Asian-Aust. J. Anim. Sci.
Vol. 19, No. 11 : 1623 - 1631
November 2006
www.ajas.info

Utilization of Steam-treated Oil Palm Fronds in Growing Saanen Goats: II. Supplementation with Energy and Urea

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ABSTRACT : The objective of this study was to evaluate the effect of protein and energy on goats fed oil palm fronds (OPF) as roughages. Twenty-four male Saanen goats aged between 7 and 8 months and weighing 23.4±1.6 kg were used in a 2×3 factorial design. Factors were three levels of urea (3%, 4% or 5%) and two levels of energy (low energy (LE) or high energy (HE)). On average, all parameters measured, including dry matter intake (DMI), nutrient digestibility, digestible nutrient intakes, ruminal ammonia-N (NH_3-N), ruminal total volatile fatty acid (total VFA) and individual VFA concentrations (mM/L), microbial N supply, P/E ratio and N retention were higher for HE compared to LE diets. Significant ($p<0.05$) interactions were found between levels of urea and energy for non-structural carbohydrate (NSC) and energy (DE) digestibilities, ruminal NH_3-N and total VFA concentrations. HE diets had higher N absorption and retention than LE diets. Interactions between urea and energy for plasma urea nitrogen (PUN), heat production (HP), and urine and faeces N excretion were significantly lower ($p<0.05$) for the HE diets than those recorded for the LE diets. The results indicated that supplementation of energy enhanced utilization of urea and resulted in higher animal performance as a consequence of improved ruminal fermentation, microbial yield and N balance. However, the optimal level of urea supplementation remained at 3% in the HE diet. (**Key Words :** Urea, Fermentable Energy, Microbial N Supply, Oil Palm Fronds, Saanen Goats)

INTRODUCTION

Poor quality roughages are characterized by their high content of lignocellulose and low nitrogen (N) content. Consequently these roughages are poorly digested and often unable to support the requirements of ruminant animals. Low intake and poor utilization of these feedstuff can be partly attributed to an inefficient rumen ecosystem and an imbalance in the products of rumen fermentation (Bird et al., 1999; Wanapat et al., 2000). Supplementation of poor quality roughage diets with rumen-degradable protein (RDP) or non-protein nitrogen (NPN) has been shown to increase voluntary feed intake (McAllen, 1991; Huntington and Archibeque, 1999), which improved nutrient digestibility and increased passage from the rumen.

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Received April 11, 2006; Accepted May 24, 2006

Our previous experiment (Paengkoum et al., 2006) showed that supplementation of NPN such as urea up to 30 g/kg DM of diet, significantly improved feed intake, nutrient digestibility, volatile fatty acid (VFA) production, N balance and microbial N supply, and resulted in a substantial body weight gain in growing goats fed steamed oil palm fronds (OPF) diets. It was postulated that supplementation of readily degraded energy will enhance the utilization of available N in the rumen and further improve the productivity of goats through an increased efficiency of utilization of ammonia-N for microbial protein synthesis (Rode and Satter, 1988; Cameron et al., 1991; Castillo et al., 2001).

The objective of this study was to investigate whether addition of fermentable energy would enhance the efficiency of use of urea when included at higher than 3% in OPF-based diets.

MATERIALS AND METHODS

Animals and management

Twenty-four male dairy goats (Saanen), 7-8 months old

Table 1. Ingredient and chemical composition of the experimental diets (%DM basis)

	Low energy			High energy		
	3% Urea	4% Urea	5% Urea	3% Urea	4% Urea	5% Urea
Ingredients						
Steamed oil palm fronds	91.66	90.43	89.20	57.10	55.88	54.65
Cassava waste	0	0	0	30.00	30.00	30.00
Molasses	4.24	4.47	4 .70	8.60	8.82	9.05
Urea	3.00	4.00	5.00	3.20	4.20	5.20
Sulphur	0.10	0.10	0.10	0.10	0.10	0.10
Min.-vit. premix	1.00	1.00	1.00	1.00	1.00	1.00
Total	100	100	100	100	100	100
Chemical compositions (g/kg DM)						
Dry matter	0.773	0.784	0.782	0.758	0.766	0.770
Ash	0.069	0.070	0.061	0.062	0.061	0.060
Crude protein	0.128	0.154	0.183	0.127	0.155	0.181
Neutral detergent fiber	0.521	0.522	0.502	0.445	0.422	0.424
Ether extract	0.022	0.022	0.021	0.022	0.022	0.023
NSC*	0.259	0.232	0.233	0.345	0.339	0.312
Gross energy (MJ/kg)	15.33	15.28	15.45	16.23	16.20	16.24

* NSC (non-structural carbohydrate) = 100-(ash+CP+NDF+EE).

and average body weight (BW) of 23.4±1.6 kg, were allocated to a 2×3 factorial experiment. The goats were housed in individual pens and allowed 3 weeks to adapt to the experimental conditions. The goats were fed a basal diet containing steamed OPF supplemented with minerals and vitamins. Cassava wastes and molasses were used as sources of energy supplement. The diet (per kg DM), contained an estimated metabolizable energy (ME) of 7.45 MJ (low energy, LE; or 1.2 times energy requirement according to NRC, 1981), and 12.38 MJ (high energy, HE; 2.0 times energy requirement), and various levels of urea (3, 4 and 5% of total ration). The dietary ingredients and their chemical compositions are shown in Table 1.

Experimental procedure

The experiment consisted of two periods of 106 days duration, with 21 days of adjustment. Each test period consisted of 33 days of feed intake and BW gain measurements followed by a week of digestion trial. The digestion trial in each month consisted of 2 days of adaptation to the metabolism crates, 7 days of total faeces and urine collection, 2 days for rumen fluid and blood collections and a day of heat production (HP) measurements.

The daily rations were offered to the animals in two equal portions at 0830 h and 1530 h. Refusals were weighed daily prior to the morning feeding to determine daily dry matter intake (DMI). Body weight of each animal was measured weekly immediately before the morning feeding. Drinking water was freely available. During the digestion trial, samples of feed refusal, faeces and urine were collected, before new feed was given each morning, for the determination of digestibility and nitrogen balance following the procedure of Schnieder and Flatt (1975).

Sampling methods

The daily fecal output of each animal was measured and a 10% sub-sample was collected and stored at -20°C. The samples were dried in a forced draught oven at 60°C, ground through 1 mm sieve and stored for chemical analysis as detailed previously (Paengkoum et al., 2006).

Rumen fluid samples from all goats were taken at 0, 2, 4 and 6 h post-feeding during the digestibility trial of each period. All samples were collected, preserved and analyzed as previously described (Paengkoum et al., 2006).

Heat production (HP) was measured using an open circuit respiration chamber (30 cm high, 30 cm long and 45 cm wide) connected with an oxygen analyzer (Model 755, Beckman). Heat production of each goat was determined from the measurement of oxygen consumption at 10 min intervals for 24 h and calculated according to Yamamoto et al. (1985).

Chemical analysis and calculations

Proximate analysis was conducted on representative samples of feed and faeces collected during the digestibility trials as described previously (Paengkoum et al., 2006).

The amount of microbial N supplied to the animal was calculated following Chen et al. (1992). The ratio of microbial protein to volatile fatty acid produced (P/E ratio) was calculated according to Czerkawski (1986).

Statistical analysis

Data were analyzed as a 2×3 factorial arrangement design using the general linear model (GLM) procedure of the Statistical Analysis System Institute (SAS) (1988). Duncan's New Multiple Range Test and Orthogonal Contrast Analysis (Steel and Torrie, 1980) were used to

Table 2. Dry matter intake (DMI), digestibility, digestible nutrient intake and body weight (BW) gain of dairy goats fed energy and urea supplemented steamed OPF based diets

	Low energy			High energy			SEM	Effect		
	Urea 3%	Urea 4%	Urea 5%	Urea 3%	Urea 4%	Urea 5%		Energy (E)	Urea (U)	E×U
DMI (/d)										
g	799.2^{ab}	647.3^{bc}	629.4^{c}	920.7^{a}	905.4^{a}	701.5^{bc}	44.6	**	**	ns
Proportion of BW	0.0253^{ab}	0.00241^{b}	0.0232^{b}	0.0290^{a}	0.0286^{ab}	0.0268^{ab}	0.007	**	**	ns
g/kg $W^{0.75}$	62.2^{ab}	54.7^{bc}	52.9^{c}	68.0^{a}	67.7^{a}	60.2^{ab}	1.85	**	**	ns
Digestibility										
Dry matter	0.497^{bc}	0.492^{c}	0.484^{c}	0.538^{a}	0.528^{ab}	0.510^{abc}	0.058	**	ns	ns
Organic matter	0.530^{ab}	0.514^{b}	0.510^{b}	0.572^{a}	0.562^{a}	0.503^{c}	0.060	**	**	ns
Crude protein	0.511^{ab}	0.487^{b}	0.471^{b}	0.553^{a}	0.538^{a}	0.503^{ab}	0.069	**	**	ns
Neutral detergent fiber	0.495^{ab}	0.489^{b}	0.460^{b}	0.548^{a}	0.529^{a}	0.492^{ab}	0.070	**	**	ns
NSC	0.459^{c}	0.447^{cd}	0.441^{d}	0.544^{a}	0.535^{a}	0.484^{b}	0.079	**	**	**
Digestible energy	0.528^{b}	0.518^{c}	0.477^{d}	0.540^{a}	0.531^{b}	0.514^{c}	0.048	**	**	**
BW gain (g/d)	35.7^{bc}	-8.9^{d}	-66.1^{d}	85.7^{a}	51.8^{ab}	5.4^{cd}	14.81	**	**	**

NSC = non-structural carbohydrate.
* $p<0.05$, ** $p<0.01$, ns = Not significantly different ($p>0.05$).

Table 3. Average pH, ammonia nitrogen (NH_3-N, mg/dL), total volatile fatty acid (TVFA, mM/L), VFA proportions (% molar) in rumen fluid, and plasma urea nitrogen (PUN, mg/dL) of dairy goats fed urea and energy supplemented steamed OPF based diets

	Low energy			High energy			SEM	Effect		
	Urea 3%	Urea 4%	Urea 5%	Urea 3%	Urea 4%	Urea 5%		Energy (E)	Urea (U)	E×U
pH	7.0^{ab}	7.0^{ab}	7.1^{a}	7.0^{ab}	6.9^{b}	6.9^{b}	0.02	ns	ns	*
NH_3-N	13.1^{d}	13.4^{d}	15.6^{b}	13.9^{c}	15.1^{bc}	17.7^{a}	0.33	**	**	**
PUN	15.2^{d}	19.3^{c}	25.2^{a}	13.7^{d}	14.2^{d}	18.8^{b}	0.83	**	**	**
TVFA	42.6^{d}	40.3^{e}	37.9^{f}	48.9^{a}	46.4^{b}	44.2^{c}	2.59	**	**	**
VFA proportion (% TVFA)										
Acetic	70.8^{b}	71.4^{ab}	72.2^{a}	68.5^{c}	68.9^{c}	70.3^{b}	0.35	ns	**	**
Propionic	16.5^{b}	16.3^{b}	16.0^{b}	18.6^{a}	18.6^{a}	16.8^{b}	0.26	ns	*	**
Butyric	8.2^{b}	7.9^{c}	7.7^{c}	8.6^{a}	8.7^{a}	8.6^{a}	0.15	*	**	**
Iso-butyric	1.4^{cd}	1.4^{cd}	1.2^{d}	1.7^{a}	1.6^{ab}	1.5^{bc}	0.05	*	**	**
Valeric	3.1^{a}	3.0^{a}	2.9^{ab}	2.9^{ab}	2.6^{b}	2.9^{ab}	0.19	ns	*	ns

* $p<0.05$, ** $p<0.01$, ns = Not significantly different ($p>0.05$).

compare treatment means. Unless otherwise noted, high significance was declared at $p<0.01$, significance was declared at $p\leq0.05$, and non-significance was declared at $p>0.05$.

RESULTS

Chemical composition, feed intake and body weight change

Chemical composition of the feed is reported in Table 1. The DM, ash and EE contents were similar for all treatments. As expected CP increased slightly with increasing level of urea supplementation, while NDF and ADF decreased slightly with increasing level of soluble carbohydrate. Gross energy and non-structural carbohydrate (NSC) increased with increasing energy supplement.

Feed intake and digestibility

Table 2 shows the DMI, nutrient digestibility and body weight change of the goats. Dry matter intakes based on g/d, % BW and g/kg $W^{0.75}$, were greater ($p<0.05$) for goats fed on HE than on LE diets. However, there was no significant interaction between energy and urea for DMI, while DMI of goats decreased ($p<0.01$) with increasing urea supplementation in the dietary treatments. The DMI of goats fed HE diets with 3 and 4% of urea (921 and 905 g/d) were higher ($p<0.05$) than those for of LE with 4 and 5% of urea (647 and 629 g/d). Intakes of digestible OM, CP, NSC and DE were greater ($p<0.01$) for goats fed on HE than on LE diets. Significant interactions between energy and urea were observed for the above parameters. Only CP digestible intake was not affected by dietary treatment.

The digestibilities of DM, OM, CP and NDF in goats fed high energy diets were significantly higher ($p<0.05$) than those of goats fed low energy diets. However, OM, CP and NDF digestibilities decreased ($p<0.01$) with increasing urea supplementation. The OM, CP and NDF digestibilities of the HE diet with 3 and 4% urea supplementation were higher ($p<0.05$) compared to those of LE diets. Body weight gain increased ($p<0.01$) with increased dietary

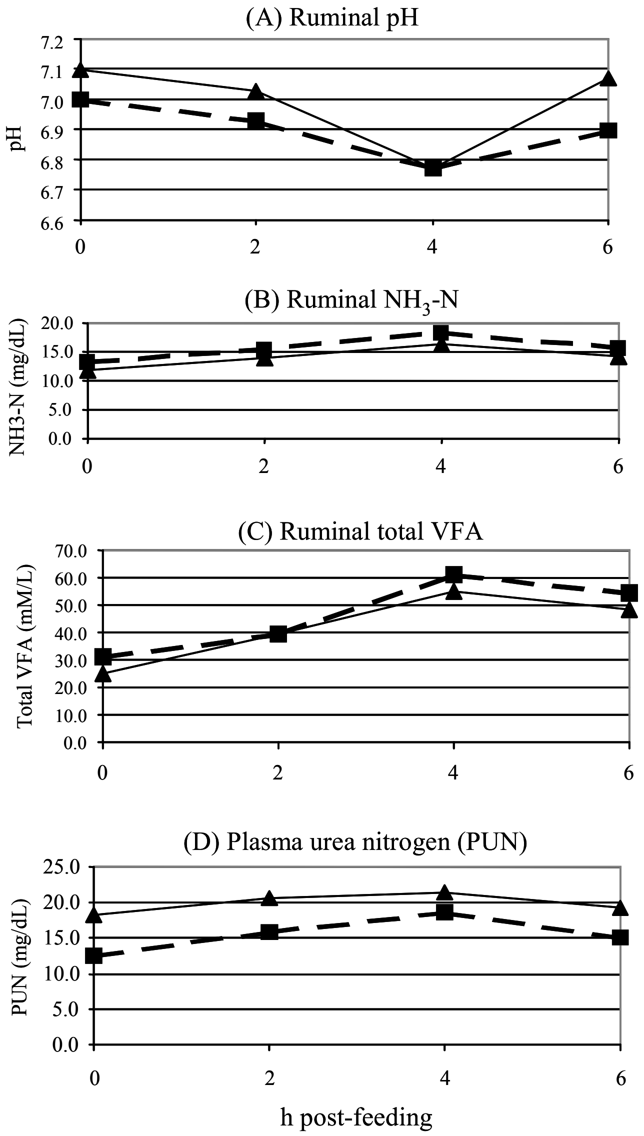

Figure 1. Ruminal pH (A), ruminal NH_3-N (B), ruminal total VFA (C) and plasma urea nitrogen (D) concentration of dairy goats fed low energy (▲) and high energy (-■-) of steamed OPF based diets.

energy supplementation, but decreased ($p<0.01$) with increasing levels of urea supplement. Body weight change in goats fed LE with 4 and 5% urea was drastically reduced to a negative value (-8.9 and -66.1 g/d, respectively).

Ruminal pH, NH_3-N and VFA concentrations

Ruminal pH, NH_3-N and total VFA levels at 0, 2, 4 and 6 h post-feeding are shown in Figure 1, and the means for total and individual VFA concentrations (mM/L) and molar proportion (% of total VFA) are given in Table 3. Ruminal pH decreased gradually after feeding, was lowest at 4 h post-feeding and increased thereafter. There were no effects of dietary treatment on pH at 0 and 2 h post-feeding, but ruminal pH at 4 and 6 h post-feeding of goats increased ($p<0.05$ and $p<0.01$, respectively) with increasing urea supplementation (Figure 1). Neither urea nor levels of energy affected ruminal pH; however, there was a significant ($p<0.05$) interaction between energy and urea for this parameter (Table 3).

Ruminal NH_3-N increased gradually after feeding, peaked at 4 h post-feeding and decreased thereafter. There were significant effects ($p<0.01$) of energy, protein and their interaction on the concentration of ruminal NH_3-N (Table 3). The average ruminal NH_3-N concentration was significantly ($p<0.01$) greater in goats on HE compared with the LE diets (15.6 vs. 14.0 mg/dL). The ruminal NH_3-N concentration of goats increased ($p<0.01$) with increasing urea supplementation in the diets.

Ruminal total VFA of goats fed HE were significantly higher ($p<0.01$) than those of goats fed LE diets, except for valeric acid which was not affected by the dietary treatments (Table 3). The proportion of acetic acid (% molar of TVFA) in goats fed LE at all levels of urea was significantly higher ($p<0.01$) than in goats fed HE with 3 and 4% urea, but not significant in goats fed HE with 5% urea. Propionic, butyric and iso-butyric acids, expressed as either concentration or % molar of TVFA, were higher ($p<0.05$) in goats fed HE than on LE diets.

Plasma urea nitrogen (PUN)

The concentration of PUN in goats fed LE was significantly higher ($p<0.01$) than in goats fed HE. Moreover, PUN increased ($p<0.01$) with increasing level of urea supplementation.

Purine derivatives, microbial N supply and others

The excretion of urinary PD, microbial N supply and P/E ratio are shown in Table 4. Allantoin and total PD concentration increased ($p<0.01$) with increasing energy supplementation, but decreased ($p<0.01$) with increasing urea supplementation. As a result, microbial N synthesis (g of N/d) and efficiency of microbial N synthesis (g of N/kg of DOMR) increased ($p<0.05$) with increasing energy supplementation, but decreased ($p<0.01$) with increasing urea. There were no significant interactions between urea and energy for microbial yield and efficiency of microbial N supply.

The energy values of VFA (MJ) produced in the rumen were calculated by multiplying the total VFA with organic matter digested in the rumen (Czerkawski, 1986). They were in the range of 1.1 to 2.5 MJ/day. The ratio of microbial protein/VFA produced (P/E ratio) of goats fed HE with 3% urea was highest (22.5 g microbial protein/MJ) among the different treatments. There were no significant differences between goats fed LE containing 3 and 4% urea (22.2 and 22.1 g microbial protein/MJ), but P/E ratios of goats fed 5% urea in both HE and LE diets (15.7 and 13.9 g

Table 4. Urinary purine derivatives (PD), microbial N supply, P/E ratio and heat production of dairy goats fed urea and energy supplemented steamed OPF based diets

	Low energy			High energy			SEM	Effect		
	Urea 3%	Urea 4%	Urea 5%	Urea 3%	Urea 4%	Urea 5%		Energy (E)	Urea (U)	E×U
Urinanary PD (mM/d)										
Allantoin	4.14^{ab}	3.15^{b}	2.65^{c}	5.89^{a}	4.64^{a}	3.59^{b}	0.23	**	**	ns
Uric acid	1.82^{b}	1.57^{b}	0.32^{c}	2.32^{a}	0.82^{bc}	0.40^{c}	0.16	ns	**	**
Hypoxanthine	0.60	0.47	0.28	0.60	0.60	0.24	0.08	ns	ns	ns
Xanthine	0.48^{a}	0.23^{c}	0.36^{b}	0.48^{a}	0.48^{a}	0.13^{d}	0.07	ns	ns	*
Total PD	7.05^{ab}	5.42^{c}	3.60^{d}	9.30^{a}	6.54^{b}	4.35^{cd}	0.42	**	**	ns
Microbial N supply										
g of N/d	5.9^{b}	4.3^{c}	2.5^{d}	7.9^{a}	5.4^{b}	3.3^{cd}	0.40	**	**	ns
g of N/kg DOMR*	22.6^{ab}	18.4^{c}	12.7^{d}	27.5^{a}	24.9^{ab}	15.1^{bc}	1.07	*	**	ns
VFA produced (E, MJ/d)	1.7^{c}	1.2^{ed}	1.1^{e}	2.2^{a}	2.0^{b}	1.3^{d}	0.50	*	**	**
P/E ratio	22.2^{a}	22.2^{a}	13.9^{b}	22.5^{a}	16.8^{b}	15.7^{b}	0.94	*	**	*
Heat production (kJ/kg $W^{0.75}$ d)	492.0^{bc}	542.4^{ab}	595.2^{a}	410.4^{c}	448.8^{c}	487.2^{bc}	28.56	**	**	**

* DOMR = digestible OM fermented in the rumen, calculated as 0.65 x DOM intake (ARC, 1984).
* p<0.05, ** p<0.01, ns = Not significantly different (p>0.05).

Table 5. Daily nitrogen balance of dairy goats fed urea and energy supplemented steamed OPF based diets

	Low energy			High energy			SEM	Effect		
	Urea 3%	Urea 4%	Urea 5%	Urea 3%	Urea 4%	Urea 5%		Energy (E)	Urea (U)	E×U
N intake (g)	16.4^{bc}	19.0^{bc}	15.6^{c}	22.7^{a}	18.4^{bc}	20.3^{ab}	0.76	**	ns	ns
N excretion										
Faeces N (g)	5.0^{b}	8.4^{a}	8.8^{a}	4.6^{b}	4.1^{b}	8.1^{a}	0.45	*	ns	ns
Urine N (g)	8.9^{c}	10.3^{b}	11.4^{a}	7.4^{d}	8.4^{c}	9.1^{c}	0.27	**	**	**
Total N loss (g)	13.9^{c}	18.7^{ab}	20.2^{a}	12.0^{c}	12.5^{c}	17.2^{b}	0.68	ns	ns	**
N absorption (g)	11.3^{b}	10.5^{bc}	6.8^{c}	18.1^{a}	14.3^{ab}	12.2^{b}	0.90	*	ns	ns
N retention (g)	2.5^{bc}	0.3^{c}	-4.6^{d}	10.6^{a}	5.9^{b}	3.16^{c}	1.12	**	ns	**
N retention (%)	14.5^{bc}	0.4^{c}	-30.9^{d}	44.6^{a}	30.9^{ab}	11.7^{c}	5.50	*	ns	**

* p<0.05, ** p<0.01, ns = Not significantly different (p>0.05).

microbial protein/MJ, respectively) were lower (p<0.05) than those of other diets.

N balance

Nitrogen intake (NI), faeces nitrogen (FN), urinary nitrogen (UN), N absorption and N retention in goats fed LE and HE with different levels of urea are presented in Table 5. N intake of goats fed HE with 3% urea (22.7 g/d) was higher (p<0.05) than those of goats in all other treatment groups. The FN and UN excretions were lower (p<0.05) in goats fed HE with 3 and 4% urea as compared to goats fed LE with 3 and 4% urea. Nitrogen excretion (faeces or urine) in goats fed both LE and HE with 5% urea was the highest and N excretion by goats fed HE was significantly lower (p<0.05) than by those fed LE. The total N excretion was also reduced for the HE diets, thus the N absorption and retention in goats fed HE were higher (p<0.05) than those fed LE diets.

DISCUSSION

Our previous study (Paengkoum et al., 2006) showed that feed intake, DM and OM digestibility of steamed OPF fed to goats increased with increasing level of dietary urea supplement up to 30 g/kg DM (3% urea). The aim of this experiment was to investigate whether addition of fermentable energy would enhance the efficiency of use of urea included at higher than 3% in a similar diet for growing dairy goats.

There were overall improvements in DMI and DM, OM and CP digestibility in goats fed HE as compared to LE diets. However, all the above values remained highest for goats fed 3% urea supplement within each energy group, with HE+3% urea being the highest, and thereafter decreased with increased urea supplementation. This observation could be due to low palatability of urea, which depressed feed intake as the level of urea in the ration was increased above 3% (Ciszuk and Lindberg, 1988). The results were similar to those obtained with low-protein forage diets, on which feed intake, rumen digestibility, N balance and microbial growth were stimulated by addition of urea or other non-protein nitrogen supplements (Van Glyswyk, 1970; Meherz and Ørskov, 1977; Preston and Leng, 1987). However, decreased ruminal DM content, low intake and digestibility were observed with increasing supplemental urea due to low palatability and toxicity (Koster et al., 1996; 1997; Sahoo et al., 2006).

Energy supplementation improved DMI of goats and resulted in higher BW gains. Goats fed all HE diets recorded positive daily BW gain with those on HE+3% urea supplement gained an impressive 86 g/d, which is about 2.4 fold higher than that recorded on the LE diet with similar urea supplementation.

Rumen pH values were not affected by the dietary treatments and were within the physiological range of 6.6-7.1 which has no negative effect on bacterial growth (Perez et al., 1967; Hoover, 1986). Chalupa (1972) suggested that a negative effect on bacterial growth might occur only if ruminal pH exceeds 7.3.

In the present study, mean ruminal NH_3-N values were between 13 and 18 mg/dL. Because of the rapid rate of urea hydrolysis, ruminal NH_3-N concentrations increased with increasing urea levels. The NH_3-N concentrations seemed to be adequate for microbial growth as they were within the range of 10-20 mg/dL required for optimum digestion (Hume and Bird, 1979; Krebs and Leng, 1984; Kraidees, 2005).

Ruminal fluid total VFA concentration was affected by dietary energy, urea level and their interaction. The production of acetic, propionic, butyric and total VFA varied according to sampling times. The values measured 4 h post-feeding were the highest compared with values measured at 0 and at 2 and 6 h post-feeding. The proportions of acetic, butyric and iso-butyric acids were higher ($p<0.05$) in goats fed HE than LE. The above observations were in agreement with Rook (1964) who reported that the proportion of branched-chain VFA tended to be higher with an energy-rich diet. The concentration of acetic acid decreased for goats fed HE, because more propionic acid was formed with the increased availability of soluble carbohydrates, thus reducing the acetic acid proportion (Hoover and Stokes, 1991; Nocek and Tamminga, 1991). Ruminal fluid iso-butyric acid (concentration and proportion) was lower in goats fed a higher urea level, probably due to reduced microbial deamination of branched-chain amino acids in the rumen with the increased NPN content of the diet (NRC, 1985; Bergman, 1990; Nguyen et al., 2005).

Increased dietary N (urea) intake has been shown to influence ruminal and blood nitrogenous metabolites (Fernandez et al., 1997; Wanapat et al., 2006). Results of the present study indicated that PUN was elevated with increasing dietary urea (N) intake which is similar to the results of Gaskins et al. (1990); Sahlu et al. (1993); Fernandez et al. (1997). Kozloski et al. (2000) demonstrated that substitution of urea (0.7-2.2% of urea in the ration) for soybean meal had no effect on the total digestibility and ruminal cellulose digestibility but, in turn, increased ruminal NH_3-N losses into the blood and decreased the microbial N flow to the small intestine.

Microbial N synthesis (g N/d) and efficiency of microbial N synthesis (g N/kg DOMR) responded positively to increasing energy supplementation but decreased with increasing urea supplementation, which is reflected in decreased PD in the urine. The results were similar to those of Herrera-Saldana et al. (1990) and Martin-Orue et al. (2000), who reported in dairy cattle that fermentable carbohydrate and a fast-release N protein stimulated greater ruminal microbial protein efficiency than asynchronous or more slowly degradable diets. The above observation is well demonstrated in the results of the present study where addition of energy (HE) significantly improved the efficiency of microbial N synthesis in goats fed all levels of urea supplementation as compared to their counterparts on LE diets.

The concurrent release of readily available energy from molasses and cassava waste, and ammonia from urea in the HE diets apparently produced better conditions for microbial growth in the rumen than on the low energy diets. Efficiencies of microbial N synthesis in cattle and sheep have been widely published (Chen et al., 1990; Liang et al., 1994; Martin-Orue et al., 2000), but not in goats. Efficiency of microbial N synthesis of goats fed 3 and 4% urea supplements in both LE and HE diets ranged from 18.4 to 27.5 g N/kg DOMR. These values were close to published values of 19.3 to 30 g N/kg DOMR (ARC, 1984; Czerkawski, 1986; Nsahlai et al., 2000).

Except for goats fed HE with 3% urea (22.5 g/MJ VFA), the P/E ratios from the present study were lower than 25-34 g/MJ VFA reported by Leng (1991). However, Jetana et al. (2000) and Paengkoum et al. (2002) reported lower P/E ratios (8.0-14.0 g/MJ VFA) for sheep and goats, respectively, from this laboratory. Generally for low quality roughage diets, P/E ratios were reported to be 4-10 g/MJ VFA (Preston and Leng, 1987). These authors showed that an imbalanced feed (low P/E ratio), which is associated a high metabolic heat production (HP), could also reduce efficiency of microbial N synthesis (Leng, 1991). Results from the present study suggested a similar relationship, i.e. goats fed low P/E ratio diets attained higher efficiency of microbial N synthesis but recorded higher HP than goats fed high P/E ratio diets. The higher HP of goats fed a low P/E ratio diet was observed in this study where HP of goats decreased with increasing P/E ratio diets. The high HP recorded for goats fed LE is postulated to be due to additional energy being required to detoxify the excessive PUN into its less poisonous form (urea), which is later excreted in the urine (Loosili and McDonald, 1986; Sun and Christopherson, 2006).

In our previous study (Paengkoum et al., 2006), it was shown that although N intake increased with increasing levels of urea supplementation (1, 2, 3, 4 and 5% of urea) in the diet, N retention (in terms of g/d and %) increased with the addition of urea only up to 3%, and thereafter decreased. The present results showed that energy supplementation had significantly increased overall N intake, but not N excretion and thus attained higher N retention. For example, addition of energy improved % N retention of goats fed HE with 3% urea by 3 fold compared to those fed LE with similar urea supplementation (44.6% vs. 14.5%). Although % N retention decreased with increasing urea supplementation above 3%, it remained positive for HE diets whereas for LE diets it decreased to near zero or negative.

Daily BW gains of goats were reflected in their respective N retentions, being the highest for goats fed HE +3% urea (86 g/d). This value was nearly 2.5 fold higher than that for LE+3% urea (36 g/d). On the other hand, goats fed LE diets supplemented with 4% and 5% urea recorded near zero and negative % N retention and attained negative BW gain.

Nitrogen excretion, particularly urine N, increased with additional urea supplementation. Kebreab et al. (2002) also reported a similar finding and suggested that high urine N excretion has an adverse impact on environmental pollution. Results of the present study showed that N absorption and thus N retention can be enhanced ($p<0.01$) with appropriate energy supplementation, implying that increasing energy concentration of the diet could improve efficiency of its N utilization and thus decrease the proportion of N excretion in urine. The above results thus support earlier reports that total N, and particularly urine N excretion, could be reduced through diet manipulation (Tamminga, 1996; Castillo et al., 2001; Kebreab et al., 2002).

CONCLUSIONS

There was an overall improvement in the performance of goats fed HE compared to LE diets. All the parameters measured indicated that although there was an overall improvement in N utilization for goats fed additional fermentable energy, there was no advantage of feeding them more than 3% urea. Moreover, N excretion, especially via the renal route, increased with the addition of urea above 3%, which could result in adverse impact on the environment. Results of the present study showed that appropriate supplementation of RDP (urea) and fermentable energy alone to an agro-industrial byproduct such as the OPF diet could achieve an impressive 86 g/d BW gain for growing dairy goats. We postulate that addition of dietary true protein to the above diet would further enhance both the efficiency of microbial synthesis and host animal performance.

ACKNOWLEGEMENTS

The authors acknowledges the Universiti Putra Malaysia (UPM) and Ministry of Science, Technology and Environment Malaysian and Suranaree University of Thecnology for facilities financial support of this experiment.

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