

EVALUATION OF AMMONIATED WHEAT STRAW IN RECEIVING AND GROWING  
DIETS

by

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## Abstract

Drought conditions in the past have created a shortage of prairie hay and other grass hays that are used as roughage sources for receiving and growing beef diets. Historically, wheat straw and other cereal crop residue has been discounted as a feedstuff due to its low nutrient content. Chemical methods, including ammonia application, can improve the feeding value of cereal crop residue while constraining costs. While there are studies that show the efficacy of utilizing ammoniated wheat straw in beef cow and maintenance diets, limited data are available characterizing the feeding value of ammoniated wheat straw in receiving and growing diets. The objective of these two studies were to evaluate cattle growth and diet digestibility for receiving and growing diets containing either wheat straw (STRW), anhydrous ammonia treated wheat straw (AMMN), or a prairie hay and alfalfa blend (CONT) at 30% inclusion. Exp. 1 utilized 288 crossbred steers (271 kg) randomized to 8 pens per treatment and fed their respective test diets for 56 d and a common diet for 14 d to equalize gastrointestinal tract fill. No effect of straw ammoniation was observed on final bodyweight (BW), average daily gain (ADG), dry matter intake (DMI), or gain to feed (G:F) ( $P \geq 0.31$ ). The 56-d BW, ADG, and G:F for CONT were significantly different from both STRW and AMMN ( $P < 0.001$ ). Exp. 2 utilized 6 ruminally fistulated Holstein heifers (288 kg) in a replicated  $3 \times 3$  Latin square design. There were no observed differences between AMMN and STRW in dry matter (DM), organic matter (OM), or ADF intake ( $P \geq 0.57$ ) although CONT differed significantly from both straw treatments in DM, OM, and ADF intake ( $P \leq 0.05$ ). Digestibility of DM, OM, and ADF were not different between AMMN and STRW ( $P \geq 0.43$ ), whereas CONT and STRW were different ( $P \leq 0.05$ ). Anhydrous ammonia treatment of wheat straw had no effect on ruminal VFA concentration ( $P \geq 0.32$ ). Ruminal pH was not affected by anhydrous ammonia application ( $P = 0.32$ ), but STRW and CONT were different ( $P \leq 0.05$ ). Fluid passage rate was not different among the three treatments ( $P = 0.33$ ). Wheat straw is a suitable replacement for ammoniated wheat straw at 30% inclusion in receiving and growing diets that contain 40% of dietary DM as wet corn gluten feed. Further research is necessary to determine the effect of varying levels of wheat straw and ammoniated wheat straw in conjunction with wet corn gluten feed and other by-product feeds in receiving and growing diets in order to capitalize on performance and efficiency gains while constraining costs.

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# **Chapter 1 - Review of Literature**

## **Introduction**

The initial receipt of cattle into a backgrounding or growing operation is critical to future cattle health, growth performance, and profit or loss potential. Stress at marketing is compounded by new feeds, noises, commingling, processing, and other novel factors on arrival at the feed yard (Galyean et al., 1999). Establishing a regimented feeding program that encourages increasing feed intake, and subsequent performance, while limiting morbidity and mortality is critical for receiving and growing facilities. High fiber diets with comparatively low concentrations of starch offer less morbidity and mortality when compared to higher starch and lower relative fiber diets. However, these low-starch diets do not offer equivalent performance and gains compared to high-starch diets. Mixed diets composed of high concentrations of fiber and comparatively low concentrations of starch have become the norm for starting young calves in a structured feeding regimen. Grains and grain byproducts, most notably from the ethanol industry, are combined with a multitude of forages to meet the nutrient requirements of young calves. Just as byproduct alternatives of grains are gaining notoriety and ever increasing in diets due to cost and feeding value, roughage sources are also being investigated to increase nutrient value and constrain cost. The persistence of drought conditions across the southern Great Plains has renewed interest among beef cattle producers in chemical methods of enhancing the feeding value of low-quality forages (Waggoner and Jaeger, 2014). As economics and availability continue to play an increasing role in diet development and ingredient inclusion, nutritional needs of cattle remain constant. Lightweight, younger calves have different nutrient requirements than older, conditioned feedlot cattle and thus their respective diets differ as well.

## **Receiving and Growing Diets**

Cattle initially arriving at a receiving feedlot undergo numerous stressors as aforementioned. The combined stress of these events manifests itself as morbidity, intake depression, meager growth performance, and increased mortality. The primary culprit of morbidity and mortality in feedlot cattle is the bovine respiratory disease complex (BRD) brought about by stress. Edwards (1996) accredits 75% of feedlot morbidities and 50% of

mortalities to BRD. Calf morbidity and mortality associated with BRD and the shipping fever complex are estimated to cost the U.S. beef industry approximately \$643 million annually (NASS, 2010). Lekeu (1996) recognizes four grades of BRD; subclinical disease, compensated clinical disease, non-compensated clinical disease, and irreversible clinical disease. Accurate identification of BRD, assignment to severity of grade, as well as timely and judicious use of proper handling and treatment procedures greatly reduce loss and improve animal performance and welfare. To further exacerbate the stressors of weaning, shipment, commingling, and restraint accrued from the source through the marketing facility and into the receiving facility, prolonged periods of feed and water deprivation can cause additional physiological changes. While studies (Loerch and Fluharty, 1999; Fluharty et al., 1994a) show that neither rumen microbe viability nor concentration is affected in calves subjected to extended feed and water deprivation associated with transport; rumen volume, DM intake, total weight of ruminal contents, and protozoal count decrease as deprivation time increases.

This commonly leads to dry matter intake during the initial 7 days after arrival of calves of 0.5% to 1.5% BW daily (Galyean and Hubbert, 1995). Although many of the metabolic changes can be corrected in 1 to 2 days, others require as long as 14 days for complete correction (Cole, 1996). A primary means to combat BRD is to ensure adequate intake of a diet that has sufficient nutrient content to prevent calves from mobilizing body stores, and bolstering immune response. Intake depression and feed intakes of 1.5% BW daily and below contribute greatly to nutrient deficiency and decreased immune response. There are a multitude of management and nutritional practices used to help in combating this. Pre-weaning creep feeding or pre-conditioning calves has increased DMI after arrival at a feedlot when compared to cohorts who were not pre-conditioned (Lusby, 1989). Additionally, those calves have the additive benefit of being familiar with a bunkline feeding system and the feed ingredients present in a mixed diet. New social hierarchy combined with unfamiliar environments, feeds, and feeding practices further reduce DMI (Grandin, 1997). Empirical evidence suggests that pre-weaning calves at 45 to 60 days before leaving the ranch of origin at a rate of 0.9 kg per day of BW gain is an economical program that offers benefit to both seller and buyer (Cole, 1996). An alternative method, creep feeding for 60 days at the ranch of origin to provide for 0.1 to 0.2 kg/d of BW gain can offer similar performance benefit to the buyer and economic benefit to the seller but at a decreased management and labor cost to the producer (Lusby, 1989; Brazle et al., 1991).

### ***Energy's Role in Morbidity and Performance***

Calves newly received at feed yards are often highly stressed from marketing, transport, new stimuli, and commingling. Animals that have been withheld from feed and water for extended periods of time are frequently utilizing body stores and are in a negative energy balance. Due to the high stress feed intake is frequently meager; additionally, for those calves that have not been previously exposed to bunkline feeding intake depression is compounded. A logical feeding program would be to feed nutrient and energy dense diets to aid in replenishing body stores and bolstering immune response to pathogens and vaccines (Berry et al., 2004a). However, high energy diets generally coincide with higher concentrations of readily fermentable carbohydrates which leads to greater health risks. Lofgreen et al. (1975) stated that increasing NE<sub>g</sub> in receiving diets correlated to increasing incidence of health treatment on diets ranging from 0.84 to 1.19 Mcal NE<sub>g</sub>/kg of DM. Conversely, Berry et al. (2004a,b) showed that calves fed more energy dense diets showed lower bacteria percentages and no difference in morbidity compared to lower energy diets. Later, Lofgreen et al. (1988) added that although incidence of morbidity increased with increasing energy in receiving diets, cost of gain tended to decrease. Rivera et al. (2005) acknowledged that morbidity increased with higher energy diets, but the economic analysis indicated that it was not sufficient to compensate for the decline in ADG when comparing 40% and 100% roughage diets.

Energy levels in beef cattle diets are readily altered by varying the concentrate to roughage ratio; however, there are limited studies that have assessed the change in energy intake level without confounding by ingredient variation (Duff and Galyeen, 2007). Traditional research suggests that cattle fed diets with lower energy, and subsequently higher roughage, compensate for lower energy concentration by increasing DM intake (Lofgreen, 1983). Lofgreen et al. (1975) evaluated the effects of feeding rations with 20, 55, 72, and 90% concentrates on highly stressed calves. They suggested that growth performance and DM intake increased in conjunction with energy level until 72% (Lofgreen et al., 1975). Berry et al. (2004a) evaluated the interactions between energy and starch concentrations for newly received calves and suggested that while energy concentration, 0.85 and 1.07 Mcal NEg/kg DM, had no effect on

performance there tended to be lower percentages of *P. multocida* and *H. somnus* in calves fed high energy diets.

An alternative methodology of starting calves, especially those calves unfamiliar with bunkline feeding, is to utilize hay only diets at receiving. Limited data and anecdotal evidence would suggest that newly received calves would prefer a diet similar in texture and composition to what they were previously accustomed (Loerch and Fluharty, 1999). In addition to aiding in “bunk breaking” calves, all hay rations offer a decreased risk of morbidity. However, gain and performance is reduced in comparison to a higher nutrient, mixed diet during the receiving period. Calves are unable to compensate for this decrease in performance at receiving during subsequent feeding periods (Lofgreen, 1988).

Diets during the receiving period need to meet a multitude of requirements for ever increasing intake and performance without large increases in morbidity and health treatments. While challenging to explain the totality of the relationship between energy concentration and roughage inclusion in receiving diets, it is reasonable to conclude that diets with greater than 55 and less than 90% concentrate offer a respectable balance of growth performance and health.

### ***Protein Concentration in Receiving Diets***

Crude protein (CP) concentration at initial receiving of calves is critical. Galyean et al. (1999) concluded that ADG and DMI increased linearly with CP concentration; equally, morbidity from BRD seemed to increase as well. Fluharty and Loerch (1995) conducted three experiments to determine the effects of CP concentration and source in receiving diets. Diets formulated to contain greater CP concentrations at initial receipt (23%), and gradually declining CP concentrations to 12.5% as DM intake increased, seemed to provide for the best growth performance in terms of ADG and feed efficiency. However, Galyean et al. (1999) stated that while calves on 12% CP compared to 16% CP diets at receiving had decreased performance, after the 42-day receiving trial on a common diet of 14% CP the lower protein calves compensated sufficiently that there were no overall growth performance effects.

Although there are limited studies that look directly at the effects of protein concentration on immune response, evidence from studies conducted using mice fed protein-free diets for 2 to 3 weeks showed a decrease in the immune system to effectively combat viral infections but did

not compromise the bacterial defenses (Jakab et al., 1981). Fluharty et al. (1994b) supported Galyean et al. (1999) that along with feed efficiency and ADG improvements with increasing CP, morbidity increased as well. Nissen et al. (1989) also showed data that supported increases in morbidity when CP increased from 5.2 to 9.5%. Galyean et al. (1999) proposed that this might be due to morbid calves fed higher CP having greater performance, healthy calves fed higher CP having greater performance, or inaccurate diagnosis of disease.

It is safe to accept that protein is a crucial part of the receiving diet, it is difficult to determine the amount required by newly arrived calves. Equations and metabolizable protein systems found in the NRC (2000) are useful in approximating the amount of protein required by beef calves. These formulas are centered on BW and feed intake, and thus are complicated by the typical state of receiving cattle. This is due to the capricious intake patterns of calves that have encountered numerous stressors and are of unknown background, as well as the large variance among contemporaries within the group. Galyean et al. (1999) noted that utilizing the NRC systems as well as adjusting by using feed intake data from previous cattle from the same or similar source could be useful in more accurately estimating protein concentration as opposed to NRC values alone.

### ***Diet Ingredients***

Diet formulation varies greatly based upon region, facilities, size of operation, availability, and cost. In 2012, operations that housed fewer than 1,000 head of cattle accounted for nearly 65% of the U.S. cattle inventory (NASS, 2012). For small operations, it is necessary to feed diets that are more easily handled, stored, and processed with minimal facilities and labor costs. Previous research has shown promising results on mixed diets at receiving composed of 50 to 80% concentrate. Data suggests that stressed calves are more likely to prefer dry hay based diets to silage-based diets (NRC, 1996). When calves are first introduced to diet-feeding, inclusion of locally sourced hays and roughage can improve feeding behaviors and intakes due to previous familiarity from grazing. The amount of roughage included in the diet (% DM basis) is also important; some evidence suggests that higher concentrate diets tend to increase morbidity (Rivera et al., 2005; Duff and Galyean, 2007), although Berry et al. (2004a) showed no difference in morbidity in higher energy diets. As feed costs are generally a product of the market price of

corn, a multitude of lower cost substitutes have been used when corn prices climb, with varying degrees of success. Inclusion of corn by-products such as distillers grains, brewers grains, and wet corn gluten feed can offer high protein and energy at a lower cost with fewer negative associative effects than corn. Wet corn gluten feed can replace a portion of roughage in the diet to increase CP and energy at receiving (Montgomery et al., 2000). Feed storage and handling become critical when operation size decreases. Because of the relatively small size of most receiving and growing facilities, diets are frequently formulated around feeds that are readily handled with minimal equipment as well as less feed spoilage over time. Finally, the driving factor behind all receiving and growing diets is to return the animal to a positive energy balance, bolster immune response, and provide for ever increasing growth performance both on farm and through the finishing phase.

### ***Wet Corn Gluten Feed***

The growth of the ethanol industry has simultaneously increased the cost of primary commodities for livestock feeds such as corn and soybeans while providing lower cost by-product and alternative feeds. Although corn is the gold standard of cattle feeding and corn prices tend to drive the livestock feeding market, corn by-products are achieving greater notoriety as lower cost alternatives that are valuable sources of protein and energy. Most energy is provided in the form of fat, fermentable fiber, and rumen-degradable protein.

Wet milling is one of the techniques utilized to produce ethanol. Whole kernel corn is steeped in a combination of water and sulfur dioxide to soften the outside of the grain, the water is drained and the germ is separated from the slurry, the oil is then removed from the germ for ethanol, the germ is ground to release starch and gluten, and finally the starch is centrifuged to release the gluten. Remaining starch is further diluted to produce corn starch product (Blasi et al., 2001). Of the remaining product, wet corn gluten feed (WCGF) is comprised of the bran remaining from the kernel and steep liquor in a 2:1 ratio (Blasi et al., 2001).

Wet corn gluten feed is a key component in many beef feeding and finishing facilities. High energy concentration provided by the availability of fermentable fiber in WCGF works to increase relative energy value compared to corn in high-roughage diets due to limited negative associative effects on fiber digestion (Blasi et al., 2001). Inclusion of WCGF in diets with excess

of 50% roughage (DM basis) improves performance and digestibility of the diet (Cordes et al., 1988). A major drawback to feeding WCGF, in particular in operations with smaller numbers of cattle on feed, is high rate of spoilage with viability as low as 7 days in hot weather (Blasi et al., 2001).

## Roughage in Receiving and Growing Diets

A key component of receiving cattle health and performance is acclimating calves to bunkline feeding and restoring a positive energy balance as quickly as possible. High energy, and subsequently high concentrate diets are frequently used to more rapidly replenish body stores depleted during shipping and transport. High concentrate diets, however, may impact cattle health and incidence of morbidity. Generally, diets that contain between 50% and 75% concentrate offer an ideal balance of growth performance and health. Due to the disparity within receiving cattle groups and frequently unknown feed and health history, initial introduction to the bunk is critical. Hay only diets can be utilized to condition large pens of cattle to bunkline feeding, but growth performance is typically paltry and is not compensated for during later feeding phases (Lofgreen, 1983, 1988). Roughage sources vary greatly by region, facility, and operation. A common practice in the Midwest is to utilize locally sourced grass hay; this provides a feedstuff that is familiar to cattle in the area when transitioning into a diet-feeding program. There are between 55 and 60 million acres of hay harvested annually within the United States, producing between 120 and 145 million tons of hay (NASS, 2014). Hay yield and quality is generally a product of weather conditions, and is heavily influenced by drought conditions in the Midwest and central plains regions. During droughty years when as much as 21% less hay is produced, demand climbs and cattle feeders look to lower cost alternatives. One such alternative is utilizing cereal grain residues, a byproduct of the agriculture industry that is generally left in the field to restore nutrients to the soil.

### *Cereal Grain Residue*

Traditionally, cereal grain residues, including stalk and chaff, have remained in the field after the harvesting of grain. This residue is used to help replenish soil nutrient loss, act as groundcover to aid in moisture accumulation and infiltration, and prevent erosion. While not efficacious to remove all residues depending upon region, specifically in arid dry land farming

regions where residue is critical in terms of future crop yield, the removal of 30 to 50% of residue is generally acceptable with nominal losses to soil nutrient or future crop yields. Cereal grain residue is typically overlooked as a feedstuff due to its low energy, CP, intake, and digestibility (Anderson, 1978). Combined with the added resources necessary to harvest, it does not generally appeal to the livestock feeding industry. However, in certain regions some cereal grain residues are routinely used as winter grazing as well as feed ingredients to a varied degree of success. Barley, oats, and wheat are the largest sectors of the cereal grain industry in the United States occupying some 2.5, 1, and 46 million acres respectively (NASS, 2014).

Calculating residue quantity is a product of yield of grain per acre as well as plant height. Schlegel et al. (2003) reported straw yields averaging as high as 3 kg of straw per 1 kg of grain yield, with yields of non-N-fertilized fields being 2.15 kg of straw per 1 kg of grain yield. This was significantly greater than the NRCS guideline of 1.75 kg of straw per 1 kg of grain, albeit straw yield varies greatly by geographic location, farming practices, and seasonal effects. Unsurprisingly, not all residue is harvestable, and yield is an outcome of machine loss and cut height; a conservative estimate is for the potential production of 50 to 100 million tons of small cereal grain straw annually. Wheat residue offers the greatest opportunity as it has the largest number of acres in production and is grown in large quantity throughout the majority of the country. Cereal grain residue is composed of several components; stems left standing as stubble and harvested as straw, as well as grain hulls, small quantities of grain, and broken straw that are generally classified as chaff (Anderson, 1978). Chaff is generally more labor intensive and costly to remove from the field to utilize in a mixed ration diet, but it does have a greater nutrient quality when compared to the straw portion. Cereal grain fields are not infrequently used as pasture for mature, dry, or pregnant beef cows in conjunction with supplementation in the form of alfalfa hay, protein blocks, liquid supplementation, and corn silage (Anderson, 1978).

Conversely, straw is readily cut and baled akin to hay allowing for easy transport and additional processing, but it lacks the nutrient content present in the chafe portion of cereal residue. Van Soest (1967) showed that cell walls of plant materials are composed primarily of hemicellulose, cellulose, and lignin. Data is limited on the nutrient availability of wheat straw to ruminants. Anderson (1978) found CP in wheat straw between 1.98 and 2.38%, Lofgreen and Christensen (1962) determined NE of barley straw to be 0.50 Mcal/kg by comparative slaughter, and Wilson

et al. (1976) reported NEm of wheat straw to be 0.84 Mcal/kg. NDF and ADF values were 81.1 and 54.4% respectively (Birkelo et al., 1986).

### ***Altering Wheat Straw to Improve Quality***

Wheat straw is the dominant small cereal grain residue available for feeding within the United States. Wheat straw is generally low in CP, phosphorous, limited in calcium, and high in fiber and lignin (Anderson, 1978). As such, it typically causes a decrease in voluntary intake, slowing of passage rate, and a decrease in digestibility. Limited success has been found in utilizing wheat straw as a significant portion of wintering cow diets and other maintenance diets (Anderson, 1978), but little research is available about its use in receiving or growing diets. Palatability as well as nutrient density has prevented straw from becoming favorable in finishing diets. There are multiple methods that have been used to increase the acceptability of wheat straw in total mixed ration diets. Physical processing such as; grinding wheat straw (Saenger et al., 1983; Zorrilla-Rios et al., 1991; Waggoner et al., 2014), grinding and pelleting (Levy et al., 1972), and reconstitution of wheat straw with or without grinding (Mandell et al., 1988; Waiss et al, 1972; Sundstøl et al., 1978; Streeter and Horn, 1984; Schneider and Flachowsky, 1990) have offered varying degrees of success at increasing voluntary intake in total mixed diets or when offered with supplementation. Grinding of straw tends in increase intake, decrease feed sorting in a bunk, and improves growth performance through increased DMI. Chemical methods of altering cereal straw quality can offer more significant improvements than physical alterations alone.

### ***Chemical Processing of Wheat Straw***

As previously noted, there is a large quantity of cereal crop residue produced annually, much of which is underutilized as a feed source for livestock animals due to complications with retrieval, handling, and low nutrient quality. Although physical processing techniques offer limited viability in improving intake and performance, chemical processing offers significantly greater improvement with varying degrees of labor and complications. Practical means of chemical treatment including urea, sodium hydroxide, and anhydrous ammonia applications have increased the values of cereal residue during times of high feed costs or drought. Urea supplementation of wheat straw tends to increase DMI, passage rate, BW gain, and ADG (Coombe and Tribe, 1962; Singh and Klopfenstein, 1998) to varied degrees. Treatment of rice

straw with 4% (wt/wt; DM basis) NaOH showed improvements in DMI, energy, and growth performance when included at 72% of the diet in studies on steers as well as feeder lambs although it does not offer supplemental N to rumen microbes (Garrett et al., 1979). A study by Klopfenstein et al. (1972) utilizing NaOH treatment (4% DM basis) of corn stalks in combination with a 50% increase in moisture from added water determined a 20% increase in OM digestibility compared to untreated stalks when fed in combination with ground alfalfa stems in lamb diets. However, this method of treatment by sodium hydroxide generally requires large quantities of water to wash out unreacted alkali in the feed. Ground wheat straw (100 g) treated with sodium hydroxide at a rate of 6% in 30 mL of water produced IVDMD values twice as large as untreated wheat straw when fed to lambs, residual alkali from treatment remained at approximately 30% unreacted 21-d after treatment without washing of the straw (Wilson and Pigden, 1964). Treatment of cereal crop residues by alkaline hydrogen peroxide offers significant reductions in lignin and hemicellulose portions of the plant cell wall, however there is generally a reduction in CP as well (Amjed et al., 1992). Similar results by Kerley et al. (1986) showed that treatment of wheat straw with alkaline solutions of hydrogen peroxide (0.26 g hydrogen peroxide per 1 g wheat straw) improved ADF and cellulose concentrations while simultaneously decreasing acid detergent lignin when compared to untreated straw (55.3, 55.8, and 4.9% and 43.7, 34.3, and 6.5% respectively) when fed at 70% of diet to whethers. Utilizing anhydrous ammonia, treatment of wheat straw provides for increased DMI, passage rate, BW gain, digestibility, CP, energy and increased N to the rumen microbe populations (Waggoner and Jaeger, 2014; Lalman et al., 2004; Saenger et al., 1983; Flachowsky et al., 1995; Horton and Steacy, 1979, Zorrilla-Rios et al., 1991) and varies depending upon the straw variety, harvest date, ammoniation level, and a multitude of other factors. Anhydrous ammonia is readily procured throughout the majority of the United States and offers significant advantages to small-scale cattle feeding operations due to availability, low overhead costs, as well as the opportunity to treat large quantities of roughage at a single time (Waggoner and Jaeger, 2014).

### ***Anhydrous Ammonia as Chemical Treatment***

The common method used for ammoniating large quantities of straw were described by Sundstøl et al. (1978) as well as updated by Kuhl and Blasi (1998). Large round straw bales are

stacked in a 3, 2 arrangement, covered with 6 mil plastic sheet, and sealed at the base using soil, rock, or the like. Anhydrous ammonia is applied through the use of pipe or hose placed at equal distances throughout the stack and connected by junction to the anhydrous tank. After the stack has been made, hose placed, and plastic sheeting sealed the anhydrous ammonia is applied slowly so that the liquid is allowed to fully volatilize to reduce loss. Stacks remain covered for a variable duration depending upon weather, with typical time periods ranging between 14 and 42 days (Waggoner and Jaeger, 2014; Birkelo et al., 1986) with duration increasing as temperature declines. The study conducted by Waggoner et al. (2014) compared two levels of anhydrous ammonia application, 1.5 and 3.0% (wt/wt; DM basis) in conjunction with wet distiller's grain for beef cows during the 2<sup>nd</sup> trimester to evaluate performance and BCS. There were significant performance gains when wheat straw ammoniated at levels of 1.5 and 3.0% were utilized as 64% of the diet, with greater relative performance gains from 0 to 1.5% than from 1.5 to 3.0%. Horton and Steacy (1979) noted that ammoniation with 3.5% (wt/wt; DM basis) increased digestibility of DM, CP, crude fiber, and GE by 5 to 8%, 0.5 to 7%, 5 to 13%, and 5 to 9% respectively. This was similar to the results found by Horton (1978) and Garrett et al. (1974). Mandell et al. (1988) looked at the effects of variable water content in wheat straw before ammoniation and effect on nutritive value for inclusion in beef cattle diets. While nominal difference was found in DM digestibility between 15, 20, 25, and 30% moisture straw, higher moisture (30%) straw tended to enhance the ammoniation process at lower temperatures. Schneider and Flachowsky (1990) evaluated the relationship of temperature, moisture content, duration and level of ammonia treatment on forage composition as well as rumen degradation. Wheat straw treated at temperatures ranging from 40 to 60° C offered improved DM degradability when compared to wheat straw treated at 20° C. This relates well to reports by Van Soest (1975). Additionally, when straw moisture content was 30% during treatment with anhydrous ammonia DM digestibility was improved compared to 12% moisture, and coincides well with Sundstøl et al. (1978). Moisture content between 15 and 20%, however, offered maximum effect in another study by Sundstøl (1983), and no differences in DM digestibility were evident between 20, 25, and 30% moisture straw in Mandell et al. (1988). Ammoniation has been shown to aid in mold and fungus inhibition in roughages that exceed 20% moisture (Lalman et al., 2004) as well.

While ammonia treatment of low quality forages tends to offer significant improvements in feeding value and digestibility compared to untreated forages, ammonia treatment of higher

nutrient forages is potentially deleterious. Imidazoles formed by the ammonia treatment of higher nutrient forages, such as immature grass hay and cereal grain hays treated with relatively large amounts of ammonia, act on the central nervous system of the animal, resulting in symptoms often referred to as “bovine bonkers”. Similar imidazoles, 4-methylimidazole specifically, has been found with ammonia treatment of molasses as well as higher nutrient forages and presented similar clinical signs. Early stages of ammoniated hay toxicity in cattle are typically characterized by excitation, running into fences, gates, and other objects as well as circling. Weiss et al. (1986) described later stages of symptoms in sheep fed ammonia treated orchardgrass hay (4%, DM basis) to include rigid stances with retraction of the head, convulsions, bruxism, frothing of the mouth, circling in a rigid gate, and potentially culminating in death. Consumption of ammonia treated forages by lactating cows causes similar negative effects in nursing calves. Calves consuming milk produced by cows fed ad libitum ammonia treated oat hay were susceptible to noise and touch sensitivities as well as excitability, running, and circling behavior (Weiss et al., 1986).

### ***Fiber Components of Cereal Grain Residue***

Fiber composition and percentage varies greatly dependent upon the cereal grain variety, residue type, and stage of plant growth. As cereal grains mature to seed-setting, the bulk of the plant's nutrients shift from roots, stem, and leaves to the grain (Anderson, 1978). As such, at the time of harvest of cereal grains the stem of the plant that is to be utilized as roughage in livestock diets has low CP, high fiber, and poor DM digestibility. Plant cell wall is composed primarily of cellulose, hemicellulose, and lignin with proportion of lignin increasing as the plant matures (Van Soest, 1967). Determining the chemistry and proportion of lignin in fiber is difficult due to the nature of the analyses used, although lignin is crucial to many theories relating chemical composition of forages to nutrient values (Van Soest, 1964). As the proportion of lignin increases, DM digestibility decreases (Van Soest, 1964; Tomlin et al., 1965). Horton (1981) proposed an increase in the solubilization of lignin and hemicellulose in ammonia treated (3.5% DM basis) wheat straw compared to untreated. In untreated straw, lignin acts as a barrier between rumen microbes and cellulose (Dehority and Johnson, 1961). Hemicellulose content of cereal residue is readily determined as the difference between NDF and ADF. Birkelo et al. (1986) reported NDF and ADF on a DM basis in untreated and ammonia treated wheat straw to

be 81.1, 54.4% and 73.3, 59.2% respectively. Saenger et al. (1983) reported a decrease of 46.5% in hemicellulose as a result of ammonia treatment, and they attributed the difference to solubilization by ammonia. Buettner et al. (1982) supported the solubilization of hemicellulose using ammonia. Saenger et al. (1983) reported NDF and ADF values on a DM basis were 74.8, 52.3% and 66.9, 54.8% for untreated and ammoniated wheat straw respectively with *in vitro* digestibility values of NDF and ADF for untreated 42.5 and 43.5% and ammoniated 67.6 and 60.4% (Saenger et al., 1983). Application of anhydrous ammonia increased *in vitro* digestibility of NDF by 59% and ADF by 39%. This was in agreement with the 49.8 and 57.0% improvements in IVDMD reported by Zorrilla-Rios et al. (1991), and a 49% greater IVDMD reported by Waggoner et al. (2014). Horton and Steacy (1979) reported CF digestibility of untreated and ammoniated wheat straws ranging from 41.9 to 45.1% and 41.9 to 44.1% respectively, with a mean increase in CF digestion of 21%.

### ***Crude Protein in Ammoniated Straw***

Crude protein content of cereal grain residues is generally low and varies greatly due to cereal grain variety, weather conditions during growth of the plant, as well as harvest time in relation to the plant stage maturity. Horton and Steacy (1979) reported CP on a DM basis in 3 varieties of barley, wheat, and oat straw with means of 3.9, 2.5, and 2.6%, respectively, for untreated and 9.2, 6.8, and 6.7% for straws ammonia treated at 3.5% (wt/wt; DM basis). Zorrilla-Rios et al. (1991) reported similar measures for untreated wheat straw of 3.4 and 3.8%, Saenger et al. (1983) reported untreated wheat straw CP of 3.6% and 3.0% (wt/wt; DM basis) ammonia treated wheat straw of 11.2% CP. Anderson (1978) reported CP on a DM basis of untreated wheat straw ranging from 2.0 to 2.4% in Oregon and Washington state with a range of 2.8 to 5.3% reported in scientific literature of the time. Crude protein was shown to increase between 100 and 300% from untreated to ammonia treated wheat straw dependent upon the initial CP of straw, the application rate of ammonia, and conditions at the time of treatment. To coincide with CP increase, N content increased 224% in a study by Birkelo et al. (1986) similar to results found by Saenger et al. (1983), Horton and Steacy (1979), and Waggoner and Jaeger (2014). Retention of ammonia N by straw was reported as 18 and 21% (Zorrilla-Rios et al., 1991), 25 and 15% (Nelson et al., 1985), and 49% (Saenger et al. 1983) suggesting that N retention is

highly variable and may be impacted by duration of treatment, ambient temperature, application rate, DM of straw, and condition of straw. Application of 3.3% (wt/wt; DM basis) anhydrous ammonia to wheat straw had a N value equivalent to 118% that of soybean meal N (Zorrilla-Rios et al., 1991). Zorrilla-Rios et al. (1991) also evaluated the effect of supplying supplemental corn gluten meal with untreated or ammonia treated wheat straw. Supplementing 0.41 kg DM of corn gluten meal offered an increase in ADG double of what is expected by the NRC. They suggested that corn gluten meal provided ruminal escape protein to increase performance through acting as 1) a delayed release of amino acids, peptides, and ammonia, 2) by increasing total protein supply to the small intestine, or 3) correcting for amino acid imbalances.

## References

- Amjad, M., H. G. Jung, and J. D. Donker. 1992. Effect of alkaline hydrogen peroxide treatment on cell wall composition and digestion kinetics of sugarcane residues and wheat straw. *J. Anim. Sci.* 70:2877-2884.
- Anderson, D. C. 1978. Use of cereal residues in beef cattle production systems. *J. Anim. Sci.* 46:849-861.
- Berry, B. A., A. W. Confer, C. R. Krehbiel, D. R. Gill, R. A. Smith, and M. Montelongo. 2004a. Effects of dietary energy and starch concentrations for newly received feedlot calves. I. Growth performance and health. *J. Anim. Sci.* 82:837-844.
- Berry, B. A., A. W. Confer, C. R. Krehbiel, D. R. Gill, R. A. Smith, and M. Montelongo. 2004b. Effects of dietary energy and starch concentrations for newly received feedlot calves. II. Acute phase protein response. *J. Anim. Sci.* 82:845-850.
- Birkelo, C. P., D. E. Johnson, and G. M. Ward. 1986. Net energy value of ammoniated wheat straw. *J. Anim. Sci.* 63:2044-2052.
- Blasi, D. A., M. J. Brouk, J. S. Drouillard, and S. P. Montgomery. 2001. Corn gluten feed: Composition and feeding value for beef and dairy cattle. Kansas Coop. Ext. Svc. MF-2538
- Brazle, F. K., G. L. Kuhl, C. E. Binns, K. O. Zoellner, L. R. Corah, and R. R. Schalles. 1991. The influence of limited-creep feeding on pre- and post-weaning performance of spring born calves. *J. Anim. Sci.* 69(Suppl 1): 76.
- Buettner, M. R., V. L. Lechtenberg, K. S. Hendrix, and J. M. Hertel. 1982. Compostion and digestion of ammoniated tall fescue (*Festuca Arundinacea* Schreb.) hay. *J. Anim. Sci.* 54:173-178.
- Cole, N. A. 1996. Review of bovine respiratory disease: Nutrition and disease interactions. *Review of Bovine Respiratory Disease – Schering-Plough Animal Health.* R. Smith, ed. Veterinary Learning Systems, Trenton, NJ, 57-74.
- Coombe, J. B., and D. E. Tribe. 1962. The feeding of urea supplements to sheep and cattle: the results of penned feeding and grazing experiments. *J. Ag. Sci.* 59:125-141.
- Cordes, C. S., K. E. Turner, J. A. Paterson, J. G. P. Bowman, and J. R. Forwood. 1988. Corn gluten feed supplementation of grass hay diets for beef cows and yearling heifers. *J. Anim. Sci.* 66:522-531.
- Crampton, E. W., and L. A. Maynard. 1938. The relation of cellulose and lignin content to the nutritive value of animal feeds. *J. Nutr.* 15:383-395.
- Dehority, B. A., and R. R. Johnson. 1961. Effect of particle size upon the in vitro cellulose digestibility of forages by rumen bacteria. *J. Dairy Sci.* 44:2242-2249.

- Duff, G. C., and M. L. Galyean. 2007. Board-invited review: Recent advances in management of highly stressed, newly received feedlot cattle. *J. Anim. Sci.* 85:823-840.
- Edwards, A.J. 1996. Respiratory diseases of feedlot cattle in the central USA. *Bovine Practitioner*. 30:5-7.
- Flachowsky, G., W. I. Ochrimenko, M. Schneider, and G. H. Richter. 1995. Evaluation of straw treatment with ammonia sources on growing bulls. *Ani. Feed Sci. Technol.* 60:117-130.
- Fluharty, F. L., S. C. Loerch, and B. A. Dehority. 1994a. Ruminal characteristics, microbial populations, and digestive capabilities of newly weaned, stressed calves. *J. Anim. Sci.* 72:2969-2979.
- Fluharty, F.L., S.C. Loerch, and F.E. Smith. 1994b. Effects of energy density and protein source on diet digestibility and performance of calves after arrival at the feedlot. *J. Anim. Sci.* 72:1616-1622.
- Fluharty, F. L., and S. C. Loerch. 1995. Effects of protein concentration and protein source on performance of newly arrived feedlot steers. *J. Anim. Sci.* 73:1585-1594.
- Galyean, M. L. and M. E. Hubbert. 1995. Effects of season, health, and management on feed intake by beef cattle. Pages 226- 234 in Symposium: Intake by Feedlot Cattle. F. N. Owens, ed. Oklahoma Agric. Exp. Stn., P-942.
- Galyean, M. L., L. J. Perino, and G. C. Duff. 1999. Interaction of cattle health/immunity and nutrition. *J. Anim. Sci.* 77:1120-1134.
- Garrett, W. N., H. G. Walker, G. O. Kohler, A. C. Waiss, R. P. Graham, N. E. East, and M. R. Hart. 1974. Nutritive value of NaOH and NH<sub>3</sub>- treated rice straws. *Proc. W. Sect. Amer. Soc. Anim. Sci.* 25:317.
- Garrett, W. N., H. G. Walker, G. O. Kohler, and M. R. Hart. 1979. Response of ruminants to diets containing sodium hydroxide or ammonia treated rice straw. *J. Anim. Sci.* 48:92-103.
- Grandin, T. 1997. Assessment of stress during handling and transport. *J. Anim. Sci.* 75:249-257.
- Horton, G. M. J. 1978. The intake and digestibility of ammoniated cereal straws by cattle. *Can. J. Anim. Sci.* 58:471-478.
- Horton, G. M. J. 1981. Composition and digestibility of cell wall components in cereal straws after treatment with anhydrous ammonia. *Can. J. Anim. Sci.* 61:1059-1062.
- Horton, G. M. J., and G. M. Steacy. 1979. Effect of anhydrous ammonia treatment on the intake and digestibility of cereal straws by steers. *J. Anim. Sci.* 48:1239-1249.
- Jakab, G. J., G. A. Warr, and C. L. Astry. 1981. Alterations of pulmonary defense mechanisms by protein depletion diet. *Infect. Immun.* 34:610-622.

- Kerley, M. S., G. C. Fahey, L. L. Berger, N. R. Merchen, and J. M. Gould. 1986. Effects of alkaline hydrogen peroxide treatment of wheat straw on site and extent of digestion in sheep. *J. Anim. Sci.* 63:868-878.
- Klopfenstein, T. J., V. E. Krause, M. J. Jones, and W. Woods. 1972. Chemical treatment of low quality roughages. *J. Anim. Sci.* 35:418-422.
- Kuhl, G., and D. A. Blasi. 1998. Ammonia treatment of low quality forages. Kansas Forage Task Force. Forage facts notebook. Kansas State University.
- Lalman, D. L., G. W. Horn, R. Huhnke, and L. A. Redmon. 2004. Ammoniation of low quality roughages. Oklahoma cooperative extension service bulletin PSS-2234. Oklahoma State University.
- Lekeu, P. 1996. Bovine respiratory disease complex. *Annales de Medecine Veterinaire*. 140:101-105.
- Levy, D., S. Amir, Z. Holzer, and H. Neumark. 1972. Ground and pelleted straw and hay for fattening Israeli-Friesian male calves. *Anim. Prod.* 15:157-165.
- Loerch, S. C., and F. L. Fluharty. 1999. Physiological changes and digestive capabilities of newly received feedlot cattle. *J. Anim. Sci.* 77:1113-1119.
- Lofgreen, G. P., and A. C. Christensen. 1962. Barley straw as an energy source for growing beef steers. *J. Anim. Sci.* 21:262-265.
- Lofgreen, G. P., J. R. Dunbar, D. G. Addis, and J. G. Clark. 1975. Energy level in starting rations for calves subjected to marketing and shipping stress. *J. Anim. Sci.* 41:1256-1265.
- Lofgreen, G. P. 1983. Nutrition and management of stressed beef calves. Pages 87-101 in Veterinary Clinics of North America: Large Animal Practice. 5: 87-101.
- Lofgreen, G. P. 1988. Nutrition and management of stressed beef calves-an update. Veterinary Clinics of North America: Food Animal Practice. 4:509-522.
- Lofgreen, G. P., M. Branine, M. Hubert, and D. Garcia. 1988. Whole-shelled corn in receiving feeds for newly received calves. Clayton Livest. Res. Ctr. Prog. Rep. No. 52. New Mexico Agric. Exp. Stn., Las Cruces.
- Lusby, K.S. 1989. Limit fed creep feeds for nursing calves. *Bovine Prac.* 21:91-95.
- Mandell, I. B., G. I. Christenson, H. H. Nicholson, and E. C. Coxworth. 1988. The effect of variation in the water content of wheat straw before ammoniation on its nutritive value for beef cattle. *Anim. Feed Sci. and Tech.* 20(2):111-124.
- Montgomery, S. P., J. S. Drouillard, J. J. Sindt, T. B. Farran, H. J. LaBrune, R. D. Hunter, J. J. Higgins, T. A. Nutsch, and R. A. Stock. 2000. Alfalfa hay levels in limit-fed, high-energy

growing diets for beef steers. Cattlemen's Day, Kansas State Univ. Res. Ext. Rep. Prog. 850. pp 29-31.

NASS. 2010. National Agricultural Statistics Service. Agricultural Statistics Board, USDA, Washington, DC.

NASS. 2012. National Agricultural Statistics Service. Agricultural Statistics Board, USDA, Washington, DC.

NASS. 2014. National Agricultural Statistics Service. Agricultural Statistics Board, USDA, Washington, DC.

Nelson, M. L., I. G. Ruch, and T. J. Klopfenstein. 1985. Protein supplementation of ammoniated roughages. II. Wheat straw supplemented with alfalfa, blood meal or soybean meal fed to wintering steers. *J. Anim. Sci.* 61:245-251,

Nissen, S. G., M. VanKoevering, and G. Link. 1989. Effect of protein intake on immune function and growth of stressed calves. *J. Anim. Sci.* 67(Suppl. 1):24 (Abstr.).

NRC. 2000. Nutrient Requirements of Beef Cattle. 7<sup>th</sup> Ed. National Academy Press, Washington, DC.

Rivera, J. D., M. L. Galyean, and W. T. Nichols. 2005. Review: Dietary roughage concentration and health of newly received cattle. *Prof. Anim. Sci.* 21:345-351.

Saenger, P. F., R. P. Lemenager, and K. S. Hendrix. 1983. Effects of anhydrous ammonia treatment of wheat straw upon in vitro digestion, performance and intake by beef cattle. *J. Anim. Sci.* 56:15-20.

Schlegel, A.J., K.C. Dhuyveller, and J.L. Havlin. 2003. Placement of UAN for Dryland Winter Wheat in the Central High Plains. *Agron. J.* 95:1532-1541.

Schneider, M., and G. Flachowsky. 1990. Studies on ammonia treatment of wheat straw: Effect of level of ammonia, moisture content, treatment time and temperature on straw composition and degradation in the rumen of sheep. *Anim. Feed Sci. Technol.* 29:251-264.

Singh, G. P., and T. J. Klopfenstein. 1998. Relative effect of feeding urea supplemented and ammoniated wheat straw of different particle size on the passage rate, particle break down rate and digestibility in sheep. *Indian J. Dairy Sci.* 51:328-334.

Streeter, C. L., and G. W. Horn. 1984. High moisture and dry ammoniation of wheat straw on its feeding value for lambs. *J. Anim. Sci.* 59:559-566.

Sundstøl, F., E. Coxworth, and D. N. Mowat. 1978. Improving the nutritive value of straw and other low quality roughages by treatment with ammonia. *Wld. Anim. Prod.* 26:13-21.

Sundstøl, F. 1983. Ammonia treatment of straw: methods for treatment and feeding experience in Norway. *Anim. Feed Sci. Technol.* 10:173-187.

- Tomlin, D. C., R. R. Johnson, and B. A. Dehority. 1965. Relationship of lignification to in vitro cellulose digestibility of greases and legumes. *J. Anim. Sci.* 24:161-165.
- Van Soest, P. J. 1964. Symposium on nutrition and forage and pastures: new chemical procedures for evaluating forages. *J. Anim. Sci.* 23(3):838-845.
- Van Soest, P. J. 1967. Development of a comprehensive system of feed analysis and its application to forages. *J. Anim. Sci.* 26:119-128.
- Van Soest, P. J. 1975. Physico-chemical aspects of fiber digestion. International Symposium on Ruminant Nutrition. University of New England. 6<sup>th</sup> Proc. pp. 351-365.
- Waggoner, J. W., and J. R. Jaeger. 2014. Performance of pregnant beef cows limit-fed diets containing wheat straw treated with two rates of anhydrous ammonia and wet distiller's grain. Roundup, Kansas State Univ. Res. Ext. Rep. Prog. 1104. pp 96-99.
- Waiss, A. C., J. Guggolz, G. O. Kohler, H. G. Walker, and W. N. Garrett. 1972. Improving digestibility of straws for ruminant feed by aqueous ammonia. *J. Anim. Sci.* 35:109-112.
- Weiss, W. P., H. R. Conrad, C. M. Martin, R. F. Cross, and W. L. Shockey. 1986. Etiology of ammoniated hay toxicosis. *J. Anim. Sci.* 63:525-532.
- Wilson, R.K. and W. J. Pigden. 1963. Effect of a sodium hydroxide treatment on the utilization of wheat straw and poplar wood by rumen microorganisms. *Can. J. Anim. Sci.* 44:122-123.
- Wilson, T. R., R. P. Kromann, K. O. Warner, J. K. Hillers, and E. L. Martin. 1976. Digestible, metabolizable and net energy values of pea scalings and wheat straw in lambs. *Proc. West. Sec. Amer. Soc. Anim. Sci.* 27:292-295.
- Zorrilla-Rios, J., G. W. Horn, W. A. Phillips, and R. W. McNew. 1991. Energy and protein supplementation of ammoniated wheat straw diets for growing steers. *J. Anim. Sci.* 69:1809-1819.

## **Chapter 2 - Evaluation of Ammoniated Wheat Straw in Receiving and Growing Diets**

### **Introduction**

The initial receipt of cattle into a receiving or backgrounding yard is a critical time in terms of future cattle health, growth performance, and profit or loss potential. Stress at marketing is compounded by new feeds, noises, commingling, processing, and other novel factors on arrival at the feed yard (Galyean et al., 1999). Establishing a regimented feeding program that encourages increasing feed intake, and subsequently growth performance, while decreasing morbidity and mortality is critical for receiving and growing facilities. Feeding high fiber diets with comparatively low levels of starch provide for decreased morbidity and mortality compared to feeding higher starch and lower fiber diets. However, high fiber low starch diets do not provide equivalent performance and gains compared to high starch low fiber. Mixed diets composed of low levels of fiber and comparatively high levels of starch are typically used for starting young calves in a structured diet-feeding regimen. Grains and grain by-products, most notably from the ethanol industry, are combined with a multitude of forages to meet the nutrient requirements of young calves. Just as byproduct alternatives of grains are gaining notoriety and ever increasing inclusion in diets due to cost and feeding value, roughage sources are also being investigated to increase nutrient value and constrain costs.

Drought conditions in the past have created a shortage of prairie hay and other grass hays that are used as the primary roughage source in receiving and growing cattle diets. Cereal grain residue, while often grazed or utilized as winter pasture for cow herds in some regions, is typically overlooked as a feedstuff due to its low energy, CP, voluntary intake, and digestibility (Anderson, 1978). This low nutritive value, combined with the added resources necessary to harvest and remove residue from the field, limits the appeal of cereal residue to the livestock feeding industry. Barley, oat, and wheat are the largest sectors of the cereal grain industry in the United States occupying 2.5, 1.0, and 46 million acres respectively (NASS, 2014). Calculating residue quantity is a product of yield of grain per acre as well as plant height. Schlegel et al. (2003) reported straw production ranging from 2 to 3 kg of straw per 1 kg of grain, considerably

higher than the NRCS guideline of 1.7 kg straw per kg of grain yield. Cereal residue left in the field after grain harvest is divided into two major classifications; the stubble left standing that can be later harvested as straw, and carryover from the combine that contains small quantities of straw, grain hulls, and small quantities of grain that is generally termed chaff (Anderson, 1978). As not all stubble residue is harvestable, or should be harvested, in order to help hold topsoil, accumulate moisture, and add nutrients back to the soil, some stubble is left in the field. A conservative estimate for harvestable straw production in the United States is between 50 and 100 million tons annually for wheat, barley, and oats; Walker et al. (1976) cited similar numbers in proportion to harvestable acres.

Historically, cereal grain straw can be purchased at a lower cost than traditional grass hay. Chemical treatment of cereal grain residues is a practice long used in the livestock feeding industry in order to improve nutritive value and to increase palatability and acceptance in cattle diets. Anhydrous ammonia treatment of straw offers significant benefit to the producer as equipment expenses are minimal and large quantities of straw can be treated at one time with minimal labor. Treatment of cereal straws with anhydrous ammonia offers improvements in digestibility and intake (Garrett et al., 1974; Horton and Steacy, 1979; and Waggoner and Jaeger, 2014). While research has been previously conducted to evaluate the efficacy of feeding ammoniated wheat straw to mature cows in a state of low energy requirements, little information exists as to the effects of including this feedstuff in receiving and growing rations.

The objective of these experiments was to determine the efficacy of including wheat straw or ammoniated wheat straw as a replacement for a traditional prairie hay and alfalfa blend in receiving and growing diets.

## **Experimental Procedure**

Animal care practices used in the following studies were approved by the Kansas State University Institutional Animal Care and Use Committee protocol 2910.12.

## ***Experiment 1. Receiving and Growing Cattle Performance Study***

### ***Animals and Experimental Design***

Three hundred one crossbred steers (271 kg BW) were procured from 3 separate sources (Lindsborg, KS; Boliver, MO; and Seymour, TX) via online live auctions, and 288 of these were used in a generalized complete block design to evaluate the efficacy of feeding ammoniated wheat straw (AMMN), wheat straw (STRW), or a prairie hay alfalfa blend (CONT) at 30% (DM basis) inclusion of a receiving and growing diet on DM basis (Table 2.1). Calves were fed once daily for 70 days with the same diets being fed for the initial 56 d and a common diet (CONT) being fed for the last 14 d in order to minimize differences in gastrointestinal tract fill. Inclusion of untreated wheat straw in the STRW diet necessitated the use of an alternative supplement containing 20% CP while both CONT and AMMN diets contained a supplement containing 5% CP in order to maintain isonitrogenous diets (Table 2.2). Feed bunks were evaluated at approximately 0700 h and feed refusal was estimated. Feed was mixed utilizing a Rotomix® drag style feed mixer, offloaded into individual tubs and weighed using a platform scale to ensure accuracy. Feed was delivered by hand at 0900 h each day in an amount sufficient to allow for approximately 0.1 kg of feed refusal per animal per day.

Cattle arrived over a 3-d period from June 4 to June 6, 2013 at the Kansas State University Beef Stocker Unit and were blocked by source (n=3). At arrival cattle were weighed individually, administered a visual “dangle” style ear tag, moved to soil surface pens ( $9.1 \times 15.2$  m) with a 9.1-m concrete fenceline bunk with ad libitum access to long-stemmed prairie hay and water and housed overnight. Thirteen animals were excluded from the trial due to pre-existing health conditions. The day following arrival (d 0), calves were stratified within block by arrival weight to groups of 12 steers and randomized to pen and treatment within block with a total of 24 pens. Blocks were of unequal size with steers from Texas, Kansas, and Missouri containing 12, 6, and 6 pens respectively. All calves were vaccinated with: a modified-live vaccine against infectious bovine rhinotracheitis (IBR), bovine virus diarrhea Types 1 and 2 (IBR), parainfluenza 3 (PI3), and killed vaccine against bovine respiratory syncytial virus (BRSV) (Zoetis, Exton, PA); Bar-Vac 7, a 7-way modified-live vaccine against a broad spectrum of clostridial bacteria (Boehringer Ingelheim, St. Joseph, MO), and Nuplura PH a *Mannheimia Haemolytica* bacterial extract-toxoid (Novartis Animal Health, Larchwood, IA). On d 0 the cattle were also dewormed

using 14 mL of Safe-guard (fenbendazole 10% suspension; Intervet, Millsboro, DE) oral drench and given a subcutaneous injection of 6 mL of Zuprevo (180 mg/mL tildipirosin; Merck Animal Health, Summit, NJ). Cattle were revaccinated on d 28 utilizing the same vaccines as on initial processing. Cattle were monitored daily by trained personnel; animals exhibiting clinical signs of sickness were identified, treated based on symptoms, and returned to pen of origin.

### ***Anhydrous Ammonia Application***

Wheat straw was baled into large round bales shortly after grain harvest to minimize quality loss. Ammonia application was applied by the stack method described by Sundstøl et al. (1978) during August of 2012, with daytime high temperatures averaging 35 °C and nighttime low temperatures of approximately 18 °C. Approximately 70 straw bales were stacked in a 3-2 configuration on bare soil and covered using 6-mil black plastic and sealed with approximately 30 cm of soil along the bottom edge of the plastic. Anhydrous ammonia was applied at a level of 3.0% (wt/wt; DM basis) by weighing a subsample of the straw bales. Three 9.1 m long, 1.3 cm diameter braided-polyvinyl anhydrous hoses were placed at approximately equal distances along the length of the stack and were incorporated under the bottom of the plastic sheeting, and connected to a 1.9 cm iron junction that was adapted to fit an anhydrous ACME fitting (Fairbanks Equipment, Wichita, KS). Anhydrous ammonia was released slowly to allow the liquid to fully volatilize and to reduce loss. Each stack was left covered for 14 d to permit for complete reaction. Bales were uncovered and spread apart at least 3 d prior to grinding to allow excess ammonia to escape. Ammoniated wheat straw, wheat straw, and prairie hay were all ground to approximately 10 cm in length through a commercial grinder (Haybuster®, Jamestown, ND) into individual bays within a covered commodities building and stored uncovered until time of feeding.

### ***Data Collection***

Cattle were weighed at arrival (d -1) to stratify to pen and treatment, at initial processing (d 0), during revaccination (d 28), at completion of the trial diets (d 56), and at the termination of the study (d 70) (Table 2.3). All BW measures, on an individual animal basis, were taken prior to feeding at approximately 0800 h on each respective weigh day. Dry matter intake, average daily gain, and feed efficiency were calculated for each pen of calves and each period (d 0 to 28, 0 to 56, 0 to 70, and 56 to 70) (Table 2.3). Feed delivered per pen was recorded daily. Feed refusals

per pen were collected and weighed on d 28, 56, and 70 prior to weighing of cattle. Feed samples were taken weekly and stored frozen (-20°C) until the completion of the trial. Feed samples were then composited by period and shipped to an independent lab (SDK Laboratories, Hutchinson, KS) for analysis of DM, CP, NDF, ADF, Ca, P, and ash content. Generalized quadratic solutions were used to determine dietary NEm and NEg values based on intake and cattle performance using the NRC (1996) equations for each pen of cattle during the 56-d trial diet feeding period.

### ***Experiment 2. Digestibility Study***

#### ***Animals and Experimental Design***

Six ruminally fistulated Holstein heifers ( $288 \pm 68$  kg initial BW) were used to determine diet digestibility and ruminal parameters. Diets used were the same as in Experiment 1 (Table 2.1). Animals were arranged in a replicated  $3 \times 3$  Latin square design with the order of diets inverted between squares. Animals were housed freely in individual stalls measuring  $3.7 \times 3.7$  m, with 2 cm thick rubber mats surfaced with  $0.75\text{ m}^3$  pine shavings inside a temperature-controlled barn (10 to 21°C). Animals were removed from their stalls once daily in pairs in order to facilitate cleaning, replacing pine shavings, and delivering feed. Feed was delivered at approximately 0900 h in a quantity to allow for 10% feed refusal. Animals were allowed free movement within their respective stalls throughout the study and were only restrained during sample collection. Three consecutive 15-d periods, each comprising 10 d for diet adaptation, 4 d for fecal collection, and 1 d for rumen fluid sampling, were used.

#### ***Data Collection***

Feed refusals were weighed daily; on d 10 through 14 of each period feed samples were collected and composited for each animal. Samples were collected at approximately 0730, and stored at -20°C until the end of the trial when they were dried at 55°C and ground through a 1-mm screen. Ten grams of Cr<sub>2</sub>O<sub>3</sub> was mixed into each diet by hand on d 4 through 14 for use as a digestion marker. Fecal samples were obtained from the rectum of the animals 3 times daily (8 h interval) on d 11 through 14 with sampling time advancing by 2 h per day so that samples were obtained at each 2-h interval post feeding. Fecal samples were stored at -20°C until the end of the experiment when they were dried at 55°C and ground through a 1-mm screen. Feed and fecal

samples were composited by animal and period and were analyzed for DM, ADF, NDF, and ash by SDK Laboratories (Hutchinson, KS). Chromium was analyzed by atomic absorption spectrophotometry as described by Williams et al. (1962).

On d 15 of each period, immediately prior to feeding, rumen fluid samples were collected (at least 20 mL), strained through 4 layers of cheese cloth, measured for pH using a portable meter (Orion, Beverly, MA), dispersed into 2 containers (16 mL rumen fluid mixed with 4 mL 25% (wt/vol) m-phosphoric acid; remainder of sample in vacant container), and immediately frozen at -20°C. Following 0-h sampling of rumen fluid, CoEDTA (0.4 g Co) was dosed into the rumen in a solution volume of 200 mL (Uden et al., 1980). Rumen fluid was subsequently collected using the same technique at 2, 4, 6, 8, 12, 18, and 24 h after dosing of CoEDTA.

Rumen fluid aliquots were analyzed for volatile fatty acid, ammonia, and cobalt concentration (Table 2.5). Passage rates were calculated from ruminal cobalt concentrations after dosing of CoEDTA from 2 to 24 h. The natural logarithm of the cobalt concentration for each animal in each period was linearly regressed against time using the nonlinear procedure of SAS (version 9.3; SAS Inst. Inc., Cary, NC) to determine passage rate (negative slope of regression).

## Statistical Analyses

### *Experiment 1*

Dry matter intakes, average daily gains, and feed efficiencies were calculated for each period for each pen of calves. Average pen body weights taken after d-0 were analyzed separately in a mixed model using the MIXED procedure in SAS (version 9.3; SAS Inst. Inc., Cary, NC) with treatment as a fixed effect, d-0 bodyweight as a fixed covariate, and source of cattle (block) as a random effect. Resulting least squares treatment means for these analysis of covariance models were computed at the mean of the d-0 body weights. All other response variables were analyzed in a mixed model with treatment as a fixed effect and source of cattle as a random effect. If there was a significant F-test for treatment ( $P \leq 0.05$ ), least square difference test was used to separate means.

## ***Experiment 2***

Data was analyzed as a replicated  $3 \times 3$  Latin square design using the MIXED procedure of SAS (version 9.3; SAS Inst. Inc., Cary, NC). The statistical model included fixed effects of treatment and period. Animal was a random effect. LSMEANS were used to calculate treatment means. Ruminal fermentation measures were analyzed as repeated measures with treatment, time, treatment  $\times$  time, and period in the model statement. The repeated term was time with animal  $\times$  period as subject, and the covariance structure was spatial power. Differences were considered significant at  $P \leq 0.05$ .

## **Results and Discussion**

### ***Experiment 1***

No effect of straw ammoniation on dry matter intake ( $P = 0.56$ ) was observed when crossbred beef steers (271 kg) were fed diets containing either wheat straw or anhydrous ammonia treated wheat straw, nor was there a difference between the two straw diets and control ( $P \geq 0.32$ ). Average daily gain was not different between AMMN and STRW ( $P = 0.45$ ); however, both were lower than CONT ( $P < 0.001$ ) for the 56-d feeding period. Feed efficiency was not different between AMMN and STRW ( $P = 0.97$ ), although similarly to average daily gain CONT was better than the other two treatments ( $P < 0.001$ ) for the 56-d feeding period. Final body weights were not different ( $P = 0.53$ ) between AMMN and STRW although both were less than CONT ( $P < 0.001$ ) at d 56 and d 70.

Waggoner and Jaeger (2014) fed pregnant cows diets that contained 0.0, 1.5, or 3.0% anhydrous ammonia treated wheat straw as 64% of the diet and found significant increases in BW gain as anhydrous ammonia concentration increased. They concluded that increases in growth performance were likely the result of increased digestibility of the wheat straw by ammonia treatment. Waggoner et al. (2014) evaluated the effects of level of anhydrous ammonia application on wheat straw on in vitro DM disappearance (IVDMD), reporting 35% and 49% greater IVDMD with treatment of 1.5 and 3.0% (wt/wt; DM basis) respectively. Although previous studies have found significant improvement in diet digestibility and performance gains by inclusion of ammoniated wheat straw compared to untreated wheat straw, some of the associative effects of wet corn gluten feed in our diet may have masked the differences between

AMMN and STRW. Montgomery et al. (2000) showed that corn gluten feed was a suitable substitute for roughage in growing diets when included at 40% of dietary DM. Additionally, corn gluten feed acts as a source of readily fermentable fiber, reduces negative associative effects on fiber degradation, and aids in increasing total digestibility of high roughage diets (Cordes et al., 1988). Furthermore, wet corn gluten feed contains a high level of ruminally degradable protein and a high level of soluble N (Hussein and Berger, 1995) that may aid in bridging the difference in digestibility between ammoniated and untreated wheat straw that has been reported in previous studies.

Very low morbidity and no mortality was observed in this study. Five animals were treated for illnesses: 1, 1, and 3 for CONT, STRW, and AMMN, respectively, with 1 of the 3 in AMMN requiring a second treatment.

## ***Experiment 2***

Digestibilities and intakes from Exp. 2 are shown in Table 2.4. Dry matter intake was greater for AMMN ( $P = 0.02$ ) and STRW ( $P = 0.01$ ) than for CONT, although DMI was not different between AMMN and STRW ( $P = 0.86$ ; Table 2.4). This does not coincide with data from Exp. 1, where DMI was not affected by treatment, however intake may be influenced due to feed wastage and the ability of wheat straw diets to be more easily sorted than CONT. Anhydrous ammonia application had no effect on ADF intake ( $P = 0.57$ ), CP intake ( $P = 0.69$ ), or OM intake ( $P = 0.70$ ) from the two straw diets (Table 2.4).

Dry matter digestibility tended to be greater ( $P = 0.08$ ) for CONT compared to STRW and tended to be greater in CONT than AMMN (Table 2.4). This could, in part, be due to the lower DMI. Anhydrous ammonia application had no effect on DM, ADF, or OM digestibility ( $P = 0.33$ ) and ( $P = 0.08$ ), respectively. This is similar to results published by Waggoner et al. (2014) who found no differences in DM and ADF content of wheat straw when treated with anhydrous ammonia at the rate of 0.0, 1.5, and 3.0%, although IVDMD may be improved by anhydrous application.

Ruminal pH was higher for AMMN ( $P < 0.01$ ) and STRW ( $P = 0.03$ ) than CONT (Table 2.4). Application of anhydrous ammonia had no effect on individual or total VFA concentrations ( $P \geq 0.75$ ). There were no treatment by time interactions for VFA concentrations ( $P \geq$

0.31). Concentration of rumen ammonia did not differ among treatments ( $P > 0.57$ ). Rumen liquid passage rate was not different between treatments ( $P > 0.33$ ). However, as animals on the study were fed once daily with passage rate being measured from a period beginning after feeding, the lack in steady state conditions as well as individual animal variations may influence calculated passage rate.

## Conclusion

There were no benefits of replacing wheat straw with ammoniated wheat straw at 30% of receiving and growing diets that contain 40% wet corn gluten feed. There were no significant differences in dry matter intake, average daily gain, feed efficiency, or final body weight between AMMN and STRW. WCGF may provide sufficient nitrogen and readily fermentable carbohydrates to diminish the positive effects of anhydrous ammonia application to low quality roughages when included at 40% of the diet for receiving and growing beef calves. Straw may be suitable to be included in receiving and growing diets at 30% inclusion when traditional roughage prices become elevated. Further research is necessary to determine the effect of varying levels of wheat straw and ammoniated wheat straw in conjunction with wet corn gluten feed and other by-product feeds in receiving and growing diets in order to capitalize on performance and efficiency gains while constraining costs.

## Literature Cited

- Anderson, D. C. 1978. Use of cereal residues in beef cattle production systems. *J. Anim. Sci.* 46:849-861.
- Cordes, C. S., K. E. Turner, J. A. Paterson, J. G. Bowman, and J. R. Forwood. 1988. Corn gluten feed supplementation of grass hay diets for beef cows and yearling heifers. *J. Anim. Sci.* 66:522-531.
- Galyean, M. L., L. J. Perino, and G. C. Duff. 1999. Interaction of cattle health/immunity and nutrition. *J. Anim. Sci.* 77:1120-1134.
- Garrett, W. N., H. G. Walker, G. O. Kohler, A. C. Waiss, R. P. Graham, N. E. East, and M. R. Hart. 1974. Nutritive value of NaOH and NH<sub>3</sub>- treated rice straws. *Proc. W. Sect. Amer. Soc. Anim. Sci.* 25:317.
- Horton, G. M. J., and G. M. Steacy. 1979. Effect of anhydrous ammonia treatment on the intake and digestibility of cereal straws by steers. *J. Anim. Sci.* 48:1239-1249.
- Hussein, H. S. and L. L. Berger. 1995. Effects of feed intake and dietary level of corn gluten feed on feedlot performance, digestibility of nutrients, and carcass characteristics of growing-finishing beef heifers. *J. Anim. Sci.* 73:3246-3252.
- Montgomery, S. P., J. S. Drouillard, J. J. Sindt, T. B. Farran, H. J. LaBrune, R. D. Hunter, J. J. Higgins, T. A. Nutsch, and R. A. Stock. 2000. Alfalfa hay levels in limit-fed, high-energy growing diets for beef steers. *Cattleman's Day, Kansas State Univ. Res. and Ext. Rep. Prog.* 850, p. 29.
- NASS. 2014. National Agricultural Statistics Service. Agricultural Statistics Board, USDA, Washington, DC.
- SAS Institute. 2012. SAS User's Guide: Statistics. Version 9.3 ed. SAS Inst. Inc., Cary, NC.
- Schlegel, A. J., K. C. Dhuyvetter, and J. L. Havlin. 2003. Placement of UAN for Dryland Winter Wheat in the Central High Plains. *Agron. J.* 95:1532-1541.
- Sundstøl, F., E. Coxworth, and D. N. Mowat. 1978. Improving the nutritive value of straw and other low quality roughages by treatment with ammonia. *Wld. Anim. Prod.* 26:13-21.
- Uden, P., P. E. Colucci, and P. J. Van Soest. 1980. Investigation of chromium, cerium and cobalt as markers in digesta rate of passage studies. *J. Sci. Food Agric.* 31:625-632.
- Waggoner, J. W., and J. R. Jaeger. 2014. Performance of pregnant beef cows limit-fed diets containing wheat straw treated with two rates of anhydrous ammonia and wet distiller's grain. *Roundup, Kansas State Univ. Res. and Ext. Rep. Prog.* 1104: 96-99.
- Waggoner, J., R. Reid, B. Oleen, W. Hollenbeck, J. Holthaus, A. Sexten, J. Petersilie, B. Weaber, S. Johnson, and D. Blasi. 2014. Wheat straw improved by half-rate application of anhydrous

ammonia and wet distiller's grain. Proc. West. Sec. Amer. Soc. Anim. Sci. 65:146-149.

Walker, H. G., G. O. Kohler, R. P. Graham, M. R. Hart, and W. N. Garrett. 1976. Upgrading cereal straws. Proc. 9<sup>th</sup> National Conference on Wheat Utilization Research. ARS-NC-40.

Williams, C. H., D. J. David, and O. Ismaa. 1962. The determination of chromic oxide in faeces samples by atomic absorption spectrophotometry. J. Agric. Sci. 59:381-385.

## Tables

**Table 2.1. Composition of diets containing wheat straw (STRW), ammoniated wheat straw (AMMN), or a blend of prairie hay and alfalfa (CONT) at 30% inclusion (DM basis) fed during Exp. 1 and Exp. 2**

Ingredient, % of DM	Diet		
	CONT	STRW	AMMN
Dry-rolled corn	23.57	23.57	23.57
Supplement 1 <sup>a</sup>	6.43	-	6.43
Supplement 2 <sup>a</sup>	-	6.43	-
Alfalfa hay	15.00	-	-
Prairie hay	15.00	-	-
Wheat straw	-	30.00	-
CP <sup>2</sup> , % of DM		3.5	
ADF <sup>2</sup> , % of DM		55.0	
Ammoniated wheat straw	-	-	30.00
CP <sup>1</sup> , % of DM			11.2
ADF <sup>1</sup> , % of DM			49.4
Wet corn gluten feed	40.00	40.00	40.00
Composition, analyzed <sup>1</sup> (Exp. 1)			
DM, %	73.0	73.4	72.2
CP, % of DM	15.7	14.6	14.5
Ca, % of DM	0.91	0.72	0.71
P, % of DM	0.56	0.52	0.52
K, % of DM	1.22	1.10	1.10
Mg, % of DM	0.26	0.27	0.25
Ether extract, % of DM	3.04	2.74	2.65
ADF, % of DM	16.2	21.8	21.2

<sup>a</sup>Provided 31 mg/kg monensin (Elanco Animal Health, Indianapolis, IN).

<sup>1</sup>Mean of 10 bale samples analyzed by SDK Labs, Hutchinson, KS.

<sup>2</sup>NRC (2000) Nutrient Requirements of Beef Cattle. 7th Ed.

**Table 2.2. Composition of supplement 1 in CONT and AMMN diet, and supplement 2 in STRW diet fed during Exp. 1 and Exp. 2**

Ingredient specifications	Supplement 1	Supplement 2
DM, %	89.1	88.7
CP, % of DM	15.1	30.3
Ca, % of DM	5.03	5.00
P, % of DM	0.70	0.83
K, % of DM	0.97	1.26
Mg, % of DM	0.99	1.00
Ether extract, % of DM	2.93	2.18
ADF, % of DM	7.50	10.3

Manufactured by Cargill Animal Nutrition, Minneapolis, MN  
 Provided 31 mg/kg monensin (Elanco Animal Health, Indianapolis, IN).

**Table 2.3. Growth performance of crossbred steers fed diets containing wheat straw (STRW), ammoniated wheat straw (AMMN), or a blend of prairie hay and alfalfa hay (CONT) at 30% inclusion during the receiving and growing periods (Exp. 1)**

Item	CONT	STRW	AMMN	SEM	P-value
No. of pens	8	8	8		
No. of animals	96	96	96		
Days on feed	70	70	70		
Calculated NEm, Mcal/kg	1.88 <sup>a</sup>	1.87 <sup>a</sup>	1.78 <sup>b</sup>	0.04	0.02
Calculated NEg, Mcal/kg	1.24 <sup>a</sup>	1.23 <sup>a</sup>	1.15 <sup>b</sup>	0.04	0.02
Initial BW, kg	279.4	279.4	279.9	10.4	0.64
d 28 BW, kg	315.7	316.6	316.6	1.15	0.78
d 56 BW, kg	362.9 <sup>a</sup>	353.8 <sup>b</sup>	354.7 <sup>b</sup>	1.57	<0.001
Final BW (d 70) <sup>1</sup> , kg	375.1 <sup>a</sup>	368.3 <sup>b</sup>	367.4 <sup>b</sup>	1.89	<0.001
DMI, kg/d					
d 0 to 28	7.50	7.64	7.50	0.18	0.52
d 0 to 56	8.51	8.33	8.44	0.25	0.59
d 56 to 70	10.62 <sup>a</sup>	9.79 <sup>b</sup>	9.98 <sup>b</sup>	0.40	0.001
d 0 to 70	8.93	8.63	8.75	0.28	0.18
ADG, kg					
d 0 to 28	1.40	1.43	1.43	0.04	0.78
d 0 to 56	1.56 <sup>a</sup>	1.40 <sup>b</sup>	1.42 <sup>b</sup>	0.06	<0.001
d 56 to 70	0.85	0.99	0.86	0.13	0.39
d 0 to 70	1.42 <sup>a</sup>	1.32 <sup>b</sup>	1.31 <sup>b</sup>	0.03	<0.001
G:F, kg/kg					
d 0 to 28	0.18	0.19	0.19	<0.01	0.73
d 0 to 56	0.18 <sup>a</sup>	0.17 <sup>b</sup>	0.17 <sup>b</sup>	<0.01	<0.001
d 56 to 70	0.08	0.10	0.09	0.01	0.19
d 0 to 70	0.16 <sup>a</sup>	0.15 <sup>b</sup>	0.15 <sup>b</sup>	<0.01	0.01

<sup>a,b</sup>Means within a row not bearing a common letter differ ( $P \leq 0.05$ ).

<sup>1</sup>Weights taken after 14 days on a common diet (CONT) to equilibrate gastrointestinal tract fill.

**Table 2.4. Effect of anhydrous ammonia treatment of wheat straw on total tract digestibility and intake of DM, OM, and ADF (Exp. 2)**

Item	CONT	STRW	AMMN	SEM	P-value
No. of observations	6	6	6		
Diet composition, % of DM					
OM	91.1 <sup>a</sup>	92.4 <sup>b</sup>	91.2 <sup>a,b</sup>	0.3	0.02
ADF	13.2 <sup>a</sup>	20.1 <sup>b</sup>	19.6 <sup>b</sup>	0.5	<0.001
Intake, kg/d					
DM	9.52 <sup>a</sup>	12.02 <sup>b</sup>	11.88 <sup>b</sup>	0.90	0.02
OM	8.65 <sup>a</sup>	11.10 <sup>b</sup>	10.83 <sup>b</sup>	0.80	0.01
ADF	1.25 <sup>a</sup>	2.42 <sup>b</sup>	2.35 <sup>b</sup>	0.14	<0.001
Digestibility, %					
DM	62.2	56.4	58.3	1.7	0.08
OM	69.3	60.4	61.2	2.7	0.08
ADF	34.2	37.1	42.6	3.7	0.33

<sup>a,b</sup>Means within a row not bearing a common letter differ ( $P \leq 0.05$ ).

**Table 2.5. Effect of anhydrous ammonia treatment of wheat straw on ruminal fermentation characteristics (Exp. 2)**

Item	CONT	STRW	AMMN	SEM	P-value
No. of observations	6	6	6		
<b>Ruminal</b>					
pH <sup>1</sup>	6.15 <sup>a</sup>	6.42 <sup>b</sup>	6.54 <sup>b</sup>	0.09	0.01
Ammonia <sup>1</sup> , mM	6.49	6.83	6.92	0.62	0.84
Total VFA <sup>1</sup> , mM	93.2	92.4	94.8	5.7	0.95
Acetate <sup>1</sup> , mM	54.8	53.4	54.3	3.4	0.96
Propionate <sup>1</sup> , mM	22.1	22.5	23.2	2.0	0.89
Butyrate <sup>1</sup> , mM	12.3	12.1	12.6	1.1	0.93
Isobutyrate <sup>1</sup> , mM	0.85	1.11	1.22	0.85	0.95
Isovalerate <sup>1</sup> , mM	1.40	1.76	1.66	0.61	0.91
Valerate <sup>1</sup> , mM	1.73	1.68	1.78	0.15	0.89
Fluid passage rate <sup>2</sup> , %/h	10.5	10.8	10.5	0.56	0.54

<sup>a,b</sup>Means within a row not bearing a common letter differ ( $P \leq 0.05$ ).

<sup>1</sup>Average of values collected 0, 2, 4, 6, 8, 12, 18, and 24 h after feeding.

<sup>2</sup>Calculated from samples collected at 2, 4, 6, 8, 12, 18, and 24 h after feeding.