0.05$) in LM area and

marbling score increased ($P = 0.02$) quadratically while dressing percent decreased (P

$= 0.04$) quadratically. Comparably, May et al. (1992) observed a linear increase ($P <$

0.01) in HCW and dressing percent as DOF increased; with a quadratic decrease ($P <$

0.01) in ADG as steers went from 28 to 196 DOF with all time points being similar (P

> 0.05) except for steers fed to d 28 which had greater ($P < 0.05$) ADG than all the

other time points. Authors attribute the higher ADG to compensatory gain that the

steers may have experienced early in the feeding period. As DOF increased marbling

score quadratically increased ($P < 0.05$); whereas fat thickness, LM area, HCW, and yield grade linearly increased ($P < 0.01$). MacDonald et al. (2007) summarized that as days on feed increase BW and HCW increase ($P < 0.01$) linearly while BW gain decreases ($P < 0.01$) and carcass weight gain remains steady ($P = 0.33$). Additionally, DMI increased ($P < 0.01$) linearly with feed efficiency improving ($P < 0.01$) on both a carcass weight and shrunk weight basis through the finishing phase (MacDonald, 2007). Dressing percent increases ($P < 0.05$) at a linear rate as days on feed increases suggesting that as an animal matures the protein to fat ratio declines (Owens et al., 1995; MacDonald et al., 2007). Bruns et al. (2004) reported a linear increase ($P < 0.01$) in HCW, dressing percent, ribeye area, and marbling score with a quadratic increase ($P = 0.02$) in 12th rib fat and yield grade. As steers are fed to longer days on feed, final BW increases (linear, $P < 0.01$), ADG decreases (quadratic, $P = 0.04$), feed efficiency decreases (quadratic, $P = 0.02$) and no difference ($P \geq 0.15$) is observed in DMI. In year one for every kg of live weight deposited, the animal gained 0.77 kg of HCW whereas, in year 2 for every kg of live weight deposited the animal gained 0.62 kg of HCW (Bruns et al., 2004).

Corn Residue Grazing

With the increase in corn price in 2006, conversion of rangeland to farm ground was widespread (Wright and Wimberly, 2013). Albert (1971) estimated that 40% of the energy value of the corn plant is left in the field following grain harvest. This leads to a significant potential for corn residue hectares to be grazed. Leaving the corn residue in the field and allowing cattle to remove the forage as apposed to using farming practices such as rake and bale to remove the residue is an economical

choice that fits well in a systems approach (Klopfenstein et al., 1987). Grazing fits a production system where spring born calves are weaned in the fall and need a place to go until grass is available for grazing in the spring and summer; thus, corn residue is a logical choice to winter calves until the spring when they will either go into the feedlot or out to graze grass.

Ruminants are not as efficient as non-ruminants at utilizing grain; therefore grazing low quality forage benefits the beef producer by using a resource that is of no value to non-ruminants such as corn residue (Klopfenstein et al. 1987). The potential problem with corn residues is that protein content and energy digestibilities are low, as the plant has already reached physiological maturity if corn residue is utilized following grain harvest. Thus, stocking the appropriate number of cattle is important so that the animals are not forced to consume the lower digestible components of the residue. Cattle are selective grazers; when grazing corn residue, cattle select for the corn grain first, followed by the husk and leaf as they contain the greatest nutritive value and are the most digestible (Fernandez-Rivera and Klopfenstein, 1989a; Watson et al., 2015).

With the abundance of corn residue and being a low cost winter system for cattle, producers still have concerns with how grazing will affect subsequent crop yields. Drewnoski et al. (2016) reported a 16-yr (1997-2013) corn residue grazing study with three grazing treatments consisting of a fall/winter grazed (November through January; 90 d), spring grazed (February to mid-April; 70 d) and ungrazed treatment to determine the impact of long-term corn residue grazing in an annual corn-soybean rotation. Results showed over the 16-year period of spring grazing

soybean yield was increased ($P = 0.03$) 1.5 bushels compared to the ungrazed treatment; whereas, there was no difference ($P = 0.96$) in corn yield between the spring grazed and ungrazed treatments. In the 10-year period where there were both spring and fall grazed treatments, the fall grazed treatment had greater ($P < 0.01$) soybean yields with a tendency ($P = 0.07$) for an improvement in corn yield. There was a tendency ($P = 0.07$) for an improvement in soybean yield between the years 2003-2013 for the spring grazed treatment as compared to the ungrazed treatment with no difference ($P = 0.27$) in corn yield between the spring and ungrazed treatment. Furthermore, Clark et al. (2003) summarized a three-year study suggesting that there was no difference ($P > 0.05$) in soil bulk density measurements before or after grazing compared to non-grazed areas. There was no difference ($P > 0.05$) in soil moisture with no difference ($P > 0.05$) in soybean yields in fields that were planted following disking or no tillage except in year three where soybean yield was 8% lower ($P < 0.05$) for fields grazed compared to ungrazed where there was no tillage.

Composition and Quality of Corn Residue

Corn residue consists of the leaf, sheath, husk and cob remaining once corn is harvested from the field. Varying amounts of corn grain remains in the field dependent on weather conditions, harvest methods and ear drop and can have a significant impact on the value of the corn residue (Perry and Olson, 1975).

Perry and Olson (1975) reported that there is an association or relationship between grain yield and the amount of residue remaining in the field following harvest. Furthermore, authors suggested that N fertilizer may have a significant

impact on the grain:residue ratio, however more research was needed to determine what factors affect the ratio and what the actual proportion is (Perry and Olson, 1975). The grain:residue ratio is important in determining the overall biomass available following harvest and subsequently used for stocking rate calculations. Smil (1983) reported that American corn proportions of grain:residue cluster closely to 1:1. Whereas, Pordesimo et al. (2004) stated that the relationship is closer to 0.8:1; however the moisture at which the grain is harvested has an impact on the grain:residue ratio as grain can vary from 18 to 31% moisture at the time of harvest. Pordesimo et al. (2004) summarized that Oursbourn et al. (1978) reported the proportion of grain:residue varied from 0.68:1 to 1:1; whereas, Smil (1983) observed a range from 0.58:1 to 4.00:1. Shinners and Binversie (2007) reported that total residue moisture could range from 66 to 47% whenever the grain moisture is 30%. In periods of adequate rainfall during grain fill, authors saw that residue was less than 45% of the total crop mass when grain moisture was less than 30%. In periods of drought when the plant is stressed during grain fill, the residue accounted for 45-50% of the total crop mass when grain moisture was less than 30%. Thus, in a three year average Shinners and Binversie (2007) determined the residue:grain moisture ratio to be 2.15:1 during the typical harvest period. Burken (2014) reported in a two-trial summary that any reduction in DM following physiological maturity of the plant could be attributed to environmental effects.

The amount of each plant component available following harvest is variable depending on the specific component type. Lamm and Ward (1981) collected residue to determine the change in mass distribution of corn plant components before and

after grazing, to show the effects of grazing as well as weathering. Results suggested that prior to grazing, residue consisted of 38.9% husk/leaf, 40% stalks, 11.2% grain and 9.1% cobs on a DM basis. The ungrazed residue collected at the end of winter consisted of 35.2% husk/leaf, 39.8% stalk, 9.3% grain and 15.6% cobs on a DM basis. Whereas the winter sample collected following grazing consisted of 30.6% husk/leaf, 54.8% stalk, 1.4% grain and 13.1% on a DM basis. The changes in mass distribution of plant components can be attributed to weathering in terms of wind loss and deterioration of the plant material. More recently, Pordesimo et al. (2004) collected residue components following harvest at grain physiological maturity and found that the mass distribution of residue in the field consisted of 50.9% stalk, 21.0% blade, 15.2% cob and 12.9% husk on a DM basis.

Burken (2014) conducted two experiments utilizing standing corn in an irrigated corn field. In Exp. 1, corn was harvested in two-week intervals from August through October with four-week intervals through December while in Exp. 2 corn was harvested in four-week intervals from October to December. For Exp. 1, authors reported that the proportion of the residue DM changed ($P < 0.01$) quadratically for the plant components stem, blade/sheath and husk/shank overtime with little change occurring once the grain reaches 15.5% moisture. Whereas, in Exp. 2 there was a quadratic increase ($P < 0.01$) over time in the proportion of residue DM for both cob and husk/shank while having a quadratic decrease ($P < 0.01$) in the proportion of the stem DM overtime with no difference ($P = 0.90$) in the proportion of residue DM for the blade/sheath component. The authors attributed the difference between experiments to the difference in harvesting dates. Experiment two had a shorter

harvest window with a more mature corn crop as harvest dates were only taken after the typical grain harvest period. In experiment one, the NDF content of the plant components of blade/sheath, husk/shank, and cob increased ($P < 0.01$) quadratically with a linear decrease ($P = 0.01$) over time in NDF content of the stem decreasing from 70.6% to 64.3%. Whereas, in experiment two there was a significant interaction ($P < 0.01$) between the two hybrids planted. For both hybrids there was no difference in NDF content of the blade/sheath and cob over time. The NDF content of the stem and husk/shank decreased ($P < 0.01$) linearly for the 119 d hybrid while there was a linear increase ($P < 0.01$) in the NDF content of the husk/shank for the 102 d hybrid and no difference ($P > 0.05$) in the NDF content of the stem, blade/sheath and cob for the 102 d hybrid. In both experiments the NDF content increased until plant physiological maturity at a grain moisture of 15.5% where the NDF content remained relatively constant. In both experiments there was no difference ($P > 0.05$) in the NDF digestibility of the blade/sheath, husk/shank and stem over time. The NDF digestibility of the cob decreased ($P < 0.04$) quadratically in experiment one and linearly in experiment two with digestibility remaining releatively constant once the plant reached physiological maturity (Burken, 2014).

Lamm and Ward (1981) reported that the grain component in the fall-harvested residue before grazing was greater ($P < 0.01$) in CP and in vitro organic matter digestibility (IVOMD) as compared to other plant part components. Crude protein of the fall-sampled residue was similar ($P > 0.05$) for the husk, leaf, stalk and cob components; the husk and leaf components were numerically greater in CP at 7.3% of DM. Additionally, there were no differences ($P > 0.05$) in IVOMD among

the husk and leaf components compared to the cob and stalk components. Similarly, in the spring harvested standing corn plants that were collected in late March, the grain component had the greatest ($P < 0.01$) CP at 12.2% and IVOMD as compared to the other plant parts. There were no differences ($P > 0.05$) in IVOMD between the stalks and husks and leaves, however they were more ($P < 0.01$) digestible than the cobs. All plant part components were composited for both the fall and spring collections, which showed that the fall sampled corn residue had a CP of 8.8% being greater ($P < 0.01$) than the spring (8.2% CP). Additionally, the fall sampled residue had greater ($P < 0.01$) IVOMD as compared to the spring collection (Lamm and Ward, 1981). Similarly, Gutierrez-Ornelas and Klopfenstein (1991) reported that as time progresses the quantity of CP and rumen undegradable protein (RUP) decreased ($P < 0.05$) where acid detergent insoluble nitrogen (ADIN) increased ($P < 0.05$) over both early and late season grazing periods.

McGee et al. (2012) conducted an experiment to determine the digestibility of individual plant part components utilizing an irrigated field in a corn/soybean rotation with three treatments (fall grazed, spring grazed and ungrazed). Treatment did not affect ($P > 0.05$) digestibility, plant part component proportions, or plant parts per bushel. The individual plant part components consisted of the top 1/3 stalk, bottom 2/3 stalk, leaf, leaf sheath, husk, shank and cob made up 3.60, 41.83, 18.72, 12.60, 7.48, 1.09, and 14.68% of plant DM with IVDMD values of 37.57, 33.85, 45.70, 38.56, 59.03, 49.75, 34.94%, respectively. Furthermore, stocking rate can have an impact on the amount of lesser digestible components consumed in a grazing period as there is a change in the IVDMD of the diet. Gardine et al. (2016) reported that on

average, per bushel of corn (15.5% moisture grain), there is 7.26 kg of highly digestible residue consisting of the leaf, leaf sheath, shank and husk. Authors observed that grazing efficiency of the cattle was approximately 50% due to weathering and trampling. Based on this assumption 3.6 kg of leaf and husk per bushel of corn is available for grazing (Gardine et al., 2016). Guiterrez-Ornelas and Klopfenstein (1991) reported that the amount of leaf blade and grain available for grazing following harvest was variable from year to year and across grazing seasons, whereas the amount of husks available was more consistent. Authors reported that weather conditions impacted the proportion of leaf blade and grain more so than husks on a DM basis due to weathering and deterioration.

Animal Selectivity

Cattle efficiency to harvest corn residue has been shown to be in the range of 50% on average but may be up to 70% on heavier stocking densities (McGee et al., 2012). Burken (2014) sampled corn components before and after grain harvest with a final sample collected following a grazing period. Results suggest that cattle selected the more digestible components first consisting of the husk/shank followed by the blade/sheath (Burken, 2014). Similarly, Lamm and Ward (1981) collected residue components before and after the grazing period to determine the effects of grazing. Authors reported the order of which the cows selected to graze the corn plant components was grain, husks/leaves, stalks and cobs during the winter grazing period (Lamm and Ward, 1981). Additionally, Guiterrez-Ornelas and Klopfenstein (1991) conducted four studies in total consisting of two early season (October to December) grazing trials and two late season (December to March) grazing trials utilizing both

irrigated and non-irrigated fields to determine the disappearance of residue

components when grazed. Results showed that more than 90% of the grain left in the

field following harvest disappeared after grazing; whereas, specific plant components

removed following grazing had different ($P < 0.05$) rates of disappearance. The grain

and husk were consumed first followed by the leaf blade with no change ($P > 0.05$) in

the amount of available stem and leaf sheaths over the grazing period (Guiterrez-

Ornelas and Klopfenstein, 1991).

Impact of Field Type

Irrigation can impact the amount of residue available for grazing, as irrigated

fields typically have more ($P < 0.05$) total residue available as compared to non-

irrigated where the proportion of leaf and husk was greater ($P < 0.05$) in non-irrigated

residue (Fernandez-Rivera and Klopfenstein, 1989a). Fernandez-Rivera and

Klopfenstein (1989a) demonstrated that total available residue for grazing was less ($P

< 0.05$), at 2,737 kg/ha, for the non-irrigated treatment whereas the irrigated treatment

had 5,907 kg/ha of available residue for grazing. Trial 2 was similar as the non-

irrigated treatment provided less ($P < 0.05$) available residue (4,982 kg/ha) compared

to the irrigated (8,298 kg/ha) treatment. Non-irrigated fields typically have greater ($P

< 0.05$) CP values in all corn residue components with less ($P < 0.05$) NDF content as

compared to irrigated residue (Fernandez-Rivera and Klopfenstein, 1989a).

Additionally, non-irrigated corn residue had a greater proportion of leaf and husk

with a lower proportion of stem as compared to irrigated residue (Fernandez-Rivera

and Klopfenstein, 1989a). Guiterrez-Ornelas and Klopfenstein (1991) determined that

weather could affect the impact of field type. In one of the two early season grazing

trials, results showed that there was no difference ($P > 0.05$) in CP, RUP or acid detergent insoluble nitrogen (ADIN) between irrigated and non-irrigated fields; however, this was attributed to the weather conditions as this specific trial was conducted in a very dry year.

Fernandez-Rivera and Klopfenstein (1989) reported that in one experiment of a 3-experiment summary, fistulated steers grazing non-irrigated corn residue selected a diet consisting of more ($P < 0.05$) CP than steers grazing irrigated corn residue with CP progressively decreasing over time until week 4 or 5 of grazing where CP levels remains relatively constant. In trial 2 the CP content of the residue decreased ($P < 0.05$) linearly over the grazing period whereas the decrease in CP was slower for the non-irrigated residue as compared to the irrigated residue at the same stocking rate. However, early on in trial 2 the CP was greater ($P < 0.05$) in extrusa taken from diet samples in steer consuming irrigated residue as compared to the non-irrigated mainly due to the greater grain content. There was an increase ($P < 0.05$) in starch content of the residue from the irrigated field as compared to the non-irrigated (Fernandez-Rivera and Klopfenstein, 1989).

Steers grazing non-irrigated corn residue had greater ($P < 0.01$) ADG compared to steers grazing irrigated corn residue; however, there was no difference ($P = 0.30$) in final BW between steers grazing irrigated and non-irrigated corn residue (Burken, 2014). The lesser ADG is presumably related to having a greater proportion of stem and NDF content as discussed above. Similarly, Fernandez-Rivera and Klopfenstein (1989) reported that steers grazing non-irrigated residue had greater ($P < 0.05$) ADG as compared to steers grazing irrigated residue.

Distillers Grains

Distillers grains are a by-product of the dry-milling industry. The dry-milling process consists of converting starch in grain to alcohol through yeast fermentation once starch is converted to sugar (Stock et al., 2000). Following fermentation of the originating starch and distillation of the carbon dioxide and alcohol what is left is the whole or spent stillage (Stock et al., 2000). The whole stillage is centrifuged to remove the courser grain particles. The liquid portion from centrifugation is known as thin stillage and contains fine grain particles and yeast cells. The thin stillage is evaporated to form a product called condensed distillers solubles (CDS). The course grain particles removed from centrifugation are known as wet distillers grains (WDG) or if dried called dried distillers grains (DDG). The CDS are either sold as a feed ingredient or added back to WDG and marketed as wet distillers grains plus solubles (WDGS) or dried and added to DDG being marketed as dried distillers grains plus solubles (DDGS; Stock et al., 2000). If all of the solubles are added back to the distillers grain product the composition is approximately 80% distillers grains and 20% CDS (Corrigan et al., 2007). However, the composition of DDGS or WDGS is variable depending on the ethanol plant as some add back more solubles than others (Buckner et al., 2011). As the level of solubles increases, the DM, CP and NDF % in DDGS decreases while the fat % rises with increasing levels of solubles (Corrigan et al., 2007).

Starch is the main component in corn grain, comprising approximately 2/3 of the total DM (NASEM, 2016). The fermentation process removes the starch component leaving 1/3 of the original DM (Stock et al., 2000). Due to the increase in

concentration, the nutrients remaining following the dry milling process are increased 3-fold (Stock et al., 2000). On average, distillers grains plus solubles contain 31% CP, 11.9% fat, 0.84% P and 0.77% S of DM (Buckner et al., 2011). A meta-analysis by Bremer et al. (2011) summarized that there was a linear response ($P < 0.01$) in G:F as DDGS inclusion increased in the diet from 0 to 40% with a quadratic response ($P < 0.01$) in G:F as MDGS and WDGS inclusion increased in the diet from 0 to 40%. Distillers grains plus solubles contain a high level of energy and protein compared to corn in forage-based diets. Ahern et al. (2016) reported that in forage based diets, WDGS included at 15% of the diet DM had a TDN value of 113.5%, which is 137% the value of DRC. Where, WDGS included at 30% of the diet DM had an TDN value of 112.7%, which is 136% the value of DRC (Ahern et al., 2016).

Summer and Trenkle (1999) fed corn residue with corn, corn gluten feed, or DDG to feedlot steers. Steers fed corn residue plus DDG resulted in an increase ($P < 0.05$) in NDF and ADF intake as compared to steers fed corn residue alone and corn residue plus corn grain, but had lower ($P < 0.05$) NDF and ADF intakes compared to steers fed corn residue plus CGF. Feeding corn residue plus DDG or CGF had an increase ($P < 0.05$) in DM, OM, NDF and ADF digestibility as compared to steers fed corn residue and corn residue plus corn. Furthermore, energy content of the diet was increased ($P < 0.05$) in diets that contained corn residue plus DDG or CGF as compared to corn residue and corn residue plus corn diets (Summer and Trenkle, 1999).

Distillers Grains Supplementation of Calves on Corn Residue

Gustad et al. (2006) fed steers increasing levels of DDGS and reported a quadratic response in ADG to increasing levels of DDGS with ADG increasing past 1.1% of BW of DDGS. Gain increased from 0.41 to 0.82 kg/d as level of DDGS increased from 0.68 to 2.95 kg (Gustad et al., 2006). Jones et al. (2015) fed increasing levels of DDGS (0.3, 0.5, 0.7, 0.9 or 1.1% of BW) to steers grazing irrigated corn residue. There was a linear increase ($P = 0.03$) in ADG as level of DDGS increased in the diet suggesting that the maximum DDGS intake was not achieved. Steers supplemented with 0.3, 0.5, 0.7, 0.9 or 1.1% of BW gained ($P < 0.01$) 0.35, 0.65, 0.78, 0.88 and 1.00 kg/d, respectively. There was no difference in IVOMD for diet samples collected throughout the grazing period for steers grazing irrigated corn residue, suggesting that stocking rate was appropriate as steers were not forced to select lowly digestible corn components (Jones et al., 2015).

Burken (2014) summarized two trials from 2012 and 2014 to determine the effects of grazing steers on corn residue. Trial 1 evaluated the effects of grazing steers on corn residue with increasing levels of DGS (0.3, 0.7 and 1.1% of BW) with DDGS and MDGS when grazing both irrigated and non-irrigated corn residue. There was no difference ($P > 0.52$) in ending BW or ADG between steers fed DDGS or MDGS. Furthermore, there was a linear increase ($P < 0.01$) in ending BW as the inclusion of DGS increased in the diet from 0.3 to 1.1% of BW where ADG increased ($P < 0.01$) quadratically as the inclusion of DGS increased in the diet. Trial 2 evaluated the effects of feeding increasing levels (0.3, 0.5, 0.7, 0.9 and 1.1% of BW) of DGS to steers grazing irrigated corn residue. There was a linear increase ($P < 0.01$) in ending

BW and ADG with increasing levels of DGS in the diet. Steers consuming 0.3, 0.5, 0.7, 0.9 and 1.1% of BW gained 0.35, 0.65, 0.78, 0.89 and 1.00 kg/d. There were no differences ($P > 0.05$) in IVOMD over time for steers grazing corn residue in experiments one and two.

Tibbitts et al. (2016) evaluated the effects of feeding different supplemental protein sources on steer performance grazing irrigated corn residue when balanced for energy. Results showed that there was a significant difference ($P < 0.01$) in ADG and ending BW across treatments. Average daily gain was 0.67, 0.60, 0.24, 0.14 and -0.08 kg/d for the treatments soy-pass, DDGS, corn/urea, corn, and control, respectively. The authors summarized that supplements high in RUP and RDP (Soy-pass, DGS) will have greater growth performance even when TDN of the supplements (corn/urea and corn) is similar (Tibbitts et al., 2016). Similarly, Wilson et al. (2004) summarized that CP, both RDP and RUP, is needed in sufficient amounts to achieve optimum growth and performance in growing cattle grazing corn residue.

Urea Supplementation in forage based diets

Tibbitts et al. (2016) evaluated the effect of supplementing corn and corn plus urea on steers grazing corn residue. Results suggest that steers fed corn did have a deficiency in RDP with no excess MP, as there was a reduction in ADG ($P < 0.01$) leading to a reduction ($P < 0.01$) in ending BW as compared to steers fed corn plus urea. Stalker et al. (2007) conducted two trials evaluating the effects of adding RDP when supplementing DDGS to heifers consuming forage-based diets to determine if there is enough recycling of excess MP to meet the RDP requirement. In trial 1 heifers were fed diets containing 58% ground corn cobs, 12% sorghum silage and

30% DDG where DDG was replaced by urea at 0, 0.4, 0.8, 1.2 or 1.6% of diet DM.

Results suggest that there was no difference ($P > 0.07$) in ending BW, ADG or G:F

between all inclusions of urea with a quadratic response ($P = 0.04$) in DMI as level of

urea increased. Trial 2 fed meadow hay ad libitum with 1.4 kg (DM) DDG and 0 or

45 g/heifer daily of urea. Similar to trial 1, there was no difference ($P > 0.10$) in

ending BW, ADG, DMI or G:F between heifers fed 0 or 45 g/heifer daily. Authors

attribute the lack of response to urea supplementation in trial 1 to urea from DDGS

being recycled back to the rumen to meet the RDP deficiency while their

retrospective modeling would show that there was a RDP deficiency. Whereas in trial

2, retrospective modeling suggests that the heifers did not have a RDP deficiency.

Huntington and Archibeque (1999) reported that protein sources high in RUP could

be utilized to meet RDP deficiencies through recycling of excess RUP to the rumen.

Excess MP is converted to urea in the liver and absorbed into the blood stream where

the urea can either be excreted in the urine, absorbed through the rumen wall or

recycled through the saliva. Once in the rumen, urea is converted into ammonia and is

used to support microbial fermentation; the portion absorbed directly across the

rumen wall can account for 10 to 42% of N intake (Huntington and Archibeque,

1999).

Conclusions

Feeding cattle in the feedlot allows for many new and innovative technologies

to help producers be more efficient and maximize their limited resources. Monensin

is a well-studied feed additive; monensin inclusion in feedlot diets has been shown in

most cases to improve feed efficiency. However, much of the literature is older and

diets have changed considerably over the years with the inclusion of byproducts, specifically, from both the dry milling and wet milling industries. Thus, research on the effect of monensin has been shown to be diet dependent and more research is needed to determine the effects of monensin in these high byproduct diets.

A survey recently taken of feedlot consulting nutritionist by Samuelson et al. (2016) reported that producers are feeding steers in the feedlot to an average of 201 days on feed. There have been numerous studies that have evaluated the effect of ractopamine hydrochloride (RAC) on finishing cattle performance showing that RAC increases ADG, G:F and HCW, but data are limited with cattle being fed to larger weights. What effect RAC has in yearling cattle that are larger and more physiologically mature is unclear.

The abundance of corn residue leads to a significant potential to graze cattle economically. Grazing cattle on corn residue takes away the need to mechanically harvest forage to feed in the winter. Corn residue is an abundant resource but is relatively low in protein and energy to meet the nutrient requirements of a growing calf. Therefore, a supplemental protein and energy source is needed to meet the deficiency in corn residue. With the expansion of the ethanol industry, distillers grains plus solubles (DGS) provides an economical solution to supplement calves on corn residue, as DGS are high in energy and protein. The extent of recycling occurring to meet protein requirements in cattle fed low quality forage-based diets supplemented with DGS is unclear.

Therefore, the objectives of these experiments were to: 1) to evaluate the effects of feeding monensin and vaccination of Titanium 5 PH-M versus Titanium 5 +

NUPLURA PH on steer growth performance and morbidity over a 28-d receiving

period when steers are fed RAMP, 2) to determine the effects of increasing days on

feed and feeding ractopamine hydrochloride on performance of large yearlings, and

3) evaluate the effects of supplementing MDGS with and without urea on the

performance of growing calves grazing corn residue.

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CHAPTER II. COMPARISON OF THE PRESENCE OR ABSENCE OF MONENSIN WITH TITANIUM 5 PH-M VERSUS TITANIUM 5 PLUS NUPLURA PH ON HEATLH AND PERFORMANCE OF NEWLY RECEIVED FEEDLOT CALVES FED RAMP

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ABSTRACT

A receiving study was conducted to evaluate the effects of RAMP with two monensin concentrations (0 or 27.6 mg/kg) given with one of two viral vaccinations (Titanium 5 PH-M or Titanium 5 plus NUPLURA PH) on steer growth performance and morbidity. Crossbred steers (n = 704; initial BW = 269; SD = 22 kg) were utilized in a generalized randomized block design with a 2×2 factorial arrangement of treatments. Factors included vaccine type and the presence or absence of monensin (Elanco Animal Health, Greenfield, IN) in the receiving diet. The first vaccine treatment (Titanium 5 PH-M; VacPH-M; Elanco Animal Health, Greenfield, IN) is labeled to deliver an effective immune response against bacteria *Mannheimia haemolytica* and *Pasteurella multocida* and viruses BVD types 1 and 2, IBR, PI_3 and BRSV. The second vaccine treatment (Titanium 5 plus NUPLURA PH; VacPH; Elanco Animal Health, Greenfield, IN) is labeled similar to VacPH-M excluding protection against *Pasteurella multocida*. All steers were fed RAMP (Cargill Corn Milling, Blair, NE) with monensin included at 0 or 27.6 mg/kg on a DM basis. Steers were weighed on arrival to establish initial BW. Initial BW was not shrunk as steers were weighed within 6 h of arrival and no feed was provided. Steers were assigned to pen based on processing order, with every fourth steer being assigned to one of four treatments. Once a pen replicate was filled, new pen replicates were started until all steers were assigned to 40 pens (10 pens per simple effect treatment). The receiving trial lasted 28 d with 5 d of limit feeding followed by 2 consecutive d weights to determine ending BW. There were no significant monensin $\times$ vaccine interactions ($P > 0.27$) observed for growth performance or morbidity. Vaccine treatments (VacPH-

M or VacPH) did not affect DMI ($P = 0.52$), ADG ($P = 0.95$), or G:F ($P = 0.79$).

Monensin level (0 or 27.6 mg/kg) did not affect DMI ($P = 0.28$), ADG ($P = 0.94$), or

G:F ($P = 0.65$). The number of steers pulled and treated for bovine respiratory disease

one or more times was not different ($P = 0.19$) for VacPH-M compared to VacPH.

Furthermore, no difference ($P = 0.52$) was observed when comparing second pull

rates between vaccine types. There was a tendency for steers fed 27.6 mg/kg of

monensin to have a lower percentage of first ($P = 0.10$) pulls as compared to steers

receiving 0 mg/kg of monensin. There was no difference ($P = 0.21$) in second pull

rate between steers fed 0 or 27.6 mg/kg of monensin. We concluded that neither

vaccine type nor monensin concentration affected steer growth performance or

morbidity rate for the first 28 d of receiving.

Key Words: monensin, receiving, vaccine

INTRODUCTION

Monensin (Rumensin; Elanco Animal Health, Greenfield, IN) is an ionophore

that has been shown to alter the rumen microbial population and is widely used in the

beef industry to improve feed efficiency (Potter et al., 1985; Duffield et al., 2012;

Samuelson et al., 2016), increase ADG (Duffield et al., 2012), lower DMI (Goodrich

et al., 1984; Duffield et al., 2012), reduce variation in feed intake (Stock et al., 1995)

and reduce the incidence of acidosis (Erickson et al., 2003). However, there has been

limited research recently evaluating the performance and morbidity impacts of

feeding monensin during the adaptation or receiving period in feedlot steers. A

common perception is that calves cannot be started on monensin as DMI will

decrease. The effect of monensin on the level of intake has been variable ranging

from a decrease of 3.1% to an increase of 14% compared to the control fed no monensin (Gill et al., 1976; Goodrich et al., 1984; Duffield et al., 2012). Steers fed an ionophore during a 28-d receiving period had a numerically reduced DMI with no change in ADG or G:F compared to steers not fed an ionophore (Duff et al., 1995).

The most prevalent disease in the beef industry is bovine respiratory disease (BRD) with the National Animal Health Monitoring System (NAHMS; USDA, 2011) estimating that 16.2% of cattle placed in feedlots were affected with respiratory disease and 13.4% of cattle placed were treated for respiratory disease with an injectable antibiotic. Respiratory disease can be caused by a combination of viral and bacterial pathogens, usually as a result of stress factors all interacting to cause morbid cattle. Titanium 5 PH-M (VacPH-M) and Titanium 5 + NUPLURA PH (VacPH) (Elanco Animal Health) are both modified live BRD vaccinations intended for beef cattle. The combination vaccine VacPH-M is labeled to deliver an effective immune response against bacteria *Mannheimia haemolytica* and *Pasteurella multocida* and viruses bovine viral diarrhea (BVD) types 1 and 2, infectious bovine rhinotracheitis (IBR), parainfluenza-3 virus (PI$_3$) and bovine respiratory syncytial virus (BRSV). The 2 shot vaccine VacPH is labeled similarly to VacPH-M excluding protection against *Pasteurella multocida*. In the industry, combination vaccines are questioned as being too potent and causing more problems than mitigating; thus, in this experiment the combination vaccine VacPH-M was compared to the 2 shot vaccine VacPH.

One common practice for receiving cattle today is feeding RAMP, a complete starter product (Cargill Corn Milling, Blair, NE) that contains a high level of Sweet Bran and a minimal amount of forage (Schneider et al., 2017). Steers fed RAMP for

the first 22-d had lower ($P = 0.03$) DMI with no difference in G:F or ADG compared to steers fed a traditional adaptation diet consisting of dry rolled corn and high moisture corn replacing alfalfa hay with Sweet Bran and supplement held at a constant inclusion (Schneider et al., 2017). Following the adaptation period, steers were finished on a common finishing diet. Steers fed RAMP on the one-ration system during the adaptation period had a greater ADG, while also having a lower DMI compared to the steers fed the traditional adaptation diet. Feed efficiency over the finishing period was greater for steers fed RAMP with no differences in carcass characteristics compared to steers fed the traditional adaptation diet. The objective of this study was to evaluate the effects of VacPH-M versus VacPH on steer growth performance and morbidity over a 28-d receiving period when steers were fed RAMP with or without monensin.

MATERIALS AND METHODS

All facilities and procedures were approved by the University of Nebraska Institutional Animal Care and Use Committee.

A feedlot receiving study was conducted to determine the effectiveness of vaccine at arrival on growth performance and health of steers over a 28-d receiving period when fed RAMP with 0 or 27.6 mg/kg (DM basis) of monensin/steer daily. The experiment was conducted at the University of Nebraska-Lincoln Eastern Nebraska Research and Extension Center (ENREC) near Mead, NE. Crossbred steers (n = 704; initial BW = 269; SD = 22 kg) were utilized in a generalized randomized block design with a 2×2 factorial treatment design with one factor being monensin concentration (0 or 27.6 mg/kg of monensin/steer daily) and the other factor being

vaccine type (Titanium 5 PH-M (VacPH-M) and Titanium 5 + NUPLURA PH (VacPH)). Upon arrival, steers were allowed access to water and processed within 6 h. Steers were weighed on d 1 to establish initial BW. Initial BW was not shrunk because steers were weighed within 6 h of arrival and had no access to feed before weighing. Steers were assigned to one of four treatments (pen) based on processing order with steers assigned singly to treatment in sets of 4, and repeated until 4 pens were filled (1 replicate). Once a pen replicate was filled, new pen replicates were started until all steers were assigned to 40 pens (10 pens per simple effect treatment) with 14-21 steers per pen (equal steers/pen within block). During processing on d 1, all steers were identified with an individual visual and electronic identification tag as well as a metal identification clip, individually weighed (Silencer Squeeze Chute; Moly Mfg. Inc., Lorraine, KS: scale readability ± 0.45 kg), and vaccinated with a *Haemophilus somnus* vaccine (Somnu Shield; Elanco Animal Health) administered at 2ml/steer and treated for internal and external parasites with an injectable wormer (Dectomax injectable; Zoetis Animal Health, Parsippany, NJ) administered at 1ml/45.4 kg of BW. Steer ID was utilized for treatment assignment to vaccine treatment based on odd or even numbers. All odd number ID tags were vaccinated with VacPH-M (2ml/steer), while all even numbered tags were vaccinated with VacPH (2ml/steer).

A common diet was fed to all four treatments consisting of 97% RAMP and 3% fine ground corn-based supplement (DM Basis). Supplements contained either 0 or 27.6 mg/kg of monensin (DM basis). Both supplements contained 479.5 mg/kg of decoquinate (Deccox; Zoetis Animal Health) to provide 125 mg/hd/d on a DM basis

at a target intake of 7.7 kg/hd/d. After the 28-d receiving trial, steers were limit-fed

(to minimize gut fill variation) a diet of 50% forage, 50% Sweet Bran (DM basis) at

2% of BW for 5 consecutive days before weighing for ending BW (Watson et al.,

2013). Ending BW was an average of 2 consecutive day weights collected before

feeding each day.

Steers were housed in open feedlot pens with 43 cm of linear bunk space and

30 to 37 m^2 of pen space per steer. Feed bunks were assessed daily at approximately

0600 for presence of feed. Feed amounts were increased or decreased daily to

maintain an ad libitum system. Cattle were fed once daily between 0700 and 0900.

Steers had ad libitum access to fresh clean water and their respective diet. Diets were

mixed and delivered daily using a truck-mounted feed mixer and delivery unit (Roto-

Mix model 420, Roto-Mix, Dodge City, KS).

Statistical Analysis

Performance data (BW, DMI, ADG, G:F) were analyzed using the MIXED

procedure of SAS (Version 9.4; SAS Inst., Inc., Cary, N.C.) with pen as the

experimental unit. The model included monensin, vaccine, and monensin $\times$ vaccine

interaction. Block (arrival) was included in the model as a fixed effect. Morbidity

incidence was evaluated as the number of cattle receiving an antibiotic or the number

of steers treated in the pen divided by the total number of steers in the pen.

Additionally, the morbidity rate of cattle receiving an antibiotic 2 or more times was

calculated as the number of steers treated at least two times divided by the total

number of steers treated once. Cattle pulled for treatment were only considered in the

analysis if deemed morbid due to BRD. Morbidity data were analyzed with the

GLIMMIX procedure of SAS using a binomial distribution and a logit-link function.

Differences are discussed at $P \leq 0.05$ and tendencies discussed between $P > 0.05$ and

$P \leq 0.10$.

RESULTS AND DISCUSSION

No significant monensin × vaccine interactions ($P \geq 0.27$) were noted for

growth performance or morbidity (Table 1). Monensin concentration did not affect

DMI ($P = 0.28$), ADG ($P = 0.94$), G:F ($P = 0.65$), or ending BW ($P = 0.83$). The

common perception in the industry is that calves cannot be fed monensin in the

receiving period as monensin can decrease DMI. In the current experiment, DMI of

steers fed monensin was not different ($P = 0.28$) from steers not fed monensin.

Similarly, Burrin et al. (1988) reported that as monensin concentration increased,

there was no effect on ADG or G:F during the initial 28 d compared to steers not

receiving monensin. In contrast, authors reported that as level of monensin increased

in the diet, there was a linear decrease in DMI for the initial 28 d of the trial. Pritchard

and Thomson (1992) observed in the first 29 d of the finishing period, steers not fed

monensin had greater DMI compared to steers fed monensin; whereas, DMI

decreased linearly as inclusion of monensin in the diet increased from 0 to 33.1

mg/kg of monensin/steer daily with no difference between steers fed 22.1 and 33.1

mg/kg of monensin. In the current study, DM offered was consistent across both

treatments (Figure 1). The DMI reported is the same as DM offered as no orts were

collected over the 28-d receiving period. The reduction in DMI observed at the

beginning of the feeding period was likely due to being ahead of the cattle in the

amount of feed offered; thus, the amount of feed offered in the feed call was lowered.

There was a tendency ($P = 0.10$; Table 1) for steers fed 27.6 mg/kg of monensin/steer daily to have 5.2 percentage units less first pulls, compared to steers receiving 0 mg/kg of monensin/steer daily. There was no difference ($P = 0.21$) in second pull rate between steers fed 0 or 27.6 mg/kg of monensin.

Vaccine type did not affect DMI ($P = 0.52$), ADG ($P = 0.95$), G:F ($P = 0.79$), or ending BW ($P = 0.58$). The number of steers pulled and treated for BRD one ($P = 0.19$) time or two or more ($P = 0.52$) times was not different ($P = 0.19$) for VacPH-M compared to VacPH. However, the numerical difference between vaccine types was similar to the numerical difference between steers fed monensin or not. While not significant, steers vaccinated with VacPH had numerically lower first pulls but higher second pulls.

Results suggest that neither vaccine type nor monensin concentration impacted steer growth performance or morbidity rate for the first 28-d of receiving. Including monensin from day 1 of receiving does not dramatically alter DMI of newly received calves fed RAMP.

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Table 1. Main effect comparisons of feeding monensin and vaccine type on performance and morbidity over a 28-d receiving period.

Item	Monensin			Vaccine[1]			SEM[2]	Interaction[3]
	0 mg/kg	27.6 mg/kg	P-value	VacPH-M	VacPH	P-value		
Initial BW, kg	267	269	0.75	271	269	0.46	2.3	0.55
Ending BW, kg	309	310	0.83	311	309	0.58	2.7	0.59
DMI, kg/day	6.23	6.08	0.28	6.20	6.11	0.52	0.10	0.94
ADG, kg	1.49	1.49	0.94	1.49	1.49	0.95	0.04	0.81
Gain:Feed	0.241	0.245	0.65	0.242	0.244	0.79	0.006	0.79
Morbidity								
First pull, %[4]	22.6	17.4	0.10	22.0	17.9	0.19	2.3	0.38
Second pull, %[5]	22.5	13.8	0.21	15.7	20.0	0.52	5.3	0.27

[1]VacPH-M is Titanium 5 PH-M and VacPH is Titanium 5 +Nuplura PH.

[2]Standard error of the treatment means.

[3]Interaction = P-value for the monensin dose × vaccine interaction.

[4]Percentage of steers treated one or more times as a % of total steers within the pen.

[5]Percentage of steers treated two or more times, expressed as a % of steers pulled once.

Figure 1. Daily DM offered to steers consuming a RAMP diet with 0 or 27.6 mg/kg of monensin.
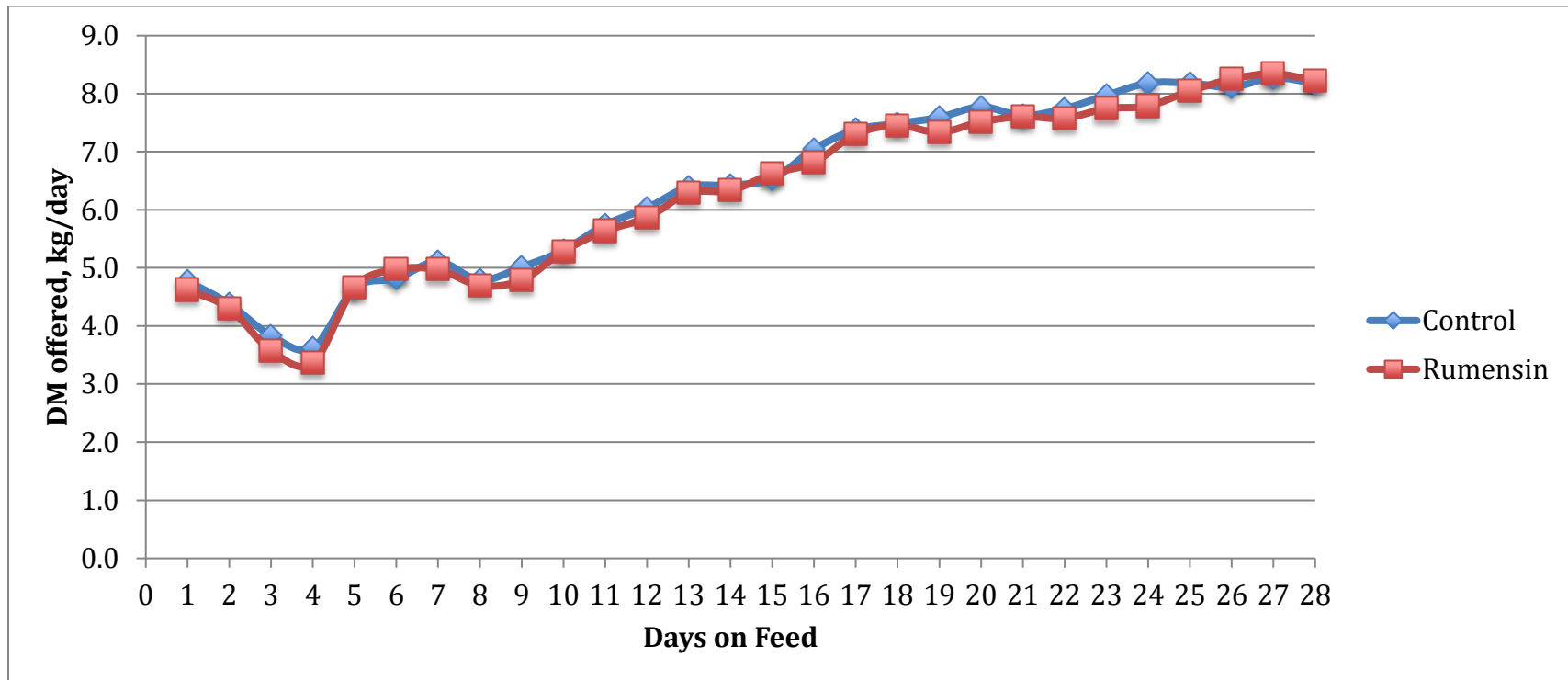
CHAPTER III. EVALUATION OF 0 OR 300 MG OF RACTOPAMINE HYDROCHLORIDE (OPTAFLEXX) ON GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF STEERS FED TO DIFFERENT DEGREES OF FINISH

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ABSTRACT

A feedlot study evaluated the effects of feeding 0 or 300 mg of ractopamine hydrochloride (RAC) on growth and carcass performance of yearling steers fed to differing degrees of finish. Crossbred yearling steers (n = 342; initial BW = 416, SD = 34 kg) were utilized in a generalized randomized block design (3 BW blocks) with a $2 \times 3 + 1$ factorial treatment design. Factors included RAC dosage (0 or 300 mg/steer daily) and different days on feed (118, 139, or 160 d) plus cattle fed 2 weeks longer (174 d) without RAC. Steers were fed RAC for the last 35 d before harvest. Steers were weighed when initiated onto RAC and every 7 d thereafter to determine interim growth performance. No significant dose $\times$ days on feed interactions ($P \geq$ 0.35) were observed for growth performance. Live final BW was 13 kg heavier ($P =$ 0.01) for steers fed 300 mg of RAC as compared to steers fed 0 mg. Steers fed 300 mg of RAC had greater carcass-adjusted ADG ($P = 0.04$) and G:F ($P = 0.05$) compared to steers fed 0 mg. There were no differences ($P = 0.24$) in DMI between RAC doses. Carcass weight and carcass-adjusted final BW were 6.9 and 10 kg greater ($P < 0.06$), respectively, for steers fed 300 mg of RAC compared to 0 mg. As days on feed increased, carcass-adjusted final BW linearly increased ($P < 0.01$) 1.75 kg/d between steers fed 118 and 174 DOF whereas, daily DMI decreased linearly ($P <$ 0.01). Carcass-adjusted ADG was constant ($P \geq 0.15$) which led to a 3.1% improvement ($P = 0.02$) in carcass-adjusted G:F, due to the reduction in DMI. Cattle performance was negatively influenced by wet, cold, muddy conditions in January and February which may have reduced ADG and HCW compared to targeted finish BW and HCW. From d 90-97 of the trial, cattle on both RAC treatments had a

negative ADG response. During d 111 to 118, live interim ADG for steers fed 118 d for both RAC and control treatments was negative. Feeding RAC at 300 mg/steer daily improved ADG, G:F, and HCW regardless of days on feed (i.e., degree of finish).

Keywords: finishing, ractopamine hydrochloride, yearling

INTRODUCTION

Feeding β – adrenergic agonists has been shown to increase protein accretion and decrease fat deposition in animal growth (Mersmann, 1998). Ractopamine hydrochloride (RAC; trade name Optaflexx; Elanco Animal Health, Greenfield, IN) has been widely used in the industry since 2004 to increase final BW, HCW, and improve feed efficiency with limited effects on USDA yield grade and quality grade in finishing cattle (Avendaño-Reyes et al., 2006; Arp et al., 2014; Quinn et al., 2016). Ractopamine hydrochloride is approved for feeding the last 28 to 42 d of the finishing period at a rate of 10.0 to 30.0 mg RAC/kg (DM basis) to provide 70-430 mg RAC/steer daily with no withdrawal period (FDA, 2003). Feeding to longer DOF increases final BW, HCW and marbling score while decreasing ADG and G:F (Van Koevering et al., 1995; Winterholler et al., 2007). However, limited data exist evaluating the effects of feeding RAC to large yearling steers, and fed to larger finished weights common today with increased days on feed (DOF). Therefore, the objective of this experiment was to evaluate the effects of increasing DOF and feeding RAC on performance of large yearling steers.

MATERIALS AND METHODS

All facilities and procedures were approved by the University of Nebraksa Instituional Animal Care and Use Committee.

A feedlot study was conducted at the University of Nebraska-Lincoln Eastern Nebraska Research and Extension Center (ENREC) near Mead, NE. Crossbred yearling steers (n = 336; initial BW = 416 ± 34 kg) were utilized in a generalized randomized block design (3 BW blocks) with a $2 \times 3 + 1$ factorial treatment design. Factors included RAC dosage (0 or 300 mg/steer daily) and days on feed (118, 139, or 160) plus cattle fed 2 weeks longer (174 d) without RAC. Steers on the 118 d treatment were fed to a target endpoint of approximately 454 kg HCW with 1.27 cm of fat thickness. Steers on the 139 d treatment were fed to a target endpoint of 476 HCW and 160 d steers were fed to a target of 499 kg HCW. Lastly, steers on the 174 d treatment were not fed RAC to compare the impact of just feeding cattle longer. Steers were received as calves in the fall of 2014 at the ENREC near Mead, NE. Within 24 hours of arrival, steers were processed and vaccinated for prevention of infectious bovine rhinotracheitis (IBR) virus, bovine viral diarrhea (BVD) types 1 and 2, parainfluenza3 (PI3) virus and bovine respiratory syncytical virus (BRSV; Bovi-Shield Gold; Zoetis Animal Health, Parsippany, NJ), treated for internal and external parasites (Dectomax injectable; Zoetis Animal Health), prevention of *Haemophilus somnus* (Somubac; Zoetis Animal Health) and individually identified with a visual identification tag, metal tag and electronic ear button. Approximately 3 weeks later, steers were re-vaccinated for prevention of *Haemophilus somnus* (Somubac; Zoetis Animal Health), prevention of infectious bovine rhinotracheitis (IBR) virus, bovine

viral diarrhea (BVD) types 1 and 2, parainfluenza3 (PI3) virus and bovine respiratory

syncytical virus (BRSV; Bovi-Shield Gold; Zoetis Animal Health) and orally

drenched for internal parasites (Safe-Guard; Merck Animal Health, Summit, NJ).

Steers were managed on corn residue through the winter and spring seasons until

moved to brome pasture in late spring; steers grazed brome pasture the duration of the

summer.

In the fall of 2015 before initiation of the trial, steers were limit fed at 2% of

BW for 5 d a diet consisting of 50% Sweet Bran (Cargill Corn Milling, Blair, NE)

and 50% alfalfa hay (DM basis) to minimize variation in gastrointestinal fill (Watson

et al., 2013). Steers were weighed (Silencer Squeeze Chute; Moly Mfg.Inc., Lorraine,

KS: scale readability $\pm$ 0.45 kg) two consecutive days (day 0 and 1) to establish initial

BW (Stock et al., 1983). Steers received an oral drench for internal parasites (Safe-

Guard; Merck Animal Health) and were implanted with 16 mg of estradiol, 80 mg of

trenbolone acetate and 29 mg of tylosin tartrate (Component TE-IS with Tylan;

Elanco Animal Health). Given variable harvest dates, multiple terminal implanting

dates were established to standardize the terminal implant window to 90 d. All steers

were re-implanted with a terminal implant that contained 20 mg of estradiol, 200 mg

of trenbalone acetate and 29 mg of tylosin tartrate (Component TE-200 with Tylan;

Elanco Animal Health). Steers were blocked by day 0 BW, stratified by BW within

blocks (light, medium, heavy), and assigned randomly to 42 pens. Pens were assigned

randomly to one of 7 treatments with 6 pens per treatment (8 steers/pen). Light,

medium, and heavy blocks consisted of 2, 3, and 1 replications, respectively.

All steers were adapted to a common finishing diet over a 21-day period consisting of four adaptation diets. The amounts of Sweet Bran and supplement included in each adaptation diet were held constant at 40 and 5% (DM basis), respectively. The amount of high moisture corn (HMC) was gradually introduced in the diet while replacing grass hay and corn silage. The first adaptation diet consisted of 0% HMC, 25% grass hay, and 30% corn silage and was fed for 3 days. The second adaptation diet was fed for 4 days and consisted of 10% HMC, 15% grass hay, and 30% corn silage. The third adaptation step was fed for 7 days and consisted of 20% HMC, 10% grass hay, and 25% corn silage. The fourth and final adaptation diet was fed for 7 days and consisted of 30% HMC, 5% grass hay, and 20% corn silage. Ingredient and nutrient composition of the common finishing diet consisted of 40% HMC, 0% grass hay, 15% corn silage, 40% Sweet Bran, and 5% dry meal supplement (DM basis; Table 1). The supplement was formulated to provide 33 mg monensin/kg DM (Rumensin, Elanco Animal Health) and to provide 6.9 mg tylosin/kg DM (Tylan, Elanco Animal Health).

Steers were housed in open feedlot pens with 91 to 122 cm of linear bunk space and 63 to 90 m^2 of pen space per steer. Feed bunks were assessed daily at approximately 0600 for presence of feed. Feed amounts were increased or decreased daily to maintain an ad libitum bunk management system. Cattle were fed once daily between 0700 and 0900. Steers had ad libitum access to fresh clean water and their respective diet. Diets were mixed and delivered daily using a truck-mounted feed mixer and delivery unit (Roto-Mix model 420, Roto-Mix, Dodge City, KS). Weekly samples of ingredients were collected by university staff and composited by month

then sent to a commercial laboratory (Ward Laboratories, Inc., Kearney, NE) to

determine DM (Gales, 1990), CP (Padmore, 1990a; Padmore, 1990b; Gavlak et al.,

1996; LECO Corporation), NDF (Mertens, 1992; ANKOM Technology, 1996;

ANKOM Technology, 1998), calcium (Campbell and Plank, 1991; Kovar, 2003) and

phosphorus (Campbell and Plank, 1991; Wolf et al., 2003; Kovar, 2003) content of

individual ingredients and of the total mixed diet. When refusals were present, orts

were weighed, sampled, frozen and later analyzed for DM. Dry matter was

determined by placing samples in a 60°C forced-air oven for 48 h (AOAC Method

935.29; AOAC, 1999). Individual ingredient samples were taken weekly and

analyzed for DM content. Ractopamine hydrochloride and monensin feed samples

were sampled in the bunk when fed (n = 3 per treatment) and submitted for RAC and

monensin assay (Covance Labs, Greenfield, IN). Acceptable tolerances or limits are

set by the food and drug administration (FDA). The percent of claim is the ratio of the

actual result and the expected level expressed on a percent basis. The percent of claim

must be within the acceptable limits to pass any assays above or below fail. The

acceptable tolerance for monensin is 85 to 115% of claim and for RAC is 80 to 120%

of claim. Cattle and their environment were visually evaluated daily by trained UNL

personnel. These observations included the following: proper functionality of the

water tanks, structural integrity of the fences and feed bunks, and notation of any

abnormal behavior of the cattle (i.e. bulling, excessive walking, appetite, etc.). When

animals were determined to be sick, steers were removed from the pen and taken to

the processing facility for diagnosis and treatment.

Ractopamine hydrochloride was initiated when steers were 35 d from their projected endpoints. Steers were pen weighed and pencil shrunk 4% on the d of treatment initiation to determine the initial BW of the RAC feeding phase. Steers were removed from their pens (approximately 0700 hours) before feeding and pen weights were collected using a pen scale (Norac M2000; NORAC Inc., Bloomington, MN). Pen scale accuracy was verified prior to each use with certified weights. All residual feed remaining in the bunk was removed, weighed and sampled for DM analysis. Pen weights were collected and pencil shrunk 4% every 7 d following RAC initiation to evaluate steer growth performance over the RAC treatment phase. Ractopamine hydrochloride was delivered daily during the treatment phase via dry supplement in the total mixed ration at 300 mg of RAC/steer daily, with fine ground corn as the carrier. Two dry supplements were used during the treatment phase, one that contained no RAC and one that provided 300 mg of RAC.

On day of shipping, steers to be shipped were pulled out of pens, weighed to determine final live BW, then placed back in pens and fed 50% of the previous d feed called. In the afternoon, all steers to be shipped were pulled from pens and loaded onto trucks. All steers were harvested at a commercial abattoir (Greater Omaha, Omaha, NE) after 118, 139, 160, or 174 days on feed, depending on treatment. Hot carcass weight and liver scores were recorded on day of harvest. After a 48-h chill, LM area, USDA marbling score, and 12th rib fat thickness were recorded. Yield grade was calculated (USDA, 1997) from the following formula: 2.50 + (0.98425*fat thickness, cm) + (0.2*2.5 [KPH, %]) + (0.00837*HCW, kg) – (0.0496*LM area, cm^2). Final live BW was pencil shrunk 4% to calculate dressing percent and live

animal performance. A common dressing percentage of 63% was used to calculate

final BW, ADG, and G:F on a carcass-adjusted basis. Carcass-adjusted DMI refers to

the DMI of the cattle calculated including the last day of feed. This differs from live

DMI as cattle were pen weighed in the morning the day of shipping and then fed half

of the previous days feed call. The amount of feed consumed the day of shipping is

not accounted for in the live DMI but is included for carcass-adjusted DMI.

Statistical Analysis

Animal performance and carcass characteristics were analyzed as a $2 \times 3 + 1$

factorial using the MIXED procedure of SAS (Version 9.4; SAS Institute, Inc., Cary,

N.C.), with pen as the experimental unit. The steer that was removed and the two that

died during experiment were not included in the analysis. The model included RAC

dose, days on feed, and dose $\times$ days on feed interaction. Block was treated as a fixed

effect. Linear and quadratic contrasts were executed for DOF main effect.

Occurrences of liver abscesses were analyzed using the GLIMMIX procedure of

SAS. Pen liver abscess severity did not converge due to small occurrences across

treatments (Table 2). Frequency data (yield and quality grade distributions) were

analyzed using multinomial proportions with the GLIMMIX procedure of SAS. The

least square means and SE of the proportions for the frequency data were determined

using the ILINK option. To determine differences between means, the quality grade

data were summarized as prime and upper 2/3 choice and low choice and select using

binomial proportions with the GLIMMIX procedure of SAS. The yield grade data

were summarized as yield grade 1, 2, and 3 and yield grade 4 and 5 using binomial

proportions with the GLIMMIX procedure of SAS. Treatment differences are

discussed at $P \leq 0.05$ and tendencies discussed between $0.05 < P \leq 0.10$.

RESULTS AND DISCUSSION

During the study, 2 steers died before RAC initiation (1 due to a prolapse on the 118-d treatment not fed RAC; 1 due to pneumonia on 160-d treatment not fed RAC) and 1 steer was removed from the study during the RAC feeding phase due to a broken leg. Total mixed ration samples were collected weekly following initiation of RAC treatment to ensure monensin and RAC inclusion levels (Table 3). Pass or fail was determined by comparing the as-is result to the expected level and calculating a % of claim. Feed assay reports showed that the RAC treatment diet failed for all testing periods except for the 1/26/16 sampling period. The control diet did not contain RAC at any time point. A sample of the RAC and control supplements were analyzed to determine efficacy of the supplements; results showed the correct concentration was present in both supplements. Monensin concentration in the control diet passed every sampling period except for the 2/3/16 sampling period. Monensin concentration in the RAC treatment supplement passed every time except 1/19/16 and 2/23/16 sampling periods.

The interaction of dose $\times$ days on feed was not significant ($P \geq 0.35$) for steer growth performance; therefore, main effects will be discussed (Table 4). Live final BW was 13 kg heavier ($P = 0.01$) for steers fed 300 mg of RAC/steer daily as compared to steers fed 0. Conversely, Strydom et al. (2009) and Hales et al. (2016) reported no difference in live final BW when steers were fed 300 mg of RAC/steer daily as compared to steers not fed RAC. Steers fed 0 or 300 mg of RAC had similar live DMI ($P = 0.25$), while ADG increased ($P < 0.01$) 5.0% for steers fed 300 mg of

RAC/steer daily compared to steers fed none. There was a 3.9% improvement ($P <$

0.01) in live G:F when steers were fed 300 mg of RAC/steer daily as compared to 0

mg. Carcass-adjusted final BW was 10 kg greater ($P = 0.05$) for steers fed 300 mg of

RAC/steer daily compared to steers fed 0 mg of RAC/steer daily. Similarly, Quinn et

al. (2016) reported that steers fed 300 mg of RAC/steer daily had a 12.6 kg increase

in carcass-adjusted final BW as compared to steers fed no RAC. In the current study,

steers fed 300 mg of RAC/steer daily had greater ($P = 0.04$) carcass-adjusted ADG

(1.88 kg) compared to steers fed 0 mg (1.81 kg). Sudbeck et al. (2016) fed 300 mg of

RAC/steer daily and reported a 2.8% increase in ADG compared to steers fed 0 mg of

RAC/steer daily. Previous literature would agree with the findings of the current

study where feeding 300 mg of RAC/steer daily had no impact on DMI compared to

steers fed none (Hales et al., 2016; Sudbeck et al., 2016). The following studies only

reported growth performance over the time RAC was fed instead of reporting growth

performance over the entire feeding period. Steers fed 300 mg of RAC over a 30 and

33 d feeding period had a 19.2 and 24.0 % increase in live ADG compared to the

steers not fed RAC (Avendaño-Reyes et al., 2006; Strydom et al., 2009). Feeding 300

mg of RAC/steer daily resulted in an improvement ($P = 0.05$) in carcass-adjusted

G:F. Likewise, Bohrer et al. (2014) reported a 16.8% improvement in feed efficiency

with Quinn et al. (2016) and Arp et al. (2014) observing a 18.8 and 20.1%

improvement in G:F for steers fed 300 mg of RAC/steer daily compared to steers fed

none. Carcass-adjusted DMI was not different ($P = 0.24$) between RAC doses.

Furthermore, performance from the RAC feeding period showed no differences in

DMI between steers fed RAC and the control (Strydom et al., 2009; Boler et al.,

2012; Bohrer et al., 2014). Whereas, two studies observed a slight (1.7%) decrease in DMI over the time RAC was fed for steers fed 300 mg of RAC/steer daily as compared to steers fed no RAC (Avendaño-Reyes et al. 2006; Quinn et al., 2016).

To appropriately distinguish the differences between steers fed 160 d that received 300 mg of RAC and steers fed 174 d that received 0 mg of RAC, simple effects will be presented (Table 5). Numerically, steers fed 174 d that received 0 mg of RAC were 13.7 kg heavier ($P = 0.20$) in carcass-adjusted final BW compared to steers that were fed 160 d and received 300 mg of RAC. There were no differences ($P = 0.24$) in carcass-adjusted ADG between steers fed 174 d receiving 0 mg of RAC compared to 160 d steers fed 300 mg of RAC. Additionally, 160 d steers fed 300 mg of RAC tended to have an improvement ($P = 0.10$) in G:F compared to steers fed 174 d receiving 0 mg of RAC. These changes can be confounded with changes in weather observed during the study, as cattle were fed during nicer weather conditions when fed longer in this study.

There were no significant dose $\times$ days on feed interactions ($P \geq 0.56$) for carcass data; therefore, main effects will be discussed (Table 6). Hot carcass weight tended to be 6.9 kg greater ($P = 0.06$) for steers fed 300 mg of RAC as compared to 0 mg. Similarly, Quinn et al. (2016) fed steers 300 mg of RAC/steer daily and reported an 8 kg increase ($P < 0.05$) in HCW compared to steers fed none. In the current study, calculated yield grade (CYG) was improved ($P < 0.01$) for steers fed 300 mg of RAC (3.7) as compared to 0 mg (3.9). Arp et al. (2014) reported no significant difference in USDA YG between steers fed 0, 200, 300 or 400 mg of RAC/steer daily. Fat thickness tended ($P = 0.08$) to be 0.07 cm less for steers fed RAC compared to steers

not fed RAC. Likewise, previous literature reported no difference in fat thickness for steers fed 300 mg of RAC/steer daily as compared to the control (Boler et al., 2012; Arp et al., 2014; Bohrer et al., 2014; Quinn et al. 2016; Sudbeck et al., 2016; Hales et al., 2016). Dressing percentage and marbling score were not impacted ($P \geq 0.31$) by RAC treatment. Dressing percentage has been variable in the literature likely due to the variation in gut fill (Watson et al., 2013) when final live BW was recorded. Arp et al. (2014) and Bohrer et al. (2014) are in agreement with the current study showing that there is no difference ($P > 0.05$) in dressing percent between steers fed 0 or 300 mg of RAC/steer daily. Conversely, Boler et al. (2012) observed a 1.8% increase ($P = 0.02$) and Avendaño-Reyes et al. (2006) observed a 2.4% increase ($P = 0.02$) in dressing percent when steers were fed 300 mg of RAC/steer daily compared to none. According to Quinn et al. (2016) and Arp et al. (2014) steers fed 300 mg of RAC/steer daily had lower marbling scores compared to steers not fed RAC. Conversely, Sudbeck et al. (2016) reported no difference in marbling score between steers fed 0 or 300 mg of RAC/steer daily.

As days on feed increased, live final BW and carcass-adjusted final BW increased linearly ($P < 0.01$). Intake and live ADG decreased linearly ($P < 0.01$) as days on feed increased, which led to no change ($P = 0.30$) in G:F (on a live basis). Because of increased ($P < 0.01$) dressing percent, carcass-adjusted ADG was constant ($P = 0.19$) which led to a small linear improvement ($P = 0.03$) in carcass-adjusted G:F, due to the reduction in DMI. The linear improvement in G:F could have been influenced by the poor weather causing the 118 and 139 d cattle to perform worse than the 160 and 174 d cattle. Thus, ADG was impacted and feed efficiency was

improved for the longer day cattle who were fed longer and had time to recover. Hot

carcass weight, dressing percent and marbling score were increased ($P < 0.01$)

linearly as days on feed increased. Longissimus muscle area, 12th rib fat and

calculated yield grade increased ($P < 0.01$) quadratically as days on feed increased.

Multinomial quality grade and yield grade distributions are presented in Table 7.

Statistical differences in quality grade and yield grade distributions among treatments

were observed ($P < 0.01$). For ease of discussion, the binomial proportions for yield

grade and quality grade will be discussed. There were no significant ($P \geq 0.37$) dose $\times$

days on feed interactions for the binomial distribution (Table 8). There was a

tendency ($P = 0.07$) for steers fed 300 mg of RAC/steer daily to have less prime and

upper choice carcasses compared to steers fed 0 mg of RAC/steer daily. There were

differences ($P = 0.03$) in the distribution of steers that graded low choice and select

between steers fed 0 or 300 mg of RAC/steer daily. Steers fed 300 mg of RAC/steer

daily had a greater ($P = 0.03$) proportion of steers grade a YG of 3 or higher and a

lower ($P = 0.03$) proportion of steers grade a 4 or lower compared to steers fed 0 mg

of RAC. As days on feed increased the distribution of quality grade shifts ($P < 0.01$)

to more prime and upper 2/3 choice carcasses and less low choice and select.

Furthermore, as days on feed increases, the yield grade distribution shifts ($P < 0.01$)

more carcasses with a yield grade of 1, 2 and 3 and the number of 4 and 5 carcasses

increases.

Similarly, Winterholler et al. (2007) reported that as days on feed (DOF)

increased from 150 to 192 d live and carcass-adjusted final BW and HCW increased

with ADG and G:F decreasing. Additionally, authors reported that as DOF increased,

dressing percent, LM area and marbling score all increased (Winterholler et al., 2007). Likewise, Van Koevering et al. (1995) observed a quadratic increase in live and carcass-adjusted BW and live ADG while carcass-adjusted G:F had a cubic response with a tendency for an increase in carcass-adjusted ADG (cubic) and DMI (linear). In their study, as DOF increased from 105 to 147 d, steers linearly increased HCW, fat thickness and USDA YG (Van Koevering et al., 1995). Additionally, authors reported a cubic response for KPH and a quadratic increase in marbling score (Van Koevering et al., 1995). Conversely, Van Koevering et al. (1995) reported a quadratic increase in the proportion of cattle grading choice, a quadratic decrease in proportion of cattle grading standard and a linear decrease in proportion of cattle grading select as DOF increased. For serial slaughter dates alone, steers fed to 139 DOF deposited 0.63 kg of HCW for every kg of live weight deposited compared to 118 d weights, steers fed to 160 DOF deposited 1.03 kg of HCW for every kg of live weight deposited compared to 139 d weights and steers fed to 174 DOF deposited 0.56 kg of HCW for every kg of live weight deposited. Wilken et al. (2015) summarized that as cattle are fed longer, live BW and HCW increase quadratically, BW gain decreases, and carcass weight gain increases at an increasing rate.

Steers fed 174 d had a greater ($P < 0.01$) live ADG during the treatment phase (last 35 d) compared to the 118, 139 and 160 d fed steers. Steers fed 118 d had the highest ($P < 0.01$) DMI (13.2 kg) during the treatment phase, with 160 d steers having the lowest. Steers fed 174 d had the lowest ($P < 0.01$) G:F compared to steers fed 118, 139, and 160 d.

Cattle performance was negatively influenced by wet, cold, muddy conditions in December and January, which potentially lowered ADG and HCW compared to targeted finish weights/HCW for the study. The first group, the 118-d steers, were harvested in February with the final group, the 174-d steers, harvested in March. Cattle ADG was dramatically reduced during the time periods of d 90-97 and 111-118. Days 90-97 (1/6/16-1/13/16) of the trial, cattle on both treatments had a negative ADG response (control = -0.12 and RAC = -0.09) as well as a loss of 0.45 kg in live interim BW. Figure 1 illustrates the change in live BW over the RAC feeding period. During days 111 to 118 (1/27/16-2/3/16), cattle performance suffered a reduction in live interim BW for steers fed 118 d for both RAC and control treatments (0.91 and 4.5 kg, respectively). Furthermore, cattle fed 139 d only had a slight increase in live interim BW for both control and RAC treatments, 0.91 and 1.36 kg respectively. During these weeks, weather was adverse with low comprehensive climate index (CCI) numbers, which presumably led to little change in BW and ADG. The negative impact of weather on ADG impacted cattle performance for cattle fed 118 or 139 d more so than cattle fed longer, cattle fed longer than 139 d had time to presumably recover in performance.

In conclusion, feeding RAC improved live final BW, carcass-adjusted ADG, carcass-adjusted G:F, and calculated yield grade similar to other studies suggesting a similar response in big yearlings. Feeding steers longer increased fatness and weights. While feeding longer decreased ADG calculated on live BW, carcass-adjusted ADG remained constant as days on feed increased. However, increasing days on feed did not impact the cattle response to RAC inclusion in the diet.

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Table 1. Ingredient and Nutrient Composition of Finishing Diet

Ingredient	DM Inclusion, %	SEM
High-moisture corn	40.0	
Corn Silage	15.0	
Sweet Bran[1]	40.0	
Dry Supplement[2]		
Fine ground corn	2.7479	
Limestone	1.7150	
Salt	0.3000	
Tallow	0.1250	
Beef trace mineral[3]	0.0500	
Vitamin A-D-E[4]	0.0150	
Rumensin-90[5]	0.0165	
Tylan-40[6]	0.0087	
Analyzed Nutrient Composition		
Dry Matter, % DM[7]	54.7	± 0.7
Crude Protein, % DM[7]	14.7	± 0.3
NDF, % DM[7]	21.7	± 1.03
NE_m, Mcal/kg[8]	2.26	
NE_g, Mcal/kg[8]	1.36	
Calcium, % DM[7]	0.77	± 0.01
Phosphorus, % DM[7]	0.65	± 0.01

[1]Sweet Bran, Cargill Corn Milling, Blair, NE.

[2]Supplement formulated to be fed at 5% of diet DM.

[3]Premix contained 6% Zn, 5% Fe, 4% Mn, 2% Cu, 0.28% Mg, 0.2% I, and 0.05% Co.

[4]Premix contained 29,974 IU/g vitamin A, 5,995 IU/g vitamin D, 7.5 IU/g vitamin E.

[5]Premix contained 199 g/kg of monensin (Rumensin; Elanco Animal Health, Greenfield, IN).

[6]Premix contained 88 g/kg of tylosin (Tylan; Elanco Animal Health, Greenfield, IN).

[7]Determined by Ward Laboratories Inc. lab analyses

[8]Calculated utilizing performance from steers not fed RAC.

Table 2. Effects of Days on Feed and RAC Dose on Liver Abscess Scores of Finishing Steers

Duration:	118d		139 d		160 d		174 d		*P* - value		
Dosage:	0	300	0	300	0	300	0	SEM	Int.	Dose	DOF
A-, n	-	5	1	-	1	2	-		*		
A, n	-	-	-	-	-	1	1		*		
A+, n	-	-	-	-	-	-	1		*		
Total abscesses, % of total n	0	1.5%	0.3%	0	0.3%	0.9%	0.6%		*		

*Limited data for convergence.

[1]Liver Score: A = 1 or 2 small abscesses, up to 2 to 4 well-organized abscesses; A+ = 1 or more large, active abscesses.

Table 3. RAC and monensin assay results.

	Control Treatment		RAC treatment	
	Monensin	RAC	Monensin	RAC
1/5/15				
Expected level	17.6	0	17.6	12.1
As-Is Result	18.7	<2.3	17.2	6.6
% of Claim	106%	N/A	98%	55%
Status	Pass	N/A	Pass	Fail
1/12/16				
Expected level	17.6	0	17.6	12.1
As-Is Result	18.5	<2.3	15.7	7.6
Percent of Claim	105%	N/A	89%	63%
Status	Pass	N/A	Pass	Fail
1/19/16				
Expected level	17.7	0	17.7	12.2
As-Is Result	17.1	<2.3	14.6	6.3
% of Claim	97%	N/A	82%	52%
Status	Pass	N/A	Fail	Fail
1/26/16				
Expected level	17.7	0	17.7	12.2
As-Is Result	18.6	<2.3	18.0	10.7
% of Claim	105%	N/A	102%	88%
Status	Pass	N/A	Pass	Pass
2/3/16				
Expected level	17.7	0	17.7	12.2
As-Is Result	20.8	<2.3	16.1	6.9
% of Claim	118%	N/A	91%	57%
Status	Fail	N/A	Pass	Fail
2/9/16				
Expected level	17.5	0	17.5	12.1
As-Is Result	15	<2.3	16.8	<2.3
% of Claim	86%	N/A	96%	N/A
Status	Pass	N/A	Pass	Fail
2/16/16				
Expected level	17.5	0	17.5	12.1
As-Is Result	18.4	<2.3	16.1	8.3
% of Claim	105%	N/A	92%	69%
Status	Pass	N/A	Pass	Fail
2/23/16				
Expected level	17.5	0	17.5	12.1

As-Is Result	14.9	<2.3	1.2	<2.3
% of Claim	85%	N/A	7%	N/A
Status	Pass	N/A	Fail	Fail
3/1/16				
Expected level	17.5	0	17.5	12.1
As-Is Result	18.2	<2.3	17.0	8.1
% of Claim	104%	N/A	97%	67%
Status	Pass	N/A	Pass	Fail
3/8/16				
Expected level	17.5	0	17.5	12.1
As-Is Result	16.8	<2.3	16.1	8.4
% of Claim	96%	N/A	92%	69%
Status	Pass	N/A	Pass	Fail
3/15/16				
Expected level	17.5	0	17.5	12.1
As-Is Result	18.2	N/A	16.5	7.5
% of Claim	104%	N/A	94%	62%
Status	Pass	N/A	Pass	Fail
2/10/16		Control Supp.		RAC Supp.
Expected level		0		385
As-Is Result		<2.3		377
% of Claim		N/A		98%
Status		N/A		Pass

[1]Results for Type C medicated supplements (PAV 80%-110%) as analyzed and reported by Covance Laboratories, Greenfield, IN.

Table 4. Main Effects of RAC Dose and Days on Feed on Performance and Carcass Characteristics of Finishing Steers

	Dosage[1]		P - value	Days on Feed			P - value				P-Value
	0	300	Dose[2]	118	139	160	DOF[3]	Linear[4]	Quad.[5]	SEM[6]	Int.[7]
Live Performance											
Initial BW, kg	416	416	0.90	416	416	415	0.69	0.62	0.46	0.8	0.98
Final BW, kg [8]	679	692	0.01	644	671	701	< 0.01	< 0.01	0.38	6.6	0.51
DMI, kg/d	13.2	13.3	0.25	13.7	13.5	12.9	< 0.01	< 0.01	0.47	0.2	0.58
ADG, kg [9]	1.80	1.89	< 0.01	1.94	1.85	1.80	< 0.01	< 0.01	0.25	0.05	0.43
G:F	0.136	0.142	< 0.01	0.142	0.137	0.140	0.30	0.37	0.40	0.003	0.57
Carcass Adj. Performance											
Final BW, kg [10]	683	693	0.05	638	665	714	< 0.01	< 0.01	0.33	7.0	0.82
DMI, kg/d	13.2	13.3	0.24	13.7	13.4	12.8	< 0.01	< 0.01	0.28	0.2	0.57
ADG, kg [11]	1.81	1.88	0.04	1.88	1.79	1.86	0.19	0.82	0.25	0.05	0.76
G:F	0.138	0.142	0.05	0.138	0.133	0.146	< 0.01	0.03	0.31	0.003	0.92
Live Treatment Phase Performance [12]											
Initial BW, kg	638	641	0.51	604	632	653	< 0.01	< 0.01	0.66	6.0	0.40
DMI, kg/d	11.5	12.1	< 0.01	13.2	12.2	10.8	< 0.01	< 0.01	< 0.01	0.2	0.45
ADG, kg	1.20	1.48	< 0.01	1.15	1.14	1.41	< 0.01	< 0.01	0.01	0.09	0.78
G:F	0.106	0.126	< 0.01	0.087	0.094	0.130	< 0.01	< 0.01	0.02	0.007	0.43
Carcass Adj. Treatment Phase Performance											
DMI, kg/d	11.4	11.9	< 0.01	13.2	11.9	10.5	< 0.01	< 0.01	< 0.01	0.2	0.39
ADG, kg	1.27	1.48	< 0.01	0.96	0.93	1.74	< 0.01	< 0.01	0.01	0.10	0.60
G:F	0.116	0.130	0.04	0.073	0.078	0.164	< 0.01	< 0.01	0.02	0.009	0.35
Carcass Characteristics											
HCW, kg	430	437	0.06	402	419	450	< 0.01	< 0.01	0.33	4.4	0.82
Dressing, % [13]	63.3	63.1	0.34	62.4	62.4	64.2	< 0.01	< 0.01	0.89	0.3	0.56
Marbling [14]	563	552	0.31	498	548	577	< 0.01	< 0.01	0.66	14.8	0.76
LM area, cm	85.8	89.7	< 0.01	86.5	84.5	88.4	< 0.01	< 0.01	0.03	1.3	0.85
12th rib fat, cm	1.52	1.45	0.08	1.19	1.55	1.57	< 0.01	< 0.01	< 0.01	0.05	0.92
CYG [15]	3.9	3.7	< 0.01	3.3	3.9	4.0	< 0.01	< 0.01	< 0.01	0.09	0.99

[1]0 = 0 mg/steer daily of ractopamine hydrochloride (Optaflexx, Elanco Animal Health, Greenfield, IN); 300 = 300 mg/steer daily of ractopamine hydrochloride.

[2]Dose = P-value for main of effect of RAC dose.

[3]DOF = Days on feed; P-value for the main effect of DOF

[4]Linear = Linear contrasts for days on feed.
[5]Quad. = Quadratic contrasts for days on feed.
[6]Standard error of the treatment means.
[7]Int. = P-value for the RAC dose × days on feed interaction.
[8]Live final BW measured by weighing cattle on pen scale day of shipping and applying a 4% pencil shrink
[9]Calculated using live final BW.
[10]Calculated from HCW divided by a common dressing percent (63%).
[11]Calculated using carcass-adjusted final BW.
[12]Performance the last 35 days based on live performance when RAC was fed.
[13]Dressing = Dressing Percent; calculated from HCW divided by live BW, with a 4% pencil shrink applied.
[14]Marbling Score: 300 = Slight, 400 = Small, 500 = Modest, etc.
[15]Calculated YG= 2.50 + (0.98425*fat thickness, cm) + (0.2*2.5 [KPH, %]) + (0.00837*HCW, kg) – (0.0496*LM area, cm^2).

Table 5. Simple effect of yearling steers fed 0 or 300 mg/steer daily of RAC on performance for the last 35 days and fed overall for 118, 139, 160 or 174 d.

Days on Feed:	118 d		139 d		160 d		174 d			*P*-value		
Dosage[1]:	0	300	0	300	0	300	0	SEM[2]	Int.[3]	Dose[4]	Days on Feed	
Live Performance:											Linear[5]	Quad.[6]
Initial BW, kg	416	416	416	416	415	415	417	0.8	0.98	0.90	0.89	0.57
Final BW, kg [7]	638	650	661	681	698	704	720	6.6	0.51	0.01	<0.01	0.39
DMI, kg/d	13.6	13.7	13.3	13.6	12.9	12.9	13.0	0.2	0.56	0.25	<0.01	0.75
ADG, kg [8]	1.89	1.99	1.77	1.92	1.78	1.81	1.76	0.05	0.43	<0.01	<0.01	0.25
G:F	0.139	0.144	0.133	0.141	0.138	0.141	0.135	0.003	0.58	<0.01	0.31	0.28
Carcass-Adjusted Performance:												
Final BW, kg [9]	632	643	657	672	711	717	731	7.0	0.82	0.05	<0.01	0.22
ADG, kg [10]	1.83	1.93	1.74	1.84	1.85	1.88	1.81	0.05	0.76	0.04	0.78	0.15
G:F	0.135	0.141	0.131	0.136	0.144	0.147	0.140	0.003	0.92	0.05	0.02	0.16
Live Treatment Phase Performance [11]:												
Initial BW, kg	602	606	627	637	656	650	668	6.0	0.40	0.51	<0.01	0.59
DMI, kg/d	12.9	13.6	11.8	12.6	10.7	10.9	10.8	0.2	0.45	< 0.01	<0.01	0.05
ADG, kg	1.04	1.26	0.99	1.29	1.25	1.57	1.53	0.09	0.78	< 0.01	<0.01	<0.01
G:F	0.081	0.093	0.085	0.103	0.116	0.144	0.143	0.007	0.43	< 0.01	<0.01	<0.01

[1]0 = 0 mg/steer daily of ractopamine hydrochloride (Optaflexx, Elanco Animal Health, Greenfield, IN); 300 = 300 mg/steer daily of ractopamine hydrochloride.
[2]Standard error of the treatment means.
[3]Int. = *P*-value for the RAC dose × days on feed interaction.
[4]Dose = *P*-value for the main effect of RAC dose.
[5]Linear = Linear contrasts for days on feed.
[6]Quad. = Quadratic contrasts for days on feed.
[7]Live final BW measured by weighing cattle on pen scale day of shipping and applying a 4% pencil shrink.
[8]Calculated using live final BW.
[9]Calculated from HCW divided by a common dressing percent (63%).
[10]Calculated using carcass-adjusted final BW.
[11]Performance the last 35 days based on live performance when RAC was fed.

Table 6. Carcass characteristics of yearling steers fed 0 or 300 mg/steer daily of RAC for the last 35 days and fed overall for 118, 139, 160 or 174 d.

Days on Feed:	118 d		139 d		160 d		174 d			P - Value			
Dosage[1]:	0	300	0	300	0	300	0	SEM[2]	Int.[3]	Dose[4]	Days on Feed	
Carcass Characteristics:											Linear[5]	Quad.[6]
HCW, kg	398	406	414	423	448	452	460	4.4	0.82	0.06	<0.01	0.22
Dressing, %[7]	62.4	62.3	62.7	62.1	64.2	64.1	63.9	1.3	0.56	0.34	<0.01	0.48
Marbling[8]	505	492	558	537	578	577	612	14.8	0.76	0.31	<0.01	0.57
LM area, cm^2	84.5	89.0	83.2	86.5	87.1	90.3	88.4	1.3	0.85	<0.01	<0.01	0.01
12th rib fat, cm	1.22	1.17	1.60	1.52	1.63	1.55	1.63	0.05	0.92	0.08	<0.01	<0.01
Calculated Yield Grade[9]	3.4	3.2	4.0	3.8	4.1	3.8	4.1	0.09	0.99	<0.01	<0.01	<0.01

[1]0 = 0 mg/steer daily of ractopamine hydrochloride (Optaflexx, Elanco Animal Health, Greenfield, IN); 300 = 300 mg/steer daily of ractopamine hydrochloride.

[2]Standard error of the treatment means.

[3]Int. = P-value for the RAC dose × days on feed interaction.

[4]Dose = P-value for the main effect of RAC dose.

[5]Linear = Linear contrasts for days on feed.

[6]Quad. = Quadratic contrasts for days on feed.

[7]Dressing = Dressing Percent; calculated from HCW divided by live BW, with a 4% pencil shrink applied.

[8]Marbling Score: 300 = Slight, 400 = Small, 500 = Modest, etc.

[9]Calculated YG= 2.50 + (0.98425*fat thickness, cm) + (0.2*2.5 [KPH, %]) + (0.00837*HCW, kg) – (0.0496*LM area, cm^2).

Table 7. Effects of Days on Feed and RAC Dose on Grade Distributions of Finishing Steers

Duration:	118 d		139 d		160 d		174 d
Dosage[1]:	0[a]	300[a]	0[ab]	300[ac]	0[d]	300[bcd]	0[d]
Quality Grade, %[2]							
Prime	0	0	10.0	14.6	10.7	14.9	29.8
Upper 2/3 Choice	15.5	13.5	43.0	33.0	43.2	21.1	24.1
Low Choice	71.7	77.9	45.5	47.6	41.7	61.9	43.8
Select	12.8	8.6	1.5	4.8	4.5	2.1	2.4
Duration:	0[a]	300[ab]	0[cd]	300[be]	0[cf]	300[ce]	0[df]
Yield Grade, %[3]							
1	0	2.8	0	0	0	0	0
2	16.7	31.1	6.5	6.5	4.5	6.3	6.8
3	77.1	56.8	48.8	68.5	42.9	58.3	35.4
4	6.3	9.3	38.1	22.6	50.3	31.3	50.0
5	0	0	6.5	2.4	2.4	4.2	8.3

[abcdef]Means in a row with different superscripts differ ($P < 0.05$).

[1]0 = 0 mg/steer daily of ractopamine hydrochloride (Optaflexx, Elanco Animal Health, Greenfield, IN); 300 = 300 mg/steer daily of ractopamine hydrochloride.

[2]The numbers above represent the proportion of cattle across the quality grade distribution. The distribution of the QG was significant $P < 0.01$.

[3]The numbers above represent the proportion of cattle across the yield grade distribution. The distribution of the YG was significant $P < 0.01$.

Table 8. Carcass grade distributions for main effects of days on feed and Optaflexx dose for steers fed to 118, 139, 160, or 174 days on feed fed 0 or 300 mg/hd/d of RAC

| | Dose[1] | | | | DOF[3] | | | | | P-value | |
	0	300	SEM[2]	P-value	118	139	160	174	SEM[2]	DOF	Int.[4]
Quality Grade, %											
Prime & Upper Choice	33.7	28.9	4	0.07	14.3	22.7	45.2	51.5	8	<0.01	0.44
Low Choice & Select	66.2	71.1	5	0.03	85.8	77.4	54.8	48.4	8	<0.01	0.44
Yield Grade, %											
1, 2 & 3	63.0	76.4	4	0.03	92.6	65.7	56.4	49.2	8	<0.01	0.37
4 & 5	37.0	23.6	4	0.03	7.3	34.3	43.6	50.8	8	<0.01	0.37

[1]0 = 0 mg/steer daily of ractopamine hydrochloride (Optaflexx, Elanco Animal Health, Greenfield, IN); 300 = 300 mg/steer daily of ractopamine hydrochloride.

[2]Standard error of the treatment means.

[3]DOF = Days on feed

[4]Int. = P-value for the RAC dose × days on feed interaction.

Figure 1. Live BW Change over RAC Feeding Period
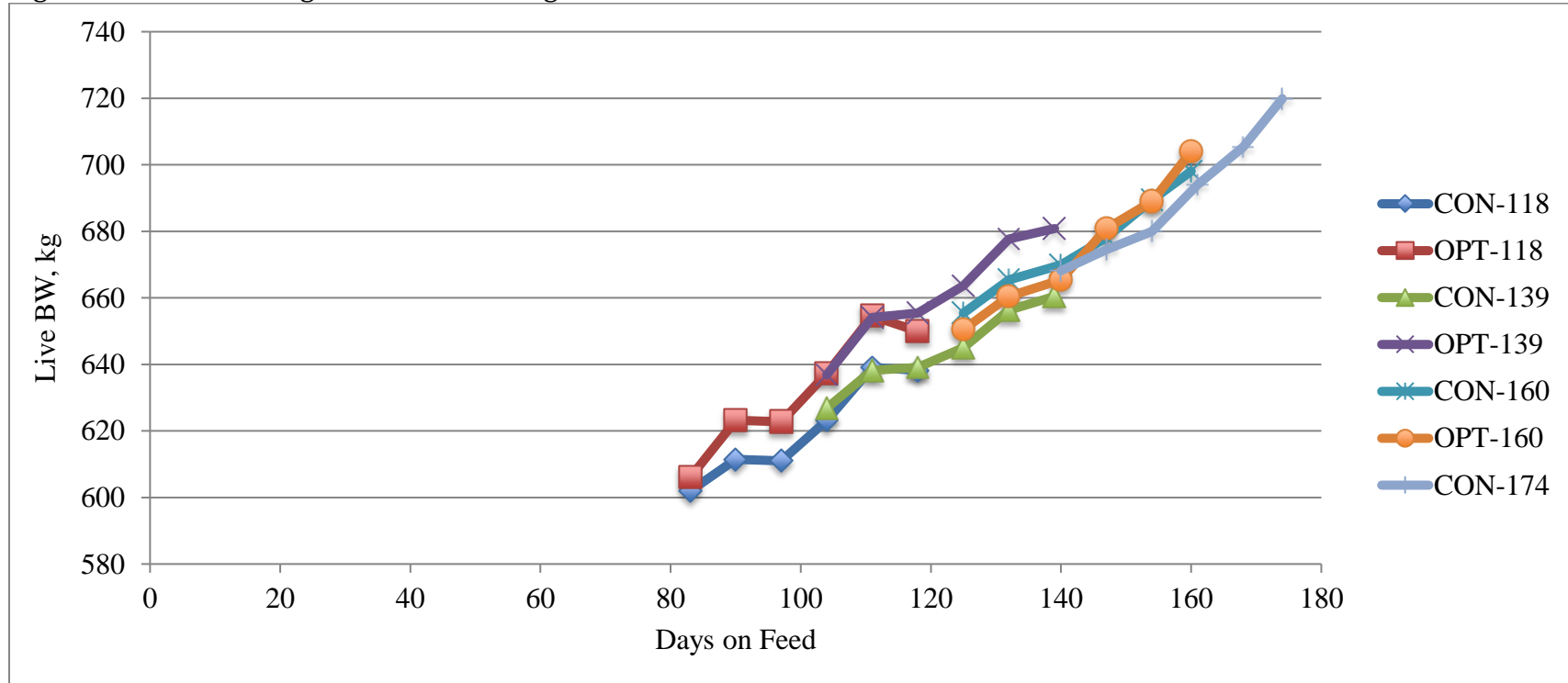
Description: The abbreviation CON-118 refers to steers harvested on d 118 receiving no RAC, OPT-118 refers to steers harvested on d 118 receiving RAC, CON-139 refers to steers harvested on d 139 receiving no RAC, OPT-139 refers to steers harvested on d 139 receiving RAC, CON-160 refers to steers harvested on d 160 receiving no RAC, OPT-160 refers to steers harvested on d 160 receiving RAC and CON-174 refers to steers harvested on d 174 receiving no RAC. The time points are weekly pen weights collected when cattle were initiated onto the RAC treatment phase 35 d before harvest and the subsequent weeks until harvest.

CHAPTER IV. STEER PERFORMANCE GRAZING CORN RESIDUE AND SUPPLEMENTED WITH MODIFIED DISTILLERS GRAINS PLUS SOLUBLES WITH OR WITHOUT UREA

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ABSTRACT

A 72-d growing study was conducted to evaluate the effects of supplementing growing calves grazing corn residue with modified distillers grains plus solubles (MDGS) at 1.4 or 2.3 kg/d with or without urea on growth performance. Crossbred steers (initial BW = 243; SD = 19 kg) were utilized in a randomized block designed experiment with a 2×2 factorial arrangement of treatments. Factors included level of MDGS supplementation and inclusion of urea in the supplement. Steers were individually supplemented daily via a Calan gate system. Beginning on November 2, steers grazed irrigated or non-irrigated corn residue depending on BW block (heavy block = irrigated field, light block = non-irrigated field). There were no significant MDGS $\times$ urea inclusion interactions observed. Urea inclusion level (0 and 0.05 kg/d) did not affect supplement DMI ($P = 0.59$), ADG ($P = 0.41$) or ending BW ($P = 0.96$). Steers fed 2.3 kg of MDGS had an increased ($P < 0.01$) ADG and a heavier ($P < 0.01$) ending BW compared to steers fed 1.4 kg MDGS daily. Corn plant components were collected before grazing to determine the in vitro organic matter digestibility (IVOMD), digestible organic matter (DOM) and CP of the residue. The husk component had the greatest IVOMD ($P < 0.01$), DOM ($P < 0.01$) and CP ($P < 0.01$) content; the leaf blade component was intermediate, and the leaf sheath component contained the least ($P < 0.01$). There were no differences ($P = 0.73$) in IVOMD or DOM among corn residue components sampled off the irrigated and non-irrigated fields.

Diet samples were collected at the beginning, middle and end of the trial to determine the nutritive value of the corn residue over the grazing period. There was a

significant ($P < 0.01$) field × time interaction for CP content of diet samples. Over time, CP of the diet samples decreased ($P = 0.04$) where samples collected from steers grazing irrigated corn residue in November was significantly ($P < 0.05$) greater in CP compared to the other samples collected. Digestibility of steer diet samples did not change ($P \geq 0.84$) between irrigated and non-irrigated corn residue over all three collection time points. As time progressed the digestibility characteristics (IVOMD and DOM) of the diet samples decreased suggesting that calves select for the more digestible corn residue components first (husk, leaf, sheath). In conclusion, supplemental urea is not necessary when supplementing at least 1.4 kg MDGS to steers grazing corn residue.

Keywords: beef cattle, distillers grains, forage

INTRODUCTION

Following the increase in corn price in 2006 many rangeland acres were converted to corn and soybean production (Wright and Wimberly, 2013). An increase in farmland acres has led to an abundance of corn residue, which can be utilized as an inexpensive feed resource for beef cattle. Corn residue is relatively low in protein and energy, especially for growing animals. Thus, it is necessary to provide a supplemental protein and energy source to meet the calves' growth requirements. Modified distillers grains plus solubles (MDGS) are high in energy (112.5% TDN; Ahern et al., 2016) and protein (29% CP), which also provides a good source of rumen undegradable protein (RUP). Previous work modeled the metabolizable protein (MP) balances of growing calves grazing corn residue and estimated that distillers grains plus solubles (DGS) supplementation results in a deficiency in rumen

degradable protein (RDP), but excess MP (Tibbits et al., 2016). The excess MP can

be recycled back to the rumen to meet a RDP deficiency, but it is unclear how

efficient recycling occurs. Increasing the amount of supplemental DGS increases the

excess MP balance such that a response to supplemental urea may be more likely

observed when less DGS is provided. Therefore, the objective of this experiment was

to determine the effects of supplementing MDGS with and without urea on the

performance of growing calves grazing corn residue.

MATERIALS AND METHODS

All animal care and management procedures were approved by the University

of Nebraska- Lincoln Institution of Animal Care and Use Committee (IACUC #902).

A corn residue grazing study was conducted to determine the effects of

feeding either 1.4 or 2.3 kg of MDGS with or without urea on growth performance.

One hundred and twenty crossbred steers (initial BW = 243; SD = 19 kg) were

utilized in a 72-d corn residue grazing experiment at the University of Nebraska –

Lincoln Eastern Nebraska Research and Extension Center (ENREC) near Mead, NE.

Treatments were arranged in a 2×2 factorial treatment design. Factors included

MDGS inclusion (1.4 or 2.3 kg/d) and urea inclusion (0 or 0.05 kg/d). Steers were

received in the feedlot and vaccinated for prevention of *Mannheimia haemolytica*,

infectious bovine rhinotracheitis (IBR), bovine viral diarrhea (BVD) type 1 and 2,

parainfluenza-3 (PI$_3$) and bovine respiratory syncytial virus (BRSV; Bovi-shield Gold

One Shot; Zoetis Animal Health, Parsippany, NJ) administered at 2 ml/steer, treated

for internal and external parasites (Dectomax injectable; Zoetis Animal Health)

administered at 5.5 ml/steer, and for prevention of *Haemophilus somnus* (Somubac;

Zoetis Animal Health) administered at 2 ml/steer. Steers received a limit fed diet and were trained to the Calan gate system (American Calan Inc. Northwood, NH) for 27 d before trial initiation. During processing on d 0, all steers were individually weighed, and revaccinated for prevention of *Mannheimia haemolytica*, infectious bovine rhinotracheitis (IBR), bovine viral diarrhea (BVD) type 1 and 2, parainfluenza-3 (PI$_3$) and bovine respiratory syncytial virus (BRSV; Bovi-shield Gold One Shot; Zoetis Animal Health) administered at 2 ml/steer and prevention of *CI. Perfringens* Types B, C and D (Ultrabac 7; Zoetis Animal Health) administered at 5 ml/steer. Steers also received an implant containing 36 mg zeranol (Ralgro; Merck Animal Health, Summit, NJ) on d 1.

Before initiation of trial, steers were limit-fed at 2% of BW a diet consisting of 50% Sweet Bran (Cargill Corn Milling, Blair, NE) and 50% alfalfa hay (DM basis) to minimize variation in gastrointestinal fill (Watson et al., 2013). Steers were weighed for 3 consecutive d to establish initial BW. Steers were blocked by d -1 and d 0 BW, stratified by BW within blocks (light and heavy), and assigned randomly to 1 of 4 treatments (n = 30). Block was assigned to field based off d -1 and d 0 weights (irrigated = heavy block, non-irrigated = light block) with 60 steers per field. Steers grazed the same field assigned at initiation for the duration of the trial. All steers were individually supplemented daily via a Calan gate system. Minerals and vitamins were added to supplements to meet nutrient requirements (Table 1). Monensin (Rumensin, Elanco Animal Health) was included in the supplement to provide 200 mg/steer daily. Urea replaced dried distillers grains plus solubles (DDGS) in the supplement. At the conclusion of the trial, steers were limit-fed the same diet consisting of 50% Sweet

Bran (Cargill Corn Milling) and 50% alfalfa hay (DM basis) for 5 d at 2% of BW and

3 d weights were collected. Forage intake was not estimated during this trial.

Stocking rate was calculated based on corn yield of the field at harvest and

previous research quantifying the amount of residue available for grazing based on

3.63 kg of leaf and husk residue per 25.4 kg of total corn plant biomass with a corn

yield of 13,860 kg per hectare (Wilson et al., 2004). Estimated forage availability was

determined using formulas consistent with UNL grazing recommendations (7.26 kg

of total husk and leaf per bushel of corn, of which 50% is assumed to be ungrazable

due to trampling, weathering, and other factors). The amount of residue calculated per

hectare was multiplied by the number of hectares harvested to get an estimate of the

total amount of available forage for each field. Total available forage was then

divided by estimated forage DMI (4.5 kg/steer daily) and multiplied by 60 steers per

field to calculate d of available grazing (Jones et al., 2015). The BCNRM (2016)

model was used to determine RDP and MP balances and assumed the following for

corn residue nutrient profile: TDN, CP, RDP (% of CP), RUP (% of CP), RUP

digestibility were 54%, 4.25%, 75%, 25%, and 6%, respectively (Table 2). Models

assumed the following for MDGS nutrient profile: TDN, CP, RDP (% of CP), RUP

(% of CP), RUP digestibility were 85%, 38%, 37%, 63%, and 96%, respectively

(Table 2). The TDN value used in the model is lower than the value of MDGS

previously stated. The protein content of MDGS is predominantly RUP

(approximately 63% of CP), which in excess can be converted to urea in the liver and

reenter the blood supply to be reused or excreted in the urine (Huntington and

Archibeque, 1999). When sufficient fermentable energy is present, urea can enter the

rumen as saliva or be absorbed through the rumen wall, converted to ammonia and be utilized to synthesize MCP (Reynolds and Kristensen, 2008). Thus, in our model we utilized the lower TDN value due to the fat content of MDGS. The greater assumption (112.5% TDN) is taking into account the energy value of MDGS on an equal ADG compared to corn. All models assumed a microbial efficiency of 10%. Models for steers receiving 1.4 kg of MDGS assumed a corn residue DMI of 4.5 kg, RDP requirement of 357 g/d and MP requirement of 389 g/d. Models for steers receiving 2.3 kg of MDGS assumed a corn residue DMI of 3.9 kg, RDP requirement of 392 g/d, and MP requirement of 451 g/d. The model estimated that steers fed 1.4 kg/d of MDGS and 4.5 kg/d of corn residue would have a RDP balance of -46 g/d and a MP balance of 140 g/d. Furthermore, the model estimated that for steers fed 2.3 kg/d of MDGS and 3.9 kg/d of corn residue would have a RDP balance of 50 g/d and a MP balance of 346 g/d.

To determine changes in forage quality throughout the grazing period, corn residue diet samples were collected at the beginning, middle, and the end of the study utilizing 6 ruminally fistulated steers. Fistulated steers grazed the irrigated corn field throughout the duration of the study and were supplemented 2.3 kg of MDGS with no urea in a separate pen daily. Prior to each rumen sample collection, rumen contents were removed from each steer with three steers grazing the irrigated field and 3 steers grazing the non-irrigated field. After approximately 30 minutes of grazing, consumed feed was collected from each steer's rumen and placed in a cooler for analysis. Residue diet samples collected were used to determine CP, in vitro organic matter digestibility (IVOMD) and digestible organic matter (DOM). Diet samples were

ground through a 1-mm screen of a Willey mill (Thomas Scientific, Swedesboro, NJ) in order to analyze for CP using a combustion-type N analyzer (Thermo Scientific Flash Smart Nitrogen Analyzer, Waltham, MA). In vitro organic matter digestibility was determined by conducting two runs with 3 tubes per sample using the Tilley and Terry method (1963) with the addition of 1 g/L of urea to the McDougall buffer (Weiss, 1994). Rumen fluid was collected from 2 ruminally cannulated steers. Four forage standards of differing nutritive values of known in vivo OM digestibilities were utilized to adjust the IVOMD values to known in vivo values (Geisert, 2007). Digestible organic matter was determined following DM determination on the IVOMD samples. Samples were weighed, ashed in a cool muffle furnace at $600°$ C for 6 hours and weighed again. The ash sample weight divided by the dry sample weight and subtracting that number from 100 computes the organic matter content of the sample. Digestible organic matter content was determined by multiplying the organic matter content of the original sample by the IVOMD content (%). Supplement refusals were collected and weighed each week. Samples were analyzed for DM by drying at $60°$ C for 48 hours in a forced air oven and weighed using a digital scale.

Before grain harvest, corn plant samples were collected. Ten consecutive whole corn plant samples harvested above the anchor root were collected from each field (irrigated and non-irrigated) with four replications taken per field. Plant samples were separated into individual plant components (leaf, sheath, husk). Plant components were composited within replication and analyzed for IVOMD, DOM and CP (Gardine et al., 2016).

Statistical Analysis

Growth performance data (BW, supplement DMI, ADG) were analyzed using the MIXED procedure of SAS (Version 9.4; SAS Institute, Inc., Cary, N.C.) with individual animal as the experimental unit. All lab data (corn plant components and corn residue diet samples) were analyzed using the MIXED procedure of SAS with run as the experimental unit. Corn plant data included field (irrigated and non-irrigated) and plant component (husk, leaf blade, and leaf sheath) as fixed effects. Data from corn residue diet samples included field (irrigated and non-irrigated) and time (beginning, middle, and end of grazing season) as fixed effects. Differences are discussed at $P \leq 0.05$ and tendencies discussed between $P > 0.05$ and $P \leq 0.10$.

RESULTS AND DISCUSSION

No significant MDGS × urea inclusion interactions ($P \geq 0.62$) were observed for growth performance, so main effects are presented. Ending BW was 17 kg heavier ($P < 0.01$; Table 3) for steers fed 2.3 kg of MDGS compared to steers fed 1.4 kg as steers receiving 2.3 kg of MDGS had greater ($P < 0.01$) ADG. Ending BW was not different ($P = 0.96$; Table 4) between urea inclusion levels, due to no difference ($P = 0.41$) in ADG. There was no difference ($P = 0.59$) in supplement intake between steers fed urea at 0 or 0.05 kg/d. Stalker et al. (2007) evaluated the effects of feeding heifers a forage diet consisting of 58% ground corn cobs, 12% sorghum silage and 30% dried distillers grains where urea replaced dry distillers grains (DDG) at 0, 0.4, 0.8, 1.2, or 1.6% of the diet DM. Heifer final BW, ADG and feed efficiency were not different among inclusion levels of urea (0, 0.4, 0.8, 1.2 or 1.6%) in the diet (Stalker et al., 2007). Results suggest that the RDP deficiency was met by endogenously

produced urea recycled back to the rumen. The BCNRM (2016) model hypothesized that RDP would be deficient for growing steers grazing corn residue fed 1.4 kg of MDGS. When modeled, steers fed 2.3 kg of MDGS had a positive RDP balance of 50 g/d and steers supplemented 1.4 kg of MDGS had a negative RDP balance of -46 g/d. Therefore, we hypothesized urea would elict an ADG response for steers fed 1.4 kg MDGS, but not 2.3 kg. Urea inclusion did not affect supplemental intake, gain or ending BW, suggesting that the RDP requirements were met in all treatments.

Microbial crude protein (MCP) synthesized in the rumen is an important component of total MP produced. Burroughs et al. (1974) estimated that microbial efficiency averaged 13.05% of TDN in all diets. The 1996 NRC calculated MCP by estimating that 13.0% of the TDN was converted to MCP in diets containing over 40% forage. In diets containing less than 40% forage, MCP was adjusted 2.2% lower for every 1% under 20% effective NDF. Lardy et al. (2004) determined that for a low-quality forage diet, a microbial efficiency of 10% of TDN intake is appropriate. Greater microbial efficiency indicates the rumen microbes are more efficient at converting fermentable energy and RDP into MCP; thus, an incorrect assumption when determining MCP can lead to incorrect estimates of the RUP or RDP requirements of the animal (NRC, 1996). Galyean and Tedeschi (2014) using metabolism studies with fistulated animals to measure MCP production summarized that the 1996 NRC overpredicted MCP yield by assuming a 13.0% microbial efficiency.

Steers fed 2.3 kg of MDGS had a 5.3% improvement in ending BW ($P <$ 0.01), and a 21.3% improvement in ADG ($P < 0.01$). These results agree with

previous research in which steers grazing corn residue were fed either dried distillers grains (DDGS) or MDGS at 0.3, 0.7, or 1.1% of BW (0.64 to 2.4 kg/steer daily on a DM basis; Jones et al., 2014). Authors reported ADG increased quadratically ($P = 0.01$) gaining 0.70, 0.92, and 0.96 kg/d for steers fed 0.3, 0.7, and 1.1% of BW, respectively, with no difference between DDGS and MDGS (Jones et al., 2014).

No significant differences ($P = 0.73$; Table 5) were observed for corn residue IVOMD or DOM between the non-irrigated and irrigated field collected prior to grain harvest. Crude protein was similar ($P = 0.35$) for plant components from the irrigated field (4.99%) compared to the non-irrigated field (4.23%). The IVOMD ($P < 0.01$) and DOM ($P < 0.01$) were greatest for the husk, intermediate for leaf blade, and lowest for leaf sheath. The CP content ($P < 0.01$) was greatest for the leaf blade, intermediate for the leaf sheath and least for the husk. This agrees with previous research by McGee et al. (2012) where the most digestible component was the husk followed by the leaf, shank, leaf sheath, top 1/3 of stalk, cob and lastly bottom 2/3 of stalk.

There was a significant time × field interaction ($P < 0.01$; Table 6) for CP content, therefore simple effects will be discussed. Diet samples were collected at the beginning, middle and end of the grazing period. Diet samples collected at the beginning (11/3/16) of the grazing period from steers grazing the non-irrigated corn residue were greater ($P < 0.05$) in CP compared to samples collected from steers grazing the irrigated residue on 11/3/16. Furthermore, CP content of diet samples collected from steers grazing the irrigated corn residue on 11/3/16 were not different from samples from the irrigated or non-irrigated corn residue on 12/12/16 or 1/20/17.

There was a significant difference ($P < 0.05$) in CP between irrigated and non-irrigated residue diet samples collected on 12/12/16 with no difference ($P > 0.05$) between irrigated and non-irrigated residue diet samples for the last (1/20/17) collection period. Figure 1 illustrates that the IVOMD of the corn residue decreased ($P < 0.01$) from 53.4% at the beginning of the grazing period to 46.5% at the end. Similarly, DOM decreased ($P < 0.01$) over time suggesting that cattle were selectively grazing the more digestible plant components early in the grazing period with no difference between irrigated and non-irrigated corn residue diet samples. Likewise, Gardine et al. (2016) reported that IVOMD and DOM of diet samples collected at the beginning and end of both a fall and spring corn residue grazing period decreased over time. Additionally, IVOMD and DOM were greatest for the husk component followed by the leaf blade and lastly the leaf sheath component (Gardine et al., 2016).

Overall, these findings suggest that additional urea is not needed when steers grazing corn residue are supplemented with 1.4 or 2.3 kg/d of MDGS. Supplementing 2.3 kg of MDGS increased ADG 21.0% compared to 1.4 kg.

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Table 1. Composition (% of supplement DM) of supplements fed to steers grazing corn residue

Supplement[2]	1.4 kg MDGS[1] no Urea	2.3 kg MDGS[1] no Urea	1.4 kg MDGS[1] with Urea	2.3 kg MDGS[1] with Urea
Dried Distillers Grains[3]	2.921	2.274	2.017	1.490
Limestone	1.572	1.572	1.572	1.572
Tallow	0.125	0.108	0.125	0.108
Urea	0	0	0.905	0.784
Salt	0.3	0.3	0.3	0.3
Beef Trace Minerals[4]	0.05	0.05	0.05	0.05
Vitamin A-D-E[5]	0.015	0.015	0.015	0.015
Monensin[6]	0.015	0.015	0.017	0.015

[1]MDGS = Modified distillers grains plus solubles; Green Plains Inc., Shenandoah, NE
[2]Supplement fed at 5% diet DM
[3]Poet Biorefining, Corning, IA
[4]Premix contained 10% Mg, 6% Zn, 4.5% Mn, 0.5% Cu, 0.3% I, and 0.05% Co
[5]Premix contained 1,500 IU of vitamin A, 3,000 IU of vitamin D, and 3.7 IU of vitamin E per g
[6]Formulated to supply Rumensin-90® (Elanco Animal Health) at 29.4 mg/kg

Table 2. Nutrient profile of modified distillers grains plus solubles and corn residue used in model assumptions

	MDGS[1]	Corn Residue
TDN[2], %	85	54
CP, %	38	4.25
RDP[3], % of CP	37	75
RUP[4], % of CP	63	25
RUP Digestibility, %	96	6

[1]MDGS = Modified distillers grains plus solubles.
[2]TDN = Total digestible nutrients.
[3]RDP = Rumen degradable protein as a % of CP.
[4]RUP = Rumen undegradable protein as a % of CP.

Table 3. Main effect of modified distillers grains plus solubles inclusion on performance of steer calves grazing corn residue with or without urea

	MDGS, kg[1]		SEM[2]	P - Value MDGS
	1.4	2.3		
Initial BW, kg	242	243	1.7	0.84
Ending BW, kg	302	319	1.9	<0.01
ADG, kg	0.83	1.05	0.01	<0.01
Suppl. DMI, kg/d	1.7	2.5	0.005	<0.01

[1]MDGS = Modified distillers grains plus solubles; No MDGS × Urea interaction ($P \geq$ 0.62).

[2]Standard error of the treatment means.

Table 4. Main effect of urea inclusion on performance of steer calves grazing corn residue supplemented with MDGS

	Urea, kg[1]		SEM[2]	P - Value Urea
	0	0.05		
Initial BW, kg	242	244	1.7	0.66
Ending BW, kg	311	310	1.9	0.96
ADG, kg	0.95	0.93	0.01	0.41
Suppl. DMI, kg/d	2.10	2.09	0.005	0.59

[1]No MDGS $\times$ Urea interaction ($P \geq 0.62$).
[2]Standard error of the treatment means.

Table 5. Composition of corn plant components by field and type collected prior to grain harvest

Field:	Irrigated			Non-Irrigated				P - value		
Type:	Husk	Sheath	Leaf	Husk	Sheath	Leaf	SEM[1]	Int.[2]	Field[3]	Type[4]
IVOMD[5], %	56.6[a]	40.6[c]	45.6[b]	54.6[a]	39.1[c]	45.9[b]	1.2	0.64	0.73	<0.01
DOM[6], %	54.8[a]	37.5[c]	41.0[b]	52.9[a]	35.9[c]	41.2[b]	1.1	0.58	0.73	<0.01
CP, %	2.80[d]	4.61[c]	7.57[a]	2.81[d]	3.73[cd]	6.15[b]	0.56	0.24	0.35	<0.01

[abcd]Means in a row with different superscripts differ ($P < 0.05$).

[1]Standard error of the treatment means.

[2]Int. = P-value for the RAC dose × days on feed interaction.

[3]Field = P-value for the main effect of field.

[4]Type = P-value for the main effect of type.

[5]IVOMD = In vitro organic matter digestibility.

[6]Digestible organic matter (as a % of DM); calculated as OM content (%) × IVOMD (%).

Table 6. Digestibility characteristics and crude protein of corn residue diet samples by time and field

| Day: | 11/3/16 | | 12/12/16 | | 1/20/17 | | SEM[2] | P-Value | | Day | |
Field:	Irrigated	Non-I[1]	Irrigated	Non-I[1]	Irrigated	Non-I[1]		Int.[3]	Field[4]	Linear[5]	Quad.[6]
IVOMD[7], %	54.6[ab]	52.2[ab]	57.2[a]	55.9[a]	43.8[c]	49.2[bc]	1.9	0.15	0.84	<0.01	<0.01
DOM[8], %	48.1[ab]	43.4[b]	52.1[a]	51.4[a]	36.9[c]	42.8[bc]	2.1	0.07	0.94	0.01	<0.01
CP, %	6.22[bc]	8.90[a]	7.82[ab]	3.85[c]	5.73[bc]	5.06[c]	0.80	<0.01	0.33	0.02	0.36

[abcd]Means in a row with different superscripts differ ($P < 0.05$).

[1]Non-I = Non-Irrigated.

[2]Standard error of the treatment means.

[3]Int. = P-value for the RAC dose × days on feed interaction.

[4]Field = P-value for the main effect of field.

[5]Linear = Linear contrasts for days on feed.

[6]Quad. = Quadratic contrasts for days on feed.

[7]IVOMD = In vitro organic matter digestibility.

[8]DOM = Digestible organic matter (as a % of DM); calculated as OM content (%) × IVOMD (%).

Figure 1. In vitro organic matter digestibility (IVOMD) of corn residue diet samples over time, from 11/3/16 to 1/20/17.

$y = -0.00004x^2 (\pm 0.00001) + 0.0027x (\pm 0.0011) + 0.5256 (\pm 0.0189)$

$P < 0.01$