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Utilization of Steam-treated Oil Palm Fronds in Growing Goats: 1. Supplementation with Dietary Urea

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ABSTRACT : Five male dairy goats (Saanen), 4.6 month old with a body weight of 21.4 (SD±1.6) kg, were used to examine 5 dietary urea treatments in a 5×5 Latin Square experimental design. The five levels of urea were 10, 20, 30, 40 and 50 g urea/kg DM of steam-treated oil palm fronds (OPF) and dry matter intake tended ($p>0.05$) to increase with increasing urea supplementation up to 30 g/kg OPF (77.7 g/kg $BW^{0.75}$), but decreased ($p<0.05$) with 40 and 50 g urea/kg OPF (67.4 and 63.7 g/kg $BW^{0.75}$, respectively) supplementation. Similarly, dry matter, organic matter, crude protein, neutral detergent fiber and hemicellulose digestibilities increased ($p<0.05$) with the addition of urea to 30 g/kg OPF but thereafter decreased ($p<0.05$) with 40 and 50 g/kg OPF. Ruminal pH, ruminal NH_3-N concentration and plasma urea concentration increased linearly ($p<0.01$) and quadratically ($p<0.01$) as a consequence of addition of urea to the diet. Excretion of total purine derivatives (PD) by goats fed 30 g of urea/kg OPF was highest ($p<0.05$) followed by goats fed 20, 40, 10 and 50 g of urea/kg OPF. Microbial N (g N/day) and efficiency of microbial N supply expressed as g N/kg organic matter apparently digested in the rumen were higher ($p<0.05$) in goats fed 30 g of urea/kg OPF (5.5 g N/day and 22.0 g N/ kg DOMR, respectively) than in goats on 10 and 50 g of urea/kg OPF treatments. However, the former did not differ from goats fed 20 g of urea/kg OPF (3.9 g N/day and 16.6 g N/kg DMOR, respectively). Ruminal VFA concentration, protein/energy ratio, N absorption and N retention increased ($p<0.05$) with the addition of urea to the diet up to 30 g/kg OPF but decreased ($p<0.05$) with 40 and 50 g/kg OPF. This implies that the optimal level of urea supplementation in an OPF based diet was about 30 g urea/kg OPF. (**Key Words :** Fermentable Protein, Urea, Oil Palm Fronds, Dairy Goats)

INTRODUCTION

Oil palm fronds (OPF) have great potential to be utilized as a roughage for ruminants (Abu Hassan et al., 1993; Islam et al., 2000). Several processing techniques have been tested to improve its feeding value. They include using urea and molasses, alkali treatment, pelletizing and enzymatic degradation (Abu Hassan and Ishida, 1992; Wan Zahari et al., 2002; Dutta et al., 2004). Bengaly et al. (2000) reported that steaming under moderate or low pressure significantly improved nutrient degradability in OPF. The authors postulated that lignin may have been bound to hemicellulose during steaming This resulted in an increase in the lignin fraction and a fall in hemicellulose. The bound lignin was probably analyzed as a chemical artifact. However, OPF contains low crude protein (3-4% CP) and several other nutrients thus restricting its utilization (Ishida et al., 1994). Therefore, supplementing nitrogen (N) to optimize the rumen environment might enhance the efficiency of utilization of steamed OPF.

The National Research Council (1988) suggested that urea can be included to 30 g/kg DM in poor quality roughages, while ARC (1980) reported that intake of up to 0.5 g urea/kg body weight (BW) is not toxic. Helmer and Barley (1971) reported N from NPN can be used at 0.3 to 0.8 g of urea/kg BW, but NPN can be fed at higher levels when the ration has sufficient soluble protein (Leng, 1997). Generally, supplementation of urea to ruminants fed low-N pastures or straw-based diets has improved feed intake, digestibility and N balance (Ørskov et al., 1971; Preston and Leng, 1987). However, the results were not consistent possibly due to differences in the types of forage or

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technique of supplementation used.

The objective was to determine effects of varying amounts of urea supplementation on performance and feed utilization by growing dairy goats fed a diet comprised solely of steamed oil palm fronds (OPF).

MATERIALS AND METHODS

Animals

Five male dairy goats (Saanen), aged 4.6 (SD±2.2) mo with a BW of 21.4 (SD±1.6) kg, were kept in individual pens. The experiment was conducted from July 2001 to January 2002 with an average temperature of 32 (SD±1.8)°C. Goats were allowed an adjustment period of 3 wk and were treated with anthelmintics against intestinal parasites.

Diets and feeding methods

Goats were fed a diet containing nutrients to achieve a daily BW gain of 100 g, in accordance with NRC (1981). Goats were fed *ad libitum* a diet of 30 g urea/kg steamed OPF plus 20 g of molasses during the 3 wk adaptation. Oil palm fronds were steamed at 10 kg/cm^2 for 20 min and oven dried at 60°C for 48 h. (Bengely et al., 2000) plus 10, 20, 30, 40 or 50 g urea/kg DM, were randomly assigned in a 5×5 Latin square Design. The treated OPF was subsequently mixed with molasses and dicalcium phosphate (1%) before feeding. Diets were offered to the respective goats' *ad libitum* twice daily at 0830 and 1530 h. Drinking water was freely available.

Feed intake and body weight change

Feed offered and refused was weighed daily prior to the morning feeding to determine the daily DM intake (DMI). The BW of each goat was measured weekly immediately before the morning feeding. Averge daily gain (ADG) was calculated as the slope of the linear regression of BW with time.

Experimental procedure

The study consisted of five periods of 33 d each being 21 d of adjustment followed by 12 d for measurements. The latter consisted of 2 d of adaptation, 7 d of digestibility and N balance studies, 2 d of rumen fluid and blood samplings and 1 d of heat production (HP) measurement. During the digestibility trial, samples of feed refusals, faeces and urine were collected to determine chemical composition.

A daily faeces of each goat was weighed and a 10% sub-sample collected and stored at -20°C. Samples were dried (60°C) and ground through a 1 mm sieve and stored until analysis.

Daily output of urine was collected into a plastic container (containing 25 ml of 10% H_2SO_4). Approximately 10% of the volume was sampled and stored at -20°C pending energy and N analysis. A separate urine sample was collected for determination of purine derivatives (PD). The urine sample was diluted 4-fold (to prevent crystallization of uric acid during storage), then filtered through Whatman cellulose membranes (25 mm, 0.2 microns) attached to a syringe, and frozen at -20°C for later analysis of PD content using high performance liquid chromatography (HPLC) according to Balcells et al. (1992).

Rumen fluid was collected from all goats using a stomach tube at 0, 2, 4 and 6 h post-feeding during the digestibility trial. It was strained through 4 layers of cheese cloth and pH measured immediately using a pH meter (Mettler Toledo MP 125) fitted with a combined electrode. The rumen fluid was then acidified with H_2SO_4 (50%, v/v) and stored at -20°C for analyses of ammonia and VFA.

Blood was sampled from the jugular vein at 0, 2, 4 and 6 h post-feeding and after rumen fluid was sampled. The blood samples were centrifuged (3,000×g for 15 min) and plasma stored at -20°C for urea analysis.

Heat production (HP) measurement was completed using an open circuit respiration chamber (35 cm×45 cm×35 cm) connected to a Beckman 755 oxygen analyser (Beckman, USA). Heat production of each dairy goat was determined from the measurement of oxygen consumption at 10 min intervals for 24 h and calculated according to the formula of Yamamoto et al. (1985) as follows:

$$HP\ (kJ/kg\ W^{0.75}/min) = 0.205 \times F \times \Delta O_2 \times Tf \times Pf/R.\ W^{0.75}$$

Where, HP = heat production, 0.205 = constant value, F = outlet air flow (approximately 32 L/min), measured by a Rota meter, Tf = correction factor for standard temperature, Pf = correction factor for standard pressure, R = recovery rate, $W^{0.75}$ = metabolic body weight

Chemical analyses, calculations and statistical analysis

Feed samples were collected twice a week. Representative samples of feed and faeces collected during the digestibility trial were analyzed according to AOAC (1984) for DM, ash and CP and fiber components (Van Soest et al., 1991). Apparent digestibility was calculated using equations of Schneider and Flatt (1975).

Total VFA and molar proportions of acetic, propionic, iso-butyric, butyric and valeric acids in rumen fluid were determined by Shimatzu GC-14 gas chromatography (Shimatzu, Japan) fitted with a Flame Ionization Detector (FID) and a packed column containing 5% Thermon -3,000/ Shincarbon A (60/80). Nitrogen was used as the carrier gas at 40 ml/min and the oven temperature was maintained at 220°C; injection and FID temperatures were fixed at 260°C. Plasma urea was determined using a urea test kit (Sigma Diagnostics INFINITY^{TM} BUN Reagent).

Table 1. Chemical composition of oil palm fronds (OPF) supplemented with different levels of urea (g/kg DM)

	g urea/kg steamed OPF				
	10	20	30	40	50
Dry matter	0.841	0.803	0.857	0.787	0.758
Ash	0.073	0.071	0.069	0.063	0.062
Crude protein	0.074	0.103	0.134	0.165	0.195
Neutral detergent fiber	0.713	0.716	0.714	0.717	0.720
Acid detergent fiber	0.422	0.418	0.431	0.426	0.424

N = 15.

The purine derivatives allantoin, uric acid, hypoxanthine and xanthine were analyzed by reverse-phase High Performance Liquid Chromatography (HPLC), which consisted of a multi-solvent delivery system Model 600 E (Waters, USA), an injector Model 712, a multi-wavelength detector Model 490E, set to 205 nm, and a double 4.6×250 mm, C-18 reverse-phase column, according to the technique of Balcells et al. (1992). The supply of microbial N was then calculated from P using the following factors: digestibility of microbial purines 0.83 and purine-N:total microbial N ratio of 0.116:1.00 (Chen et al., 1992):

$$\text{Microbial N supply (g/day)} = \frac{(P\times 70)}{(0.83\times 0.116\times 1{,}000)}$$

$$= 0.727\times R$$

Where, P = the corresponding amount of microbial purines absorbed (mmol/day).

The ratio of microbial protein synthesis/VFA energy (P/E ratio) was calculated using a constant factor according to Czerkawski (1986).

The data were analyzed using the general linear models 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 compare treatment means. Unless otherwise noted, high significance was declared at $p<0.01$, significance was declared at $p<0.05$, trend was declared at $0.05\leq p\leq 0.10$, and non-significance was declared at $p>0.10$.

RESULTS

Chemical composition, feed intake, body weight change and digestibility

The DM, OM, NDF and ADF contents of the diets were similar for all treatments (Table 1). As anticipated, CP increased with increasing urea supplementation.

The DMI and digestibility values are shown in Table 2. The results showed that intake of OPF by goats increased quadratically, ($p<0.01$) with increasing urea supplementation up to 30 g/kg OPF and thereafter, decreased ($p<0.05$). The ADG of goats supplemented with 20 and 30 g urea/kg OPF was significantly higher ($p<0.05$) than of those supplemented with 10, 40 and 50 g urea/kg OPF.

The DM and OM digestibility increased ($p<0.05$) with the addition of urea to the diet up to 30 g/kg OPF and thereafter decreased ($p<0.05$) (Table 2). Similarly, CP digestibility increased with the addition of urea to the diet up to 30 g/kg OPF, with the value for 10 g/kg OPF being significantly lower ($p<0.05$) than for 20, 30, 40 and 50 g/kg OPF. The latter values were not significantly ($p<0.05$) different. Digestibility of NDF increased ($p<0.05$) with the addition of urea to the diet up to 30 g/kg OPF and thereafter decreased ($p<0.05$) with 40 and 50 g urea/kg OPF. However, ADF digestibility was not affected by the dietary treatments.

Ruminal pH and NH_3-N

Ruminal pH and NH_3-N concentration increased linearly ($p<0.01$) and quadratically ($p<0.01$) as a consequence of addition of urea (Table 3, Figure 1A, B). The pH decreased gradually and reached a minimum (6.95)

Table 2. Dry matter intake, digestibility and body weight change of dairy goats fed steamed OPF based diets and supplemented with varying levels of urea

	g urea/kg steamed OPF					SEM	Contrast[1]		
	10	20	30	40	50		L	Q	C
Dry matter intake									
g/d	813^{ab}	844^{ab}	877^{a}	754^{bc}	668^{c}	19.7	*	ns	ns
Proportion of BW	0.0339^{ab}	0.0325^{ab}	0.0346^{a}	0.0293^{bc}	0.0290^{c}	0.007	*	ns	ns
g/kg $BW^{0.75}$	73.3^{ab}	73.4^{ab}	77.7^{a}	67.4^{bc}	63.7^{c}	1.35	**	ns	ns
Digestibility									
DM	0.493^{b}	0.511^{ab}	0.531^{a}	0.488^{b}	0.463^{c}	0.057	ns	*	ns
OM	0.499^{bc}	0.513^{b}	0.531^{a}	0.493^{bc}	0.476^{c}	0.052	ns	*	ns
CP	0.356^{b}	0.428^{ab}	0.531^{a}	0.505^{a}	0.431^{ab}	0.223	ns	*	ns
NDF	0.439^{ab}	0.467^{ab}	0.506^{a}	0.445^{ab}	0.399^{b}	0.128	ns	*	ns
ADF	0.394	0.411	0.484	0.437	0.372	0.157	ns	ns	ns
BW gain, (g/d)	22.4^{a}	47.1^{b}	48.6^{b}	20.2^{a}	-5.8^{c}	1.022	ns	***	ns

[1] contrast effects (L= linear, Q = quadratic and C = cubic).

* $p<0.05$, ** $0.05\leq p\leq 0.01$, *** $p<0.01$, ns = Not significantly different ($p>0.10$).

Table 3. Average pH, ammonia N (NH_3-N, mg N/dL), plasma urea N (PUN, mg N/Dl), total volatile fatty acid (TVFA, mM/L) and proportions of VFAs of dairy goats fed steamed OPF based diets and supplemented with varying levels of urea

	g urea/kg steamed OPF					SEM	Contrast[1]		
	10	20	30	40	50		L	Q	C
pH	7.03^{e}	7.15^{d}	7.25^{c}	7.35^{b}	7.58^{a}	0.040	***	***	ns
NH_3-N	4.1^{d}	7.1^{d}	12.7^{c}	16.5^{b}	22.6^{a}	1.37	***	***	***
PUN	6.2^{e}	10.4^{d}	15.0^{c}	19.1^{b}	25.4^{a}	1.15	***	***	ns
TVFA	37.2^{b}	44.0^{a}	49.1^{a}	37.9^{b}	32.5^{b}	1.25	*	ns	ns
VFA proportion (% total VFA)									
Acetic (C_2)	63.0	64.6	63.7	65.1	29.6	1.02	ns	ns	ns
Propionic (C_3)	24.7	23.7	22.0	21.7	27.1	0.22	ns	ns	ns
Butyric	5.6^{b}	5.3^{b}	7.9^{a}	6.7^{ab}	6.4^{ab}	0.11	ns	*	**
Iso-butyric	1.6	1.4	1.7	1.6	1.7	0.01	ns	ns	ns
Valeric	5.2	5.1	4.7	4.8	5.2	0.07	ns	ns	ns
C_2:C_3	2.6	2.8	2.9	3.1	2.4	0.05	ns	ns	ns

[1] Contrast effects (L= linear, Q = quadratic and C = cubic).

* $p<0.05$, ** $0.05\leq p\leq 0.01$, *** $p<0.01$, ns = Not significantly different ($p>0.10$).

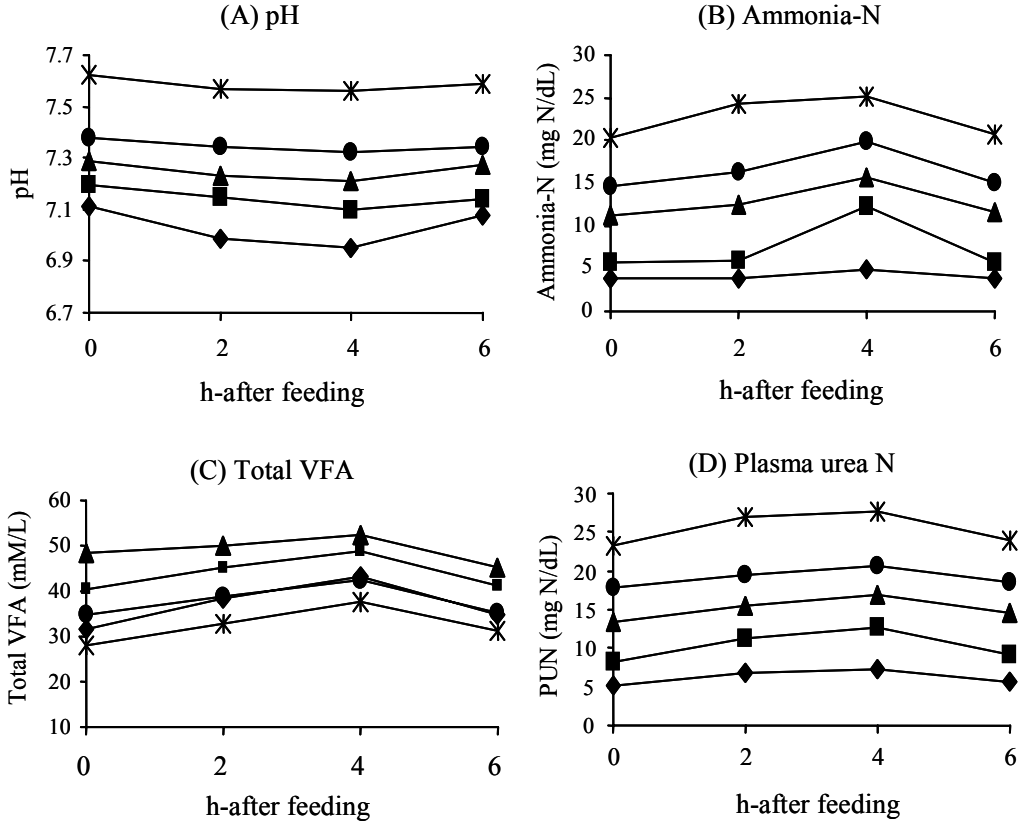

Figure 1. Ruminal pH (A), ammonia N (B), total VFA (C) and plasma urea N (D) of dairy goats fed 10 (♦), 20 (■), 30 (▲), 40 (●) and 50 (*) g urea/kg steamed OPF.

at 2 to 4 h after feeding. In all cases the maximum NH_3-N on urea supplemented diets was achieved at 4 h after feeding. The average ruminal NH_3-N concentration of goats fed 50 g urea/kg OPF was the highest ($p<0.01$) followed by 40, 30, 20 and 10 g/kg OPF.

The relationship between ruminal NH_3-N (NH_3-N, mg/dL) and the levels of urea (UREA, g/kg OPF) was expressed by the following equation: NH_3-N = 0.46 UREA-1.16; R^2 = 0.91, ($p<0.05$). Plasma urea nitrogen (PUN, mg/dL) concentration was linearly correlated ($p<0.01$) with ruminal NH_3-N concentration (NH_3-N, mg/dL) as described by the following equation: PUN = 2.69+0.99 NH_3-N; R^2 = 0.98.

Plasma urea nitrogen

The pattern of PUN concentration (Table 3, Figure 1D)

Table 4. Purine derivatives (PD) excretion, microbial N supply, P/E ratio and heat production (HP) of dairy goats fed steamed OPF based diets and supplemented with varying levels of urea

	g urea/kg steamed OPF					SEM	Contrast[1]		
	10	20	30	40	50		L	Q	C
PD excretion, mM/d									
Allantoin	2.29^{c}	3.86^{ab}	4.93^{a}	2.76^{bc}	1.94^{c}	0.285	ns	ns	ns
Uric acid	0.35^{b}	0.50^{ab}	0.74^{a}	0.39^{c}	0.28^{c}	0.054	ns	ns	ns
Hypoxanthine	0.19^{b}	0.40^{ab}	0.53^{a}	0.26^{ab}	0.30^{ab}	0.053	ns	ns	ns
Xanthine	0.14^{b}	0.19^{ab}	0.40^{a}	0.12^{b}	0.11^{b}	0.052	ns	ns	ns
Total PD	2.96^{c}	4.95^{b}	6.60^{a}	3.54^{bc}	2.84^{c}	0.365	ns	ns	*
Microbial N supply									
g of N/d	1.4^{c}	3.9^{ab}	5.5^{a}	2.3^{c}	1.5^{c}	0.40	ns	ns	ns
g of N/kg of DOMR[1]	6.0^{c}	16.6^{ab}	22.0^{a}	10.3^{bc}	6.2	1.45	ns	ns	ns
Calculated	1.6^{b}	4.2^{a}	2.7^{b}	2.6^{b}	1.7^{b}	0.24	ns	**	**
VFA produced (E, MJ/d)									
P/E ratio	5.7^{b}	6.2^{b}	13.3^{a}	6.0^{b}	5.2^{b}	0.99	ns	ns	*
HP (kJ/kgW$^{0.75}$)	23.4^{a}	21.2^{a}	30.3^{b}	29.6^{b}	31.1^{b}	0.93	**	**	**

[1] DOMR = digestible OM fermented in the rumen, calculated as 0.65×DOMI (ARC, 1984).
[2] Contrast effects (L = linear, Q = quadratic and C = cubic).
* p<0.05, ** 0.05≤p≤0.01, *** p<0.01, ns = Not significantly different (p>0.10).

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

	g urea/kg steamed OPF					SEM	Contrast[1]		
	10	20	30	40	50		L	Q	C
N intake (g)	9.6^{c}	13.9^{b}	18.8^{a}	19.9^{a}	20.8^{a}	1.25	**	**	*
N excretion (g)									
Faeces N	6.1^{c}	8.0^{bc}	8.8^{b}	9.3^{ab}	11.8^{a}	0.31	**	ns	ns
Urine N	0.5^{e}	1.9^{d}	2.6^{c}	6.7^{b}	9.4^{a}	0.74	***	**	**
Total N	6.6^{e}	9.9^{d}	11.4^{c}	16.0^{b}	21.1^{a}	0.99	***	**	**
N absorption, (g)	3.6^{b}	6.0^{b}	10.0^{a}	10.0^{a}	9.1^{a}	0.98	**	ns	ns
N absorption (% of N intake)	36.6^{b}	42.8^{ab}	53.1^{a}	50.5^{a}	43.1^{ab}	0.23	ns	ns	ns
N retention, (g)	3.1^{b}	4.0^{b}	7.4^{a}	3.3^{b}	-0.3^{c}	0.49	*	ns	*
N retention (% of N intake)	31.6^{a}	29.0^{ab}	39.3^{a}	16.6^{b}	-2.4^{c}	1.85	**	ns	*

[1] Contrast effects (L= linear, Q = quadratic and C = cubic).
* p<0.05, ** 0.05≤p≤0.01, *** p<0.01, ns = Not significantly different (p>0.10).

was similar to the pattern of ruminal NH_3-N concentration. Concentration of PUN was greater than that of ruminal NH_3-N concentration, moreover, PUN increased linearly (p<0.01) and quadratically (p<0.01) as a consequence of addition of urea, with the highest being for goats fed 50 g urea/kg OPF.

Plasma urea nitrogen concentration increased in a linear (PUN = 0.45 UREA+1.34; R^2 = 0.82, p<0.01) and quadratic manner (p<0.01) as urea supplementation increased.

Volatile fatty acids

The average ruminal total VFA concentrations after morning feeding for the different treatments are presented in Table 3 and Figure 1C. Molar proportions of total VFA were not significantly (p<0.05) affected by urea supplements, except that butyric acid proportions in goats fed 30, 40 and 50 g urea/kg OPF were significantly (p<0.05) higher than in goats fed 10 and 20 g urea/kg OPF. However, the total VFA was significantly (p<0.05) affected by urea supplementation. Total VFA concentration, acetic, propionic, butyric and valeric acids in ruminal fluid increased (p<0.05) with the addition of urea to the diet up to 30 g/kg OPF, and thereafter decreased (p<0.05) with increased urea supplementation.

The relationship between total VFA concentration in rumen fluid (TVFA, mM/L) and the levels of urea supplementation (UREA, g/kg OPF) was expressed by the following equation: TVFA = 1.59 (1-e $^{0.029UREA}$)+24.39; R^2 = 0.64, (p<0.001).

Purine derivatives excretion and microbial N supply

The average PD excretion rates and the estimated microbial N supply are shown in Table 5. The results showed that total PD excretion rate of goats fed 30 g of urea/kg OPF was the highest (p<0.05) followed by goats fed 20 and 40 g of urea/kg OPF. Microbial N (g N/day) and efficiency of microbial N supply (g N/kg OM apparently digested in the rumen (OMDR)) were significantly higher (p<0.05) in goats fed 30 g of urea/kg OPF than on all other dietary treatments except for goats fed 20 g of urea/kg OPF.

The relationship between microbial N synthesis (MP, g N/d) and the level of urea (UREA, g/kg OPF) was

expressed by the following equation: MP = 0.48 (1-$e^{0.008\ UREA}$)-2.42; R^2 = 0.50, p<0.001.

P/E ratio and others

P/E ratio of goats fed 30 g urea/kg OPF diet was higher than for all the other treatments (Table 4). Heat production (MJ/d) increased linearly (p<0.01) and quadratically (p<0.01) as a consequence of urea addition 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 1.63 to 2.71 MJ/day, and similar patterns were observed for ruminal total VFA concentration. The P/E ratio of goats fed 30 g urea/kg OPF treatment (13.28 g microbial protein/MJ VFA) was significantly higher (p<0.05) than those of other diets.

The non-linear equation between heat production (kJ/kg $W^{0.75}$ d) and the level of urea supplementation for goats was HP = 1.16 (1-$e^{0.029UREA}$)+14.52; R^2 = 0.90, p<0.03.

N balance

Nitrogen intake and urinary N excretion of goats fed OPF increased linearly (p<0.01), quadratically (p<0.01) and cubically (p<0.05) as a consequence of addition of urea (Table 5). Similarly, fecal N excretion increased linearly (p<0.05) as a consequence of addition of urea to the diet. However, N absorption and N retention (g/d and %) increased (p<0.05) with the addition of urea to the diet up to 30 g urea/kg OPF, and thereafter decreased (p<0.05) with additional urea.

There was a linear relationship (p<0.001) between urinary N excretion (Urine N, g/d) and N intake (N intake, g/d) which was expressed by the following equation: Urine N = 0.58 N intake-5.41; R^2 = 0.61.

DISCUSSION

Dry matter intake of goats increased up to 30 g urea /kg OPF, and thereafter significantly decreased (p<0.05) with increased urea supplementation which is consistent with Koster et al. (1997), Haddad et al. (2005). Helmer and Barley (1971) have shown that ruminants can attain positive N balance without affecting DMI when urea supplies the only N source in a diet containing as much as 74% of purified cellulose. Negative BW change of goats fed the highest level of supplementation (50 g urea/kg OPF) was a result of low DMI, probably due to low palatability of the diet containing a high concentration of urea and toxicity arising from excessive plasma ammonia. However, the ADGs of goats fed 20 and 30 g urea/kg OPF recorded in the present study were impressive. The above values were similar to the 45 to 50 g/d weight gains reported for goats fed 60% grass hay and 40% concentrate by Souri et al. (1998). The present result reconfirmed previous studies of Koster et al. (1997) and Rush et al. (1976), which optimum level of urea inclusion is between 2 to 3% of the total ration. However, Dahlan et al. (2000) reported that DM intake, OM intake and BW gain increased with 4% urea supplementation of an OPF based mixed pellet.

The DM and OM digestibilities of goats supplemented with urea at 30 g/kg OPF were highest followed by 20 g/kg OPF. The latter was not different (p<0.05) when 10, 40 and 50 g of urea/kg OPF were used. In terms of fibre digestibility, NDF and hemicellulose digestibilities increased (quadratic, p<0.05) with increasing urea supplementation. Only ADF digestibility showed negative significant responses to urea level in the ration. This is in agreement with Wanapat et al. (2000a); Badamana and Sutton (1992) observed increasing NDF and ADF digestibilities with increasing N levels in the ration.

Ruminal pH was maintained within 6.95 to 7.59, and reached the minimal value between 2 to 4 h post feeding. Mould and Ørskov (1993) and Wanapat et al. (2000a) demonstrated that cellulose digestion is limited when ruminal pH reaches values below 6.0. In the present study, pH increased linearly with the addition of urea during 2 to 4 h after feed ingestion, a fact that may have favored the early activity of the cellulolytic species of bacterial population. Wallace (1979) observed that supplementation with urea at 30 g/kg of DM caused a higher concentration of ruminal NH_3-N and an increase in bacterial numbers and activity in sheep receiving barley diets.

Total VFA in the goats increased with increasing urea supplementation up to 30 g/kg OPF DM, and thereafter declined (p<0.05) when the proportion of urea was more than 40 g/kg DM. Ruminal VFA concentrations are correlated with (Leng and Leonard, 1965; McDonald et al., 1995) and this relationship was also demonstrated in the present study (total VFAs and digestibilities). Koster et al. (1996) reported that total VFA increased dramatically in response to supplemental RDP fed to beef cows that were consuming similar forage.

Increased concentration of PUN agreed with the data of Cressman et al. (1980), who observed linear increases in plasma urea concentration when dietary CP percentages of 12, 15 and 18% were fed to cattle. In this experiment, even though DMI of goats fed 40 and 50 g urea/kg OPF declined, HP and PUN remained high. The low DMI, nutrient digestibility and microbial protein synthesis coupled with higher PUN and HP in goats fed 40 g, and especially 50 g, urea/kg OPF treatments were reflected in their low BW gains. Sun and Christopherson (2005) reported that PUN concentration was positively related with diet CP content.

The 22 g N/kg OMDR obtained in this study for goats fed 30 g of urea/kg OPF was approaching the values of 25-35 g N/kg OMDR suggested in the literature (ARC, 1984;

Czerkawski, 1986; Sinclair et al., 1995). The marginally lower efficiency of the present study as compared to published data in the tropical regions (Jetana et al., 2000; Chanjula et al., 2004; Chang et al., 2005), is not surprising as the experimental diets contained solely OPF, a poor quality agro-industrial byproduct of the oil palm industry with only urea as the N supplement. This is because efficiency of capture of degraded N is known to vary and depends upon the availability of N substrates (amino acids or NH_3-N) and energy (ATP).

Microbial protein/VFA produced (P/E ratio) in the rumen of goats in this study was between 5.24-13.28 g/MJ of VFA. These values were lower than the value of 17 g/MJ for animals fed a tropical roughage diet (Leng, 1990). Once again the differences in the values were probably due to defences in quality of energy and protein of the roughage used. P/E ratio in goats fed 30 g urea/kg OPF (13.28 g/MJ VFA) was similar to those reported by Jetana et al. (2000) and Paengkoum et al. (2002) (8.0 to 14.0 g/MJ VFA) earlier in our laboratory.

Nitrogen degradability had a major effect on urinary N output because of excess soluble N in the rumen from diets with a high RDP (Tamminga, 1996). The imbalance of N availability and N capture by microbes in diets of high RDP resulted in surplus N in the rumen, then via the blood system through conversion to urea and excretion in urine. Based on this, Kebreab et al. (2002) showed that the amount of N excretion via faeces or urine can be manipulated through diet.

CONCLUSIONS

Urea supplementation up to 30 g/kg OPF, significantly improved intake, DM and nutrient digestibility and microbial N supply of diets containing solely OPF. Similarly, ruminal total VFA and individual VFA concentrations, P/E ratio, N absorption and N retention increased ($p<0.05$) with the addition of urea up to 30 g/kg OPF, but thereafter decreased ($p<0.05$) with additional urea. Based on the above findings, the optimal level of urea supplementation to an OPF diet is 30 g/kg OPF. However we postulated that supplementing more than 30 g urea/kg in an OPF diet is feasible if additional soluble carbohydrate is made available to the microbes at the same time.

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