Nutritive Evaluation of Two Legumes (*Strophostyles*) Supplemented to Goats Fed a High Quality Coastal Bermudagrass (*Cynodon dactylon*) Hay Diet

J.L. Foster
J.P. Muir
Texas AgriLife Research Station, 1229 N. U.S. Hwy 281, Stephenville, Texas
W.C. Ellis
Texas A&M University, 471 Kleberg Center, College Station, Texas
B. D. Lambert
Texas AgriLife Research Station, 1229 N. U.S. Hwy 281, Stephenville, Texas
Tarleton State University, Box T-0070, Stephenville, Texas

ABSTRACT

The objective of this study was to compare effects of supplementing coastal bermudagrass (*Cynodon dactylon*; CBG) hay with *Strophostyles helvula* (98 g crude protein (CP)/kg dry matter (DM), 476 g neutral detergent fiber organic matter basis (NDFOM)/kg DM, *S. leiosperma* (117 g CP/kg DM, 497 g NDFOM /kg DM), or cottonseed meal (506 g CP/kg DM, 352 g NDFOM /kg DM; CSM) on intake of CBG hay (127 g CP /kg DM, 691 g NDFOM /kg DM) and apparent digestibility of dietary DM, organic matter (OM), NDFOM, and CP by goats. Six Boer × Spanish cross wethers (46.22 ± 3.99 kg) were fed CBG plus *S. helvula*, *S. leiosperma*, or CSM at 122 or 216 g/kg DM intake in a 6 × 6 Latin square with 3 × 2 factorial arrangement of treatments. There were no (*P* = 0.53) supplement type × amount interactions. Intake of DM, OM, and NDFOM of CBG was unaffected (*P* = 0.33) by supplementation with CSM, *S. helvula*, and *S. leiosperma.* Although intake of CBG was not affected, total diet NDFOM intake was 10.5% less (*P* = 0.01) when CSM and *S. helvula* were supplemented than when *S. leiosperma* was used. Supplement type did not affect (*P* = 0.21) OM digestibility, but OM digestibility increased (*P* = 0.05) 6.4% at the 216 versus 122 g/kg DM level of supplementation with the legumes or CSM. Supplementation with CSM and *S. leiosperma* improved (*P* = 0.02) NDFOM digestibility 7% versus supplementation with *S. helvula*. As supplement amount increased NDFOM digestibility increased (*P* = 0.02) by 5.5%. The diet supplemented with CSM had the greatest CP digestibility, and *S. helvula* CP was 6% less digestible (*P* = 0.02) than *S. leiosperma*. As supplement amount increased, CP digestibility increased (*P* = 0.01) 7%. Considering digestibility and intake, CSM and *S. leiosperma* were the best supplements fed in this experiment. *Strophostyles leiosperma* is recommended as a forage supplementation for goats when CBG hay basal diet is fed.

KEYWORDS: Boer × Spanish cross goats; Forage legumes; Trailing wild bean; Smooth-seeded wild bean; *Strophostyles*

This research was funded in part by Texas Higher Education Commission Board ATP grant 000517-0245-2001.

INTRODUCTION

Goat producers in the USA are unable to meet consumer demand, which is expected to rise as population increases. In the USA, most pastures are grass based, and in the south central region the primary cultivated grass utilized is coastal bermudagrass (*Cynodon dactylon*) (Redmon, 2002). Even with quality coastal bermudagrass fed at maximum intake, goat requirement for protein may not be met without supplementation (NRC, 1981; Packard et al., 2007). Previous experiments fed goats coastal bermudagrass hay at various maturities with up to 149 g crude protein (CP)/kg dry matter (DM) and 760 g neutral detergent fiber (NDF)/kg DM and the nutritional requirement of the goats were not met (Luginbuhl, 1984).

Warm-season grasses, such as coastal bermudagrass, contain greater concentrations of neutral detergent fiber organic matter basis (NDFOM), acid detergent fiber organic matter basis (ADFOM), and lignin which limit forage intake by the ruminant animal because of decreased forage quality (Johnson et al., 2001). Legumes may have greater intake rates than grasses due to less rumination time and quicker rate of passage because legumes tend to break into smaller particle size in the rumen versus warm-season grasses (VanSoest, 1994; Wilson, 1994). For the warm-season, there is currently no widely adapted legume species capable of competing with coastal bermudagrass in mixed swards in the southern USA (Muir et al., 2005b).

Native warm-season legumes are adapted to local climate and soil, and retain greater quality even under stress conditions such as drought (Muir et al., 2005a; Muir et al., 2005b). However, they are currently not widely seeded in improved pasture or native grassland production systems (Call, 1985). If warm-season perennial grasses, including bermudagrass, are inter-seeded with a warm-season legume, nutritional limitations can be mitigated and agronomic benefits can improve warm-season grass pasture systems.

Smooth-seeded wild bean (*Strophostyles leiosperma*; LEIO) and its close relative, trailing wild bean (*S. helvula*; HELV), are native North American annual, warm-season legumes that often colonize open, disturbed areas (Diggs et al., 1999; Muir et al., 2005a). Both are persistent and productive even when sod grasses are dominant (Gee et al., 1994; Muir et al., 2005a). Trailing wild bean has been documented as an important range plant throughout the United States and Canada while smooth-seeded wild bean, perhaps because it produces less herbage, has been researched less despite reports of its existence as far north as Illinois (Diggs et al., 1999). In previous experiments HELV produced 372 g ADFOM/kg DM, 80.6 g lignin/kg DM, and 101 g CP/kg DM and less for plants defoliated to 10-cm stubble height (Muir et al., 2005a). In the same experiment LEIO produced 314 g ADFOM/kg DM, 67.5 g lignin/kg DM, and 145 g CP/kg DM and was not affected by defoliation (Muir et al., 2005a). While agronomic data was available for these two legume species, no animal response trials had been completed.

The objective of this study was to determine effects of two levels of HELV, LEIO, or cottonseed meal (CSM) supplementation upon intake of coastal bermudagrass hay (CBG) and apparent digestibility of dietary DM, organic matter (OM), NDFOM, and CP.

MATERIALS AND METHODS

Animals and Diets

Seed of HELV and LEIO were collected from the Cross Timbers region of Texas and from research plots at the Texas AgriLife Research Station (TARS) in Stephenville, Texas, and were used to establish pastures of these annual legumes in Windthorst fine sandy loam soil. Plants were harvested at early reproductive stages 5 cm from the ground, and dried in a forced air oven at 55°C for 72 h. Coastal bermudagrass hay was harvested June 2003 from fields at TARS in Stephenville, and stored in a fully enclosed barn. Solvent-extracted CSM was purchased at a local feed store. Boer × Spanish cross wether goats (46.22 ± 3.99 kg; 18 months old) were each assigned to a 7-d adaptation phase followed by a 7-d data collection phase in metabolism crates for each diet. Water and purchased mineral blocks containing 0.35% Zn, 0.2% Fe, 0.2% Mn, 0.03% Cu, 0.005% Co, and 0.007% I were available to the goats at all times. After drying, HELV and LEIO hay was chopped with a mechanical mulcher (at least 2.5 cm particle size) to reduce refusal rates by the wethers.

Intake and Digestibility Measurements

Six diets consisting of 0.34 or 0.68% of goat body weight (BW) of HELV, LEIO, or CSM as supplement to a basal diet of CBG *ad libitum* were fed in a 6 × 6 Latin square design to each of six goats with a 3 × 2 factorial arrangement consisting of three types of supplement fed at two amounts. The CBG plus CSM diet was utilized as a non-leguminous control to determine effects of legume supplemented versus non-legume supplemented diet.

Total dietary intake was estimated as 225 g DM/kg of BW (Van Soest, 1994) and the amount of supplement (150 or 300 g/kg DM of intake) was calculated for each feeding period based on the weight taken the first day of the adjustment period, resulting in supplementation rates of 34 or 68 g DM/kg of BW. Legume and CSM supplements were fed in two equal feedings twice daily at 0800 h and 1700 h. Coastal bermudagrass hay was fed *ad libitum* and orts were collected daily to determine total intake. Because supplement and basal diet were fed separately, intake of each dietary component was used to calculate total diet nutritive value. Random forage samples were collected from each of CBG, CSM, HELV, and LEIO, and all forage samples dried at 55°C in a forced-air oven. Feces were collected every 24 h and the total excretion of feces weighed, a 10% aliquot taken, and frozen until dried at 55°C.

Laboratory Analyses

Forage, ort, and fecal samples were ground to pass a 1 mm screen of a sheer mill (Wiley, Arthur H. Thomas Co., Philadelphia, PA). Samples were placed in a forced air oven at 100°C in a crucible for 4 h to determine DM (AOAC, 1990). The OM concentration was determined by incineration in a muffle furnace at 540°C for 4 h (AOAC, 1990). Nitrogen (N) concentrations were determined using a modified aluminum block digestion (Gallaher et al., 1975) and analyzed by semi-automated colorimetry (Hambleton, 1977) using a Technicon Autoanalyzer II (Technicon Industrial Systems, Tarryton, NY). Procedures of Van Soest and Robertson (1980) were utilized to determine NDFOM, ADFOM, and lignin of forage and fecal samples. Digestibility of

DM, OM, NDFOM, and CP were calculated based on forage, ort, and fecal sample analyses.

Statistical Analyses

The general linear model procedure of SAS based on the 6 × 6 Latin square (6 goats and 6 dietary treatments) with 3 × 2 (supplement type by supplement amount) factorial arrangement of treatments was utilized for statistical analysis (SAS, 1991). When the restriction level and treatments are equal, such as number of animals and dietary treatments in this experiment, treatments may be arranged factorially in a Latin square designed experiment (Montgomery, 2004). The model included period, animal, supplement type, supplementation level, and the supplement type × level interaction. Dependent variables measured were apparent digestibility of dietary DM, OM, NDFOM, and CP, and DM, OM, NDFOM, ADFOM, lignin, and CP intakes of CBG and total diet. Studentized differences among least-squares means (LSM) were utilized for mean separation (SAS, 1991). Significance was declared at $P \leq 0.05$ and tendencies at $P \geq 0.05$ and ≤ 0.10.

RESULTS

There were no interactions between supplement type and supplement amount for any of the response variables. Because actual total intake differed from the estimated 225 g DM/kg of BW, the actual amount supplemented differed from the original target 150 or 300 g/kg DM intake and averaged 122 and 216 g/kg DM intake supplement in the total diet. There were no supplement refusals during this experiment.

Forage Laboratory Analyses

Neutral detergent fiber concentration of CBG was at least 39% greater and ADFOM concentration at least 3% greater than any of the supplements fed in this experiment (Table 1). Diets containing LEIO had 32% less CP and HELV diets 47% less CP than CSM containing diets (Table 2). When supplemented at the 122 g/kg DM intake level, total diet NDFOM was 3.4% and ADFOM was 2.2% greater than the 216 g/kg DM intake supplementation (Table 2). At the lower level of supplementation lignin and CP concentrations were 3.8 and 7.5% less, respectively, than at the 216 g/kg DM intake supplementation level.

Table 1. Chemical composition (g/kg DM) of coastal bermudagrass hay (CBG), Strophostyles helvula (HELV), S. leiosperma (LEIO), and cottonseed meal (CSM).

	DM	OM	NDFOM	ADFOM	Lignin	CP
Feedstuff			g/kg DM			
CBG	953	883	691	335	40	127
HELV	953	894	476	279	47	98
LEIO	952	892	497	324	60	117
CSM	948	879	352	171	64	506

Table 2. Mean chemical composition of coastal bermudagrass diets supplemented with *Strophostyles helvula* (HELV), *S. leiosperma* (LEIO), or cottonseed meal (CSM) at two levels of supplementation.

	OM	NDFOM	ADFOM	Lignin	CP
			g/kg DM		
Supplement type					
HELV	885.1	648.5	326.1	41.1	122.4
LEIO	884.8	652.9	333.3	43.1	125.5
CSM	882.8	631.0	309.9	43.7	185.0
Supplement amount					
122 g/kg DM of intake	883.9	655.5	326.8	41.8	139.2
216 g/kg DM of intake	884.4	633.5	319.7	43.4	149.6

Intake

Coastal bermudagrass DM, OM, NDFOM, ADFOM, lignin, and CP intakes were not affected by supplement types or amounts (Table 3). The total diet intakes of DM, OM, and CP were not different among the supplement types. Goats fed LEIO had greater intakes of NDFOM and ADFOM than CSM or HELV diets, whereas goats fed LEIO and CSM supplements had a tendency for greater (P = 0.1) lignin intake than goats supplemented with HELV. Goats supplemented at the 122 g/kg DM intake level had less DM, OM, NDFOM, and ADFOM intakes than goats fed the 216 g/kg DM intake supplementation level. However, intakes of lignin and CP were not different (P = 0.12) between supplementation levels.

Apparent Digestibility

There was a tendency for differences (P = 0.07) in the digestibility of DM among diets containing the three supplement types (Table 4). Dry matter digestibility of diets supplemented with CSM and LEIO were greater than the DM digestibility of HELV containing diets. There were no differences in OM digestibility among diets containing either the legumes or CSM supplements. Diets with CSM and LEIO supported greater digestibility than diets with HELV. Digestibility of CP differed for all three supplement types. The diet supplemented with CSM had the greatest CP digestibility, and HELV tended to be 6% less digestible (P = 0.1) than LEIO.

At the higher supplementation level, DM digestibility tended to be 5.3% greater (P = 0.08) than DM digestibility of the low supplementation level (Table 4). As supplementation level increased, OM digestibility increased by 6.4% regardless of whether leguminous or non-leguminous supplement was fed. Diet NDFOM digestibility at the 216 g/kg DM intake supplementation level was 5.5% greater than at the 122 g/kg DM intake supplementation level. When goats were fed the higher supplementation level, CP digestibility was 7% greater than the 122 g/kg DM intake supplementation amount.

Table 3. Intake of coastal bermudagrass hay (CBG) and of CBG supplemented with *Strophostyles helvula* (HELV), *S. leiosperma* (LEIO), or cottonseed meal (CSM) at two levels of supplementation.

	Supplement type				Supplement amount (g/kg DM intake)		
Item	HELV	LEIO	CSM	SEM	122	216	SEM
CBG intake g/kg DM/kg BW							
DM	25.7	26.8	26.8	0.8	30.3	32.3	0.7
OM	22.7	23.7	23.7	0.7	27.0	25.9	0.6
NDFOM	12.2	12.8	12.7	0.4	23.9	22.9	0.3
ADFOM	8.6	9	8.9	0.2	9.2	8.6	0.1
Lignin	1	1.1	1.1	0.03	1.1	1	0.02
CP	3.3	3.3	3.3	0.1	3.4	3.2	0.1
Total diet intake g/kg DM/kg BW							
DM	30.6	31.7	31.6	0.8	30.3[b]	32.3[a]	0.7
OM	27.1	28.1	27.9	0.7	26.8[b]	28.6[a]	0.6
NDFOM	14.6[b*]	16.1[a]	14.4[b]	0.4	14.5[b]	15.6[a]	0.3
ADFOM	10.0[b]	10.6[a]	9.8[b]	0.2	10.0[b]	10.3[a]	0.1
Lignin	1.3[b]	1.4[a]	1.4[a]	0.03	1.3	1.4	0.02
CP	3.8	3.9	3.7	0.1	3.2	3.7	0.1

[*] Values in the same row followed by different superscript letters differ ($P \leq 0.05$) according to least-squares means (LSM) multiple range test.

DISCUSSION

The greater NDFOM concentration in the CBG hay vis-á-vis both legumes is consistent with previous research that indicates grasses generally contain greater concentrations of NDFOM than legumes (Johnson et al., 2001). The greater amount of lignin in the legumes versus the CBG hay is likewise consistent with previous research that indicates that legumes often contain greater lignin concentrations because of differences in plant structure of legumes, namely more developed stem tissue than grasses (Collins and Fritz, 1995). The greater CP concentration in the CBG hay versus the legumes is consistent with high N fertilization rates (Johnson et al., 2001). The two legume hays were harvested in mid-reproductive stages and would likely have had greater nutritive value had they been cut earlier, but values here are consistent with previous trials utilizing plants not defoliated until final harvest (Muir et al., 2004). Wild bean forage concentration varies from 80 g CP/kg DM in mature plant material to 220 g CP/kg DM in re-growth following defoliation (Muir et al., 2005a).

The DM intake of CBG hay did not increase with increased supplementation amount and/or type, but as supplement level increased total diet intake increased. This is consistent with a study comparing *Chloris gayana* (61.9 g CP/kg DM; 829 g NDFOM /kg DM) hay diet supplemented with maize or one of three legumes; goats on the control diet consumed more hay than those supplemented with legumes (Mupangwa et al., 2000). In that study, diets supplemented with legumes did not differ in hay intake but total diet

Table 4. Apparent digestibility (g/kg DM intake) of coastal bermudagrass hay diets supplemented with either *Strophostyles helvula* (HELV), *S. leiosperma* (LEIO), or cotton seed meal (CSM) at two levels of supplementation.

	Supplement type				Supplement amount (g/kg DM intake)		
Nutrient	HELV	LEIO	CSM	SEM	122	216	SEM
DM	595.1[*b]	639.0[a]	646.5[a]	16.3	610.1[b]	644.2[a]	13.3
OM	598.2[b]	632.5[a]	638.8[a]	16.8	602.6[b]	643.8[a]	13.7
NDFOM	601.7[b]	646.0[a]	647.9[a]	12.4	614.0[b]	649.7[a]	10.1
CP	658.0[c]	692.2[b]	718.0[a]	14.4	673.5[b]	705.3[a]	11.8

[*] Values in the same row followed by different superscript letters differ ($P \leq 0.05$) according to least-squares means (LSM) multiple range test.

intake did increase (Mupangwa et al., 2000). The legume and CSM supplements were additive to the CBG hay basal diet, indicating that they are all high quality supplements when supplemented to a basal bermudagrass hay diet. Neutral detergent fiber organic matter basis and ADFOM intakes of LEIO were greater than that of the other supplement types because of a greater concentration of NDFOM and ADFOM.

As the amount of supplement increased, digestibility increased, regardless of supplementation type. Although the legumes used as supplement in this experiment contained greater amounts of ADFOM and less CP than CSM; as the amount of supplement increased, total dietary CP increased. Because of the greater ADFOM and lignin concentrations of LEIO, the 5% greater CP digestibility of LEIO versus HELV is unusual. The increase in CP digestibility at increasing supplementation rates was unusual because the CP concentration of the CBG exceeded the amount in the legumes, and supplementing with legumes did not increase CP concentration of the diet. However, the amount of digestible CP did increase indicating that legume CP was more digestible than the grass CP (Wilson, 1994). In a pasture situation, goats would likely select a greater proportion of legumes than grasses than was fed in this experiment, especially as grass matures (Singh and Shankar, 2000; Muir, 2002; Pande et al., 2002; Goodwin et al., 2004). Greater selection of the leaves of young legumes should increase digestible CP concentration of the diet (Ahmed and Nour, 1997; Singh and Shankar, 2000).

The digestibility of DM, OM, NDFOM, and CP when LEIO was supplemented was greater than that of HELV despite the greater ADFOM and lignin concentration of LEIO, likely because LEIO has smaller stems than that of HELV. This morphological characteristic of LEIO may have promoted more particle size reduction in the rumen through microbial degradation and mastication than when HELV was supplemented. The increased intake and digestibility of LEIO indicates that it would support improved animal performance when supplemented to CBG hay.

CONCLUSIONS

Although CBG hay intake was not affected by supplementation, digestibility increased indicating that CSM and *S. leiosperma* allowed the same dietary intake to be utilized more efficiently than *S. helvula.* Considering digestibility of CP and NDFOM, the best supplements fed in this experiment were CSM and *S. leiosperma*, with *S. leiosperma* being as digestible as the CSM supplement. The 216 g/kg DM intake supplementation level tended to improve digestibility of all factors considered, and was found to be the better level of supplementation of the two in this experiment. Because the *S. leiosperma* hay used in this trial had comparable NDFOM and CP digestibility (but not concentration) to CSM, this native legume could be a resource to improve the poor quality of pasture grasses in mid-summer. Pasture studies are recommended for follow up as they may produce different results from those of this study, primarily because protein concentrations of legume hays in this study were likely low relative to live plants as a result of leaf shattering and late harvest of mature plants.

REFERENCES

Ahmed, M.M.M., and Nour, H.S. 1997. Legume hays as a supplement for dairy goats during the dry season. Small Rumin. Res. 26, 189-192.

AOAC. 1990. Official Methods of Analysis, 15th edition, vol. 1, 976.06. Association of Official Analytical Chemists, Arlington, VA, USA, pp. 72-74.

Call, C.A. 1985. Storage life of Illinois bundleflower and western indigo seed. J. Range Manage. 38, 500-503.

Collins, M., and Fritz, J.O. 1995. Forage quality. In: Barnes, R.F., Miller, D.A., Nelson, C.J. (Eds), Forages: An Introduction to Grassland Agriculture, Sixth edition, Iowa State University Press, Ames, IA, USA, pp. 363-390.

Diggs, Jr., G.M., Lipscomb, B.L., and O'Kennon, R.J. 1999. Shinner & Mahler's Illustrated Flora of North Central Texas. Botanical Research Institute of Texas, Fort Worth, TX, USA, 1626 pp.

Gallaher, R.N., Weldon, C.O., and Futral, J.G. 1975. An aluminum block digester for plant and soil analysis. In: Proc. Am. Soil Sci. Soc. 39, 803-806.

Gee K.L., Porter, M.D., Demarais, S., Bryant, F.C., and Van Vreede, G. 1994. White-tailed Deer: Their Foods and Management, Second Edition. Samuel Roberts Noble Foundation, Ardmore, OK, USA, 118 pp.

Goodwin, D.J., Muir, J.P., and Wittie, R.D. 2004. Goat performance, forage selectivity,and forage quality dynamics in three cultivated warm season pastures in north-central Texas. Small Rumin. Res. 52, 53-62.

Hambleton, L.G. 1977. Semiautomated method for simultaneous determination of phosphorus, calcium and crude protein in animal feeds. J. AOAC. 60, 845-852.

Johnson, C.R., Reiling, B.A., Mislevy, and P., Hall, M.B. 2001. Effects of nitrogen fertilization and harvest date on yield, digestibility, fiber, and protein fractions of tropical grasses. J. Anim. Sci. 79, 2439-2448.

Luginbuhl, J.-M. 1984. Fiber utilization in sheep, goats and cattle. MS Thesis. North Carolina State Univ. Raleigh, NC, USA.

Montgomery, D.C., 2004. Design and Analysis of Experiments, Fifth edition, John Wiley and Sons, Inc., New York, pp. 209.

Muir, J.P. 2002. Hand-plucked forage yield and quality and seed production from annual and short-lived perennial warm-season legumes fertilized with composted manure. Crop Sci. 42, 897-904.

Muir, J.P., Reed, R.L., and Malinowski, D.P. 2005a. Forage and seed of *Strophostyles* species as affected by location and harvest height. Native Plant J. 6, 123-130.

Muir, J.P., Taylor, J. and Interrante, S.M. 2005b. Herbage and seed from native perennial herbaceous legumes of Texas. Rangel. Ecol. Manage. 58, 643-651.

Mupangwa, J.F., Ngongoni, N.T., Topps, J.H., and Hamudikuwanda, H. 2000. Effects of supplementing a basal diet of *Chloris gayana* hay with one of three protein-rich legume hays of *Cassia rotundifolia*, *Lablab purpureus* and *Macroptilium atropurpureum* forage on some nutritional parameters in goats. Trop. Anim. Health and Prod. 32, 245-256.

NRC. 1981. Nutrient Requirement of Goats: Angora, Dairy, and Meat Goats in Temperate and Tropical Countries. National Academic Press, Washington, DC, pp. 10-11, 27, 34.

Packard, C.E., Muir, J.P. and Wittie, R.D., 2007. Groundnut stover and bermudagrass hay for wethers on winter hardwood range in north central Texas. Small Rumin. Res. 67, 1-6.

Pande, R.S., Kemp, P.D., and Hodgson, J. 2002. Preference of goats and sheep for browse species under field conditions. N. Z. J. Agric. Res. 45, 97-102.

Redmon, L. 2002. Forages for Texas. Texas Cooperative Extension: Texas A&M University System Soil and Crop Sci. Communications. SCS-2002-14. Overton, TX, USA.

SAS. 1991. SAS Users Guide. Release 6.12. Statistical Analysis System, Cary, NC.Singh, J.P., and Shankar, V. 2000. Forage choice of goats grazing in a protein bank cafeteria. Range Manage. & Agroforestry. 21, 1-9.

Van Soest, P.J., and Robertson, J.B. 1980. Systems of analysis for evaluating fibrous feeds. p. 49. *In Standardization of Analytical Methodology for Feeds:* Proc. Int. Workshop, Ottawa, ON. Mar 12-14 1979 W.J. Pigden et al. (ed.) Rep. IDRC-134e. Int. Dev. Res. Ctr., Ottawa, ON, Canada and Unipub, New York, NY, USA.

Van Soest, P.J. 1994. Nutritional Ecology of the Ruminant. Second Edition, Cornell University Press, Ithaca, NY, 476 pp.

Wilson, J.R. 1994. Cell wall characteristics in relation to forage digestion by ruminants. J. of Agric. Sci. 122, 173-182.