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Supplementing Maize or Soybean Hulls to Cattle Fed Rice Straw: Intake, Apparent Digestion, *In situ* Disappearance and Ruminal Dynamics*

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ABSTRACT : Steers with *ad libitum* access to rice straw were assigned to four diets to evaluate the effects of maize or soybean hull supplementation on intake, *in vivo* digestibility, ruminal pH, VFA, ammonia-nitrogen (NH_3-N) and *in situ* ruminal disappearance of feed nutrients by cattle consuming rice straw. Supplement treatments were: no supplement (RS); soybean meal at 0.127% BW (SBM); cracked maize at 0.415% BW plus 0.044% BW soybean meal (MAIZE); or soybean hulls at 0.415% BW plus 0.044% BW soybean meal (HULLS). The MAIZE and HULLS diets were formulated to provide approximately 4 MJ of NE_m per kg of diet. Rice straw DMI was not affected (p = 0.34) by supplement. Apparent dry matter (DM) digestibility was greater (p<0.001) for MAIZE and HULLS (56.6 and 60.0%, respectively) than for steers consuming SBM or RS (51.8 and 44.4%, respectively). Apparent NDF digestibility was greater (p<0.0004) for HULLS than MAIZE (61.7 vs. 58.0%, respectively) and apparent ADF digestibility was greater (p<0.0008) for HULLS than MAIZE (61.1 vs. 49.2%, respectively). There was no difference in apparent hemicellulose digestibility (p = 0.43). Analysis of ruminal fluid collected 0, 2, 4, 6, and 8 h post-feeding revealed ammonia-nitrogen was greatest (p<0.05) for steers on SBM and HULLS diets at 2 h (24.08 and 22.57 mg/dl, respectively) and total volatile fatty acids was greatest (p<0.05) for HULLS at 4 h (230 mM/L). *In situ* disappearance, measured at 0, 2, 4, 6, 8, 16 and 24 h, indicated that SBM, MAIZE and HULLS tended to enhance the digestibility of DM and fiber components of rice straw. *In situ* disappearance of rice straw DM was greatest for SBM and/or HULLS from 4 to 24 h (p = 0.03). Rice straw NDF and ADF disappearance was enhanced by supplementation from 16 to 24 h (p<0.02). Rice straw DM, NDF and ADF disappearances at 24 h were similar for MAIZE and HULLS treatments. When feeding cattle rice straw diets, energy and protein-based supplements are essential. This study showed that fiber-based supplements are just as, if not more, effective as starch-based supplements in rice straw utilization. This study shows that soybean hulls, in spite of their high fiber content, are as efficient as maize for supplementing rice straw primarily because fiber in soybean hulls is highly digestible as shown by *in vivo* digestibility and *in situ* disappearance. (**Key Words :** Supplementation, Rice Straw, Soybean Hulls, *In situ* Disappearance, Ruminal Metabolism)

INTRODUCTION

Rice straw (*Oryza sativa*, IRN: 1-03-925) is considered poor quality forage for ruminants but is produced in abundance throughout the rice growing areas of the tropics and subtropics. Better quality forages are usually available in temperate countries so rice straw as feed has not been given much attention by cattle (*Bos taurus*) producers or animal scientists. However, refuse burning is becoming more restrictive, and as a result, rice producers in the USA are facing economic and environmental problems of rice straw disposal. Rice straw has been successfully treated with urea to improve fiber digestibility (Wanapat, 1990; Elseed et al., 2003), improving its use as a cattle feed and in turn serve as an additional source of revenue for rice producers. Supplementation strategies have also improved the utilization of rice straw (Pradhan et al., 1996; Chowdhury, 2001).

Cattle fed medium or low quality forages respond differently to types and amounts of energy supplements. Reduced intake and fiber digestion of low quality forages with maize (*Zea mays*, IRN: 4-20-698) supplementation is well documented (Sanson et al., 1990; Higgins et al., 1991; Garces-Yepez et al., 1997). It has been shown, however, that supplementation with soybean hulls (*Glycine max*, IRN: 5-04-612) does not affect intake or digestibility of forages (Martin and Hibberd, 1990; Wheeler et al., 1999; St. Louis et al., 2002). Associative effects between low quality forages and supplements with different nutrients are not

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Table 1. Nutrient composition (%, DM) of cracked maize, soybean hulls, soybean meal, and rice straw fed to steers for different treatments[1]

Nutrient	Feedstuffs offered (%)			
	Cracked maize	Soybean hulls	Soybean meal	Rice straw
DM	86.5	88.3	88.1	89.1
OM	98.3	94.9	92.1	84.1
Ash	1.7	5.1	7.9	15.8
NDF	43.2	66.2	19.2	68.9
ADF	4.0	46.2	4.1	41.3
CP	10.3	12.8	50.4	3.8

[1] Treatment diets on DM basis: RS = Rice straw diet with no supplement; SBM = Rice straw diet supplemented with soybean meal (0.127% BW); MAIZE = Rice straw diet supplemented with maize (0.415% BW) and soybean meal (0.044% BW); HULLS = Rice straw diet supplemented with soybean hulls (0.415% BW) and soybean meal (0.043% BW).

well established. First, National Research Council (1996) equations based on NE_m fail to accurately predict dry matter intake (DMI) of beef cattle fed all-forage diets. Second, supplements are often predicted by these equations to substitute for forages in the total diet, not allowing for additive effects on intake (St. Louis et al., 2002).

In companion studies, Orr et al. (2007) and Nguyen et al. (2007), found that supplementing soybean hulls or maize enhanced total tract digestibility of low quality bermudagrass hay (*Cynodon dactylon*, IRN: 1-00-700). In the same studies they found that soybean hulls, in spite of their high fiber content, resulted in more rapid *in situ* disappearance of hay constituents, while producing a greater volume of total VFA in the rumen. Their data also suggest that, when fed at least 0.5% of BW, soybean hulls are more efficient than maize as a supplement in feeding systems using low quality forages because of their additive and associative effects. The objective of this trial was to evaluate the effects of maize or soybean hull supplementation on intake, *in vivo* digestibility, ruminal pH, volatile fatty acids (VFA), ammonia-nitrogen (NH_3-N), and *in situ* ruminal disappearance of feed nutrients by cattle consuming rice straw.

MATERIALS AND METHODS

Animals and experimental design

Four steers were assigned to one of four diets during four consecutive 24-d periods using a 4×4 Latin square to evaluate apparent nutrient digestibility, ruminal environment, and *in situ* ruminal digestibility of individual feeds. Angus, Hereford, and(or) Charolais steers with ruminal cannulae (initial BW 225±18.9 kg) were fed rice straw *ad libitum* and were assigned to one of four treatments, receiving a new supplement each period. Treatments were: no supplement (RS); soybean meal at 0.127% BW (SBM); cracked maize at 0.415% BW plus soybean meal at 0.044% BW (MAIZE); or pelleted soybean hulls at 0.415% BW plus soybean meal at 0.044% BW (HULLS) (Tables 1 and 2). Soybean meal was included in both MAIZE and HULLS diets so the supplemented diets would be isonitrogenous thus preventing the confounding of protein and energy effects of the supplements.

Rice straw from small square bales was fed without chopping by offering a weighed amount to each animal at 0800 daily, after feeding the treatment supplements. Whole-shelled maize was cracked with a hammer mill with the screen removed in order to grind as course as possible within the restrictions of equipment used. The resulting cracked maize contained various particle sizes, from half-kernel to flour size, somewhat finer than from a roller mill. Soybean hulls, a flaky byproduct (170 kg/m^3) of soybean oil extrusion, are usually pelleted to increase bulk density (513 kg/m^3) for transportation and storage and to reduce waste and segregation in feeding (comparison, rice bran = 320 kg/m^3). The soybean hull pellets of this study were typical for commercial trade, measuring approximately 5 mm diameter by 15 mm long.

Body weights were obtained with no dietary restrictions to determine quantity of supplement to be fed during each period. To facilitate diet adaptation (14 d), steers were housed together in a pen with *ad libitum* access to rice straw.

Table 2. Steer body weight (BW), diet composition (% BW) and estimated dietary energy (MJ/kg) and protein (% DM) for different treatments

Item	Treatment diets[1]			
	RS	SBM	MAIZE	HULLS
Diet formulation				
Rice straw (% BW)	*Ad libitum*	*Ad libitum*	*Ad libitum*	*Ad libitum*
Soybean meal (% BW)	-	0.127	0.044	0.043
Cracked maize (% BW)	-	-	0.415	-
Soybean hulls (% BW)	-	-	-	0.415
Nutrient density of diet [2]				
Dietary NE_m (MJ/kg)	2.21	2.95	4.54	3.58
Dietary NE_g (MJ/kg)	0.38	0.95	3.26	2.44
Dietary CP (%)	3.83	15.53	14.45	15.44

[1] Treatment diets on DM basis: RS = Rice straw diet with no supplement; SBM = Rice straw diet supplemented with soybean meal (0.127% BW); MAIZE = Rice straw diet supplemented with maize (0.415% BW) and soybean meal (0.044% BW); HULLS = Rice straw diet supplemented with soybean hulls (0.415% BW) and soybean meal (0.043% BW).

[2] Estimated using 1.3% BW intake of rice straw for all treatments, DM basis.

During this time, steers were separated daily and individually fed their supplement. Mineral blocks were offered free choice only during diet adaptation (92.0-98.5% NaCl with added Zn, Fe, Mn, Cu, I, and Co; Akzo Nobel Salt, Inc., Clarks Summit, PA, USA). After diet adaptation, steers were placed into individual digestion stalls (2.44× 0.876 m), with separate troughs and automatic waterers, and allowed three days for acclimation immediately followed by five days of data collection for *in vivo* digestion. While in the stalls, steers remained haltered and tied, but able to stand or lie down at will.

Total fecal collections began 17 d after being introduced to treatments (d 18). Apparent nutrient digestibility was determined by weighing and analyzing daily DMI and total fecal excretion from d 18 through 24. Rice straw and supplements offered, and rice straw refused (i.e., orts), were sampled daily from d 18 to d 23 and composited for each steer and sampling period. There were no supplement orts. Total fecal excretion was weighed daily and sampled, taking a 5% aliquot.

Rumen environment

Variation in ruminal digestion due to supplementation was evaluated from d 22 through d 24 by measuring NH_3-N, VFAs, pH, and *in situ* disappearance. On d 22 ruminal fluid was sampled at 0, 2, 4, 6, and 8 h post-feeding of supplements beginning at 0800. Rumen fluid was collected by sampling ruminal contents from four to five locations within the rumen, which was pressed through four layers of cheesecloth. Collected ruminal fluid was immediately placed on ice. After chilling, the pH was determined using Thermo-Orion combination electrode meter (model 290A meter, Beverly, MA, USA). Ruminal fluid was sub-sampled (two replicates of each original sample) and centrifuged (900×g, 20 min). Supernatant was transferred to plastic vials (sorted by date, steer, and h of collection) containing m-phosphoric acid (25% wt/vol) at a 5 sample/1 acid ratio. After mixing, vials were placed on ice until subsequent ruminal fluid collections were completed; samples were then frozen (-20°C) until VFA and NH_3-N analysis.

Upon VFA analysis, frozen ruminal fluid was thawed and shaken, and 5 ml sub-samples were centrifuged (30,000 ×g, 4°C, 20 min). To the resulting supernatant, 2-ethyl butyric acid was added (2 g/L) followed by VFA analysis using gas chromatography equipped with mass spectrophotometer. Gas chromatography analysis was based on procedures described by Grigsby et al. (1992) and temperature gradient program described by Bateman et al. (2002), who also modified the procedure by using helium as the carrier gas with an injection flow rate of 60 ml/min.

Ammonia-N was analyzed using original ruminal fluid samples (i.e., without 2-ethyl butyric acid). Samples were thawed, vortexed, and centrifuged (3,500×g, 4°C, 15 min) followed by analysis using a direct colorimetric method described by McCullough (1967). Samples were incubated at 91% humidity, 5% CO_2, and 37°C for at least 35 minutes prior to colorimetric analysis. Preliminary data necessitated revising McCullough's (1967) method such that the samples were not deproteinated prior to NH_3-N determination.

***In situ* study**

On d 22, 23, and 24 *in situ* ruminal digestion was evaluated. For each period, pooled samples of daily feed offered during the *in vivo* collection were ground to pass a 2-mm screen. *In situ* samples consisting of 3 g of ground rice straw, 5 g of soybean meal, 5 g of ground maize, or 5 g of soybean hulls were directly weighed into separate nylon *in situ* bags (No. 510; 5 cm×10 cm; 50±20 μm, Ankom, Fairport, NY, USA). Each steer received 12 *in situ* samples of rice straw and 12 *in situ* samples of the supplement (soybean meal, maize or soybean hulls) assigned to that steer's diet (SBM, MAIZE, or HULLS, respectively). *In situ* samples for rice straw and supplements were held in separate mesh bags allowed to move freely within the rumen. At 0800, mesh bags containing *in situ* samples were immersed in a bucket of warm water prior to placement in the rumen to dampen samples and facilitate immediate microbial inoculation. At 2, 4, 6, 8, 16, and 24 h after initiation, two *in situ* samples of rice straw and two *in situ* samples of supplement were randomly withdrawn from each steer and immediately placed in ice water to cease microbial digestion. All harvested *in situ* samples were washed by hand according to a procedure described by Vanzant et al. (1996). Dried bags were weighed, and the remaining sample was analyzed as described below.

Laboratory analysis

Rice straw, supplements, and fecal samples were ground in a Thomas Wiley Mill (model 4, Thomas Scientific, Swedesboro, NJ, USA) to pass through a 2-mm screen. Samples were analyzed for DM, ash, CP, NDF, and ADF (Van Soest et al., 1991; AOAC 2003) using the Fiber Analyzer (ANKOM Technology, Fairport, NY, USA). Analysis for NDF included sodium sulfite to aid in the removal of complex proteins; in addition α-amylase was used. Neither NDF nor ADF were corrected for ash content. After ruminal incubation, dried *in situ* bags with their remaining samples were analyzed for DM, NDF, and ADF. Not enough feedstuffs remained in the *in situ* bags to analyze for CP. *In situ* nutrient disappearance was expressed as a ratio of incubated to initial feed nutrient content. All laboratory analyses were conducted in duplicate.

Calculations and statistical analysis

Weights for rice straw, supplements and feces were recorded to field sheets daily for each steer. Weights and

Table 3. The effect of supplementing maize or soybean hulls on DM intake of steers consuming rice straw during a digestion trial

	Diets[1]				SEM	p-values
	RS	SBM	MAIZE	HULLS		
	Dry matter intake					
Rice straw (kg/d)	3.07	3.64	3.00	3.15	0.129	0.34
Total (kg/d)[2]	3.07 [b]	4.19 [a]	4.10 [a]	4.28 [a]	0.173	0.04
Rice straw (% BW)	1.27	1.56	1.36	1.40	0.045	0.38
Total (% BW)[2]	1.27 [b]	1.80 [a]	1.86 [a]	1.91 [a]	0.068	0.02

[1] Treatment diets on dry matter basis: RS = Rice straw diet with no supplement; SBM = Rice straw diet supplemented with soybean meal (0.127% BW); MAIZE = Rice straw diet supplemented with maize (0.415% BW) and soybean meal (0.044% BW); HULLS = Rice straw diet supplemented with soybean hulls (0.415% BW) and soybean meal (0.043% BW).

[2] Total = Dry mater intake of rice straw plus supplement.

[a, b] Within rows, means without a common superscript differ (p<0.05).

sample analyses were entered and categorized by steer, treatment and period on electronic spreadsheets for further calculations (also by period, day and hour for ruminal and *in situ* data).

From DMI and fecal excretion, apparent digestibilities were calculated as percent disappearance of DM, OM, NDF, ADF, hemicellulose (HC) and CP. Hemicellulose was calculated as difference between NDF and ADF residues. Response variables were analyzed as a 4×4 Latin square, using the GLM procedure in SAS (V9.1, SAS Institute Inc., Cary, NC, USA). Planned comparisons of RS vs. other treatments and SBM vs. MAIZE and HULLS were conducted using GLM CONTRAST statements so probabilities could be reported. When significant, means were separated using Ryan-Einot-Gabriel-Welsh multiple-range test (REGWQ) to minimize risk of Type 1 errors.

Ruminal environment data (NH_3-N, pH and VFAs) were analyzed as a 4×4 Latin square, where two samples were collected from each steer, using the GLM procedure for each sampling time (0, 2, 4, 6 and 8 h). The previous REGWQ procedure for mean separations and CONTRAST statements were not used. Instead, least-squares means were separated using multiple pairwise t-tests when treatment effects were significant (p<0.05).

In situ degradation ratios for DM, NDF and ADF were analyzed for each sampling time (0, 2, 4, 6, 8, 16 and 24 h) as a 4×4 Latin square, using the MIXED procedure of SAS, where two samples were collected from each steer. All laboratory analyses were preformed in duplicate. Steer and time period were anaylzed as fixed factors; subsamples and sub-subsamples were analyzed as random factors.

Least-squares means were reported for each treatment by time for ruminal environment and *in situ* degradation results and were separated using multiple pairwise t-tests when treatment effects were significant (p<0.05).

RESULTS AND DISCUSSION

Digestion trial

Rice straw in this study typified the low quality reported by others. Most of the rice in the Mississippi delta area is grown in a dry seeded culture, where the permanent flood is not established until the five-leaf stage. Cocodrie, Cheniere, and CL 161 are the most popular varieties with average yields about 5800 t/ha (MSUcares, 2007). Whether this straw is significantly different from that of other countries is doubtful when comparing the nutrient composition of rice straw in Table 1 with other published data. High ash concentrations (15.8%, Table 1), agrees with the 16.5 to 21.4%, reported by Gohl (1984) who indicated silica was the predominant mineral present. With its high fiber and low CP (3.8%), rice straw alone obviously will not meet maintenance requirement of ruminants. Consumption of rice straw and other low quality forages is often suppressed as shown in the present study (1.2 to 1.6% BW, Table 3), which is in agreement with previous work (Saadulah et al., 1983; Preston and Leng, 1984; Wanapat, 1990; Nguyen, 1996). The DMI of rice straw was not affected by treatment (p = 0.34, Table 3). As a result, steers offered SBM, MAIZE or HULLS diets had greater (p = 0.008) total DMI compared to steers not supplemented. However, data indicates that supplements were not substitutive of basal forage diet (Table 3). Also, steers on the RS diet had reduced apparent digestion of DM, OM, and CP compared to those receiving supplements (p<0.0001, Table 4). Probably because the SBM diet had a smaller quantity of actual supplement, apparent digestibility of NDF was less compared with HULLS and MAIZE diets (p = 0.004). Apparent DM digestibilities of MAIZE and HULLS were similar (p = 0.12) indicating that soybean hulls and cracked maize have similar feeding value for supplementing low quality forages at the level of this study. Why soybean hulls, with more fiber, can still have similar digestibility to cracked maize, with more starch, can be partially explained because apparent NDF and ADF digestibility was greater (p<0.0008) for HULLS than MAIZE, and there was no difference in apparent HC digestibility (p = 0.43).

Weidner and Grant (1994) reported that non-forage fiber sources, such as soybean hulls, may increase ruminal rate of passage and reduce NDF digestibility due to small particle size and greater specific gravity. Garleb et al. (1988) reported non-forage fiber sources have potential to replace

Table 4. The effect of supplementing maize or soybean hulls on apparent nutrient digestibility during digestibility trial

	Diets[1]				SEM	p-values
	RS	SBM	MAIZE	HULLS		
	Apparent nutrient digestibility (%)					
DM	44.4 [c]	51.8 [b]	56.6 [ab]	60.0 [a]	1.63	0.0009
OM	50.2 [c]	57.7 [b]	60.8 [ab]	64.9 [a]	1.52	0.0007
NDF	42.8 [c]	47.6 [c]	58.0 [b]	61.7 [a]	2.13	0.0004
ADF	42.2 [b]	44.1 [b]	49.2 [b]	61.1 [a]	2.02	0.0008
HC [2]	43.7 [b]	52.6 [ab]	66.6 [a]	62.7 [a]	2.80	0.01
CP	10.9 [c]	60.3 [a]	30.3 [b]	41.2 [b]	4.90	0.0001

[1] Treatment diets on dry matter basis: RS = Rice straw diet with no supplement; SBM = Rice straw diet supplemented with soybean meal (0.127% BW); MAIZE = Rice straw diet supplemented with maize (0.415% BW) and soybean meal (0.044% BW); HULLS = Rice straw diet supplemented with soybean hulls (0.415% BW) and soybean meal (0.043% BW).
[2] HC = Hemicellulose as difference between ADF and NDF. [a, b, c] Within a row, means without a common superscript differ ($p<0.05$).

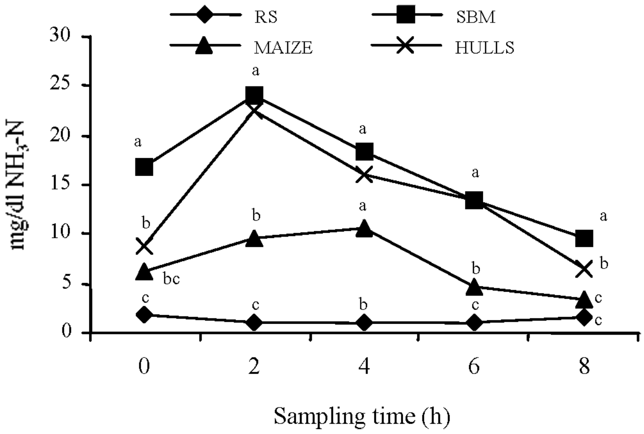

Figure 1. The effect of supplementing maize or soybean hulls on ruminal ammonia-N concentration (mg/dl) measured 0 to 8 h after feeding supplements. Treatment diets: RS = Rice straw diet with no supplement; SBM = Rice straw diet supplemented with soybean meal (0.127% BW); MAIZE = Rice straw diet supplemented with maize (0.415% BW) and soybean meal (0.044% BW); HULLS = Rice straw diet supplemented with soybean hulls (0.415% BW) and soybean meal (0.043% BW). Treatment×time interaction. Means within time differ: 0 h ($p<0.0001$), 2 h ($p<0.0001$), 4 h ($p<0.01$), 6 h ($p<0.0001$), and 8 h ($p<0.0001$). [a, b, c] Means within sampling time differ, $p<0.05$.

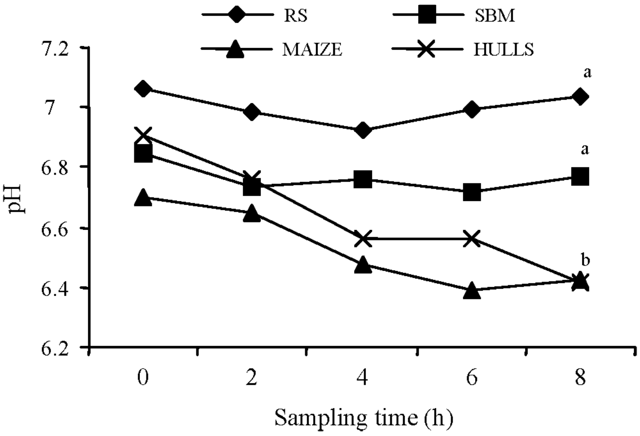

Figure 2. Change in ruminal pH from 0 to 8 h after feeding supplements to steers consuming rice straw. Treatment diets: RS = Rice straw diet with no supplement; SBM = Rice straw diet supplemented with soybean meal (0.127% BW); MAIZE = Rice straw diet supplemented with maize (0.415% BW) and soybean meal (0.044% BW); HULLS = Rice straw diet supplemented with soybean hulls (0.415% BW) and soybean meal (0.043% BW). Treatment×time interaction. Means within time differ: 0 h ($p = 0.26$), 2 h ($p = 0.46$), 4 h ($p = 0.17$), 6 h ($p = 0.13$), and 8 h ($p<0.01$). [a, b, c] Means within sampling time differ, $p<0.05$.

dietary forage, due to their low concentration of lignin and because they contain a large portion of digestible fiber.

Apparent CP digestibility was least for RS (10.9%), because rice straw contains very little protein (Table 1) and likely because most of the CP in rice straw is bound in the cell wall matrix (Cherney, 2000), making it less available to microbial fermentation. Apparent CP digestibility was greatest for SBM followed by HULLS and MAIZE ($p<0.0001$, Table 4).

Ruminal characteristics

Compared to RS, supplementation increased ($p<0.0001$) ruminal NH_3-N concentration pre- and post-feeding with the exception of MAIZE prior to feeding (Figure 1). Diets HULLS and SBM had similar and greatest NH_3-N concentration at 2 and 4 h post-feeding ($p = 0.63$ and 0.57, respectively) but were different pre-feeding and 8 h post-feeding ($p<0.04$). Concentration of NH_3-N for the MAIZE diet measured highest 2 h later (4 h) and was intermediate between RS and the other two supplemented diets (HULLS and SBM, Figure 1). Because not all ruminal bacteria share the same N requirement, ruminal ammonia may be affected by microbial metabolism of available N (Hungate, 1966; Chalupa et al., 1970; McAllen and Smith, 1983). Ruminal ammonia also depends on recycled ammonia and, more importantly, on the extent of carbohydrate fermentation. In this study, ammonia values for supplemented animals exceeded the optimal range (2 to 5 mg/dl) proposed by Satter and Slyter (1974).

As seen in Figure 2, ruminal pH of RS and SBM remained elevated and relatively stable with means ranging between 6.9 and 7.1 for RS and between 6.7 and 6.8 for SBM, and were not different from each other ($p>0.08$).

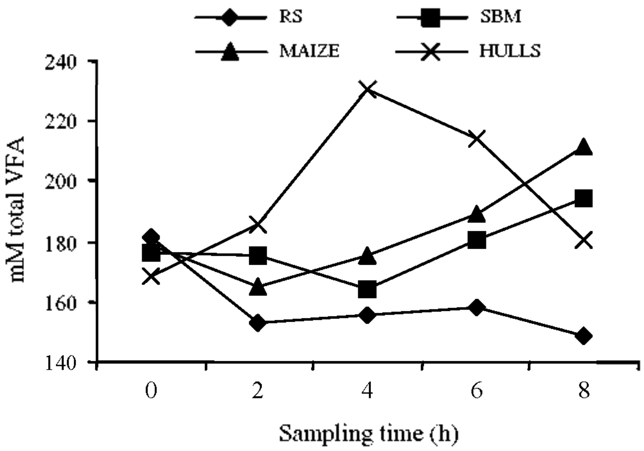

Figure 3. Total volatile fatty acid concentration (m*M*) of steers fed bermudagrass hay and supplemented with maize or soybean hulls from 0 to 8 h after feeding supplements to steers consuming rice straw. Treatment diets: RS = Rice straw diet with no supplement; SBM = Rice straw diet supplemented with soybean meal (0.127% BW); MAIZE = Rice straw diet supplemented with maize (0.415% BW) and soybean meal (0.044% BW); HULLS = Rice straw diet supplemented with soybean hulls (0.415% BW) and soybean meal (0.043% BW). Treatment×time interaction. Means within time differ: 0 h (p = 0.91), 2 h (p = 0.65), 4 h (p = 0.10), 6 h (p = 0.23), and 8 h (p = 0.14).

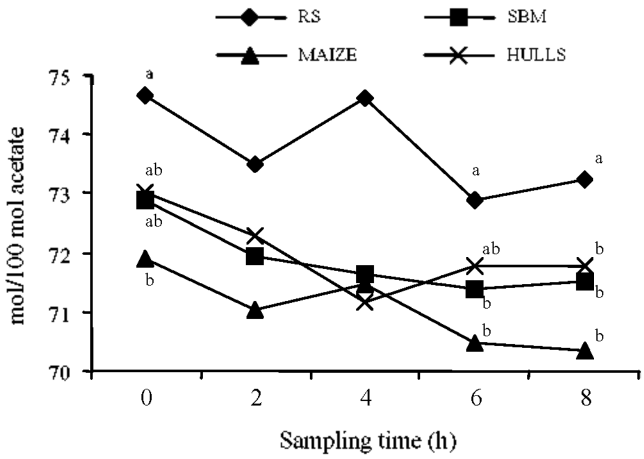

Figure 4. Molar proportions of acetate 0 to 8 h after feeding supplements to steers consuming rice straw. Treatment diets: RS = Rice straw diet with no supplement; SBM = Rice straw diet supplemented with soybean meal (0.127% BW); MAIZE = Rice straw diet supplemented with maize (0.415% BW) and soybean meal (0.044% BW); HULLS = Rice straw diet supplemented with soybean hulls (0.415% BW) and soybean meal (0.043% BW). Treatment×time interaction. Means within time differ: 0 h (p = 0.05), 2 h (p = 0.09), 4 h (p = 0.12), 6 h (p<0.05), and 8 h (p<0.05). [a, b]Means within sampling time differ, p<0.05.

Prior to feeding, ruminal pH of MAIZE remained numerically more acidic than RS (6.7 vs. 7.1 pH, p = 0.07). Ruminal pH of both MAIZE and HULLS remained similar (p = 0.13) at all points measured, declining to 6.42 and 6.41 by 8 h, respectively. A similar study by Nguyen et al. (2007) reported greater change in ruminal pH, 8 h after supplementing forage with cracked maize (6.1) or pelleted soybean hulls (5.9) where soybean hulls were p<0.001 than maize. Lack of differences in the current trial might have occurred because rice straw diets with no supplement had lower apparent DM digestibility (44.4%) than the bermudagrass hay of Nguyen et al. (2007) (52.9%). On the other hand, Paengkoum (1998) supplemented rice straw with urea treated cassava chips at 0.5% BW, and ruminal pH reached its lowest level of 6.1 (2 h) whereas our lowest level was 6.4 for MAIZE (6 h). Apparent DM digestibilty of Paengkoum's (1998) diet was 58.8%, similar to 56.6% and 60.0% for our MAIZE and HULLS diets, respectively.

Fermentation byproducts such as VFAs and lactic acid readily reduce ruminal pH (Burrin and Britton, 1986; Olson et al., 1999), and research has shown that feeding soybean hulls prevented drastic reductions in pH providing a ruminal environment more conducive to fiber digestion (Klopfenstein and Owen, 1987, Sung et al., 2007). In the present study neither maize nor soybean hulls reduced pH below normal physiological range. However, feeding soybean hulls resulted in a reduction of ruminal pH equal to that of maize. Shriver et al. (1986) reported that a ruminal pH of 5.8 was characterized by a 43% reduction in the proportion of microbes associated with fiber particles, indicating fiber digestion was favored in the present study.

As seen in Figure 3, total VFA concentration for steers consuming RS remained relatively stable averaging between 149 and 182 m*M*/L, which was numerically less by contrast comparing RS vs. other treatments across all times (p = 0.0025). Total VFA concentrations were not different among treatments pre- and post feeding (p>0.10), but at 4 h post-feeding, HULLS produced a numerical increase, followed by a decrease in total VFA concentration while both SBM and MAIZE exhibited a numerical increase from 6 to at least 8 h post-feeding. Increased total VFA concentrations immediately followed peaks of ruminal NH_3-N (Figures 2 and 3). Ammonia should increase pH, but didn't in this study (Figures 1 and 2), indicating available N is being utilized by ruminal microflora, confirming the required synchrony between N and energy availability. In contrast, Nguyen et al. (2007), supplementing bermudagrass hay with maize and soybean hulls showed that the reduction in pH coincided with the increase in total VFA concentrations for the various feedstuffs. The present study showed a similar relationship between total VFA concentrations and pH, although not as pronounced. One exception occurred when steers were supplemented with SBM. For reasons not yet understood, total VFA concentrations increased while ruminal pH remained stable. In the current study, the peak total VFA concentration was 230 m*M* for HULLS 4 h post-feeding compared to Nguyen et al. (2007) who reported 185 m*M* peak 6 h post-feeding

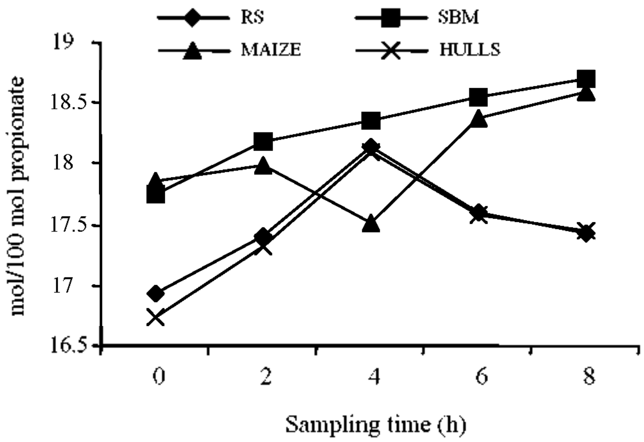

Figure 5. Molar proportions of propionate 0 to 8 h after feeding supplements to steers consuming rice straw. Treatment diets: RS = Rice straw diet with no supplement; SBM = Rice straw diet supplemented with soybean meal (0.127% BW); MAIZE = Rice straw diet supplemented with maize (0.415% BW) and soybean meal (0.044% BW); HULLS = Rice straw diet supplemented with soybean hulls (0.415% BW) and soybean meal (0.043% BW). Treatment×time interaction. Means within time differ: 0 h (p = 0.32), 2 h (p = 0.50), 4 h (p = 0.62), 6 h (p = 0.40), and 8 h (p = 0.20).

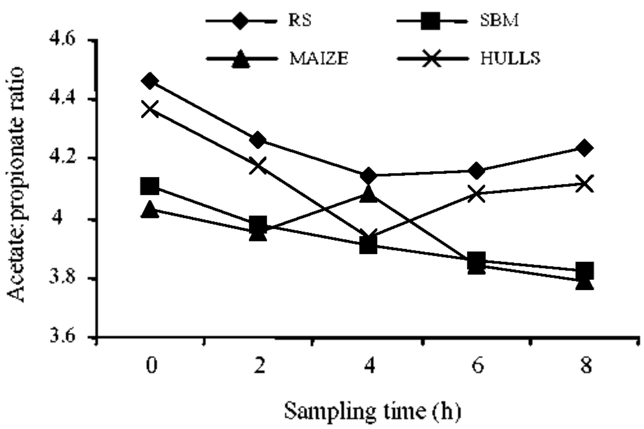

Figure 6. Acetate:Propionate ratio 0 to 8 h after feeding supplements to steers consuming rice straw. Treatment diets: RS = Rice straw diet with no supplement; SBM = Rice straw diet supplemented with soybean meal (0.127% BW); MAIZE = Rce straw diet supplemented with maize (0.415% BW) and soybean meal (0.044% BW); HULLS = Rice straw diet supplemented with soybean hulls (0.415% BW) and soybean meal (0.043% BW). Treatment×time interaction. Means within time differ: 0 h (p = 0.25), 2 h (p = 0.40), 4 h (p = 0.61), 6 h (p = 0.27), and 8 h (p = 0.12).

for soybean hulls fed at 0.607% BW. It is possible that HULLS peaked at 4 h in the present study, as opposed to 6 h reported previously, because there were fewer total digestible nutrients available from RS as shown by its reduced digestibility of rice straw compared with bermudagrass. Diurnal fluctuations in total VFA concentrations for steers consuming highly fibrous HULLS

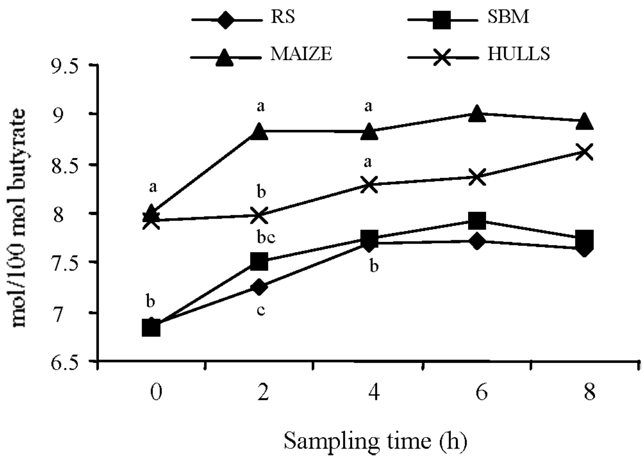

Figure 7. Molar proportions of butyrate 0 to 8 h after feeding supplements to steers consuming rice straw. Treatment diets: RS = Rice straw diet with no supplement; SBM = Rice straw diet supplemented with soybean meal (0.127% BW); MAIZE = Rice straw diet supplemented with maize (0.415% BW) and soybean meal (0.044% BW); HULLS = Rice straw diet supplemented with soybean hulls (0.415% BW) and soybean meal (0.043% BW). Treatment×time interaction. Means within time differ: 0 h ($p<0.05$), 2 h ($p<0.01$), 4 h ($p<0.05$), 6 h (p = 0.11), and 8 h (p = 0.09). [a, b, c] Means within sampling time differ, $p<0.05$.

indicate that it was readily digestible in the rumen even though (66.2% NDF and 46.2% ADF; Table 1). Previous research reported soybean hulls to be digested as much as 75% *in vivo* (Streeter and Horn, 1983; Hsu et al., 1987).

Acetate and propionate are the two primary fatty acids produced in the rumen. Consumption of grains usually results in a relative increase in molar proportions of propionate whereas fiber increase relative proportions of acetate. Supplementation with soybean hulls has shown mixed results with regard to ruminal acetate and propionate concentrations. Although soybean hulls contain mostly fiber and very little starch, trials reported by Nguyen et al. (2007) and Martin and Hibberd (1990) showed supplementation with soybean hulls decreases molar proportions of acetate and increases that of propionate. In contrast, this study showed no change (p = 0.2; Figure 5) in relative proportions of propionate and agrees with Grigsby et al. (1992) who fed approximately 90% soybean hulls and reported an increased ruminal acetate concentrations and reduced ruminal propionate concentrations.

Figure 4 shows molar proportions of acetate tended to be greatest for the RS diet 2 through 6 h post-feeding. By 8 h, acetate was greatest ($p<0.05$) for RS (Figure 4). Similarly, Galloway et al. (1993) who found maize or soybean hulls to decrease ($p<0.06$) the molar proportion of propionate. However, the acetate:propionate ratio tended to decrease during the present study whereas, Grigsby et al. (1992) reported acetate:propionate ratios to increase linearly when low quality bromegrass was substituted with 15, 30, 45, or

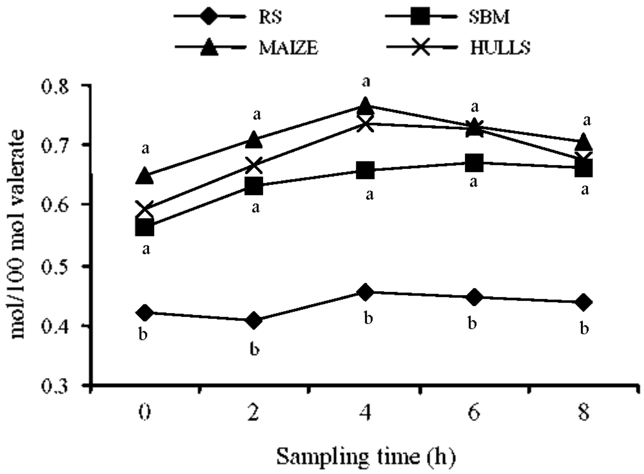

Figure 8. Molar proportions of valerate 0 to 8 h after feeding supplements to steers consuming rice straw. Treatment diets: RS = Rice straw diet with no supplement; SBM = Rice straw diet supplemented with soybean meal (0.127% BW); MAIZE = Rice straw diet supplemented with maize (0.415% BW) and soybean meal (0.044% BW); HULLS = Rice straw diet supplemented with soybean hulls (0.415% BW) and soybean meal (0.043% BW). Treatment×time interaction. Means within time differ: 0 h ($p<0.05$), 2 h ($p<0.001$), 4 h ($p<0.0001$), 6 h ($p<0.0001$), 8 h ($p<0.01$). [a, b] Means within sampling time differ, $p<0.05$.

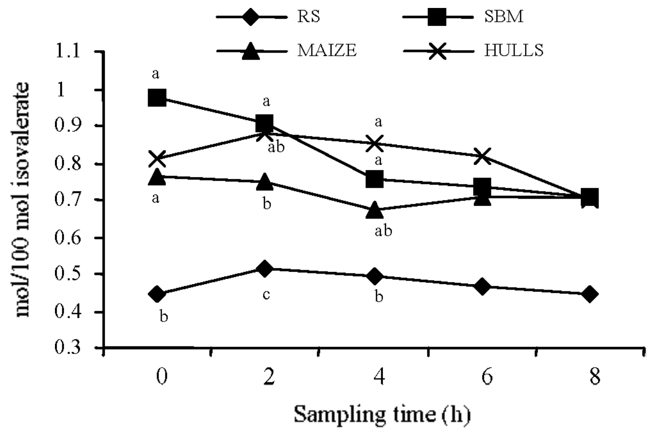

Figure 9. Molar proportions of isovalerate 0 to 8 h after feeding supplements to steers consuming rice straw. Treatment diets: RS = Rice straw diet with no supplement; SBM = Rice straw diet supplemented with soybean meal (0.127% BW); MAIZE = Rice straw diet supplemented with maize (0.415% BW) and soybean meal (0.044% BW); HULLS = Rice straw diet supplemented with soybean hulls (0.415% BW) and soybean meal (0.043% BW). Treatment×time interaction. Means within time differ: 0 h ($p<0.05$), 2 h ($p<0.05$), 4 h ($p<0.05$), 6 h ($p = 0.11$), 8 h ($p = 0.11$). [a, b, c] Means within sampling time differ, $p<0.05$.

60% soybean hulls. However, agreement with these finding was reported by Chase and Hibberd (1987) who found that native grass hay supplemented with 0, 1, 2, or 3 kg ground maize to linearly decrease the acetate:propionate ratio. In addition, these results are also in agreement with Martin and Hibberd (1990) reporting acetate:propionate ratios to decrease with increasing soybean hulls supplementation.

In the present study, the molar proportions of acetate for MAIZE was not different ($p<0.11$) from SBM or HULLS from 0 h to 8 h. However, molar proportion of acetate for RS remained numerically elevated ($p<0.16$) above the other treatments from 0 to 8 h (Figure 4). Molar proportions of propionate remained relatively stable post-feeding ($p<0.20$), ranging from the least of 16.7 mol/100 mol for HULLS at 0 h to the greatest of 18.7 mol/100 mol for SBM at 8 h (Figure 5).

The molar proportions of butyrate differed at 0, 2, and 4 h with MAIZE remaining more concentrated than RS and SBM but not different from HULLS except at 2 h ($p<0.001$). Butyrate was similar among treatments from 6 to 8 h post-feeding (Figure 7). Molar proportions of isobutyrate remained stable from 0 to 8 h for all treatments, ranging between 0.69 and 1.00 mol/100 mol (data not shown), and showed no treatment differences ($p<0.11$). Valerate concentrations were markedly affected by supplementation from 0 to 8 h ($p<0.05$) but SBM, MAIZE, and HULLS did not differ (Figure 8). Isovalerate concentrations followed a similar trend to valerate except that MAIZE was associated with less proportions of isovalerate than SBM at 2 h and was not different from RS or other supplements at 4 h (Figure 9).

In situ disappearance of nutrients

In situ disappearance of rice straw DM from the rumen (Table 5) was greatest for the SBM treatment 6 to 24 h post-feeding ($p<0.04$). Rice straw NDF and ADF disappearance tended to be greatest for supplemented steers (16 to 24 h, $p<0.02$). Reduction in rice straw disappearance in RS diet is likely due to an insufficient supply of metabolizable protein within the rice straw (Tables 1 and 2) because RS did not include soybean meal.

The ruminal DM disappearance of cracked maize in the MAIZE diet was greater ($p<0.05$) than soybean hulls in the HULLS diet from 2 to 8 h after feeding supplements. At 24 h, ruminal soybean hull disappearance exceeded ($p<0.05$) that of maize, likely because much of the maize starch would have been digested or washed out of the sample bags. Although soybean hulls were digested slower than maize, they still proved to be highly digestible, which is supported by previous studies evaluating the digestion of soybean hulls by cattle (Quicke et al., 1959; Hintz et al., 1964; Ludden et al., 1995).

Comparing MAIZE and HULLS, the differences in apparent fiber (NDF and ADF) digestibilities shown in Table 4 can be explained by *in situ* disappearances of rice straw and supplements in Table 5 and 6. By implication, the fiber digestion of HULLS in Table 4 involved fiber from both rice straw and soybean hulls. Because there were no differences in *in situ* fiber (NDF and ADF) disappearance

Table 5. Least squares means of ruminal remained ratios of incubated to initial rice straw nutrient content between supplemented and non-supplemented steers

Incubation (h)	Treatment[1]				SEM	p-value[2]
	RS	SBM	MAIZE	HULLS		
	---- DM ----					
0	0.787	0.786	0.788	0.793	0.003	0.3339
2	0.787	0.784	0.787	0.788	0.002	0.3404
4	0.783 ^{a}	0.773 ^{b}	0.782 ^{a}	0.777 ^{ab}	0.002	0.0380
6	0.769 ^{b}	0.756 ^{c}	0.774 ^{a}	0.765 ^{ab}	0.003	0.0012
8	0.759 ^{a}	0.734 ^{b}	0.750 ^{a}	0.749 ^{a}	0.003	0.0012
16	0.720 ^{a}	0.664 ^{c}	0.706 ^{ab}	0.684 ^{bc}	0.006	<0.0001
24	0.675 ^{a}	0.594 ^{c}	0.643 ^{b}	0.623 ^{b}	0.008	<0.0001
	---- NDF ----					
0	0.973	0.975	0.984	0.978	0.003	0.3440
2	0.984	0.982	0.973	0.975	0.004	0.6192
4	0.974	0.959	0.978	0.957	0.005	0.0890
6	0.904	0.946	0.970	0.941	0.009	0.0564
8	0.911	0.903	0.941	0.917	0.010	0.6027
16	0.893 ^{a}	0.802 ^{b}	0.882 ^{a}	0.857 ^{a}	0.010	0.0017
24	0.843 ^{a}	0.748 ^{c}	0.796 ^{b}	0.777 ^{b}	0.007	<0.0001
	---- ADF ----					
0	0.986	0.990	0.999	0.994	0.004	0.7685
2	1.005	1.006	0.987	1.005	0.004	0.4146
4	0.990	0.976	1.001	0.994	0.005	0.4349
6	0.960	0.969	0.992	0.978	0.005	0.2937
8	0.958	0.942	0.962	0.957	0.006	0.4609
16	0.905 ^{a}	0.841 ^{b}	0.896 ^{a}	0.872 ^{ab}	0.007	0.0229
24	0.863 ^{a}	0.761 ^{c}	0.809 ^{b}	0.792 ^{bc}	0.009	0.0011

[1] Treatment diets on dry matter basis: RS = Rice straw diet with no supplement; SBM = Rice straw diet supplemented with soybean meal (0.127% BW); MAIZE = Rice straw diet supplemented with maize (0.415% BW) and soybean meal (0.044% BW); HULLS = Rice straw diet supplemented with soybean hulls (0.415% BW) and soybean meal (0.043% BW).

[2] Probability of effects due to treatment within each time. [a, b, c] Within a row, means without a common superscript differ (p<0.05).

Table 6. Least squares means of ruminal remained ratios of incubated to initial nutrients from soybean meal, maize, and soybean hulls in respective supplemented steers

Incubation (h)	Supplement by treatment[1]			SEM	p-value[2]
	Soybean meal	Maize	Soybean hulls		
	---- DM ----				
0	0.645 ^{c}	0.786 ^{b}	0.832 ^{a}	0.018	<0.0001
2	0.638 ^{c}	0.764 ^{b}	0.813 ^{a}	0.016	<0.0001
4	0.604 ^{c}	0.735 ^{b}	0.790 ^{a}	0.017	<0.0001
6	0.566 ^{c}	0.711 ^{b}	0.751 ^{a}	0.017	<0.0001
8	0.515 ^{c}	0.677 ^{b}	0.719 ^{a}	0.019	<0.0001
16	0.311 ^{b}	0.603 ^{a}	0.601 ^{a}	0.030	<0.0001
24	0.145 ^{c}	0.528 ^{a}	0.468 ^{b}	0.037	<0.0001
	---- NDF ----				
0	1.392 ^{a}	0.510 ^{c}	1.037 ^{b}	0.084	0.0001
2	1.646 ^{a}	0.421 ^{c}	0.977 ^{b}	0.107	0.0003
4	1.600 ^{a}	0.689 ^{b}	0.989 ^{b}	0.094	0.0040
6	1.653 ^{a}	0.634 ^{b}	0.904 ^{b}	0.100	0.0053
8	1.723 ^{a}	0.605 ^{b}	0.884 ^{b}	0.092	0.0001
16	1.320 ^{a}	0.420 ^{b}	0.769 ^{b}	0.085	0.0009
24	0.444 ^{b}	0.461 ^{b}	0.593 ^{a}	0.025	0.0773
	---- ADF ----				
0	2.016 ^{a}	0.559 ^{b}	1.205 ^{ab}	0.214	0.0250
2	1.977 ^{a}	0.826 ^{b}	1.394 ^{b}	0.230	0.0048
4	1.796 ^{a}	1.040 ^{b}	1.110 ^{ab}	0.185	0.0332
6	1.860 ^{a}	0.782 ^{b}	0.432 ^{b}	0.150	0.0056
8	2.991 ^{a}	1.452 ^{b}	0.948 ^{b}	0.233	0.0029
16	4.066 ^{a}	0.810 ^{b}	0.493 ^{b}	0.398	0.0036
24	2.181 ^{a}	0.618 ^{b}	0.672 ^{b}	0.142	0.0265

[1] Treatment diets on dry matter basis: SBM = Rice straw diet supplemented with soybean meal (0.127% BW); MAIZE = Rice straw diet supplemented with maize (0.415% BW) and soybean meal (0.044% BW); HULLS = Rice straw diet supplemented with soybean hulls (0.415% BW) and soybean meal (0.043% BW).

[2] Probability of effects due to treatment within each time. [a, b, c] Within a row, means without a common superscript differ (p<0.05).

from the rice straw (Table 5), then the differences between MAIZE and HULLS in apparent total tract digestibilities came from the supplements (maize and soybean hulls, respectively). This seems in conflict with Table 6 which shows a more rapid disappearance of NDF and ADF for maize than for soybean hulls. However, the initial concentration of these fiber components was much less to begin with (Table 1). Disappearance ratios greater than 1 in Table 5 and 6 are most likely explained by partial escape of sample material from *in situ* bags. Current *in situ* findings differ from a similar study of Nguyen et al. (2007) who reported a difference in ADF *in situ* disappearance of bermudagrass hay. They suggested that supplying a fibrous feedstuff to the rumen would promote fiber-digesting bacteria while suppressing starch bacteria. They also suggested that feeding at least 0.5% of BW of soybean hulls can enhance forage digestion through additive and associative effects resulting in a more efficient supplement than maize. Current data does not concur with these findings likely do to the differences in forage quality and digestibility between bermudagrass and rice straw.

In summary, steers were fed diets of rice straw *ad libitum* supplemented with maize or soybean hulls at 0.4% BW to provide approximately 4 MJ NE_m per kg of diet. Rice straw DMI was not affected by supplementation, indicating no substitutive effects. In addition, maize or soybean hulls enhanced digestibility of the fiber in rice straw when protein requirements were met with soybean meal.

In spite of high fiber content of soybean hulls, this study suggests that they are as efficient as maize for supplementing rice straw primarily because fiber in soybean hulls are highly digestible as shown by *in vivo* digestibility and *in situ* disappearance. Our understanding of the associative effects of soybean hulls, when supplementing low quality forages such as bermudagrass, has become clearer in recent years. Rice bran should perform similarly to soybean hulls (Orden et al., 2000; Chaudhary et al., 2001). This study shows that rice straw, even with its lower protein and higher silica content, has similar associative effects, when additional protein is also provided, because fiber digestion is similar. When feeding cattle rice straw diets, energy and protein-based supplements are essential, but highly digestible fiber-based supplements may tend to increase rice straw utilization.

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