JARQ 41 (3), 253 – 260 (2007) http://www.jircas.affrc.go.jp

Comparative Study on Energy and Nitrogen Metabolism of Brahman Cattle and Sheep Given Ruzi Grass Hay with Different Levels of Soybean Meal

Tomoyuki KAWASHIMA[1,4]*, Witthaya SUMAMAL[2], Pimpaporn PHOLSEN[2], Ramphrai CHAITHIANG[2] and Fuminori TERADA[3]

[1] Animal Production and Grassland Division, Japan International Research Center for Agricultural Sciences (JIRCAS) (Tsukuba, Ibaraki 305–8686, Japan)
[2] Khon Kaen Animal Nutrition Research Center, Department of Livestock Development (Thapra, Khon Kaen 40260, Thailand)
[3] National Institute of Livestock and Grassland Science, National Agriculture and Food Research Organization (Tsukuba, Ibaraki 305–0901, Japan)

Abstract

Metabolism trials were conducted on six wethers and four Brahman steers given Ruzi grass hay with different levels of soybean meal in order to compare the effects of protein levels on energy and nitrogen balances, and fiber digestion between the two animal species. Crude protein (CP) contents in four dietary treatments were 3.4%, 6.9%, 10.4%, and 13.9% with the different levels of soybean meal supplement. Digestibilities of crude fiber, neutral detergent fiber and acid detergent fiber were greatly improved in sheep by the supplement of soybean meal until the CP content in the whole ration reached 10%. The difference was more than 10 units in each fiber fraction. While in cattle, fiber fraction digestibilities in the animals given Ruzi grass hay without soybean meal supplement were relatively high. The values were then improved by the smallest amount of supplement (6.9% CP). Beyond this level, there was no effect of the supplement. Although digestibility of CP was lower in sheep when no protein supplement was given, it was higher in sheep when high protein diets were given (10.4 and 13.9% CP). The total digestible nutrient and digestible energy contents well represented overall features of the differences in nutrient digestibilities between sheep and cattle. With lower levels of soybean meal supplement, these values were lower in sheep than in cattle. While, with higher levels of the supplement, there was no difference in the values between the animals. Sheep are often studied as a model animal for cattle in order to examine nutritive value of feed resources. It was suggested in the design of feeding trials using sheep, that CP content of whole ration, in which a target feed resource is included, should be more than 10%.

Discipline: Animal industry
Additional key words: fiber digestion, protein supplement

Introduction

The establishment of a proper feeding management for ruminants has been urged for the sustainable development of animal production in Thailand. The animals and feed resources available in the country are different from those in temperate countries. A series of studies are being carried out to establish feeding standards and feed tables in the country. Digestibility of feed for ruminants is com-

This paper reports the results obtained from the collaborative research between Japan International Research Center for Agricultural Sciences (JIRCAS), Japan and Department of Livestock Development, Thailand, entitled "Improvement of cattle production with locally available feed resources in Northeast Thailand", conducted from 1994–1999 under the Comprehensive Research Project "Sustainable Agricultural Systems in Northeast Thailand".
Present address:
[4] Functional Feed Research Team, National Institute of Livestock and Grassland Science, National Agriculture and Food Research Organization (Tsukuba, Ibaraki 305–0901, Japan)
*Corresponding author: e-mail tkawa@affrc.go.jp
Received 15 June 2006; accepted 6 November 2006.

monly determined with sheep with the assumption that cattle and sheep have equal digestive capacity. However, this assumption is not fully proven by experimental results[1]. Playne[15] reported that dry matter (DM) digestibility of a low quality tropical grass hay was much higher in cattle than in sheep. Terada et al.[20] compared digestibility of nutrients among cattle, sheep and goats given rice straw wafer and rolled barley with different kinds of protein sources, i.e. soybean meal and urea, and reported large differences in total digestible nutrient (TDN) content between cattle and sheep when they were given low protein diets. When sheep were fed the diets containing more than 10% CP, however, the TDN content rose to the same level as that for cattle. Ruminants in the tropics tend to be fed with low quality diets, and are considered to adapt such low quality feed better than ruminants in a temperate zone. The ability to utilize protein might be better in ruminants native to the tropical zone. This study is aimed at comparing the digestibility of nutrients and the effect of protein levels on fiber digestion between cattle and sheep given low quality tropical grass with different levels of soybean meal supplement in order to characterize protein and energy metabolism in these species. A respiration trial is additionally conducted with cattle in order to obtain more precise information on energy metabolism in Brahman cattle. The outcome would contribute to the establishment of a feeding strategy for tropical ruminants.

Materials and methods

1. Experimental design

Six wethers (50% Catadine and 50% native cross) and four Brahman steers (average body weight at the beginning of the trial, 37.3 kg and 419 kg, respectively) were housed individually in metabolic crates with free access to water and subjected to the following four dietary treatments:

1) 100% of Ruzi grass hay (*Brachiaria ruziziensis*).
2) 92% of Ruzi grass hay and 8% of soybean meal on DM basis.
3) 84% of Ruzi grass hay and 16% of soybean meal on DM basis.
4) 76% of Ruzi grass hay and 24% of soybean meal on DM basis.

All animals were treated to remove endo- and ectoparasites prior to the start of the experiment. In sheep, the treatments were conducted in the manner of the Latin square design in which two duplications were included. In cattle, the treatments were conducted in this order. Before starting the treatment, a one-week additional preliminary period was assigned to every animal for the purpose of adaptation to the new roughage and metabolic crate. Feeds were offered in two equal meals at 0800 and 1700 h. The daily amounts given were 1.7% of the animal's body weight. Each treatment consisted of a 9-day preliminary period and 5-day collection period. When the hay was refused during the collection period in treatment 1, the refusal was collected and subjected to chemical analysis. When the feed was refused during the preliminary period of the other treatments, the amount was reduced so that the animals could consume all the feed. Commercial mineral and vitamin premix with the following composition was given to each animal at 6 g and 70 g per day in sheep and cattle, respectively: Vitamin A, 150,000 IU; Vitamin D_3, 30,000 IU; Vitamin E, 100 IU; Na, 11.81 g; Cl, 18.22 g; Ca, 330.00 g; P, 171.32 g; S, 1.03 g; Zn, 1.20 g; Fe, 499.30 mg; Mg, 6.03 g; Co, 15.10 mg; Cu, 205.30 mg; I, 15.30 mg; Mn, 499.5 mg; Se, 7.00 mg; Mo, 5.00 mg; K, 4.70 mg; and filler (mixed all up to 1 kg total).

2. Sample collection and analysis

The amount of feces was measured over the five-day collection period. An aliquot of feces sample was dried at 60ºC, left in a room, and measured as air dry matter. Five feces samples collected from each animal during the collection period were ground, mixed and subjected to chemical analysis. An aliquot of ground feces was dried at 120ºC and measured as dry matter (DM). The total amount of urine was collected into acid and measured over the five-day collection period. After the last dietary treatment, only cattle were fasted for 4 days. Furthermore, the total amount of urine was collected over the last 2 days of the fasting period.

Cattle were subjected to a respiration trial. Oxygen consumption and the productions of carbon dioxide and methane were measured with the ventilated flow-through method using a face mask during the last 4 days of the feeding period and the last 2 days of the fasting period. The system consisted of a face mask (Sanshin Kogyo Ltd., Japan), flow cell (Thermal flow cell FHW-N-S, Japan Flow Cell Ltd., Japan), oxygen analyzer (Xentra 4100, Servomex Ltd., UK), and carbon dioxide and methane analyzers (Infra-red gas analyzer, VIA300, Horiba, Japan). Gas analyzers were calibrated against certified gases (Saisan Ltd., Japan) with known gas concentrations at least two times a day. These measurements were conducted 7 times per day, each 6–10 min in duration, with the following schedule: 0700, 1000, 1300, 1600, 1900, 2200, and 0100 h. The details of the respiration trial are described in the report of Kawashima et al.[9].

The DM, crude protein (CP), ether extract (EE), crude fiber (CF), and ash in oven-dried (60ºC) feed and feces samples were determined by the method of AOAC[3], acid detergent fiber (ADF) by the method of Goering and Van Soest[7], and neutral detergent fiber (NDF) by the method of Van Soest et al.[22]. The nitrogen content in urine was determined by the method of AOAC[3]. Heat of combustion of oven-dried feed and feces samples and oven-dried (60ºC, 48 hours) urine were also determined using an adiabatic calorimeter (Shimadzu CA-4PJ, Japan). Heat production (HP, kJ) was calculated by the equation, $HP = 16.18 \times O_2 + 5.02 \times CO_2 - 2.17 \times CH_4 - 5.99 \times N$, where O_2, CO_2 and CH_4 represent volumes of oxygen consumed, carbon dioxide and methane produced (l), and N is the quantity of urinary nitrogen excreted (g)[5].

3. Statistical analysis

A general linear model[19] was used to analyze the effects of species and dietary treatments and their interaction with a model including treatments, species and individual animals. Duncan's multiple range test was applied to analyze the difference among the treatments within each species and the difference between species within each treatment.

Results

The chemical composition of feed and the ratio of the ingredients are shown in Tables 1 and 2, respectively. The CP contents of Ruzi grass hay and soybean meal were 3.4% and 46.7%, respectively. The CP contents of feed ranged from 3.4% to 13.9% depending on the levels of soybean meal. As both animals were given feed at 1.7% of their body weight at the beginning of the trial, the DM intake on the basis of metabolic body size was higher in cattle. While some sheep refused feed only in treatment 1, cattle refused feed in treatments 1 and 2.

The digestibilities of nutrients are shown in Table 3. Significant effects of species and treatments, and an interaction between species and treatments were found in DM digestibility. DM digestibility in sheep was the lowest in treatment 1 and followed by that of treatment 2. There was no difference in DM digestibility between treatments 3 and 4 in sheep. While there was no difference in DM digestibility among treatments 2, 3 and 4 in cattle, that in treatment 1 was lower than the others. Consequently, there was a difference in DM digestibility between sheep and cattle in treatment 2. A similar trend was found in OM, CF and NDF digestibilities. On the other hand, CP digestibility was not different between the species in treatments 1 and 2. However, it was higher in sheep than in cattle in treatments 3 and 4. The digestibility of EE was generally higher in sheep than in cattle, and it was significantly higher in sheep in treatment 4. In the digestibility of NFE, there was no significant interaction between species and treatments. It was generally higher in cattle than in sheep and significantly higher in the treatments including higher levels of soybean meal. While ADF digestibility in sheep showed a similar trend as DM, OM, CF, and NDF, that in cattle did not show a consistent trend.

The energy and nitrogen balance was compared between the species on the basis of dry matter intake

Table 1. Chemical composition of feed

	DM	CP	EE	CF	Ash	NFE	NDF	ADF	GE
	(%)				(% DM)				(MJ/kg)
Ruzi grass hay	91.3	3.4	1.5	35.6	6.3	53.3	73.8	45.5	17.5
Soybean meal	90.2	46.7	7.8	5.5	6.0	34.1	14.7	7.5	20.9

DM: dry matter, CP: crude protein, EE: ether extracts, CF: crude fiber, NFE: nitrogen-free extracts, NDF: neutral detergent fiber, ADF: acid detergent fiber, GE: gross energy.

Table 2. Feed composition and DM intake

Treatment	Sheep				Cattle			
	1	2	3	4	1	2	3	4
Ingredients (% of DM)								
Ruzi grass hay	100.0	91.9	83.8	75.6	100.0	92.0	83.9	75.9
Soybean meal	0.0	8.1	16.2	24.4	0.0	8.0	16.1	24.2
CP content (%)	3.4	6.9	10.4	13.9	3.5	6.8	10.3	13.8
DM intake (g/$BWkg^{0.75}$)	42.6	42.6	44.1	44.8	60.7	69.0	79.6	77.9

DM: dry matter, CP: crude protein, BW: body weight.

Table 3. Digestibility (%) of nutrients of sheep and cattle given Ruzi grass hay with different levels of soybean meal

Treatment[1)]	Sheep					Cattle					Effect[2)]		
	1	2	3	4	SE	1	2	3	4	SE	A	T	A × T
DM	45.5^{c}	54.5^{bx}	59.7^{a}	62.3^{a}	1.3	53.2^{b}	60.5^{ay}	59.2^{a}	62.4^{a}	1.3	**	**	*
OM	47.5^{c}	56.8^{bx}	62.0^{a}	64.9^{a}	1.3	55.5^{c}	63.1^{aby}	61.2^{b}	65.2^{a}	1.1	**	**	*
CP	24.1^{c}	62.8^{b}	74.2^{ax}	80.3^{ax}	2.3	35.1^{c}	65.3^{b}	72.8^{ay}	78.2^{ay}	2.2	NS	**	*
EE	38.2^{c}	61.0^{b}	68.5^{ab}	74.9^{ax}	2.6	38.4^{c}	54.2^{b}	64.4^{a}	68.8^{ay}	1.5	*	**	NS
CF	46.1^{c}	54.3^{bx}	58.2^{ab}	60.2^{a}	1.7	54.3^{b}	61.9^{ay}	57.4^{ab}	59.2^{a}	1.6	*	**	*
NFE	50.1^{cx}	57.2^{bx}	61.5^{ax}	62.6^{a}	1.1	58.2^{cy}	63.0^{bcy}	73.9^{ay}	67.7^{ab}	2.1	**	**	NS
NDF	44.0^{cx}	51.7^{bx}	56.4^{ab}	57.7^{a}	1.6	53.8^{by}	61.0^{ay}	55.3^{b}	58.0^{ab}	1.4	**	**	**
ADF	43.3^{c}	52.3^{bx}	56.2^{ax}	56.2^{a}	1.2	50.0^{b}	57.5^{ay}	50.7^{by}	53.1^{ab}	1.5	NS	**	**

1): Treatment 1, 100% Ruzi grass hay (RGH); Treatment 2, RGH and 8% of soybean meal (SBM); Treatment 3, RGH and 16% of SBM; Treatment 4, RGH and 24% of SBM; SE, standard error.
DM: dry matter, OM: organic matter, CP: crude protein, EE: ether extracts, CF: crude fiber, NFE: nitrogen free extracts, NDF: neutral detergent fiber, ADF: acid detergent fiber.
2): A, an effect of animals; T, an effect of treatments; A × T, an interaction between animals and treatments.
**: P<0.01, *: P<0.05, NS: not significant.
a, b, c: Means with different superscripts among treatments within each animal differ significantly (P<0.05).
x, y: Means with different superscripts between each animal in each treatment differ significantly (P<0.05).

Table 4. Energy and nitrogen balances and nutritive value

Treatment[1)]	Sheep					Cattle					Effect[2)]		
	1	2	3	4	SE	1	2	3	4	SE	A	T	A × T
Energy balance (MJ/kgDM intake)													
Intake	17.50	17.76	18.03	18.31		17.45	17.75	18.03	18.30				
Excretion Feces	9.92^{ax}	8.34^{bx}	7.41^{c}	6.85^{c}	0.26	8.16^{ay}	7.12^{by}	7.52^{ab}	6.80^{b}	0.22	**	**	**
Urine	0.489	0.560^{x}	0.631	0.619	0.089	0.414	0.458^{y}	0.450	0.491	0.030	*	NS	NS
Retention	7.09^{dx}	8.86^{cx}	9.99^{b}	10.84^{a}	0.26	8.88^{cy}	10.17^{by}	10.06^{b}	11.01^{a}	0.22	**	**	**
Nitrogen balance (gN/kgDM intake)													
Intake	5.44	11.02	16.60	22.27	0.03	5.59	10.95	16.52	22.11	0.02			
Excretion Feces	4.12	4.09	4.29	4.39^{x}	0.12	3.63^{b}	3.80^{b}	4.49^{a}	4.83^{ay}	0.14	NS	**	*
Urine	3.20^{bx}	5.09^{bx}	9.33^{a}	8.44^{a}	0.96	1.63^{dy}	3.24^{cy}	5.32^{b}	8.18^{a}	0.47	**	**	NS
Retention	–1.88^{cx}	1.83^{bx}	2.99^{b}	9.44^{a}	0.93	0.33^{dy}	3.92^{cy}	6.71^{b}	9.10^{a}	0.46	**	**	NS
Nutritive value													
TDN[2)] (% DM)	45.3^{c}	54.7^{bx}	60.3^{a}	63.7^{a}	1.2	52.7^{c}	60.4^{aby}	59.4^{b}	63.7^{a}	1.0	**	**	*
DE (MJ/kgDM)	7.58^{dx}	9.42^{cx}	10.62^{b}	11.46^{a}	0.27	9.29^{cy}	10.63^{by}	10.51^{b}	11.50^{a}	0.22	**	**	**
DE/GE	0.433^{cx}	0.530^{bx}	0.589^{a}	0.626^{a}	0.015	0.532^{cy}	0.599^{aby}	0.583^{b}	0.628^{a}	0.013	**	**	**
DCP (% DM)	0.82^{d}	4.33^{c}	7.70^{bx}	11.18^{ax}	0.08	1.23^{d}	4.47^{c}	7.52^{by}	10.80^{ay}	0.09	NS	**	**

1): Treatment 1, 100% Ruzi grass hay (RGH); Treatment 2, RGH and 8% of soybean meal (SBM); Treatment 3, RGH and 16% of SBM; Treatment 4, RGH and 24% of SBM; SE, standard error.
TDN: total digestible nutrient, DM: dry matter, DE: digestible energy, GE: gross energy, DCP: digestible crude protein.
2): A, an effect of animals; T, an effect of treatments; A × T, an interaction between animals and treatments, **: P<0.01, *: P<0.05, NS: not significant.
a, b, c, d: Means with different superscripts among treatments within each animal differ significantly (P<0.05).
x, y: Means with different superscripts between each animal in each treatment differ significantly (P<0.05).

(Table 4). Significant effects of species and treatments, and a significant interaction were found in energy excretion into feces. Energy excretion became smaller in both species when the animals were given higher levels of soybean meal. While energy excretion into feces was significantly higher in sheep than in cattle in treatments 1 and 2, it was not different in treatments 3 and 4. Energy excretion into urine tended to be higher in sheep than in cattle and it was significantly higher in treatment 2. Energy retention revealed a completely opposite trend to the fecal excretion. Soybean meal supplementation clearly improved energy retention in both species. In the lower supplementation, i.e. treatments 1 and 2, the retention was lower in sheep than in cattle.

The nitrogen intake differed according to the levels of soybean meal supplementation. While nitrogen excretion into feces was not different among the treatments in sheep, it became higher in cattle according to the levels of soybean meal. Consequently, it was significantly different between sheep and cattle in treatment 4. Nitrogen excretion into urine became higher according to the levels of soybean meal given, and generally higher in sheep than in cattle. It was significantly higher in sheep in treatments 1 and 2. Nitrogen retention accurately reflected the difference in urinary nitrogen excretion. Metabolic fecal N excretion was estimated by the regression analysis of fecal N excretion per DM intake (gN/kgDM) against CP content in feed (%). The values were 3.97 and 3.11 gN/kgDM in sheep and cattle, respectively.

Nutritive values in terms of TDN, DE, the ratio of DE to GE, and DCP are also shown in Table 4. The TDN, DE and the ratios of DE to GE clearly represented the features of nutrient digestibilities and energy balance. These were generally improved by the addition of soybean meal in both species, and were lower in sheep when the animals received none or small amounts of soybean meal. The DCP largely changed according to the levels of soybean meal in both species. However, it was higher in sheep in treatments 3 and 4.

The following equation was obtained by the regression analyses of TDN, DE and DCP values between sheep and cattle in treatments 1–4:

$$TDN_{cattle} = 0.5336 \times TDN_{sheep} + 29.168 \quad (R = 0.930, p<0.1)$$

$$DE_{cattle} = 0.5064 \times DE_{sheep} + 5.5351 \quad (R = 0.937, p<0.1)$$

$$DCP_{cattle} = 0.9219 \times DCP_{sheep} + 0.4664 \quad (R = 1.00, p<0.01)$$

Table 5 shows the comparison of the fiber fraction digestibilities, i.e. CF, NDF and ADF, of Ruzi grass in each treatment between cattle and sheep. The fiber fraction digestibilities of soybean meal were calculated by an extrapolation of data in treatments 3 and 4, and in treatments 1–4 of sheep and cattle, respectively, because there was a clear associative effect on nutrient digestibilities by the addition of soybean meal in sheep. The values of Ruzi grass hay in each treatment were then calculated by using the values of soybean meal obtained from each species. The CF, NDF and ADF digestibilities were the lowest in treatment 1 in both species. These values improved as the ration included higher soybean meal, especially in sheep. The differences of the values between treatments 1 and 4 were more than 10 units. While in cattle, the values improved substantially even by the smallest amount of soybean meal. An additional supplement of soybean meal did not improve fiber digestibilities.

The energy balances including the results of the respiration trial in cattle are shown in Table 6. The GE, DE and ME intakes on the basis of metabolic body size increased according to the levels of soybean meal. There was no difference in these values between treatments 3 and 4, although the animals in treatment 4 received more soybean meal which has a higher GE content. This was due to the increase in body weight, as the amount of feed given was calculated from the initial body weight. Energy loss into methane was higher in treatments 3 and 4 than in treatments 1 and 2. Heat production significantly increased according to the levels of soybean meal supplement. The fasting heat production was not significantly

Table 5. Comparison in the change of fiber fraction digestibility of Ruzi grass hay according to the supplement of soybean meal between cattle and sheep

Treatment[1)]		Sheep					Cattle					Effect[2)]		
		1	2	3	4	SE	1	2	3	4	SE	A	T	A × T
CF	%	46.1^{b}	53.7^{ax}	57.0^{a}	58.3^{a}	1.9	54.3^{b}	61.4^{ay}	56.1^{ab}	57.2^{ab}	1.9	*	**	*
NDF	%	44.0^{bx}	50.9^{ax}	54.7^{a}	55.0^{a}	1.7	53.8^{by}	60.5^{ay}	54.0^{b}	56.1^{ab}	1.9	**	**	**
ADF	%	43.3^{b}	52.2^{ax}	56.1^{ax}	56.1^{a}	1.5	50.0^{b}	57.4^{ay}	50.3^{by}	52.5^{ab}	1.9	NS	**	**

1): Treatment 1, 100% Ruzi grass hay (RGH); Treatment 2, RGH and 8% of soybean meal (SBM); Treatment 3, RGH and 16% of SBM; Treatment 4, RGH and 24% of SBM; SE, standard error.
CF: crude fiber, NDF: neutral detergent fiber, ADF: acid detergent fiber.
2): A, an effect of animals; T, an effect of treatments; A × T, an interaction between animals and treatments.
**: P<0.01, *: P<0.05, NS: not significant.
a, b: Means with different superscripts among treatments within each animal differ significantly (P<0.05).
x, y: Means with different superscripts between each animal in each treatment differ significantly (P<0.05).

Table 6. Energy and nitrogen metabolisms in Brahman cattle given Ruzi grass hay with different levels of soybean meal

Treatment[1)]		1	2	3	4	5	SE
Body weight	kg	412[b]	404[c]	408[bc]	419[a]	404[c]	1
GE intake	kJ/BWkg$^{0.75}$	1,060[c]	1,225[b]	1,435[a]	1,425[a]	–	30
DE intake	kJ/BWkg$^{0.75}$	566[c]	734[b]	836[a]	896[a]	–	27
ME intake	kJ/BWkg$^{0.75}$	479[c]	637[b]	717[ab]	776[a]	–	26
Energy loss into							
Feces	kJ/BWkg$^{0.75}$	494[b]	491[b]	598[a]	530[b]	–	13
Urine	kJ/BWkg$^{0.75}$	25[bc]	32[ab]	36[a]	38[a]	21[c]	2
Methane	kJ/BWkg$^{0.75}$	62[b]	66[b]	83[a]	81[a]	–	2
Heat production	kJ/BWkg$^{0.75}$	332[c]	377[b]	453[a]	460[a]	271	6
Energy retention	kJ/BWkg$^{0.75}$	147[b]	260[a]	265[a]	316[a]	–292[c]	22
DE/GE		0.532[c]	0.599[ab]	0.583[b]	0.628[a]	–	0.013
ME/GE		0.450[b]	0.519[a]	0.500[a]	0.545[a]	–	0.013
ME/DE		0.843	0.866	0.858	0.867	–	0.007
Urine/GE	MJ/100MJ GE intake	2.4	2.6	2.5	2.7	–	0.2
Methane/GE	MJ/100MJ GE intake	5.9	5.4	5.8	5.7	–	0.2
Heat production/GE	MJ/100MJ GE intake	31.5	30.8	31.5	32.3	–	0.7
Retention/GE	MJ/100MJ GE intake	13.5[b]	21.1[a]	18.5[ab]	22.2[a]	–	1.7

1): Treatment 1, 100% Ruzi grass hay (RGH); Treatment 2, RGH and 8% of soybean meal (SBM); Treatment 3, RGH and 16% of SBM; Treatment 4, RGH and 24% of SBM; Treatment 5, fasting; SE, standard error.
GE: gross energy, ME: metabolizable energy, DE: digestible energy.
a, b, c, d: Means with different superscripts among treatments differ significantly ($P<0.05$).

different from that in treatment 1. The ratio of DE to GE was the lowest in treatment 1, and followed by that of treatment 3. It was highest in treatment 4. That in treatment 3 was not different from treatments 2 and 4. The ratio of ME to GE, i.e. metabolizability, was the lowest in treatment 1 and was not different among treatments 2, 3 and 4. The ratio of ME to DE was not different among the treatments. The ratios of energy loss into urine, methane and heat production to GE were not different among the treatments.

Discussion

It is generally understood that the digestibility of nutrients is affected by the intake and is reduced with the increase in intake[21]. Therefore, a comparison of digestibility between species would be better carried out with the maintenance level of feed intake. Numerous researchers noted the differences in energy requirements or efficiencies of energy utilization among breeds of cattle. However, because of differences in procedures and approaches as well as diversity of breeds compared, direct comparison among available data is difficult[14]. The feed intake was tentatively designed at 1.7% of body weight in this study, as the nutrient requirements for maintenance in the breeds of the animals applied in this study were not yet well established. Because of this, the dry matter intake on the basis of metabolic body size was higher in cattle than in sheep. As most sheep could consume most of the feed in each treatment, there was not much difference in the dry matter intake on the basis of metabolic body size among the treatments in sheep. While in cattle, the amount of feed was reduced in treatments 1 and 2 so that they could consume all of the feed. Thus the amount actually consumed averaged 1.33% and 1.48% of the initial body weight in treatments 1 and 2, respectively. The digestibility of NDF and ADF was significantly higher in treatment 2 than in treatment 3. A similar trend was found in TDN, DE and the ratio of DE to GE. These differences might be partly due to the difference in the feed intake between the treatments. Tyrrell and Moe[21] described the linear depression in TDN value by the regression: $RTDN = 105.27 - 4.58 \times LI$, where RTDN and LI are relative to TDN value and intake in multiples of maintenance, respectively. The TDN requirement for maintenance was tentatively calculated to be 23.0 g/BWkg$^{0.75}$ from the regression analysis between TDN intake and energy retention on the basis of metabolic body size in treatments 1–4. It was slightly lower than the value (23.90 g/BWkg$^{0.75}$) in the Japanese Feeding Standard for Beef Cattle[2]. The intakes in multiples of maintenance in treatments 1–4 were 1.39, 1.79, 2.04, and 2.19, respectively. From this value, 1.2% of the difference in TDN between treatments 2 and 3 would account for the difference in feed intake. The differences in the digestibilities of NDF and ADF exceeded this range. There may be additional unknown factors for the relatively higher digestibility in treatment 2.

There are several reports suggesting the difference in fiber digestion between cattle and sheep. Bird[4] and Playne[15] suggested that the difference in the utilization of nitrogen and sulfur affected the activities of rumen micro-organisms, when low quality diet was given. Rees and Little[18], Poppi et al.[16] and Prigge et al.[17] suggested that the difference in the flow rate in the digestive tract would be the main reason for the difference in fiber digestion. Terada et al.[20] compared the digestibility of nutrients among cattle, sheep and goats given rice straw wafer and rolled barley with different kinds of protein sources, i.e. soybean meal and urea. They suggested that the difference in fiber digestion between cattle and sheep increased as the animals received lower protein diets. The present study confirmed this result.

The change in fiber digestibility of Ruzi grass hay according to the amounts of soybean meal supplement given revealed accurately a specific difference between cattle and sheep. The CF, NDF and ADF digestibilities were improved by the soybean meal supplement until the CP content in the whole ration reached 10% in sheep. The difference in fiber fraction digestibilities of the hay between the sheep given only the hay and those given soybean meal supplement so as to increase CP content of the whole ration more than 10% was more than 10 units in each fiber fraction. Beyond this level there was no effect of the soybean meal supplement on fiber fraction digestibilities. In cattle, fiber fraction digestibilities were relatively high in the animals even if they were not given soybean meal supplement. The values were then improved by a small amount of supplement by which CP content in the whole ration increased to 6.8%. Beyond this level there was no effect of supplement.

The digestibility of NFE was higher in cattle than in sheep in the present study. Terada et al.[20] also reported that the digestibility of NFE was higher in cattle than in sheep when roughage-based diet was given to the animals, and there was no difference in the digestibility of NFE between the animals when large amounts of concentrate was given.

The nitrogen excretion into feces did not correspond to the levels of soybean meal supplement in sheep and was relatively constant. While in cattle, it increased when higher supplements were given. These were related to the differences in metabolic fecal nitrogen excretion, which was relatively higher in sheep than in cattle. Sheep would have a higher ability to absorb nitrogen in digestive tracts, but have higher metabolic fecal nitrogen excretion. Consequently, apparent CP digestibility was lower in sheep given low protein diets and higher in sheep given high protein diets.

Prigge et al.[17] observed higher rumen NH_3-N in sheep in comparison with cattle given the same roughage and suggested that the higher apparent CP digestibility in sheep would be due to less incorporation of NH_3-N into microbial protein and greater urinary N output as opposed to fecal N in sheep. Poppi et al.[16] also reported higher NH_3-N in sheep than in cattle. Terada et al.[20] reported that while N excretion into urine was lower in cattle than in sheep, N excretion into feces was higher in sheep. They also suggested these findings would indicate the ratio of N incorporated by rumen microbes would be lower in sheep than in cattle. In the present study, N excretion into urine was generally higher in sheep and N excretion into feces was higher in cattle only when the highest amount of soybean meal was given.

TDN, DE and the ratio of DE to GE were well representative of the overall features of nutrient digestibilities. With lower levels of soybean meal supplementation, these values were lower in sheep than in cattle. While, at the higher levels of the supplementation, there were no differences in the values between the animals. Sheep are often studied as a model animal for cattle in order to examine the nutritive values of feed resources. It would be one method to apply the above-mentioned equation to correct the value of sheep for cattle. It would be more practical, however, to modify the design of the feeding trial using sheep so that the CP content in the whole ration, in which a target feed resource is included, becomes more than 10%. The results can then be directly applied for cattle.

Methane is considered a 'greenhouse gas'. Methane production by cattle typically accounts for 5.5–6.5% of GE intake[8]. The value in the present study ranged from 5.4% to 5.9%, which was generally equivalent to the published value. The supplement of soybean meal did not affect the energy loss into methane on the basis of GE intake. Crutzen et al.[6] applied the value of 35 kg CH_4 per cattle per year in the estimates of methane yield from animals in the developing world. The estimates of methane from buffalo were partly based on the study by Krishna et al.[13], in which they estimated higher CH_4 yields of 9% in Indian cattle fed on a slightly higher maintenance diet and low quality feed. On the other hand, Kurihara et al.[11] reported that methane production per unit of DM intake increased with the rise in CP content of diets from 4% to 9% in cattle. The assumption that the animals fed on low quality feed produce more methane, which was applied by Crutzen et al. for the estimation of methane production by ruminants, cannot be simply applied to every situation of cattle production. In the light of this, the values of methane emission from buffalo by Crutzen et al.[6] may be over estimated. However, Kurihara et al.[12] measured methane production by Brahman cattle given either Angleton grass (CP 2.4%) or Rhodes grass (CP 8.9%) and energy loss as methane was 10.4 and 11.4%, respectively. Therefore, more data on methane emission from ruminants in the tropics has to be accumulated in order to estimate global methane emission from ruminants.

According to our previous report[10], the fasting heat production of Brahman cattle was 337 kJ/BWkg$^{0.75}$, which was relatively higher than that of this study. In the previous report, the value was considerably high in comparison with the heat production when the animals were fed, and it was suggested this would be related to some metabolic disorder. While, in the present study, the value would be appropriate and considered to be close to net energy (NE) for maintenance. Although it is too early to conclude NE and ME for maintenance from the present study, accumulation of data on energy metabolism will enable us to establish feeding standards of tropical cattle and it will contribute to the development of proper feeding management in the tropics.

References

1. Aerts, J. V. et al. (1984) Comparative digestibility of feedstuffs by sheep and cows. *Anim. Feed Sci. Tech.*, **12**, 47–56.
2. Agriculture, Forestry and Fisheries Research Council Secretariat (1995) Japanese feeding standard for beef cattle. Ministry of Agriculture, Forestry and Fisheries, Japan.
3. AOAC (1975) Official methods of analysis (12th ed.). Ed. Horowitz, W., Association of Official Analysis Chemists, Washington, D. C.
4. Bird, P. R. (1974) Sulphur metabolism and excretion studies in ruminants. XIII. Intake and utilization of wheat straw by sheep and cattle. *Aust. J. Agric. Sci.*, **25**, 631–642.
5. Brouwer, E. (1965) Report of sub-committee on constants and factors. *In* Energy metabolism, ed. Blaxter, K. L., Academic Press, London, 441–443.
6. Crutzen, P. J., Aselmann, I. & Seiler, W. (1986) Methane production by domestic animals, wild ruminants, other herbivorous fauna, and humans. *Tellus*, **38B**, 271–284.
7. Goering, H. H. & Van Soest, P. J. (1970) Forage fiber analysis (apparatus, reagents, procedures and some applications). Agric. Handbook No. 379, ARS, USDA, Washington, D. C.
8. Johnson, D. E. & Ward, G. M. (1996) Estimates of animal methane emissions. *Environ. Monit. Assess.*, **42**, 133–141.
9. Kawashima, T. et al. (2001) Respiration trial system using ventilated flow through method with a face mask. *JIRCAS J.*, **9**, 53–74.
10. Kawashima, T. et al. (2006) Comparative study on energy and nitrogen metabolisms between Brahman cattle and swamp buffalo fed with low quality diet. *JARQ*, **40**(2), 183–188.
11. Kurihara, M. et al. (1997) Methane production and its dietary manipulation in ruminants. *In* Rumen microbes and digestive physiology in ruminants, eds. Onodera, R. et al., Japan Sci. Soc. Press, Tokyo/S. Karger, Basel, 199–208.
12. Kurihara, M. et al. (1999) Methane production and energy partition of cattle in the tropics. *Br. J. Nutr.*, **81**, 227–234.
13. Krishna, G., Razdan, M. N. & Ray, S. N. (1978) Effect of nutritional and seasonal variations on heat and methane production in *Bos indicus*. *Indian J. Anim. Sci.*, **48**(5), 366–370.
14. National Research Council (1996) Nutrient requirements of beef cattle. National Academy Press, Washington, D. C.
15. Playne, M. J. (1978) Differences between cattle and sheep in their digestion and relative intake of a mature tropical grass hay. *Anim. Feed Sci. Tech.*, **3**, 41–49.
16. Poppi, D. P., Minson, D. J. & Ternouth, J. H. (1980) Studies of cattle and sheep eating leaf and stem fractions of grasses. I. The voluntary intake, digestibility and retention time in the reticulo-rumen. *Aust. J. Agric. Res.*, **32**, 99–108.
17. Prigge, E. C., Baker, M. J. & Varga, G. A. (1984) Comparative digestion, rumen fermentation and kinetics of forage diets by steers and wethers. *J. Anim. Sci.*, **59**, 237–245.
18. Rees, M. C. & Little, D. A. (1980) Differences between sheep and cattle in digestibility, voluntary intake and retention time in the rumen of three tropical grasses. *J. Agric. Sci.*, **94**, 483–485.
19. SAS Institute (1989) SAS/STAT User's guide, Version 6, 4th ed., vol. 2. SAS Institute Inc., Cary, NC.
20. Terada, F. et al. (1987) Comparison of nutritive values among cattle, sheep and goats fed the same diet. *Jpn. J. Zootech. Sci.*, **58**(2), 131–137 [In Japanese].
21. Tyrrell, H. F. & Moe, P. W. (1975) Effect of intake on digestive efficiency. *J. Dairy Sci.*, **58**, 1151–1163.
22. Van Soest, P. J., Robertson, J. B. & Lewis, B. A. (1991) Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *J. Dairy Sci.*, **74**, 3583–3597.