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Intake and Digestibility of Tall Fescue Supplemented With Co-Product Feeds

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Abstract

Satisfying an animals' nutritional needs can help optimize performance and keep an animal healthy. Meeting these nutritional requirements is often complicated by the low quality characteristics of hay, requiring supplementation with concentrate feedstuffs to offset this low nutrient density. The objectives of this study were to determine the impact of supplementation with soybean hulls (SH), distiller's dried grains with solubles (DDGS), or a 50:50 mixture of the two (MIX) on ruminal fermentation characteristics and in situ forage disappearance in lactating and non-lactating ruminally-cannulated cows offered tall fescue hay. For this experiment, a basal diet of tall fescue hay was offered for ad libitum consumption from large round bales along with supplements of either SH, DDGS, or MIX fed at 0.5% of each cow's body weight. The study consisted of six, 21-d periods using six ruminally-cannulated cows (679 ± 18.7 kg body weight), three lactating and three non-lactating, and the three supplements. Following a 14-d adaptation period to the diets, Dacron bags containing 5 g of ground fescue hay were placed individually into the rumen of each cow at specified intervals over a period of 7 d. On d 21, the bags were removed and washed in a top-loading washing machine ten times. Rumen fluid samples were collected on d 21 of each period at 2 h intervals from 1600 h to 2400 h for analyses of ruminal ammonia and volatile fatty acids. Ruminal forage disappearance was not affected ($P \geq 0.44$) by diets. Total VFA were greater ($P < 0.05$) from SH but the proportion of propionate was greater ($P < 0.05$) from DDGS. Therefore, supplementation with DDGS should improve the energy status of cows being fed poor-quality hay as compared to being offered SH or MIX.

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Dedication

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Table of Contents

ABSTRACT

ACKNOWLEDGEMENTS

DEDICATION

LIST OF ABBREVIATIONS

CHAPTER 1: REVIEW OF LITERATURE 1

1. Literature Review 1

2. Literature Cited 8

CHAPTER 2: INTRODUCTION 12

1. Materials and Methods 12

2. Laboratory Procedures 15

3. Statistical Analyses 16

CHAPTER 3: RESULTS 16

1. Discussion 18

CHAPTER 4: CONCLUSION 19

CHAPTER 5: Literature Cited

CHAPTER 6: Tables and Figures 21

1. Tables 21

1.1: Table 1: Quality measurement of soybean hulls, distillers dried grains with solubles, tall fescue hay and masticate offered to lactating and non-lactating cows. 21

1.2: Table 2: Body weight, body weight change, in lactating and non-lactating cows offered a basal diet of tall fescue hay and supplemented with soybean hulls, distillers dried grains, or a mix of the two at 0.5% of cow body weight 22

1.3: Table 3: In-situ forage dry matter disappearance characteristics of tall fescue hay in lactating and non-lactating cows offered a basal diet of tall fescue hay and supplemented with soybean hulls, distillers dried grains, or a mix of the two at 0.5% of cow body weight..... 24

1.4: Table 4: Ruminal fermentation measurements from cows offered a basal diet of tall fescue hay and supplemented with soybean hulls, distillers dried grains, or a mix of the two at 0.5% of cow body weight	25
2. Figures	26
2.1: Figure 1: Molar percent of acetate over time after feeding co-product feedstuffs	26
2.2: Figure 2: Molar percent of propionate over time after feeding co-product feedstuffs	27
2.3: Figure 3: Molar percent of butyrate over time after feeding co-product feedstuffs	28

List of Abbreviations

ADF	acid detergent fiber
ADIA	acid detergent insoluble ash
APL	alkaline-peroxide lignin
BCS	body condition score
BW	body weight
d	day(s)
DDGS	distillers dried grains with solubles
DM	dry matter
g	grams
h	hour(s)
kg	kilogram(s)
M	molar (concentration)
N	nitrogen
NDF	neutral detergent fiber
NH ₃	ammonia
OM	organic matter
SH	soybean hulls
μL	microliter(s)
Wt	weight(s)

LITERATURE REVIEW

Nutrition is a vital component of the livestock industry. Practicing proper livestock nutrition strategies can include feeding livestock as they should be fed, insuring that whatever the livestock animal is consuming is being used to its fullest extent, and insuring that nutritional requirements of the livestock are being met.

Cattle are one of the most economically important livestock species in the US. Cattle are ruminant animals, meaning that rather than having a one compartment stomach, they have a four compartment stomach. One of the compartments of the ruminant stomach known as the rumen, which is one of the most refined in-body fermenters utilized for nutrition (Bergman, 1990). The rumen is the site of microbial digestion in ruminant animals (Welch and Hooper, 1988). The microbes located inside of the rumen can digest cellulose from plants and thereby significant energy is derived from this process (Welch and Hooper, 1988).

Forages comprise the majority of the cattle diet. Forages can differ in terms of stage of maturity, variety, and management practices, and can also vary in terms of dry matter (**DM**) digestibility, crude protein (**CP**), and palatability (Bohnert et al, 2011). Many ruminants, including cattle, consume low-quality forages (<7% **CP**) for extended periods of time, especially during the winter months (Turner and DelCurto, 1991). When feeding low-quality forages, it is common to have inadequate ruminal nitrogen (**N**) concentrations (Köster et al., 1996). This leads to deficient ruminal ammonia (**NH₃**) which is used by the microbes to produce microbial protein. This in turn would limit microbial CP synthesis and growth which in turn would also limit microbial fermentation and ultimately limit forage intake (Maeng et al, 1976; Egan, 1980). These factors combine so that low-quality forages also do not normally meet the energy

requirements needed to maintain adequate body weight (**BW**) or body condition scores (**BCS**) of cattle and other livestock animals.

Tall fescue (*Lolium arundinaceum* [Schreb.]Darbysh) is a cool-season perennial that is most commonly used as a ruminant forage in the eastern half of the United States in the transition zone between the northeast and the southeast (Aiken and Strickland, 2013). Although tall fescue is a very popular forage to feed, especially during the winter months, it may not be of the highest quality if it is allowed to mature. Poor animal performance has been documented for livestock grazing tall fescue, and tall fescue does not adequately meet energy requirements when fed alone (Stuedemann and Hoveland, 1988).

Tall fescue is unique in that it contains ergot alkaloids which are produced by fungal endophytes that are present in the forage. Some ergot alkaloids such as *Neotyphodium coenophialum* can assist with improving tolerances to environmental stresses such as moisture, heat, drought, and insects, and the ergot alkaloids can also improve the hardiness and persistence of tall fescue (Burke et al, 2010). However, ergot alkaloids can also cause negative side effects such as severe lameness and fescue toxicosis in grazing cattle. Feeding tall fescue without the endophyte results in excellent animal performance, but it lacks in persistence and grazed stands of these cultivars rapidly deteriorate (Aiken and Strickland, 2013). Endophytes have been discovered that produce very few or no ergot alkaloids. These “novel endophytes” combine the plant persistence of endophyte-infected tall fescue with the improved animal performance of non-endophyte infected tall fescue (Beck et al, 2008).

When feeding livestock a diet comprised mainly of forages, especially low-quality forages, it is necessary to provide some sort of concentrate supplementation in addition to the forage in order to meet the animals’ energy and(or) protein requirements (Horn and McCollum,

1987; Galyean and Goetsch, 1993). Energy supplementation is a common practice for cow-calf operations as well as other livestock operations, but the labor costs associated with the feeding of supplements contribute significantly to the overall cost of operating and maintaining cattle operations (Miller et al., 2001). Also, instances of lower ruminal pH and acidosis can occur if high enough levels of cereal grains are fed. The pH of the rumen determines both the biodiversity of the rumen microbes and the overall health of the animal (Aschenbach et al., 2011), which helps explain why lower than expected energy intake were observed when corn and corn by-products were used as supplementation along with low-quality forages (Chase and Hibberd, 1987). This is because feeding starch-based supplements such as cereal grains as the source of supplemental energy had negative effects on fiber digestibility, thereby causing a decrease in forage intake (Chase and Hibberd, 1987), particularly when these supplements are offered to cattle grazing low-quality, protein-deficient forages (Horn and McCollum, 1987).

Stocker cattle grazing dormant tall fescue and other low-quality forages require supplementation in order to gain weight during those months when the forage is dormant (Bodine and Purvis, 2003). Properly feeding supplements along with low-quality forages optimizes utilization of the low-quality forage and maintains proper animal performance (Köster et al., 1996) including reproductive performance (Wiley et al., 1991) through increased forage intake and digestibility, bodyweight and BCS gain. When the protein content of the forage is low, it is ideal to feed supplements that contain adequate levels of degradable intake protein (DIP; Köster et al., 1996). Degradable intake protein promotes increased forage intake and the flow of nutrients into the small intestines (Hannah et al., 1991) through the mechanisms described above. However, feedstuffs that are high in DIP are generally expensive relative to other commodity feeds, thereby limiting their use in feedstuffs for beef cattle.

A common source of supplements that are used to reduce costs are co-products, which are secondary products resulting from the manufacturing of a primary product such as ethanol or high-fructose corn syrup. Use of co-products as ruminant feedstuffs is necessary from an economic and environmental point of view, since co-products could potentially cause disposal problems (Iraira et al., 2013). Compared with corn, these co-products generally contain lower starch and greater protein and fiber. Therefore, cattle are able to consume co-products as sources of non-forage fiber. Co-product supplements such as corn gluten feed and soybean hulls can be fed as sources of supplemental energy. These supplements have less of a negative effect on ruminal pH, thereby having less of a negative impact on forage intake and digestibility (Bowman and Sanson, 1996) than cereal grains.

A common co-product used as a supplemental feedstuff for grazing cattle and other ruminants is soybean hulls. Soybean hulls, also referred to as soyhulls, are a co-product of the soybean milling industry and are produced in large quantities. Soybean hulls are starch-free, contain a low amount of lignin, and are high in fiber (Hsu et al., 1987). Soybean hulls contain large amounts of cellulose and hemicellulose and are extensively fermented by bacteria in the rumen (Miron et al., 2001). This gives soyhulls the potential to be an alternative energy source to grains in ruminant diets (Conrad and Hibbs, 1961). Growing ruminants, including cattle, can be fed soybean hulls in place of corn in the diet and still maintain adequate performance (Anderson et al., 2009).

Various studies have shown that soybean hulls have been successfully fed to ruminant animals as a substitute for grain in hay-based diets. Soybean hulls have the advantage over corn in that soybean hulls contain higher amounts of digestible fiber rather than starch, resulting in energy supplementation while minimizing changes to ruminal fermentation (Anderson et al.,

1988) and fewer negative associative effects on fiber digestion than when corn was fed as an energy supplement (McDonnell, 1982). Favorable responses have also been noted by Grigsby et al (1992) and Slater et al (2000) including increased ruminal volatile fatty acid (VFA) production, and increased digestibility of dry matter, organic matter, and plant cell walls. One negative factor associated with soybean hulls is that their quality may vary due to processing methods, source, or degree of maturity (Martin and Hibberd, 1990). Also, previous studies have shown that soybean hulls could potentially decrease forage intake. Soybean hulls swell very rapidly when exposed to fluid, and the amount of swelling that occurs could possibly decrease hay intake due to ruminal fill (Martin and Hibberd, 1990). However, in a study done by Martin and Hibberd (1990), hay organic matter intake decreased only when 3 kg of soybean hulls were fed as a supplement. This occurrence indicated that ruminal distension from soybean hulls was not the main factor that hindered hay intake. It has also been proposed that soybean hulls, despite physical dissimilarities, could possibly replace forage in the ruminant diet because of the high fiber concentrations (NRC, 2007) Because of these factors, soybean hulls are a common choice for livestock producers to use as a supplement when feeding low-quality hay.

Another common co-product feedstuff that is widely used by livestock operations is distiller's dried grains with solubles (**DDGS**). The expansion in the biofuels industry in recent years has increased ethanol production which has resulted in an increase in availability of DDGS (Winterholler et al., 2009). Stock et al. (2000) described the process of dry milling where corn is fermented in order to produce ethanol. Two-thirds of corn is starch, and starch is the component of corn that is fermented in order to produce ethanol. The components that remain after fermentation are recovered, and water is removed in order to produce DDGS. Since the starch is removed, the levels of protein, fat, and fiber are greater in DDGS compared with corn.

Distiller's grains are gaining popularity as a supplement for cattle consuming forage-based diets due to availability, nutrient value, and economic effectiveness (Leupp et al., 2009). Distiller's grains contain approximately 30% crude protein (**CP**), 11% fat, which acts as a source of energy, and is less generally expensive than corn (NASS, 2008). Distillers grains are commonly used as a protein source because of their high (approx. 30%) protein concentrations (Klopfenstein et al., 1978).

Distiller's dried grains with solubles also have relatively high neutral detergent fiber (**NDF**) levels, (Ham et al., 1994) which are slowly fermentable in the rumen. This may decrease the rate of acid production in the rumen and prevent ruminal pH levels from decreasing. Supplementation with DDGS improved gains by stocker steers and heifers grazing bermudagrass and mixed bermudagrass and crabgrass pastures by 0.16 to 0.26 kg/d (Beck et al., 2014). Body weight gain was similar and intake was less from growing steers offered DDGS compared with corn and soybean meal at 25% of a corn-silage based diet (Segers et al., 2013), resulting in a greater feed conversion ratio steers by offered DDGS. Body weight and BCS changes increased linearly in cows offered increasing levels of DDGS during gestation and lactation while fed low-quality tall grass prairie hay (Winterholler et al., 2015). It is therefore apparent that DDGS has potential to be used as a supplemental feed for different classes of cattle consuming high-roughage diets.

Livestock are fed forages as a main source of fiber and energy. Overall quality of these forages can vary substantially depending on the seasons in which they are most prevalent and varying levels of maturity. Higher quality forages require little to no supplementation, but lower-quality forages are typically fed due to availability and mismanagement. Tall fescue is a common forage that is fed to ruminant animals in the southeast, and it is considered a low-quality forage,

primarily because it is difficult to harvest as hay before it reaches advanced maturity. When low-quality forages are fed, it is often necessary to supplement these forages with concentrate feedstuffs in order to insure that energy and nutrient requirements of animals are being satisfied. Co-products such as soybean hulls and DDGS contain higher amounts of fiber and utilizable energy which aid in meeting energy requirements of ruminant animals with fewer negative effects on ruminal pH. However, information about the effects of feeding these co-products singularly or in combination on ruminal fermentation and digestibility by lactating cows is limited. Therefore, our objective was to compare SH, DDGS and a 1:1 ratio of SH and DDGS on digestibility and ruminal fermentation measurements by lactating and non-lactating ruminally-cannulated cows.

Literature Cited

- Aiken, G. E., and J. R. Strickland. 2013. FORAGES AND PASTURES SYPOSIUM: Managing the tall fescue-fungal endophyte symbiosis for optimum forage-animal production. *J. Anim. Sci.* 91:2369-2378.
- Anderson, J. L., K. F. Kalscheur, A. D. Garcia, D. J. Schingoethe, and A. R. Hippen. 2009. Ensiling characteristics of wet distillers grains mixed with soybean hulls and evaluation of the feeding value for growing Holstein heifers. *J. Anim. Sci.* 87:2113-2123.
- Anderson, S. J., J. K. Merrill, and T. J. Klopfenstein. 1988. Soybean hulls as an energy supplement for the grazing ruminant. *J. Anim. Sci.* 66:2959-2964.
- Aschenbach, J. R., G. B. Penner, F. Stumpff, and G. Gäbel. 2011. RUMINANT NUTRITION SYMPOSIUM: Role of fermentation acid absorption in the regulation of ruminal pH. *J. Anim. Sci.* 89:1092-1107.
- Beck, P. A., S. A. Gunter, K. S. Lusby, C. P. West, K. B. Watkins, and D. S. Hubbell III. 2008. Animal performance and economic comparison of novel and toxic endophyte tall fescues to cool-season annuals. *J. Anim. Sci.* 86:2043-2055.
- Beck, P., B. Stewart, S. Gadberry, J. Tucker, D. Hubbell, J. Butterbaugh, T. Hess, K. Coffey, and B. Rudolph. 2014. Effect of daily or alternate-day distillers grains supplementation with or without monensin on performance of grazing calves. *Prof. Anim. Sci.* 30:515-526.
- Bergman, E. N. 1990. Energy contributions of volatile fatty acids from the gastrointestinal tract in various species. *Physiol. Rev.* 70:567-590.
- Bodine, T. N., and H. T. Purvis. 2003. Effects of supplemental energy and/or degradable intake protein on performance, grazing behavior, intake, digestibility, and fecal and blood indices by beef steers grazed on dormant native tallgrass prairie. *J. Anim. Sci.* 81:304-317.
- Bohnert, D. W., T. DelCurto, A. A. Clark, M. L. Merrill, S. J. Falck, and D. L. Harmon. 2011. Protein supplementation of ruminants consuming low-quality cool- or warm-season forage: Differences in intake and digestibility. *J. Anim. Sci.* 89:3703-3717.
- Bowman, J. G., and D. W. Sanson. 1996. Starch- or fiber-based energy supplements of grazing ruminants. *Proc. West. Sect. Am. Soc. Anim. Sci.* 47(Suppl. 1):118-135.
- Burke, J. M., S. W. Coleman, C. C. Chase Jr., D. G. Riley, M. L. Loofer, and M. A. Brown. 2010. Interaction of breed type and endophyte-infected tall fescue on milk production and quality in beef cattle. *J. Anim. Sci.* 88:2802-2811.
- Chase, C. C., Jr., and C. A. Hibberd. 1987. Utilization of low-quality native grass hay by beef cows fed increasing quantities of corn grain. *J. Anim. Sci.* 65:557-566.
- Conrad, H. R. and J. W. Hibbs. 1961. Nitrogen metabolism in dairy cattle. 11. Soybran flakes versus oats as principal sources of digestible carbohydrates for nitrogen utilization. *J. Dairy Sci.* 44:1903-1909

- Egan, A. R., 1980. Host animal-rumen relationships. *Proc. Nutr. Soc.* 39:79-87.
- Galyean, M. L., and A. L. Goetsch. 1993. Utilization of forage fiber by ruminants. Pages 33–71 in *Forage Cell Wall Structure and Digestibility*. H. G. Jung, D. R. Buxton, R. D. Hatfield and J. Ralph, ed. Am. Soc. Agron., Madison, WI.
- Grigsby, K. N., M. S. Kerley, J. A. Paterson, and J. C. Weigel. 1992. Site and extent of nutrient digestion by steers fed a low-quality bromegrass hay diet with incremental levels of soybean hull substitution. *J. Anim. Sci.* 70:1941–1949.
- Ham, G. A., R. A. Stock, T. J. Klopfenstein, E. M. Larson, D. H. Shain, and R. P. Huffman. 1994. Wet corn distillers byproducts compared with dried corn distillers gains with solubles as a source of protein and energy for ruminants. *J. Anim. Sci.* 72:3246–3257.
- Hannah, S. M., R. C. Cochran, E. S. Vanzant, and D. L. Harmon. 1991. Influence of protein supplementation on site and extent of digestion, forage intake, and nutrient flow characteristics in steers consuming dormant bluestem-range forage. *J. Anim. Sci.* 69:2624-2633.
- Horn, G. W., and F. T. McCollum. 1987. Energy supplementation of grazing ruminants. Pages 125–136 in *Proc. Grazing Livest. Nutr. Conf.*, Jackson, WY.
- Hsu, J. T., D. B. Faulkner, K. A. Garleb, R. A. Barclay, G. C. Fahey, Jr. and L. L. Berger. 1987. Evaluation of corn fiber, cottonseed hulls, oat hulls and soybean hulls as roughage sources for ruminants. *J. Anim. Sci.* 65:244-255.
- Iraira, S. P., J. L. Ruiz de la Torre, M. Rodriguez-Prado, S. Calsamiglia, X. Manteca, and A. Ferret. 2013. Feed intake, ruminal fermentation, and animal behavior of beef heifer fed forage free diets containing nonforage fiber sources. *J. Anim. Sci.* 91:3827-3835.
- Klopfenstein, T., J. Waller, N. Merchen, and L. Petersen. 1978. Distillers grains as a naturally protected protein for ruminants. *Distillers Feed Conference Proceedings*. 33:38-46.
- Köster, H. H., R. C. Cochran, E. C. Titgemeyer, E. S. Vanzant, I. Abdelgadir, and G. St-Jean. 1996. Effect of increasing degradable intake protein on intake and digestibility of low-quality, tall-grass-prairie forage by beef cows. *J. Anim. Sci.* 74:2473-2481.
- Leupp, J. L., G. P. Lardy, K. K. Karges, M. L. Gibson, and J. S. Caton. 2009. Effects of increasing levels of corn distillers dried grains with solubles to steers offered moderate-quality forage. *J. Anim. Sci.* 87:4064-4072.
- Maeng, W. J., C. J. Van Nevel, R. L. Baldwin, and J. G. Morris. 1976. Rumen microbial growth rates and yields: effect of amino acids and protein. *J. Dairy Sci.* 59:68-79.
- Martin, S. K., and C. A. Hibberd., 1990. Intake and digestibility of low-quality native grass hay by beef cows supplemented with graded levels of soybean hulls. *J. Anim. Sci.* 68:4319-4325.
- McDonnell, M. L. 1982. Means of improving the performance of ruminants fed corn residues. Ph. D. Dissertation. Univ. of Nebraska, Lincoln.

- Miller, A. J., D. B. Faulkner, R. K. Knipe, D. R. Strohbehm, D. F. Parrett, and L. L. Berger. 2001. Critical control points for profitability in the cow-calf enterprise. *Prof. Anim. Sci.* 17:295–302.
- Miron, J., E. Yosef, and D. Ben-Ghedalia. 2001. Composition and in vitro digestibility of monosaccharide constituents of selected byproduct feeds. *J. Agric. Food Chem.* 49:2322–2326.
- NASS. 2008. National Agricultural Statistics Service. http://www.nass.usda.gov/Publications/Ag_Statistics/2008/TOC2008.pdf. Accessed Nov. 13, 2008.
- NRC. 2007. Nutrient Requirements of Small Ruminants. Sheep, Goats, Cervids, and New World Camelids. Natl. Acad. Press, Washington, DC.
- Segers, J. R., A. M. Stelzleni, T. D. Pringle, M. A. Froetschel, C. L. Ross, and R. L. Stewart, Jr. 2013. Use of corn gluten feed and dried distillers grains plus solubles as a replacement for soybean meal and corn for supplementation in a corn silage-based stocker system. *J. Anim. Sci.* 91:950-956.
- Slater, A. L., M. L. Eastridge, J. L. Firkins, and L. J. Bidinger. 2000. Effects of starch source and level of forage neutral detergent fiber on performance of dairy cows. *J. Dairy Sci.* 83:313–321.
- Stock, R. A., J. M. Lewis, T. J. Klopfenstein, and C. T. Milton. 2000. Review of new information on the use of wet and dry milling feed by-products in feedlot diets. *J. Anim. Sci.* 78:1-12 (E-Suppl.)
- Stuedemann, J. A., and C. S. Hoveland. 1988. Fescue endophyte: History and impact on animal agriculture. *J. Prod. Agric.* 1:39-44.
- Turner, H. A., and T. DelCurto. 1991. Nutritional and managerial considerations for range beef cattle production. *Vet. Clin. North Am. Food Anim. Pract.* 7:95-125.
- Welch, J. G., and A. P. Hooper. 1988. Ingestion of feed and water In: D. C. Church, editor, *The ruminant animal: Digestive physiology and nutrition*. Prentice Hall, Englewood Cliffs, NJ. P 108-117.
- Wiley, J. S., M. K. Petersen, R. P. Ansotegui, and R. A. Bellows. 1991. Production from first-calf beef heifers fed a maintenance or low level of prepartum nutrition and ruminally undegradable or degradable protein postpartum. *J. Anim. Sci.* 69:4279–4293.
- Winterholler, S. J., D. L. Lalman, T. K. Dye, C. P. McMurphy, and C. J. Richards. 2009. In situ ruminal degradation characteristics of by-product feedstuffs for beef cattle consuming low-quality forage. *J. Anim. Sci.* 87:2996-3002.
- Winterholler, S. J., C. P. McMurphy, G. L. Mourer, C. R. Krehbiel, G. W. Horn, and D. L. Lalman. 2012. Supplementation of dried distillers grains with solubles to beef cows consuming low-quality forage during late gestation and early lactation. *J. Anim. Sci.* 90:2014-2025.

Introduction

Low-quality forages, such as tall fescue, often require supplementation in order to meet the nutritional requirements of ruminant animals. Previous studies have evaluated the effects of supplementation on low-quality forage intake and digestibility by supplementing with co-product feeds such as soybean hulls (**SH**) (Grigsby et al., 1992; Slater et al., 2000) and distiller's dried grains with solubles (**DDGS**) (Ham et al., 2004; Klopfenstein et al., 1978). Increased concentrations of volatile fatty acids (**VFA**) and increased digestibility of dry matter (**DM**) have been reported from feeding SH as a supplement (Grigsby et al., 1992; Slater et al., 2000). Distiller's dried grains with solubles fed as a supplement has been reported to act as an adequate protein and energy source when fed up to 40% of a finishing diet, and cattle require less fiber from forage in the diet to maintain rumen function (Ham et al., 1994; Klopfenstein et al., 1978). Feeding a combination of SH and DDGS resulted in improved digestibility compared with either co-product fed individually in a limit-feeding concentrate scenario (Smith, 2014). However, little information is available about the associative effects of feeding combinations of co-product feedstuffs on a basal diet of low-quality forage. Therefore, the objectives of this study were to determine the impact of supplementation with SH, DDGS, or a 50:50 mixture of the two (**MIX**) on ruminal fermentation characteristics and in-situ forage disappearance kinetics in lactating and non-lactating ruminally-cannulated beef cows fed tall fescue hay.

Materials and Methods

This experiment was conducted in accordance with procedures approved by the University of Arkansas Institutional Animal Care and Use Committee (Protocol # 12023). Three lactating and three non-lactating ruminally-cannulated Angus x Gelbvieh crossbred beef cows (679 ± 18.6 kg body weight; **BW**) were offered tall fescue hay for ad libitum consumption from

large round bales along with supplements fed at 0.5% of BW of each individual cow.

Supplements fed included SH, DDGS, and MIX.

Cows within each production status (lactating or non-lactating) were allocated to separate 3×3 Latin Squares, and those squares were repeated for a total of six observations on each supplement within each production status. During the course of the experiment, the cows were housed together in a drylot pen and then sorted randomly into individual pens each day and offered their respective supplements at 1600 h. Calves of the lactating cows were not allowed in the pen with their dams while their dams were offered their supplements. The cows were allowed thirty min. to consume the supplements and then were returned to their drylot pen. Each period lasted 21 d, having a 14 d adaptation period at the beginning of each period.

On d 8 of each period, 100 grams (± 0.01 g) of a supplement containing 10 g of an external marker of TiO_2 along with 90 g of a mixture of SH, DDGS, and liquid molasses (42.5:42.5:5) was added to each supplement prior to being given to each cow and was fed for the remainder of each period. During the last 7 d of each period, various samples were taken. Samples included fecal grab samples from each cow during the morning and afternoon along with samples of the tall fescue hay, SH, and DDGS each day during this 7-d period. Fecal and feed samples were dried to a constant weight at 50°C in a forced-air drying oven and then ground to pass through a 1-mm screen using a Wiley mill (Arthur H. Thomas, Philadelphia, PA, USA). Fecal samples were composited by cow and period, and feed samples were composited by type and period prior to grinding.

On d 15 of the study, an extra cow was used to gather a sample of consumed hay via the ruminal evacuation technique. Total ruminal contents were removed, and the cow was returned to the drylot pen and allowed to consume tall fescue for fifteen minutes. After the allotted time,

the masticate sample was removed from the rumen, and the original contents were returned to the rumen. Masticate samples were lyophilized, ground, and composited by period for further analyses. This process was repeated on d 21 of each period. During the last 7 d of each period, Dacron bags (10 x 20 cm; 50 μ m pore size) containing approximately 5 g of tall fescue that was ground to pass through a 2-mm screen using a Wiley mill (Arthur H. Thomas, Philadelphia, PA, USA) were sealed with rubber bands and then placed inside of a mesh bag which was placed inside of the rumen of each cow. The bags were inserted at specified intervals to achieve ruminal incubation times of 0, 6, 12, 22, 34, 52, 76, 100, 124, and 148 h.

At 2000 h on d 21 of each period, the mesh bags containing the Dacron in-situ bags were removed from the rumen of each cow and immediately submerged in cold water to suppress further microbial activity. The in situ bags were then removed from the mesh bag, rinsed again in cold water, and washed in a top loading washer ten times with one minute of agitation followed by two minutes of spinning for each cycle. The in situ bags were then placed into a drying oven and dried to a constant weight at 50° C.

Also on d 21 of each period, rumen fluid samples were taken from each cow at 2-h intervals from 1600 h through 2400 h to correspond to times immediately prior to feeding and 2, 4, 6, and 8 h after feeding. Rumen contents were removed from various parts of the rumen and placed in a plastic bucket. The contents were then mixed and folded into eight layers of cheesecloth and the rumen fluid was strained into a specimen cup. The rumen contents were placed back into the rumen of each cow after straining. The cows remained in their respective pens without access to hay during the period between 1600 and 2400 h.

Immediately after taking rumen fluid samples, the pH of each rumen fluid sample was recorded. Rumen fluid samples (1000 μ L) from each cow at each time period were combined

with 200 μL of a metaphosphoric acid solution containing 2-ethylbutyric acid as an internal standard in a centrifuge tube for later volatile fatty acid (VFA) analysis and placed into a cooler on ice. Also, 800 μL of rumen fluid was combined with 400 μL 0.1 M HCl in a centrifuge tube for ammonia-N analysis and placed in a cooler on ice. These samples were then placed into a freezer at 0° C and frozen until analyses were completed. At the end of the sampling period, the cows were returned to their drylot pen. The following morning, the cows were gathered, weighed, and assigned to their new supplement for the beginning of the next period.

Laboratory Procedures

Dry matter (DM) was determined on all hay, feed, and fecal samples by being dried to a constant weight at 105° C. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed non-sequentially using the ANKOM200/220 Fiber Analyzer (ANKOM Technology Corporation, Fairport, NY, USA; Vogel et al., 1999). Organic matter was determined on all samples in a muffle furnace (Method 942.05; AOAC, 2000). Acid-detergent insoluble ash (ADIA) content of feed and fecal samples was determined using the methods outlined for the ADF procedure followed by combustion in a muffle furnace. Volatile fatty acids were analyzed by gas chromatography using the methods and equipment described by Akins et al. (2009). Ammonia-N concentrations in frozen rumen fluid samples were determined colorimetrically (Broderick and Kang, 1980). All samples were corrected to a DM basis.

Titanium dioxide concentrations of the supplement and fecal samples were determined using the procedures of Myers et al. (2004). Alkaline-peroxide lignin (APL) concentrations of masticate and fecal samples were determined using the procedures of Cochran et al. (1988). Fecal output was determined by dividing the daily dosage of TiO_2 by the TiO_2 concentration in the feces. Digestibility and forage intake were then determined by the following equations:

$$\text{DM digestibility} = 100 - 100 \times \frac{\text{APL concentration in the feed}}{\text{APL concentration in feces}}$$

$$\text{DM intake} = \frac{\text{Fecal DM output}}{1 - (\text{diet digest}/100)}$$

Statistical Analyses

Statistical analysis was conducted using the mixed models procedure of SAS[®] (SAS Institute, Cary, NC, USA). The experimental design of this project was a replicated 3 × 3 Latin Square design within production status. There were two cows per supplement per period (one lactating and one non-lactating), and each cow was considered the experimental unit since each cow received their daily supplement allocation individually. Fixed effects in this model included the effects of supplement, production status, and the supplement × production status interaction. Random effects in this model include the period and the animal. The model for VFA and ammonia-N concentrations included sampling time as a repeated measurement and cow (supplement × period) as the subject.

The proportion of DM remaining in the in situ bags at each incubation time were fit to the non-linear model of Mertens and Loftén (1980) using PROC NLIN of SAS (SAS Institute, Inc.). This model fractionated the forage into multiple fractions and assessed the disappearance characteristics of the forage from the Dacron bags. Fraction A is the immediately soluble fraction and fraction B is that fraction that disappeared at a measurable rate (fraction B). The disappearance lag time, and the rate of DM disappearance (K_d) were also derived directly from the model. The undegradable fraction (fraction U) was calculated as $100 - B - A$. Effective ruminal disappearance was estimated as $A + [B \times (K_d / (K_d + K_p))]$ (Ørskov and McDonald, 1979) where K_p is the rate of passage that was estimated at 0.035 h^{-1} . Data derived from the non-linear model were analyzed using mixed-models procedures of SAS (SAS Institute, Inc.) as described

previously. Statistical significance was designated as ($P < 0.05$) and ($0.05 < P < 0.10$) was considered a tendency in all instances.

Results

Although BW differed ($P < 0.05$) because of status, effects of supplement ($P = 0.47$) or status ($P = 0.19$) were not observed for BW change during the 21-d feeding periods (Table 2). In-situ forage disappearance measurements were not different ($P \geq 0.46$) among DDGS, SH, or MIX. In situ effective ruminal disappearance was greater ($P < 0.05$) and rate of forage disappearance tended ($P = 0.05$) to be greater in non-lactating cows compared with lactating cows (Table 3). The supplement \times production status interaction tended ($P = 0.06$) to affect effective ruminal disappearance, but other ruminal disappearance kinetic measurements were not different ($P \geq 0.19$) among supplements or production status.

Concentrations of ruminal $\text{NH}_3\text{-N}$ and total VFA were affected ($P < 0.05$) by supplement and sampling time, but not by status ($P = 0.94$) or the supplement \times sampling time interaction ($P = 0.19$). Ruminal $\text{NH}_3\text{-N}$ concentrations were greater ($P < 0.05$) from DDGS than from SH or MIX whereas total VFA were greater ($P < 0.05$) from SH compared with MIX and with MIX compared with DDGS.

The supplement \times sampling time interaction affected ($P < 0.05$) molar concentrations of acetate (Figure 1). Immediately prior to feeding, molar concentrations of acetate did not differ ($P > 0.10$) among supplements (Figure 1). At 2 h post-feeding, molar concentrations of acetate were greater ($P < 0.05$) from SH compared with MIX, and did not differ ($P > 0.10$) between MIX and DDGS. From 4 h to 8 h post-feeding, molar concentrations of acetate were greatest ($P < 0.05$) from SH compared with MIX and from MIX compared with DDGS.

The supplement × sampling time interaction also affected ($P < 0.05$) molar concentrations of propionate (Figure 2). Immediately prior to feeding, molar concentrations of propionate did not differ ($P > 0.10$) between SH and MIX, or between MIX and DDGS, but were greater ($P < 0.05$) from DDGS compared with SH. At 2 h to 8 h post-feeding, molar concentrations of propionate were greater ($P < 0.05$) from DDGS compared with MIX and from MIX compared with SH.

The supplement × sampling time interaction affected ($P < 0.05$) the molar concentrations of butyrate (Figure 3). Immediately prior to feeding, molar concentrations of butyrate did not differ ($P > 0.10$) among supplements. From 2 h to 8 h post-feeding, molar concentrations of butyrate were greater ($P < 0.05$) from DDGS compared with MIX and from MIX compared with SH.

The supplement × sampling time interaction affected ($P < 0.05$) the molar concentrations of isovalerate. Immediately prior to feeding, molar concentrations of isovalerate were greater in SH compared with MIX or DDGS. At 8 h post feeding, molar concentrations of isovalerate were greater ($P < 0.05$) from DDGS compared with those from SH and MIX. However, molar concentrations of isovalerate did not differ ($P > 0.10$) among supplement from 2 h to 6 h post-feeding.

There were no supplement × sampling time interactions for isobutyrate and valerate. Isobutyrate concentrations were greater ($P < 0.05$) from DDGS and MIX than from SH (Table 4). Valerate concentrations differed ($P < 0.05$) among all three supplement treatments with the greatest concentrations from DDGS and the lowest concentrations from SH.

The supplement × sampling time interaction affected ($P < 0.05$) the molar concentrations of total branched-chain VFA. Immediately prior to feeding and 2 h post-feeding, total branched

chain vfa did not differ ($P > 0.10$) between DDGS and MIX, but these concentrations were greater ($P < 0.05$) than those from SH. Molar concentrations of total branched-chain vfa did not differ ($P > 0.10$) among supplements at 4 h and 6 h post-feeding. At 8 h post-feeding, total branched-chain vfa were greater ($P < 0.05$) from DDGS compared with those from MIX and SH which did not differ ($P > 0.10$) from each other.

Discussion

In the present study, it is feasible that differences in in-situ forage disappearance were not detectable due to the low amounts of supplements fed or that all supplements were offered at the same proportion of BW. In a previous study (Smith, 2014), initial in-situ forage disappearance was reduced ($P < 0.05$) when cows were offered limit-fed SH and limit-fed distillers dried grains with solubles but not from cows offered a mix of SH and DDGS (Smith, 2014). In that study, the different co-product feedstuffs were offered to meet the metabolizable energy requirement of the cows which meant that they were offered at considerably greater levels than those offered in the present study. Each cow in the present was only offered supplements at 0.5% of total BW. This was done in order to meet the NRC (2000) requirements for the lactating cows while attempting to still meet the majority of their energy requirements with the poor-quality hay. .

Ruminal ammonia-N concentrations and molar concentrations of propionate were greatest when cows were fed DDGS. Therefore, DDGS may better meet both the energy and protein requirements of cows offered poor-quality hay than SH or MIX. Although supplementation with SH resulted in greater total VFA and acetate concentrations, propionate is utilized more efficiently in the body once absorbed resulting in greater energy return compared with the other VFA. A study by Ashenbach et al. (2011) makes a point that measurements taken from ruminal fluid can vary. They state that ruminal fluid is not homogeneous throughout the

rumen and that different sampling techniques will produce varied results (Ashenbach et al., 2011). It is possible that the technique used in this study for rumen fluid collection caused VFA results to vary. However, samples were pulled from four different sections of the rumen, mixed together, and strained through cheesecloth in the present study to minimize these effects.

Supplement \times sampling time interactions were observed in the molar concentrations of acetate, propionate, butyrate, and total branched-chain amino acids. It appears that the differences in molar concentration occurred during later hours of the afternoon and into the evening (after 1800 h). No differences were detectable in most cases immediately prior to feeding, which implies that the impacts of the different supplements had subsided by that time.

Conclusion

Overall, minimal differences were observed in in-situ forage disappearance measurements among lactating and non-lactating cows and none were observed because of to the supplements offered. Supplementation with DDGS improved molar concentrations of propionate and butyrate for at least 8 h after feeding. Since these VFA result in greater energy production once absorbed by the cow, combined with the greater ruminal ammonia-N concentrations, DDGS should improve the energy and protein status of cows offered poor-quality tall fescue hay compared with those offered supplementation with SH or MIX.

Literature Cited

- Akins, M.S., Kegley, E. B., Coffey, K. P., Caldwell, J. D., Lusby, K. S., Moore, J. C., Coblenz, W. K., 2009. Comparison of bloat potential between a variety of soft-red versus a variety of hard-red winter wheat forage. *J. Anim. Sci.* 87:3278-3287.
- AOAC, 2000. Official methods of analysis of the Association of Official Analytical Chemists International (17th Ed). Gaithersburg, MD.
- Aschenbach, J. R., Penner, G. B., Stumpff, F., and Gabel, G. 2011. RUMINANT NUTRITION SYMPOSIUM: Role of fermentation acid absorption in the regulation of ruminal pH. *J. Anim. Sci.* 89:1092-1107.
- Broderick, G. A., Kang, J. H., 1980. Automated simultaneous determination of ammonia and total amino acids in ruminal fluid and in vitro media. *J. Dairy. Sci.* 63:64-75.
- Grigsby, K. N., M. S. Kerley, J. A. Paterson, and J. C. Weigel. 1992. Site and extent of nutrient digestion by steers fed a low-quality bromegrass hay diet with incremental levels of soybean hull substitution. *J. Anim. Sci.* 70:1941–1949.
- Ham, G. A., R. A. Stock, T. J. Klopfenstein, E. M. Larson, D. H. Shain, and R. P. Huffman. 1994. Wet corn distillers byproducts compared with dried corn distillers gains with solubles as a source of protein and energy for ruminants. *J. Anim. Sci.* 72:3246–3257
- Klopfenstein, T., J. Waller, N. Merchen, and L. Petersen. 1978. Distillers grains as a naturally protected protein for ruminants. *Distillers Feed Conference Proceedings.* 33:38-46.
- Mertens, D. R., and J. R. Loften, 1980. The effect of starch on forage fiber digestion kinetics in vitro. *J. Dairy Sci.* 63, 1437-1446.
- NRC, 2000. Nutrient Requirements of Beef Cattle (7th Ed.). National Academy Press, Washington, DC.
- Ørskov, E. R., and I. McDonald, 1979. The estimation of protein degradation in the rumen from incubation measurements weighted according to rate of passage. *J. Agric. Sci.* 92, 449-503.
- Slater, A. L., M. L. Eastridge, J. L. Firkins, and L. J. Bidinger. 2000. Effects of starch source and level of forage neutral detergent fiber on performance of dairy cows. *J. Dairy Sci.* 83:313–321.
- Smith, W. B., Coffey, K. P., Rhein, R. T., Kegley, E. B., Philipp, D., Caldwell, J. D., and Young, A. N., 2014. Effect of limit-fed co-product feedstuffs on production, digestion, fermentation, and rumen function in beef cattle. Ch 3. Effect of limit-fed co-product feedstuffs on production, digestion, fermentation and rumen function in beef cattle. 102-122.

Vogel, K. P., Pederson, J. F., Masterdon, S. D., Toy, J. J., 1999. Evaluation of a filter bag system for NDF, ADF, and IVDMD forage analysis. *Crop Sci.* 39:276-279.

Table 1: Quality measurement of soybean hulls, distillers dried grains with solubles, tall fescue hay and masticate offered to lactating and non-lactating cows.

Item ^a	Soybean	Distillers dried		
	Hulls	grains + solub.	Hay	Masticate ^b
----- % of DM -----				
Ash	5.3	4.6	7.5	8.9
NDF	64.2	45.4	73.9	73.7
ADF	49.7	18.3	nd ^c	46.6
ADIA	0.36	0.05	nd	3.48
CP	12.2 ^d	30.4 ^d	nd	nd
Fat	2.1 ^d	10.7 ^d	nd	nd

^a NDF = neutral detergent fiber; ADF = acid detergent fiber; ADIA = acid-detergent insoluble ash; CP = crude protein.

^b Masticate represents samples of hay selected by a ruminally-cannulated cow following total ruminal evacuation.

^c nd = not determined.

^d represents values reported by NRC (2000).

Table 2: Body weight, body weight change, in lactating and non-lactating cows offered a basal diet of tall fescue hay and supplemented with soybean hulls, distillers dried grains, or a mix of the two at 0.5% of cow body weight

Item	Supplement				Status			Effect ^a
	Distillers	Mix	Soyhulls	SE	Lactating	Open	SE	
Body Wt, kg	676.8	675.4	678.1	18.6	624.7	728.9	25.6	ns
Body Wt Change, kg	-0.5	5.1	2.3	3.3	-0.2	4.8	2.8	ns

^a ns = not significant

Table 3: In-situ forage dry matter disappearance characteristics of tall fescue hay in lactating and non-lactating cows offered a basal diet of tall fescue hay and supplemented with soybean hulls, distillers dried grains, or a mix of the two at 0.5% of cow body weight

Item ^a	Supplement			SE	Status		SE	Effect ^b
	Distillers	Mix	Soyhulls		Lactating	Open		
A, %	15.8	15.6	15.6	0.84	15.7	15.7	0.81	ns
B, %	59.0	59.5	60.1	1.46	59.6	59.5	1.44	ns
U, %	25.3	24.9	24.3	1.20	24.8	24.9	1.23	ns
k, h ⁻¹	0.029	0.030	0.027	0.0019	0.026	0.031	0.0020	ns
lag, h	2.6	2.4	2.7	0.54	2.7	2.5	0.49	ns
Extent of disappear., %	74.8	75.1	75.7	1.20	75.2	75.2	1.22	ns
Effective disappear., %	42.3	42.6	41.4	1.24	40.6	43.6	1.25	St

^a A= immediately soluble fraction; B = fraction that disappeared at a measurable rate; U = undegradable fraction and was calculated as 100 – B – A, k = rate of disappearance from the Dacron bags; lag = time from bag insertion until measurable disappearance of the B fraction occurred; Extent of disappearance = A + B; Effective disappearance = $A + B[k_d/(k_d+k_p)]$.

^b ns = not significant ($P \geq 0.10$);

Table 4: Ruminal fermentation measurements from cows offered a basal diet of tall fescue hay and supplemented with soybean hulls, distillers dried grains, or a mix of the two at 0.5% of cow body weight

Item	Supplement			SE	Status		SE	Effect ^a
	Distillers	Mix	Soyhulls		Lactating	Open		
Rumen NH ₃ -N,								
mM	6.1 ^b	4.4 ^c	3.8 ^c	0.63	4.8	4.7	0.71	S
total vfa, mM	90.5 ^d	94.2 ^c	100.9 ^b	3.59	96.2	94.2	3.82	S, T
	----- mole/100 mole -----							
acetate	67.6	69.6	71.4	0.28	69.9	69.2	0.26	S, T, St, S*T, St*T
propionate	19.3	18.5	17.5	0.22	18.4	18.5	0.20	S, T, S*T, St*T
isobutyrate	0.9	0.8	0.8	0.04	0.8	0.8	0.04	S, T, St, St*T
butyrate	10.3	9.2	8.6	0.17	9.2	9.6	0.17	S, T, St, S*T, S*T
isovalerate	1	1	0.9	0.06	0.9	0.9	0.07	S, T, S*T, St*T
valerate	1	0.9	0.8	0.04	0.8	0.9	0.04	S, T, S*St, S*T, St*T
total branched								
chain vfa	1.8	1.8	1.7	0.1	1.7	1.8	0.10	S, S*T, St*T

^a S = supplement effect ($P < 0.05$); T = time effect ($P < 0.05$); St = status effect ($P < 0.05$); S*T = supplement \times time effect ($P < 0.05$); St*T = status \times time effect ($P < 0.05$); S*St = supplement \times status effect ($P < 0.05$).

^{b,c,d} Main effect means within a row and either supplement or production status category with a common superscript letter are different ($P < 0.05$).

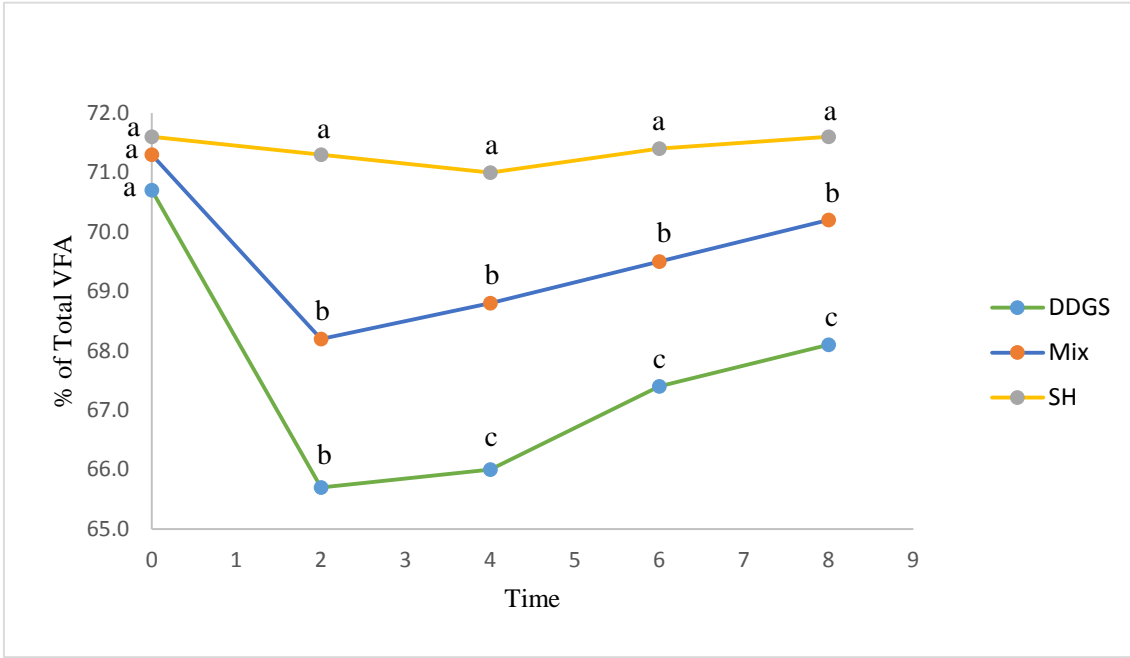


Figure 1. Molar percent of acetate over time after feeding co-product feedstuffs. DDGS = distillers dried grains with solubles; MIX = 50:50 mixture of DDGS and soybean hulls; SH = soybean hulls

a,b,c Means within a sampling time without a common superscript differ ($P < 0.05$)

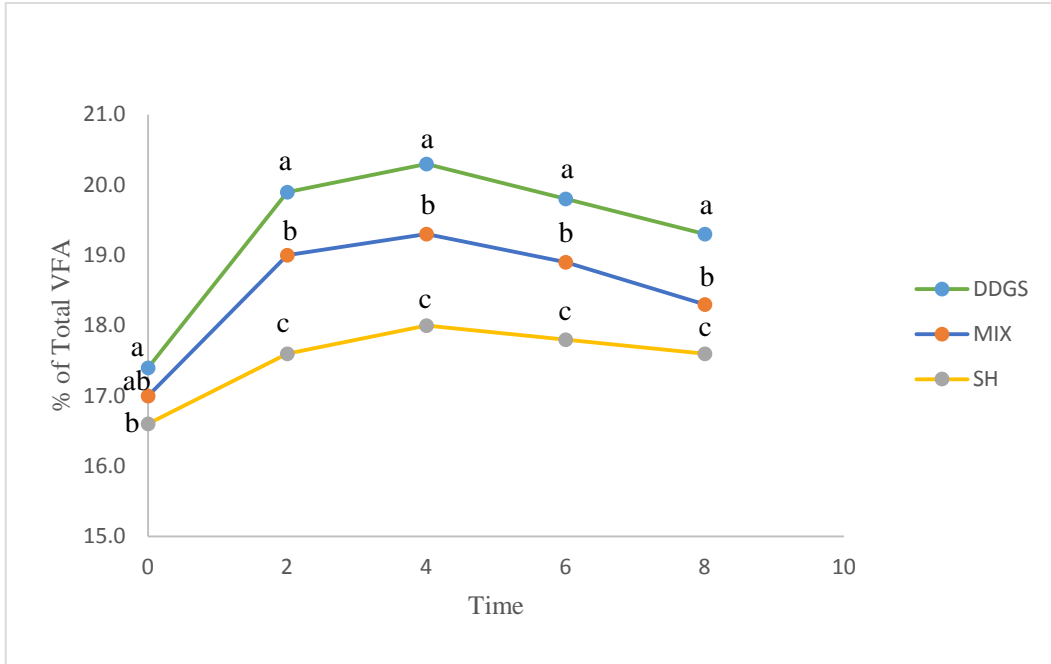


Figure 2. Molar percent of propionate over time after feeding co-product feedstuffs. DDGS = distillers dried grains with solubles; MIX = 50:50 mixture of DDGS and soybean hulls; SH = soybean hulls.

^{a,b,c} Means within a sampling time without a common superscript differ ($P < 0.05$)

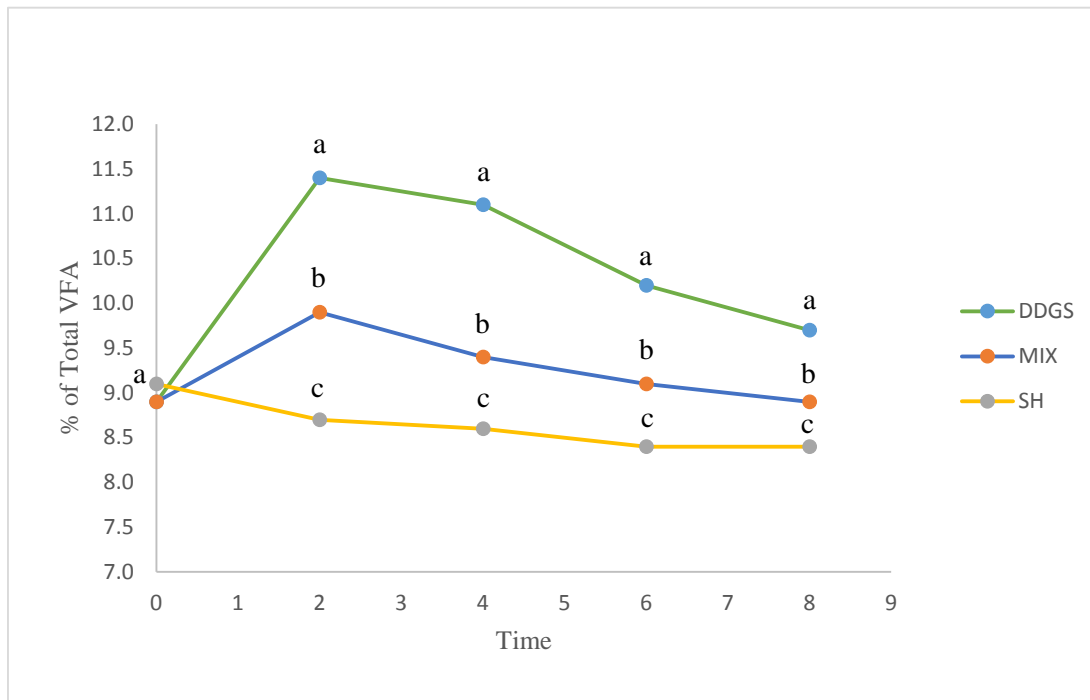


Figure 3. Molar percent of butyrate over time after feeding co-product feedstuffs. DDGS = distillers dried grains with solubles; MIX = 50:50 mixture of DDGS and soybean hulls; SH = soybean hulls
^{a,b,c} Means within a sampling time without a common superscript differ ($P < 0.05$)