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Effects of Protein or Energy Supplementation on *In Situ* Disappearance of Low- and High-Quality Coastal Bermudagrass Hay in Goats

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ABSTRACT

The objective of this research was to determine if supplementing protein or energy would improve the ruminal *in situ* disappearance of two qualities of (5.8 or 13.4% CP) Coastal Bermudagrass (*Cynodon dactylon* (L.) Pers.) hay in goats. Treatments were arranged in a 4 × 4 Latin Square design and consisted of either sodium caseinate (0.122% BW), corn starch (0.15% BW), or dextrose (0.15% BW) administered daily into the rumen; compared to a hay-only control. Goats had *ad libitum* access to Coastal Bermudagrass hay (5.8 and 13.4% CP for experiment 1 and 2, respectively) at all times during the experiment. Each period consisted of 14 days for treatment adaptation and followed by incubation of *in situ* bags. *In situ* hay samples were analyzed for dry matter, organic matter, neutral detergent fiber, and acid detergent fiber disappearance after ruminal incubation. Dry matter, organic matter, neutral detergent fiber, and acid detergent fiber disappearance were not affected ($P > 0.05$) by protein or energy supplementation in when either high- or low-quality bermudagrass was fed. Further research is needed to determine if this was due to the nutritive value of the basal diet, or the value of the diet selectively ingested by the goats from the basal diet.

KEY WORDS: small ruminant, digestion, supplements, nutritive value, forage quality

INTRODUCTION

The goat population in U.S. increased by 3% during 2007 to a total of 3.02 million head (NASS 2008), due in part to the increase of ethnic diversity in the country (Oman et al., 1999) and land fragmentation of rural areas. Because their ability to utilize woody vegetation and preference for browse and forbs, goats thrive on land with a low concentration of grasses, where bulk grazers, such as cattle, are not as well adapted (Papachristou et al., 1999; Ott et al., 2004). Because of land fragmentation of cattle ranches, goats are often raised on cultivated pastures originally designed for bulk grazers and have limited access to browse (Goodwin et al., 2004). As a result, producers often rely on grass or grass hay as a primary source of goat feed, despite their preference for browse and forbs. Browse and forbs often allow for greater selectivity by goats resulting in an intake that has greater nutrient and lesser fiber concentrations compared to grasses. Grasses can play a constructive, supportive role in goat production. It has been reported (Packard et al., 2007a) that as the quantity of accessible browse decreased, supplementation of Bermudagrass (*Cynodon dactylon*) hay aided in increasing average daily gain (ADG) in growing meat goats.

Protein is the first limiting nutrient of cattle grazing low-quality grass forages (National Research Council 1981; Heldt et al., 1999a). Forages with a crude protein (CP) concentration less than 6 to 7% (National Research Council 1981; Titgemeyer et al., 2004) will compromise intake, digestibility (Mathis et al., 2000), and growth in ruminant animals. Degradable intake protein (DIP) in cattle is known to increase ruminal ammonia nitrogen (NH_3 N) concentrations and volatile fatty acids (VFA; Heldt et al., 1999a), as well as increase dry matter (DM), and organic matter (OM) intake and digestibility of low-quality forage (Bodine et al., 2000; Köster et al., 1996; Schmidt et al., 2006). Degradable intake protein requirements for goats have not been extensively studied. Currently, the recommended requirement for goats is 9% of total digestible nutrients (TDN; National Research Council 2007).

Cattle that graze low-quality forages are often deficient in digestible energy and protein. Although many producers supplement grains to increase energy in cattle grazing low-quality forages (Brokaw et al., 2001), it has been suggested (Caton et al, 1997) that energy supplementation reduced grazed forage intake in ruminants due to decreases in ruminal fiber digestion. The efficacy and efficiency of feeding energy concentrates to grazing ruminants in general, and browsing ruminants in particular, whose digestive systems are adapted to utilizing fibrous energy sources, requires more study.

In contrast to the vast amount of data available concerning supplementation of cattle consuming low-quality forages, data concerning energy or protein supplementation of goats is lacking. The objective of this experiment was to determine if supplementing sodium caseinate (0.122% BW), corn starch (0.15% BW), or dextrose (0.15% BW) would improve the ruminal digestion of two different qualities of (5.8 or 13.4% CP) Coastal Bermudagrass hay in goats.

MATERIALS AND METHODS

Experimental Design.[1] Four mature, ruminally-cannulated wethers were used (average BW 62 kg) in two 4 × 4 Latin Square design experiments. Each of the four treatment periods consisted of 21 days. The first 14 days were for adaptation and the final 7 days for *in situ* incubations. Goats were fed low-quality (5.8% CP; Experiment 1) or high-quality (13.4% CP; Experiment 2) Coastal Bermudagrass hay (Table 1) *ad libitum* and had continuous access to clean water and a trace mineralized salt block. Supplement treatments consisted of sodium caseinate (0.122% BW/day), corn starch (0.15% BW/day), or dextrose (0.15% BW/day) administered directly into the rumen daily at 1700 h; compared to a hay-only control. Protein (sodium caseinate) treatment levels administered were the lowest level estimated to provide sufficient DIP to maximize forage intake and digestion based on previous work with cattle (Heldt et al., 1999a; Köster et al., 1996). Energy (starch or dextrose) treatment levels administered were

[1] The Tarleton State University Institutional Agricultural Animal Care and Use Committee approved all experimental protocols.

chosen to simulate quantities of ruminally digestible starch, commonly fed to cattle as a cereal grain supplement (Heldt et al., 1999a).

Table 1. Chemical composition (% DM) of low- and high-quality Coastal Bermudagrass hay utilized in this study.

	Low-Quality	High-Quality
DM[1]	96.4	94.4
OM	95.2	93.3
CP	5.8	13.4
NDF	72.5	71.3
ADF	39.4	37.5

[1]Organic matter, OM; Crude protein, CP; Neutral detergent fiber, NDF; Acid detergent fiber, ADF.

In Situ Methodology. Ground (2-mm screen) samples of Coastal Bermudagrass hay (2 g) were placed in dacron sample bags (Ankom Technology, Macedon NY); 50 ± 15 µ porosity, 5 × 10 cm size) to give a sample:surface area ratio of 20 mg:cm^2. Quadruplicate samples were incubated for 0, 2, 4, 8, 16, 24, 48, or 72 h in the rumen of the goats. Because not all bags were able to be incubated simultaneously, the incubation period was conducted over 7 days. Ten bags were placed in the goat rumen at each time tied to a tube (31 cm length). After removal, bags were stored frozen at -20°C, thawed to rinse with quadruplicate zero hour bags in water, according to procedures previously described by Vanzandt et al. (1998), and dried at 55°C in a forced-air oven for 48 h. Dry *in situ* bags were weighed upon removal from oven in order to obtain DM disappearance (DMD). Bags were opened and batched by animal and incubation time and ground using a Wiley Mill to pass through a 1-mm screen. *In situ* and control samples were analyzed for DM and OM (AOAC 1990) neutral detergent fiber (NDF; ANKOM Technology, Macedon, NY USA), and acid detergent fiber (ADF; ANKOM Technology).

The degradation profiles of DM and OM were determined using a model previously described by Ørskov and McDonald (1979). Potential degradability was calculated as PD = $a + b\ (1\text{-exp}^{-k(t-L)})$, where "*a*" is the soluble fraction, "*b*" is potentially degradable insoluble fraction, "k" is the degradation rate of "*b*," and "*L*" is the lag of degradation of "b."

Statistical Analysis. Data was statistically analyzed using SAS (SAS Inst. Inc., Cary, NC USA). The NLIN procedure was used to estimate fiber disappearance parameters. The GLM procedure was used to compare a, b, k, L, and PD across treatments. Dependent variables were a, b, k, L, and PD and the model contained the effect of treatment, goat, and period.

RESULTS

Experiment 1 (Low-Quality Hay).

Table 2. Rumen *in situ* dry matter (DM), organic matter (OM), acid detergent fiber (ADF) and neutral detergent fiber (NDF) disappearance characteristics for low-crude protein (5.8%) Coastal Bermudagrass hay in unsupplemented goats (control) or goats supplemented with sodium caseinate (0.12% BW/day), dextrose (0.15% BW/day), or corn starch (0.15% BW/day).

Treatment	a[1] (% of DM)	b (% of DM)	PD (% of DM)	k (/h)	L (h)
DM					
Control	18.6 ± 0.8	34.6 ± 2.6	53.2 ± 2.0	0.050 ± 0.011	1.99 ± 0.56
Casein	18.9 ± 0.8	34.8 ± 2.6	53.6 ± 2.0	0.051 ± 0.011	1.28 ± 0.56
Dextrose	16.8 ± 0.8	39.2 ± 2.6	56.0 ± 2.0	0.060 ± 0.011	1.71 ± 0.56
Starch	19.2 ± 0.8	34.9 ± 2.6	54.0 ± 2.0	0.057 ± 0.011	2.95 ± 0.56
OM					
Control	17.1 ± 0.4	36.0 ± 2.2	53.1 ± 1.9	0.049 ± 0.001	1.90 ± 0.46
Casein	17.2 ± 0.4	35.9 ± 2.2	53.0 ± 1.9	0.052 ± 0.001	1.26 ± 0.46
Dextrose	16.9 ± 0.4	38.0 ± 2.2	55.0 ± 1.9	0.061 ± 0.001	2.09 ± 0.46
Starch	17.5 ± 0.4	36.0 ± 2.2	53.6 ± 1.9	0.057 ± 0.001	2.95 ± 0.46
ADF					
Control	10.6 ± 0.5	27.5 ± 2.9	38.2 ± 2.6	0.060 ± 0.008	6.09 ± 1.36
Casein	9.2 ± 0.5	30.9 ± 2.9	40.2 ± 2.6	0.055 ± 0.008	1.16 ± 1.36
Dextrose	8.1 ± 0.5	32.7 ± 2.9	40.8 ± 2.6	0.048 ± 0.008	2.69 ± 1.36
Starch	9.8 ± 0.5	30.2 ± 2.9	39.9 ± 2.6	0.049 ± 0.008	3.85 ± 1.36
NDF					
Control	40.6 ± 11.0	412.8 ± 1.7	45.3 ± 1.5	0.058 ± 0.009	0.24 ± 0.53
Casein	57.1 ± 11.0	392.1 ± 1.7	45.0 ± 1.5	0.063 ± 0.009	0.31 ± 0.53
Dextrose	37.9 ± 11.0	429.2 ± 1.7	46.7 ± 1.5	0.062 ± 0.009	0.31 ± 0.53
Starch	53.6 ± 11.0	400.8 ± 1.7	45.5 ± 1.5	0.062 ± 0.009	1.87 ± 0.53

[1]a, soluble fraction; b, potentially degradable insoluble fraction, PD degradable fraction; k, degradation rate of b; L is the lag before degradation of b.

Rates of ruminal DM disappearance for sodium caseinate, dextrose, corn starch, and control treatments (0.051, 0.059, 0.057, and 0.050 per hour, respectively) did not differ ($P > 0.8$; Table 2). Extent of ruminal DM disappearance among sodium caseinate, dextrose, corn starch, and control treatments (53.6, 56.1, 54.1 and 53.2%, respectively) were also not affected ($P > 0.9$) by treatment. Rates of ruminal OM disappearance among sodium caseinate, dextrose, corn starch, and control treatments (0.052, 0.061, 0.057, and 0.049, respectively) were not affected ($P > 0.7$) by treatment. Extent of ruminal OM disappearance among sodium caseinate, dextrose, corn starch, and control treatments (53.0, 54.9, 53.5, and 53.1%, respectively) were not affected ($P > 0.9$) by supplement treatment. Rate of ruminal NDF disappearance among sodium caseinate, dextrose, corn starch, and control treatments (0.063, 0.062, 0.062, and 0.058%, respectively) were not affected ($P > 0.9$) by treatment. Extent of ruminal NDF disappearance between casein, dextrose, corn starch, and control treatments (44.9, 46.7, 45.4, and 45.3%, respectively) were not affected ($P > 0.6$) by treatment. Rates of ruminal ADF disappearance between sodium caseinate, dextrose, corn starch, and control treatments (0.055, 0.048, 0.049, and 0.60%, respectively) were not affected ($P > 0.4$) by treatment. Extent of ruminal ADF disappearance between sodium caseinate, dextrose, corn starch, and control treatments (40.1, 40.8, 39.9, and 38.1%, respectively) were not affected ($P > 0.7$) by treatment.

Experiment 2 (High-Quality Hay).

Table 3. Rumen *in situ* dry matter (DM), organic matter (OM), acid detergent fiber (ADF) and neutral detergent fiber (NDF) disappearance characteristics for high-crude protein (13.4%) Coastal Bermudagrass hay in unsupplemented goats (control) or goats supplemented with sodium caseinate (0.12% BW/day), dextrose (0.15% BW/day), or corn starch (0.15% BW/day).

Treatment	a[1] (% of DM)	b (% of DM)	PD (% of DM)	k (/h)	L (h)
DM					
Control	17.8 ± 0.5	49.4 ± 1.0	67.2 ± 1.0	0.035 ± 0.001	0.95 ± 0.63
Casein	20.0 ± 0.5	47.3 ± 1.0	67.3 ± 1.0	0.038 ± 0.001	3.40 ± 0.63
Dextrose	19.2 ± 0.5	48.6 ± 1.0	67.8 ± 1.0	0.036 ± 0.001	1.82 ± 0.63
Starch	19.3 ± 0.5	48.7 ± 1.0	68.0 ± 1.0	0.032 ± 0.001	1.55 ± 0.63
OM					
Control	15.2 ± 0.6	51.6 ± 1.0	66.8 ± 1.0	0.035 ± 0.001	0.97 ± 0.62
Casein	17.4 ± 0.6	49.5 ± 1.0	66.9 ± 1.0	0.039 ± 0.001	3.47 ± 0.62
Dextrose	16.7 ± 0.6	51.4 ± 1.0	67.6 ± 1.0	0.035 ± 0.001	1.55 ± 0.62
Starch	16.4 ± 0.6	51.2 ± 1.0	67.6 ± 1.0	0.032 ± 0.001	1.36 ± 0.62
ADF					
Control	2.2 ± 0.9	54.5. ± 1.7	56.7 ± 1.0	0.042 ± 0.008	1.87 ± 1.56
Casein	4.0 ± 0.9	51.3 ± 1.7	55.3 ± 1.0	0.060 ± 0.008	6.15 ± 1.56
Dextrose	2.9 ± 0.9	54.5 ± 1.7	57.4 ± 1.0	0.042 ± 0.008	2.17 ± 1.56
Starch	3.4 ± 0.9	54.5 ± 1.7	57.9 ± 1.0	0.036 ± 0.008	1.85 ± 1.56
NDF					
Control	1.4 ± 0.4	60.4 ± 1.3	61.8 ± 0.9	0.039 ± 0.001	0.67 ± 0.32
Casein	4.2 ± 0.4	57.1 ± 1.3	61.3 ± 0.9	0.042 ± 0.001	2.91 ± 0.32
Dextrose	2.4 ± 0.4	58.8 ± 1.3	61.2 ± 0.9	0.040 ± 0.001	1.10 ± 0.32
Starch	2.4 ± 0.4	59.5 ± 1.3	61.9 ± 0.9	0.035 ± 0.001	0.74 ± 0.32

[1]a, soluble fraction; b, potentially degradable insoluble fraction, PD degradable fraction; k, degradation rate of b; L is the lag before degradation of b.

Rates of ruminal DM disappearance for sodium caseinate, dextrose, corn starch, and control treatments (0.038, 0.036, 0.032, and 0.035 per hour, respectively) were least for corn starch and greatest for casein, with both the control and dextrose treatments being intermediate (Table 3). Extent of ruminal DM disappearance among sodium caseinate, dextrose, corn starch, and control treatments (67.3, 67.8, 68.0, 67.2%, respectively) were not affected ($P > 0.15$) by treatment. Rates of ruminal OM disappearance among sodium caseinate, dextrose, corn starch, and control treatments were 0.039, 0.035, 0.032, 0.035 per hour, respectively and did not differ. Extent of ruminal OM disappearance among sodium caseinate, dextrose, corn starch, and control treatments (66.9, 67.6, 67.6, 66.8%, respectively) were not affected (P > 0.15) by treatment. Rate of ruminal NDF disappearance among sodium caseinate, dextrose, corn starch, and control treatments were 0.042, 0.040, 0.035, 0.039 per hour, respectively with the corn starch treatment exhibiting the lesser (P < 0.05) rate of NDF disappearance. Extent of ruminal NDF disappearance between casein, dextrose, corn starch, and control treatments (61.3, 61.2, 61.9, and 61.8%, respectively) were not affected (P > 0.2) by supplement. Rates of ruminal ADF disappearance between sodium caseinate, dextrose, corn starch, and control treatments (0.060, 0.042, 0.036, 0.420 per hour, respectively) were not affected (P > 0.5) by treatment. Extent of ruminal ADF disappearance between sodium caseinate, dextrose, corn starch, and control treatments (55.3%, 57.4%, 57.9%, and 56.7%, respectively) were not affected (P > 0.16) by treatment.

DISCUSSION

The purpose of the this study was to determine if supplemental DIP in the form of sodium caseinate, or energy in the form of dextrose or corn starch, would affect *in situ* nutrient disappearance in goats fed either high-quality or low-quality Coastal Bermudagrass hay. There were no significant (P > 0.05) differences among *in situ* DM, OM, NDF, and ADF disappearance when sodium caseinate, dextrose, or corn starch were supplemented in goats consuming either low-quality (5.8% CP) or high-quality (13.4% CP) Coastal Bermudagrass hay.

It has been previously reported (Olson et al., 1999) that cattle consuming low-quality (4.9% CP) tallgrass-prairie hay showed a linear increase (P < 0.01) in forage DM, OM, and NDF intake when fed supplemental DIP in the form of sodium caseinate (0.12% BW/day). They also found that the addition of supplemental starch in the form of corn grits (0.15% BW/day) decreased (P < 0.01) forage DM, OM, and NDF intake linearly. Beaty et al. (1994) reported a quadratic increase in wheat straw (3.1% CP) intake by cattle with an increase up to 30% CP concentration in supplementation.

In further contrast to our results with goats, it has been found that cattle consuming low-quality (5.2% CP) forages had 22.1% (P < 0.01) greater OM digestibility and 10.8% (P = 0.03) greater NDF digestibility when supplemented with dextrose at 7.9% of the diet (P = 0.04), compared to starch supplementation at the same levels (Heldt et al., 1999a,b). Conversely, beef steers fed Bermudagrass (8.2% CP) exhibited no change (P > 0.41) in forage OM or NDF intake (P > 0.20) with supplemental DIP (Mathis et al., 2000).

Many researchers have found that cattle consuming forages with a CP concentration of 7% or less show a positive intake response to protein supplementation (Bandyk et al., 2001; Beaty et al, 1994; Bohnert et al, 2001; Farmer et al., 2001). Protein supplementation in the form of DIP is generally considered to be the dietary component that is first limiting to the utilization of low-quality forages in cattle (Koster et al., 1996).

Bacterial CP can supply from 50% to essentially all microbial protein required by beef cattle. The DIP requirement for beef cattle is 13% of TDN, which is equivalent to the assumed ruminal microbial CP requirement (National Research Council 2000). By contrast, the reported degradable protein intake requirement for goats is only 9% of TDN (National Research Council 2007). The predicted DIP difference in the DIP requirement of goats, as compared to cattle, could be the result of differences in rates of nutrient passage; an increased ability to conserve N by goats through recycling (National

Research Council 2007). Another possible explanation for the differences between cattle and goats, with respect to DIP requirement, is selectivity of forages; even when forage is fed as hay. Packard et al. (2007a, b) found that rejected orts left by goats, who were offered bermudagrass *ad libitum*, was lower in nutritive value than the original material offered. This supports previous reports by Pfister and Malecheck (1986), that goats are more selective in their feeding habits than sheep. Because forage intake is positively associated with rate of passage, it is possible that goats will select greater quality diets and, as a result, have greater intakes than cattle and sheep.

Goats appear to digest low-quality forages while maintaining adequate levels of production; however, some have suggested that supplementing goats with additional protein and energy feedstuffs will serve as a management tool in preventing weight loss during dry periods, when browse availability is limited (Ott et al., 2004). These authors also suggested that additional protein and energy supplementation may improve productivity of rangeland-fed goats in areas where browse is available.

There was no effect of sodium caseinate, corn starch, or dextrose on coastal Bermudagrass disappearance in goats consuming Coastal Bermudagrass hay with a total plant CP concentration either 5.8 or 13.4% CP. When we consider that bovine studies, using the same procedures, did show positive effects from these same supplement levels, we must conclude that there is an animal species difference. Greater N recycling by goats, species-specific differences in selectivity of ingested forages, and or rumination due to metabolic body size differences, and potentially smaller CP requirements for goats, are all possible explanations for the lack of response of goats fed supplements. The literature would predict positive responses in bovines.

Experiments should be conducted to determine at what point DIP and/or energy supplementation becomes beneficial for goats consuming a range of low to high-quality forages; fed in such a manner as to deprive animals of chance for selectivity, thereby depriving goats the possibility of increasing forage nutritive value intake vis-à-vis forage nutritive value offered. Until those trials are conducted, we can conclude that, unlike bovines, goats allowed to selectively feed on low-quality long-stem hay may not benefit from protein or energy supplements as readily as do bulk-grazing ruminants such as cattle.

REFERENCES

AOAC, 1990. Official Methods of Analysis, 15th ed. Washington, DC, USA.

Bandyk, C.A., R.C. Cochran, T.A. Wickersham, E.C. Titgemeyer, C.G. Farmer, J.J. Higgins. 2001. Effect of ruminal vs. postruminal admistration of degradable protein on utilization of low-quality forage by beef steers. Journal of Animal Science. 79: 225-231.

Beaty, J.L., R.C. Cochran, B.A. Linzenich, E.S. Vanzant, J.L. Morrill, R.T. Brandt, Jr, D.E. Johnson. 1994. Effect of Frequency of Supplementation and Protein Concentration in Supplements on Performance and Digestion Characteristics of Beef Cattle Consuming Low-Quality Forages. Journal of Animal Science. 72**:** 2475-2486.

Bodine, TN., H.T. Purvis II, C.J. Ackerman, C.L. Goad. 2000. Effects of supplementing prairie hay with corn and soybean meal on intake, digestion, and ruminal measurements by beef steers. Journal of Animal Science. 78**:** 3144-3154.

Bohnert, D.W., C.S. Schauer, M.L. Bauer, T. DelCurto. 2002. Influence of rumen protein degradability and supplementation frequency on steers consuming low-quality forage: I. Site of digestion and microbial efficiency. Journal of Animal Science. 80**:** 2967-2977.

Brokaw, L., B.W. Hess, D.C. Rule. 2001. Supplemental soybean oil or corn for beef heifers grazing summer pasture: Effects on forage intake, ruminal fermentation, and site and extent of digestion. Journal of Animal Science. 79**:** 2704-2712.

Caton, J.S., D.V. Dhuyvetter. 1997. Influence of Energy Supplementation on Grazing Ruminants: Requirements and Responses. Journal of Animal Science. 75**:** 533-542.

Farmer, C.G., R.C. Cochran, D.D. Simms, J.S. Heldt, C.P. Mathis. 2001. Impact of different wheat milling by-products in supplements on the forage use and performance of beef cattle consuming low-quality, tallgrass-prairie forage. Journal of Animal Science. 79: 2472-2480.

Goodwin, D.J., J.P. Muir, R.D. Wittie, T.F. Brown. 2004. Goat weight gains, forage selectivity and forage quality dynamics in three cultivated warm season pastures in north-central Texas. Small Ruminant Research. 52: 53-62.

Heldt, J.S., R.C. Cochran, C.P. Mathis, B.C. Woods, K.C. Olson, E.C. Titgemeyer, T.G. Nagaraja, E.S. Vanzant, D.E. Johnson. 1999a. Effects of Level and Source of Carbohydrate and Level of Degradable Intake Protein on Intake and Digestion of Low-Quality Tallgrass-Prairie Hay by Beef Steers. Journal of Animal Science. 77: 2846-2854.

Heldt, J.S., R.C. Cochran, G.L. Stokka, C.G. Farmer, C.P. Mathis, E.C. Titgemeyer, T.G. Nagaraja. 1999b. Effects of Different Supplemental Sugars and Starch Fed in Combination with Degradable Intake Protein on Low-Quality Forage Use by Beef Steers. Journal of Animal Science. 77: 2793-2802.

Köster, H.H., R.C. Cochran, E.C. Titgemeyer, E.S. Vanzant, I. Abdelgadir, G. St-Jean. 1996. Effect of Increasing Degradable Intake Protein on Intake and Digestion of Low-Quality, Tallgrass-Prairie Forages by Beef Cows. Journal of Animal Science. 74: 2473-2481.

Mathis, C.P., R.C. Cochran, J.S. Heldt, B.C. Woods, I.E.O. Abdelgadir, K.C. Olson, E.C. Titgemeyer, E.S. Vanzant. 2000. Effects of supplemental degradable intake protein on utilization of medium- to low-quality forages. Journal of Animal Science. 78: 224-232.

National Agricultural Statistics Service (NASS), 2008. Data and statistics, USDA. http://www.nass.usda.gov/Data_and_Statistics/

National Research Council, 1981. Nutrient Requirements of Goats: Angora, Dairy, and Meat Goats in Temperate and Tropical Countries. National Academy Press. Washington, DC.

National Research Council, 2000. Nutrient Requirements of Beef Cattle. National Academy Press. Washington, DC.

National Research Council, 2007. Nutrient Requirements of Small Ruminants: Sheep, Goats, Cervids, and New World Camelids. National Academy Press. Washington, DC.

Olson, K.C., R.C. Cochran, T.J. Jones, E.S. Vanzant, E.C. Titgemeyer, D.E. Johnson. 1999. Effects of Ruminal Administration of Supplemental Degradable Intake Protein and Starch on Utlilization of Low-Quality Warm-Season Grass Hay by Beef Steers. Journal of Animal Science. 77: 1016-1025.

Oman, J.S., D.F. Waldron, D.B. Griffin, J.W. Savell. 1999. Effect of Breed-Type and Feeding Regimen on Goat Carcass Traits. Journal of Animal Science. 77: 3215-3218.

Ørskov, E.R., I. McDonald. 1979. The estimation of protein degradability in the rumen from incubation measurements weighted according to passage rates. Journal Agricultural Science. 92: 499-503.

Ott, J.P., J.P. Muir, T.F. Brown, R.D. Wittie. 2004. Peanut meal supplementation for growing doe kids on woodland range. Small Ruminant Research. 52: 63-74.

Packard, C.E., J.P. Muir, R.D. Wittie. 2007a. Effects of groundnut stover or Bermudagrass hay supplementation to doe kids on winter hardwood range. Small Ruminant Research. 67: 1-6.

Packard, C.E., J.P. Muir, R.D. Wittie, R.M. Harp, M.A. Carr. 2007b. Peanut Stover and Bermudagrass Hay for Wethers on Summer Hardwood Rangeland in North Central Texas. Sheep and Goat Research Journal. 22: 7-14.

Papachristou, T.G., P.D. Platis, V.P. Papanastasis, C.N. Tsiouvaras. 1999. Use of deciduous woody species as a diet supplement for goats grazing Mediterranean shrublands during the dry season. Animal Feed Science and Technology. 80: 267-279.

Pfister, J.A., J.C. Malechek. 1986. The Voluntary Forage Intake and Nutrition of Goats and Sheep in the Semi-Arid Tropics of Northeastern Brazil. Journal of Animal Science. 63: 1078-1086.

Schmidt, T.B., K.C. Olson, M.L. Linville. 2006. Effect of Starch, Fiber, or Protein Supplementation on Intake and Digestion of Low-Quality Tall Fescue Hay by Growing Dairy Heifers. Professional Animal Scientist. 22: 432-437.

Titgemeyer, E.C., J.S. Drouillard, R.H. Greenwood, J.W. Ringler, D.J. Bindel, R.D. Hunter, T. Nutsch. 2004. Effect of forage quality on digestion and performance responses of cattle to supplementation with cooked molasses blocks. Journal of Animal Science. 82: 487-494.

Vanzant, E.S., R.C. Cochran, E.C. Titgemeyer. 1998. Standardization of *in situ* techniques for ruminant feedstuff evaluation. Journal of Animal Science. 76: 2717-2729.