Intake, digestibility, and nitrogen retention by sheep supplemented with warm-season legume hays or soybean meal


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ABSTRACT: The increasing cost of feed supplements necessitates evaluation of alternatives for ruminant livestock grazing poor quality warm-season grasses. This study determined how supplementing bahiagrass hay (Paspalum notatum Flügge cv. Pensacola) with soybean (Glycine max (L.) Merr.) meal or warm-season legume hays affected intake, digestibility, and N utilization by lambs. Dorper × Katahdin crossbred lambs (30.6 ± 5.5 kg; n = 42) were fed bahiagrass hay (73.8% NDF, 8.1% CP) for ad libitum intake and supplemented with nothing (control), soybean meal, or hays of annual peanut (Arachis hypogaea (L.) cv. Florida MDR98; 46.2% NDF, 14.7% CP), cowpea (Vigna unguiculata (L.) Walp. cv. Iron clay; 43.3% NDF, 11.7% CP), perennial peanut (Arachis glabrata Benth. cv. FloriGraze; 43.3% NDF, 15.2% CP), pigeonpea (Cajanus cajan (L.) Millsp. cv. GA-2; 78.6% NDF, 12.2% CP), or soybean (cv. Pioneer 97B52; 59.0% NDF, 13.5% CP). Legume hays were supplemented at 50% of total diet DM, and soybean meal was supplemented at a level (4.25% of diet DM) that matched the average dietary CP content (10.8%) of the legume hay-supplemented diets. The cowpea, pigeonpea, and soybean were harvested at respective maturities that maximized DM yield and nutritive value, and the peanuts were first cuttings. Diets were fed to 6 lambs per treatment for 2 consecutive 21-d periods. Supplementation with hays of annual and perennial peanut, cowpea, and soybean increased (P < 0.01) DMI vs. control, but apparent DM digestibility was only increased (P = 0.03) by supplementation with annual or perennial peanut hay. Compared with the control, N intake, digestibility, and retention were increased (P < 0.01) by supplementation with legume hay or soybean meal. Responses were greatest when annual or perennial peanut hays were fed. Ruminal ammonia concentration was increased (P < 0.01) by all legume hay supplements vs. the control. Microbial N synthesis and ruminally degraded OM were increased (P = 0.03) by perennial and annual peanut hay supplementation, but efficiency of microbial synthesis was not different (P = 0.52) among diets. Unlike other supplements, annual and perennial peanut hays increased DM and N intake and digestibility and improved microbial N synthesis; therefore, they were the best supplements for the bahiagrass hay under the conditions of this study.

Key words: bahiagrass, digestibility, intake, nitrogen retention, supplementation, tropical/subtropical legume

INTRODUCTION

Bahiagrass (Paspalum notatum Flügge) and bermudagrass [Cynodon dactylon (L.) Pers.] are the main forage grasses in Florida and much of the southern United States. The yield of these grasses is normally sufficient to meet intake requirements of most ruminant livestock during the grazing season; however, their quality is insufficient for growing or lactating ruminants due to low DM digestibility and CP concentration (Duble et al., 1971; Johnson et al., 2001). Because of rapidly escalating fertilizer and feedstuff commodity prices, ruminant feeding strategies that are less dependent on these inputs merit evaluation. Supplementing poor quality basal grass diets with legume forage has increased feed intake and diet digestibility by ruminant livestock (Minson and Milford, 1967; Getachew et al., 1994). Legume supplementation improves N retention by the ruminant when grass diets that do not meet ruminant energy and N requirements are fed (Mosi and Butterworth, 1985; Matizha et al., 1997).

Alfalfa (Medicago sativa L.), the legume fed most commonly to livestock in the United States, does not persist in the warm, humid climate of the Gulf Coast
region (Prine et al., 1981). Perennial peanut \((Arachis glabrata\) Benth.) is the main warm-season forage legume in Florida, but it is sprig-planted and takes 1 to 2 yr to establish and is therefore costlier to establish than seeded, warm-season legumes like cowpea \([Vigna unguiculata\) (L.) Walp.], soybean \([Glycine max\) (L.) Merr.], or annual peanut \([Arachis hypogaea\) (L.)\] (French et al., 2006). Effects of supplementing bahiagrass hay with these legume hays on animal performance are unknown. This study determined the feed intake, digestibility, and N retention of lambs fed bahiagrass (cv. Pensacola) hay supplemented with soybean meal, or hays of perennial peanut (cv. Florigraze), annual peanut (cv. Florida MDR 98), soybean (cv. Pioneer 97B52), cowpea (cv. Iron clay), or pigeonpea \([Cajanus cajan\) (L.) Millsp. cv. GA-2].

**MATERIALS AND METHODS**

All animal procedures were approved by the University of Florida Institutional Animal Care and Use Committee.

**Forage Production**

Legume hays were produced at the North Florida Research and Education Center in Marianna (31°N) and fed at the Department of Animal Sciences, University of Florida, Gainesville. Soil on the experiment site was Chipola loamy sand (loamy, kaolinitic, thermic, Arenic Kanhapludults) and Orangeburg loamy sand (fine-loamy, kaolinitic, thermic, Typic Kandiudults). Dolomite (3,300 kg/ha) and fertilizer (330 kg/ha of 0:20:40:0.5 ratio of N:P2O5:K2O:B with gypsum filler) were applied, and the field was chisel plowed before seeded legumes were planted. Seeds of cowpea, soybean, and pigeonpea were inoculated with \(Bradyrhizobium\) spp. (Royal Peat, Becker Underwood Inc., Ames, IA) and drilled at 56 kg/ha and 15-cm row spacing on 0.405-ha plots. The legumes were planted in May and harvested in August and September of 2005 at the recommended maturity stage for maximizing DM yield and nutritive value. This was when pods began to turn yellow for cowpea (NDA, 1997), pod setting for pigeonpea (Le Houérou, 2004), and stage R6 (pod with full size seed at 1 of the 4 uppermost nodes and completely unrolled leaves) for soybean (Coffey et al., 1995; Sheaffer et al., 2001). Established stands of perennial (4-yr-old) and annual peanut (6-yr-old; self reseeding) were harvested as first cuttings in June and September of 2005, respectively. Both peanut plants were mature at harvest, as indicated by the height of the perennial peanut (approximately 20 cm; Cook, 1992) and the ripened pods of the annual peanut (maturity stage 89; Munger et al., 1998). Each legume was harvested using a mower-conditioner (Haybine model 474, New Holland Agriculture, New Holland, PA) and turned with an inverter (New Holland model 144) after 24 h. Perennial and annual peanut and cowpea were harvested to a stubble height of 10 cm, whereas soybean and pigeonpea were harvested to stubble heights of 20 and 40 cm based on previous recommendations for the respective forages (Romero et al., 1987; Le Houérou, 2004; Mislevy et al., 2005). Cowpea, soybean, and pigeonpea were rolled into 200-kg round bales using a Vermeer 504 L baler (Vermeer Manufacturing Inc., Pella, IA). Annual and perennial peanut were stored as square bales (50 kg). An established stand of bahiagrass (11-yr-old) was fertilized (130 kg/ha of 70:0:40:8 ratio of N:P2O5:K2O:S) in the spring and harvested as a 6-wk regrowth to a stubble height of 8 cm (Claas Disco 2650 mower, Claas Manufacturing, Omaha, NE) and rolled (Claas Rollant 660 baler, Claas Manufacturing) into round bales. Each hay bale was stored in a fully enclosed barn for no more than 5 mo and chopped subsequently to approximate-ly 8-cm particle length in a tub grinder (Roto Grind, model 760, Burrows Enterprises, Greeley, CO) to limit refusals.

**Animals, Feeding, and Housing**

Dorper × Katadhin cross ram lambs \((n = 42)\) weighing 30.6 ± 5.5 kg were used for the experiment. Before the experiment, all lambs were vaccinated with a 3-way enterotoxemia, coccidiosis, and tetanus vaccination (Bar Vac CD-T, 2 mL/head, Boehringer Ingelheim Vetmedica Inc., St. Joseph, MO), de-wormed (Cydectin, 1.5 mg/kg of BW, Fort Dodge, Overland Park, KS), weighed, and their hooves were trimmed. Lambs were stratified by BW and assigned randomly to 7 treatments (6 lambs per treatment per period) within each BW stratum. The experiment was analyzed as a completely randomized block design with 2 periods \((n = 12)\). Each period consisted of 14 d of adaptation to diets and 7 d of measurement, and each lamb received a different diet in each period. Lambs were fitted with canvas fecal-collection bags and housed in individual metabolism crates \((0.5 \times 1.5 \text{ m})\). Thirty-eight crates were also adapted for collection of urine; therefore, in each period, urine was collected from 5 lambs from 3 randomly chosen treatments and from all lambs on the remaining treatments. These decisions were made before each collection period. Water was provided for ad libitum intake, and 20 g of a mineral premix (Ranch House Trace Mineralized Salt, United Salt Corp., Houston, TX) was added to the diet of each lamb daily. The mineral mix contained 90% NaCl, 3% Ca, 1% S, 0.3% Mn, 0.3% Zn, 0.2% Fe, 150 mg/kg of Cu, 90 mg/kg of I, 25 mg/kg of Co, and 10 mg/kg of Se. Lambs were fed for ad libitum intake (110% of intake of the previous day) diets consisting of bahiagrass hay supplemented with nothing (control), soybean meal, or hays of perennial peanut, annual peanut, cowpea, pigeonpea, or soybean. Legume hays were fed at 50% of total diet DM, and soybean meal was fed at a level (4.25% of diet DM) that matched the average CP concentration (10.8% DM basis) of the legume hay diets. The bahiagrass and respective legume supplements were hand-mixed and of-
fere in the same feed trough at 0800 and 1500 h daily. The soybean meal was top dressed on the bahiagrass hay and fed at the same time as the other diets.

Sample Collection

Samples (1 kg) of each hay and soybean meal were taken daily during the 7-d collection period, and daily orts were weighed and stored. Total fecal output was collected daily from each lamb, weighed, and a 10% subsample was frozen (−20°C) for subsequent analysis. The weight and volume of daily urine output was recorded. Sulfuric acid was added to subsamples of urine to ensure that the pH remained below 3.0, and the urine was stored (−20°C) for further analysis. Lambs were weighed and blood sampled by jugular venipuncture on d 0, 21, and 42. A Vacutainer tube (BD, Franklin Lakes, NJ) containing sodium heparin anticoagulant was used to collect 10 mL of whole blood from each lamb, and the tubes were stored on ice and processed within 2 h. The blood was centrifuged at 1,920 × g for 20 min at 4°C to separate the plasma, which was stored at −20°C until analyzed. Ruminal fluid (100 mL) was collected from 28 lambs (4 selected randomly per treatment) on the last day of period 2 by aspiration from orally inserted stomach tubes at 0, 2.5, 5, 7.5, and 10 h after the morning feeding. A representative (100 mL) sample was analyzed immediately for pH (Accumet, model HP-71, Fischer Scientific, Pittsburgh, PA), acidified with concentrated H2SO4, centrifuged for 30 min at 4°C and 2,795 × g, and frozen (−20°C) for subsequent analysis.

Chemical Analyses

Samples of hays, soybean meal, orts, and feces were composited by period and analyzed for DM by oven drying at 105°C overnight, and for ash by combustion in a muffle furnace at 600°C overnight. Samples reserved for additional analyses were dried at 60°C for 48 h in a forced air oven and ground to pass through a 1-mm screen in a Wiley mill (Arthur H. Thomas Company, Philadelphia, PA). Total N was determined by rapid combustion using a macro elemental N analyzer (Elementar, vario MAX CN, Elementar Americas, Mount Laurel, NJ) and used to calculate CP (N × 6.25). Neutral detergent fiber was analyzed using the method of Van Soest et al. (1991). Amylase and sodium sulfite were used for NDF analysis, and the results were expressed on a DM basis. Apparent digestibility of DM, OM, N, and NDF were calculated. Feed samples were analyzed for ADF and ADL with the method of AOAC (1990). The ADIN concentration of the hays was measured with the elemental N analyzer on ADF residues. The Van Soest et al. (1966) method and an Ankom DaisyII Incubator (Ankom Technologies, Macedon, NY) were used to measure in vitro true DM digestibility (IVTD) of hays. Condensed tannin (CT) concentration of hays was analyzed with the method of Terrill et al. (1992). Quebracho tannin (Unitán ATO, Buenos Aires, Argentina) was purified with Sephadex LH-20 (GE Healthcare Life Sciences, Piscataway, NJ) according to Asquith and Butler (1985) as modified by Hagerman (1994). Condensed tannin results were expressed as quebracho tannin equivalents.

Urine was analyzed for N by rapid combustion with the elemental N analyzer and for total purine derivatives as allantoin (Borchers, 1977). Xanthine, hypoxanthine, and uric acid were converted to allantoin using the procedure of Fujihara et al. (1987). Microbial protein supply to the small intestine was calculated from the urinary output of purine derivatives using the equation of Chen et al. (1992). Microbial efficiency was calculated as grams of microbial N per kilogram of OM apparently digested in the total tract.

Volatile fatty acids in ruminal fluid were measured using the method of Canale et al. (1984) via HPLC (Hitachi, FL 7485, Tokyo, Japan) coupled to a UV detector (Spectroflow 757, ABI Analytical Kratos Division, Ramsey, NJ) set at 210 nm. The column was a Bio-Rad Aminex HPX-87H (Bio-Rad laboratories, Hercules, CA) with 0.015 M H2SO4 mobile phase and a flow rate of 0.7 mL/min at 45°C. Ruminal fluid NH3-N concentration was determined by an ALPKEM auto analyzer (ALPKEM Corporation, Clackamas, OR) with an adaptation of the Noel and Hambleton (1976) procedure that involved colorimetric quantification of N.

Plasma urea-N (PUN) and glucose (PGlc) concentrations were measured using adaptations for a Technicon AutoAnalyzer II (Bran-Luebbe, Elinsford, NY) of methods of Coulombe and Favreau (1963) and Gochna and Schmitz (1972), respectively.

Statistical Analyses

Data were analyzed with PROC MIXED (SAS Inst. Inc., Cary, NC). The model for intake, digestibility, N excretion and retention, microbial protein parameters, PUN, and PGlc included dietary treatment, period, dietary treatment × period, and lamb (random variable). The model for ruminal fluid pH, NH3-N, and VFA included dietary treatment, time of collection (repeated measure), dietary treatment × time of collection, and lamb (random variable). Means were separated with a PDIFF statement. Significance was declared at P ≤ 0.05.

RESULTS

Forage Chemical Composition

Dry matter concentrations were not different among hays, but OM concentration was less (P = 0.04) in perennial peanut than in all other hays (Table 1). As expected, CP concentration was least (P < 0.01) in bahiagrass hay. Among legume hays, CP concentrations were greater in annual and perennial peanut hays than in cowpea and pigeonpea hays. Concentration of
NDF was greatest \((P < 0.01)\) in pigeonpea hay followed by bahiagrass hay, and least in annual and perennial peanut hays. The greatest \((P < 0.01)\) ADF concentration was in pigeonpea hay, and the least \((P = 0.02)\) in perennial peanut hay. Lignin \((P = 0.10)\) and ADIN \((P < 0.01)\) concentrations were greater in pigeonpea hay than the other hays. In vitro true digestibility was greatest \((P < 0.01)\) in perennial peanut hay followed by annual peanut hay. Bahiagrass hay contained less \((P < 0.01)\) IVTD than all legume hays except pigeonpea hay, which contained the least \((P < 0.01)\) IVTD. Condensed tannin concentrations were low in all hays. Extractable CT concentration was greatest \((P < 0.01)\) in perennial peanut hay followed by cowpea hay. Bound CT concentration was greatest \((P < 0.01)\) in perennial and annual peanut hays followed by pigeonpea hay.

**Intake and Digestibility**

With the exception of pigeonpea hay, legume hay supplementation increased intake of DM, OM, and NDF (Table 2). Intakes of DM, OM, and NDF were greatest \((P = 0.04)\) in lambs supplemented with perennial peanut hay, followed by annual peanut hay and were least \((P = 0.04)\) in lambs consuming bahiagrass hay alone or pigeonpea hay compared with those consuming other legume hays. Intakes of DM, OM, and NDF were not improved by addition of soybean meal. Digestibilities of DM and OM were greatest \((P = 0.03)\) when diets were supplemented with perennial peanut hay, followed by annual peanut hay. Addition of the other supplements did not affect digestibility of DM or OM except that pigeonpea hay supplementation reduced \((P = 0.04)\) OM digestibility. Digestibility of NDF was greater \((P < 0.01)\) in lambs fed bahiagrass hay alone, soybean meal, or perennial peanut hay than in lambs supplemented with cowpea hay.

**Nitrogen Utilization and Plasma Metabolites**

Nitrogen intake was increased \((P < 0.01)\) by supplementation regardless of supplement type and was greatest \((P < 0.01)\) in lambs fed perennial peanut hay, followed by \((P < 0.01)\) annual peanut hay (Table 3). Fecal N output was greatest \((P < 0.01)\) in lambs fed perennial peanut hay, followed by annual peanut and soybean hays, and was least in lambs fed bahiagrass hay alone, soybean meal, or pigeonpea hay. Urinary N excretion was greater \((P = 0.04)\) in lambs fed perennial and annual peanut or soybean hays than in those fed bahiagrass alone, bahiagrass plus cowpea hay, or bahiagrass plus pigeonpea hay. Nitrogen retention and digestibility were increased by supplementation, and the greatest \((P < 0.01)\) values occurred in lambs fed pre-

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**Table 1. Chemical composition and in vitro true DM digestibility (IVTD) of hays fed to lambs**

<table>
<thead>
<tr>
<th>Item</th>
<th>Bahiagrass</th>
<th>Annual peanut</th>
<th>Perennial peanut</th>
<th>Cowpea</th>
<th>Pigeonpea</th>
<th>Soybean</th>
<th>SEM (^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM, %</td>
<td>91.1</td>
<td>91.0</td>
<td>90.8</td>
<td>91.5</td>
<td>91.8</td>
<td>91.6</td>
<td>1.8</td>
</tr>
<tr>
<td>OM, % of DM</td>
<td>94.5 (^a)</td>
<td>92.4 (^a)</td>
<td>90.8 (^b)</td>
<td>92.6</td>
<td>94.7</td>
<td>93.8 (^b)</td>
<td>0.53</td>
</tr>
<tr>
<td>CP, % of DM</td>
<td>8.1 (^b)</td>
<td>14.7 (^b)</td>
<td>15.2 (^b)</td>
<td>11.7</td>
<td>12.2</td>
<td>13.5 (^b)</td>
<td>1.0</td>
</tr>
<tr>
<td>NDF, % of DM</td>
<td>73.8 (^b)</td>
<td>46.2 (^b)</td>
<td>3.3 (^b)</td>
<td>62.2</td>
<td>78.6 (^b)</td>
<td>59.0 (^b)</td>
<td>0.40</td>
</tr>
<tr>
<td>ADF, % of DM</td>
<td>39.8 (^b)</td>
<td>37.8 (^b)</td>
<td>32.1 (^c)</td>
<td>48.7</td>
<td>60.2 (^b)</td>
<td>42.8 (^b)</td>
<td>1.3</td>
</tr>
<tr>
<td>ADIN, % of N</td>
<td>15.1 (^d)</td>
<td>7.1 (^d)</td>
<td>6.5 (^d)</td>
<td>13.4</td>
<td>25.4 (^c)</td>
<td>9.1 (^d)</td>
<td>0.43</td>
</tr>
<tr>
<td>ADL, % of DM</td>
<td>6.2 (^b)</td>
<td>7.9 (^b)</td>
<td>6.7 (^b)</td>
<td>9.5</td>
<td>17.1 (^b)</td>
<td>9.6 (^d)</td>
<td>1.1</td>
</tr>
<tr>
<td>IVTD, % of DM</td>
<td>50.7 (^d)</td>
<td>71.4 (^d)</td>
<td>77.2 (^d)</td>
<td>57.9</td>
<td>35.1 (^d)</td>
<td>57.4 (^d)</td>
<td>1.1</td>
</tr>
<tr>
<td>Total CT, % of DM</td>
<td>0.46 (^d)</td>
<td>2.68 (^b)</td>
<td>3.82 (^d)</td>
<td>1.03 (^e)</td>
<td>1.13 (^e)</td>
<td>0.20 (^d)</td>
<td>0.14</td>
</tr>
<tr>
<td>Extractable CT, % of DM</td>
<td>0.12 (^d)</td>
<td>0.16 (^d)</td>
<td>1.56 (^c)</td>
<td>0.56 (^b)</td>
<td>0.26 (^b)</td>
<td>0.05 (^d)</td>
<td>0.07</td>
</tr>
<tr>
<td>Bound CT, % of DM</td>
<td>0.34 (^d)</td>
<td>2.52 (^d)</td>
<td>2.26 (^a)</td>
<td>0.57 (^b)</td>
<td>0.87 (^b)</td>
<td>0.15 (^d)</td>
<td>0.11</td>
</tr>
</tbody>
</table>

\(^a–f\)Within a row, means without a common superscript letter differ \((P < 0.05)\).

1SEM values reflect the variation of samples collected daily and composited within each of 2 periods (n = 2).

2CT = condensed tannin.

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**Table 2. Intake and apparent digestibility (DM basis) by lambs fed bahiagrass hay diets supplemented at 50% of DM with warm-season legume hays or at 4.25% of DM with soybean meal (SBM)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Bahiagrass</th>
<th>SBM</th>
<th>Annual peanut</th>
<th>Perennial peanut</th>
<th>Cowpea</th>
<th>Pigeonpea</th>
<th>Soybean</th>
<th>SEM (^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total intake, g/d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM</td>
<td>665 (^d)</td>
<td>726 (^b)</td>
<td>975 (^b)</td>
<td>1,105 (^a)</td>
<td>803 (^d)</td>
<td>612 (^b)</td>
<td>864 (^c)</td>
<td>29</td>
</tr>
<tr>
<td>OM</td>
<td>629 (^d)</td>
<td>685 (^b)</td>
<td>911 (^b)</td>
<td>1,034 (^a)</td>
<td>752 (^d)</td>
<td>570 (^b)</td>
<td>811 (^c)</td>
<td>28</td>
</tr>
<tr>
<td>NDF</td>
<td>500 (^c)</td>
<td>522 (^b)</td>
<td>594 (^b)</td>
<td>654 (^a)</td>
<td>558 (^d)</td>
<td>468 (^b)</td>
<td>583 (^c)</td>
<td>19</td>
</tr>
<tr>
<td>Digestibility, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM</td>
<td>58.5 (^d)</td>
<td>60.3 (^c)</td>
<td>64.3 (^b)</td>
<td>67.8 (^a)</td>
<td>58.8 (^d)</td>
<td>56.3 (^b)</td>
<td>60.7 (^b)</td>
<td>0.9</td>
</tr>
<tr>
<td>OM</td>
<td>60.6 (^d)</td>
<td>61.4 (^c)</td>
<td>65.4 (^b)</td>
<td>68.7 (^a)</td>
<td>59.7 (^d)</td>
<td>57.5 (^b)</td>
<td>61.7 (^b)</td>
<td>1.0</td>
</tr>
<tr>
<td>NDF</td>
<td>60.8 (^d)</td>
<td>60.8 (^d)</td>
<td>57.9 (^d)</td>
<td>62.2 (^a)</td>
<td>56.6 (^d)</td>
<td>58.7 (^d)</td>
<td>58.9 (^d)</td>
<td>1.0</td>
</tr>
</tbody>
</table>

\(^a–d\)Within a row, means without a common superscript letter differ \((P < 0.05)\).
Table 3. Nitrogen balance, microbial N synthesis, apparently digested OM (DOM), and blood metabolites of lambs fed bahiagrass hay diets supplemented at 50% of DM with warm-season legume hays or at 4.25% of DM with soybean meal (SBM)

<table>
<thead>
<tr>
<th>Item</th>
<th>Bahiagrass</th>
<th>SBM</th>
<th>Annual peanut</th>
<th>Perennial peanut</th>
<th>Cowpea</th>
<th>Pigeonpea</th>
<th>Soybean</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen intake, g/d</td>
<td>8.8e</td>
<td>12.1d</td>
<td>17.7b</td>
<td>21.3a</td>
<td>12.9d</td>
<td>11.8i</td>
<td>15.6b</td>
<td>0.54</td>
</tr>
<tr>
<td>Fecal N output, g/d</td>
<td>4.8i</td>
<td>5.1d</td>
<td>6.5b</td>
<td>7.3a</td>
<td>5.8e</td>
<td>5.2i</td>
<td>6.4b</td>
<td>0.20</td>
</tr>
<tr>
<td>Urinary N output, g/d</td>
<td>2.1c</td>
<td>2.7b</td>
<td>4.3c</td>
<td>3.6ab</td>
<td>2.5</td>
<td>2.6b</td>
<td>4.0c</td>
<td>0.35</td>
</tr>
<tr>
<td>Retained N, g/d</td>
<td>2.0i</td>
<td>4.2</td>
<td>7.0b</td>
<td>10.5a</td>
<td>4.6</td>
<td>4.1c</td>
<td>5.1i</td>
<td>0.54</td>
</tr>
<tr>
<td>N digestibility, %</td>
<td>46.5v</td>
<td>56.8v</td>
<td>62.4v</td>
<td>66.8v</td>
<td>54.0v</td>
<td>55.6v</td>
<td>58.1v</td>
<td>1.1</td>
</tr>
<tr>
<td>PD1 output, mmol/d</td>
<td>7.4v</td>
<td>6.3</td>
<td>10.1i</td>
<td>11.0a</td>
<td>6.2</td>
<td>7.2c</td>
<td>9.7b</td>
<td>1.0</td>
</tr>
<tr>
<td>Microbial N, g of N/d</td>
<td>6.4v</td>
<td>5.5</td>
<td>8.7</td>
<td>9.5a</td>
<td>5.4</td>
<td>6.2c</td>
<td>8.4b</td>
<td>0.91</td>
</tr>
<tr>
<td>DOM, g/d</td>
<td>385b</td>
<td>437v</td>
<td>587v</td>
<td>681v</td>
<td>469v</td>
<td>336v</td>
<td>500v</td>
<td>21</td>
</tr>
<tr>
<td>Microbial efficiency, g of microbial N/kg of OM apparently digested</td>
<td>16.0</td>
<td>13.2</td>
<td>16.6</td>
<td>14.8</td>
<td>12.4</td>
<td>16.4</td>
<td>17.2</td>
<td>1.9</td>
</tr>
<tr>
<td>Plasma urea-N, mg/dL</td>
<td>12.5abc</td>
<td>8.3c</td>
<td>13.5a</td>
<td>13.2ab</td>
<td>11.0bc</td>
<td>10.1c</td>
<td>10.8bc</td>
<td>1.0</td>
</tr>
<tr>
<td>Plasma glucose, mg/dL</td>
<td>70.1b</td>
<td>73.7abc</td>
<td>74.0ab</td>
<td>76.8a</td>
<td>72.3b</td>
<td>70.2bc</td>
<td>72.5b</td>
<td>1.4</td>
</tr>
</tbody>
</table>

*Within a row, means without a common superscript letter differ (*P < 0.05*).

DISCUSSION

Table 4. Ruminal fluid pH, NH₃-N, and VFA concentrations of lambs fed bahiagrass hay diets supplemented at 50% of DM with warm-season legume hays or at 4.25% of DM with soybean meal (SBM)

<table>
<thead>
<tr>
<th>Item</th>
<th>Bahiagrass</th>
<th>SBM</th>
<th>Annual peanut</th>
<th>Perennial peanut</th>
<th>Cowpea</th>
<th>Pigeonpea</th>
<th>Soybean</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ruminal pH</td>
<td>7.1</td>
<td>7.1</td>
<td>7.0</td>
<td>7.1</td>
<td>7.1</td>
<td>6.9</td>
<td>7.0</td>
<td>0.055</td>
</tr>
<tr>
<td>Ammonia N, mg/dL</td>
<td>2.5</td>
<td>3.7e</td>
<td>6.6</td>
<td>7.0</td>
<td>6.1</td>
<td>5.5b</td>
<td>5.5b</td>
<td>0.70</td>
</tr>
<tr>
<td>Total VFA, mmol/L</td>
<td>112.0</td>
<td>114.8</td>
<td>121.6</td>
<td>125.7</td>
<td>107.2</td>
<td>105.1</td>
<td>110.8</td>
<td>6.2</td>
</tr>
<tr>
<td>Acetate, mol/100 mol</td>
<td>57.1</td>
<td>56.6</td>
<td>57.0</td>
<td>55.5</td>
<td>58.1</td>
<td>58.9</td>
<td>58.4</td>
<td>0.86</td>
</tr>
<tr>
<td>Propionate, mol/100 mol</td>
<td>23.9</td>
<td>23.3b</td>
<td>21.9b</td>
<td>21.2</td>
<td>21.1c</td>
<td>20.7</td>
<td>20.0e</td>
<td>0.64</td>
</tr>
<tr>
<td>Isobutyrate, mol/100 mol</td>
<td>2.0</td>
<td>3.0</td>
<td>3.4</td>
<td>3.8</td>
<td>3.9</td>
<td>3.9</td>
<td>3.9</td>
<td>0.62</td>
</tr>
<tr>
<td>Butyrate, mol/100 mol</td>
<td>10.8</td>
<td>11.1</td>
<td>10.9</td>
<td>11.6</td>
<td>10.9</td>
<td>11.8</td>
<td>11.8</td>
<td>0.58</td>
</tr>
<tr>
<td>Isovalerate, mol/100 mol</td>
<td>4.8b</td>
<td>4.8h</td>
<td>5.4ab</td>
<td>6.8a</td>
<td>4.5b</td>
<td>5.2h</td>
<td>4.3b</td>
<td>0.53</td>
</tr>
<tr>
<td>Valerate, mol/100 mol</td>
<td>1.7</td>
<td>1.6</td>
<td>1.5</td>
<td>1.3</td>
<td>1.0</td>
<td>1.1</td>
<td>1.7</td>
<td>0.46</td>
</tr>
<tr>
<td>Acetate:propionate, mol/mol</td>
<td>2.38c</td>
<td>2.52v</td>
<td>2.49h</td>
<td>2.61ab</td>
<td>2.75hb</td>
<td>2.74ab</td>
<td>2.93a</td>
<td>0.13</td>
</tr>
</tbody>
</table>

**Within a row, means without a common superscript letter differ (**P < 0.05**).
of cowpea was similar to that reported for Iron clay cowpea grown in Florida (Higuera et al., 2001), but the NDF, ADF, and ADL concentrations were almost twice as great as those of Iron clay cowpea harvested at an earlier maturity stage (canopy close) in Texas (Muir et al., 2001). The CP concentration and IVTD of pigeonpea were much less than those reported (20% and 49 to 55% IVDMR, respectively) for similar early maturing cultivars that were harvested earlier (50% flowering) and cut at a greater stubble height (0.6 m; Alexander et al., 2007). The CP concentration of soybean was similar to those reported for other cultivars (Seiter et al., 2004), but the NDF and ADF concentrations were greater.

Perennial and annual peanut hays had greater IVTD than other legume hays because they contained less NDF and ADF. Although the values were not identical, the ranking of forages by IVTD was the same as that by in vivo apparent DM digestibility, indicating that the IVTD method is suitable for comparing these warm-season legume forages. All forages contained low concentrations of CT. Condensed tannins reduce forage quality at concentrations of 6% of DM or greater (Waghorn et al., 1994), but concentrations of 2 to 4% of DM usually result in improved forage nutrient utilization by ruminants (Min et al., 2003, 2005). Condensed tannin concentrations were consistent with those reported previously for soybean (Reddy et al., 1985), annual peanut (Karchesy and Hemingway, 1986), cowpea (Baloyi et al., 2001), pigeonpea (Alexander et al., 2007), and perennial peanut (Valencia et al., 2007) forages.

Legume hays contained less CP than anticipated based on concentrations of CP in the standing plants (Foster, 2008) primarily because of leaf shatter during harvest and chopping, indicating that harvest management practices that minimize such losses are critical for preserving the quality of the hays. Nevertheless, supplementation with all legume hays, except pigeonpea, increased DM and OM intake, though only supplementation with annual and perennial peanut hay also increased DM and OM digestibility. Moore et al. (1999) reported that supplements decreased voluntary forage intake when forage TDN:CP ratio was <7 with a few exceptions such as when basal forage intake was >1.75% of BW as for our bahiagrass diet. The intake responses in this study typify effects of legume forage supplementation to poor quality basal grass diets (Said and Tolera, 1993). The reticulate venation of legume leaves confers less resistance to ruminal degradation than the parallel venation of grass leaves (Frame, 2005).

Consequently, legumes are degraded more easily and rapidly by ruminal microbes than grass leaves. In addition, lesser structural carbohydrate concentrations in legumes vs. grasses contribute to the faster degradation and passage rates of legumes (Waghorn et al., 1989; Wilson, 1994; Jung and Allen, 1995; Dewhurst et al., 2003). Collectively, these factors increase feed intake due to the decreased rumen fill resulting from faster degradation and passage rates (Mertens, 1973; Reid et al., 1988). Relative differences in DMI and digestibility among legume hay-supplemented diets reflect partly the structural fiber concentrations and morphological characteristics of the legumes. Annual and perennial peanut had less NDF and ADF than the other legume hays; consequently, they were more digestible. Pigeonpea hay had greater NDF, ADF, and ADL concentrations because of its thick, woody stems, which probably decreased DM and OM intake and OM digestibility. As in other studies (Mir and Mir, 1993; Hadeld, 2000; Mupangwa et al., 2000), legume supplementation did not increase NDF digestibility partly because legumes had more lignin than grasses (Wilson, 1994).

Legume hay supplementation increased N intake because of the greater CP concentrations of the legumes vs. bahiagrass, as well as the greater DMI of most of the legume-grass diets by lambs. Nitrogen retention increased accordingly because all supplements increased N digestibility and most decreased the proportion of intake N lost as urine. Legume supplementation increased ruminal NH₃-N concentrations because it increased N intake relative to the control diet and most of the protein in legumes is in the form of soluble protein or rumen-degradable protein (Broderick, 1995). Legume supplementation ensured that ruminal NH₃-N concentrations exceeded the recommended concentration (5.0 mg/dL; Satter and Slyter, 1974) for maximizing microbial N synthesis. Microbial N synthesis was only increased by supplementation with annual or perennial peanut diets, partly because they provided more energy (apparently digested OM) for microbial growth (Clark et al., 1992) than other supplements. Soybean meal supplementation increased N intake and retention, reflecting the greater N concentration of soybean meal; however, the small amount of soybean meal that was fed was not sufficient to significantly improve other measures of digestion.

The total VFA concentration and molar proportions of VFA were typical of the ruminal fluid of ruminants fed a forage-based ration (Bergman, 1990). Ruminal passage rates usually increase with DMI, and this can decrease the ruminal propionate proportion (Harrison et al., 1975, 1976); therefore, greater intake of legume-supplemented diets vs. the control diet may explain the lesser propionate proportion of legume-supplemented treatments. This decrease in ruminal propionate proportion and the attendant increase in acetate:propionate ratio of most legume diets suggests that legume supplementation reduced the efficiency of ruminal fermentation. Chalupa (1977) stated that fermentation is less efficient at greater dilution rates because less metabolic hydrogen is recovered in VFA, but more α-linked glucose polymer escapes the rumen.

Concentrations of PUN and PGlc were within physiologically normal ranges (8 to 20 and 50 to 80 mg/dL, respectively; Kaneko, 1989). That legume supplementation increased ruminal NH₃-N concentration, but not PUN, suggests that adequate energy was supplied in relation to the ruminal effective degradable protein supply from the legume diets (MacRae et al., 2006).
Supplementation with N from legume hays or soybean meal increased N intake, digestion, and retention, indicating that supplementation may improve the performance of lambs on bahiagrass diets. Due to the relatively small amount of soybean meal supplemented, annual and perennial peanut hay supplements were more effective than soybean meal supplementation at improving N intake, digestion, retention, and microbial N production. Because of these positive effects on N metabolism, perennial peanut and annual peanut hays were the best legume hay supplements for the lambs, although soybean and cowpea hays also showed some promise. Pigeonpea hay was the least desirable supplement because it did not improve DMI and reduced OM digestibility. Pigeonpea should be harvested at greater stubble heights for use as a legume supplement, though this would reduce biomass yields. Future research should determine the optimal inclusion rates of perennial peanut, annual peanut, cowpea, and soybean hays in the diets of growing lambs and beef calves.

**LITERATURE CITED**


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