CHAPTER IV

EXPERIMENT II: A STUDY OF ENERGY UTILIZATION IN THAI NATIVE CATTLE FED TROPICAL FEEDS

4.1 Introduction

In tropical areas such as Thailand, traditionally the farmers feed their cattle with green forage in natural pastures as the main feed resource (Sruamsiri, 2008). They face shortage lacking of both quantity and quality of roughage, especially in the dry season. Several studies have been conducted to determine the nutritive values of tropical feedstuffs and agro-industry by-products (Cheva-Isarakul et al., 2008; Napasirth et al., 2008; Sruamsiri, 2008; Suzuki et al., 2008b). Farmers use both Pangola grass (*Digitaria eriantha*) and cassava chip roughage and concentrate, respectively. Agro-industry by-products such as cassava pulp and brewery waste are also locally available all year round. However, previously data on the energy utilization of this local feed in beef cattle is very limited, and there are some feedstuffs in Thailand that have no reference information from literature databases.

Thai native cattle (*Bos indicus*) are considered to be well adapted to heat stress, diseases and parasites and have the ability to utilize low quality feed. However, scientific work has not yet been completed to clarify their nutrient requirements. Current feeding standards used for beef cattle in tropical countries are mainly based on the data obtained from cattle breeds raised in the temperate zone such as Europe or North America where the climatic conditions are also different from those in tropical environments. NRC (2000) suggested that *Bos indicus* beef cattle require about 10 % less energy for maintenance than *Bos taurus.* Previous research documents also indicated that energy requirement for maintenance of *Bos indicus* breed of cattle are lower than *Bos taurus* and *Bos taurus* crossbred (Ferrell and Jenkins, 1998b; Kawashima et al, 2007; Chizzotti et al., 2007a, b). Thus, it is possible that the actual nutrient requirements of tropical cattle breeds are different from those of temperate breeds in temperate environmental conditions. As the species/breed of cattle, climatic conditions and available feed resources are all different from those in temperate zones; the nutritive value of feed stuffs and nutrient requirements of cattle in Thailand may not be the same as recommended for temperate zones. Thus, it might not be appropriate to use those animal requirements and nutritive value data from temperate zone for Thai native cattle and for feed resources in Thailand and/or the tropical region, respectively.

Accurate data on nutritive value and energy content of feedstuffs and energy requirements of animal are essential for farmers to use for diet formulation and tropical beef cattle feeding management. One very large component of energy requirement is the energy requirement for maintenance. Previous studies are available on the energy requirements and energetic efficiency (Solis et al., 1988, Ferrell and Jerkins, 1998a, Liang and Young, 1995, Williams and Jenkins, 2003a,b; Derno et al. 2005 Chaokaur et al., 2007 Ferrell and Otjen, 2008). However, there is very limited research on the energy requirements of Thai native cattle using respiration calorimetry in Thailand.

Therefore, the objective of this work was to investigate metabolizable energy (ME) value of some local tropical feedstuffs with an emphasis on energy metabolism and requirement for maintenance in Thai native beef cattle using open-circuit indirect calorimetry.

4.2 Materials and methods

4.2.1 Animals and diets

Four mature Thai native beef steers, average body weight (BW) 185 (±16) kg, were used in the open-circuit indirect calorimetry study. The energy requirement for maintenance study was carried out from January until May 2006 at Khon Kaen Animal Nutrition Research and Development Center (KKANRDC), Khon Kaen, Thailand in collaboration with Japan International Research Center for Agricultural Sciences (JIRCAS). [For temperature and humidity data of this site see Appendix I, page 154] The animals were fed four dietary treatments in a 4 x 4 Latin Square Design with 20-d experimental periods, consisting of 14-d preliminary period and 6-d sampling collection period. The chemical compositions of feedstuffs and feed formulation and are shown in Table 4.1 and Table 4.2, respectively. The rations were formulated to obtain iso-nitrogenous feed. Animals were housed individually in adjacent holding pens and adapted to individual metabolism crate with gas exchange respiration calorimetry stanchions.

4.2.2 Digestion trial procedure

Steers were individually housed and fed in metabolism crates after acclimation and achievement of 1.5 % of BW dry matter intake (estimated above the energy requirement for maintenance level). Animals were weighed at first day of the preliminary period, and the BW was used to determine the 1.5 % of BW feeding level in each period. Daily feed intake of individual steers was determined by subtracting the daily amount of feed refusal from the amount of feed offered.

The digestion trial consisted of a 6 - d total collection period after 14 - d preliminary feeding. During the total collection period feces and urine were total collected and sampled daily (at 9.30 a.m.). Aliquots of orts, feces (1 kg), and acidified (15% H_2SO_4) urine (500 ml) were collected daily, and on the last day of each period, samples of each animals' wastes were hand mixed at a fixed ratio before sampling (feces 4 kg and urine 1000 ml), and stored at -20°C for later processing and analyses.

Feed, orts, and fecal samples were dried in a forced-air oven at 60°C for 72 h and ground to pass a 1-mm screen (Retsch, Model: SM 2000/695 Upm. GmbH&Co.kG Rheinische straße 36, 42781 Haan. Germany). Dry matter (DM), crude protein (CP), ether extract (EE), crude fiber (CF) and ash contents of the feed, orts, and feces were determined by the method of AOAC (1990). Nitrogen (N) content of urine was determined by the method of AOAC (1990). Gross energy (GE) contents of feed, feces, orts, and urine were determined by using SHIMADZU auto-calculating adiabatic bomb calorimeter (SHIMADZU CA-4PJ, SHIMADZU Corporation, Japan). Neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were determined according to the procedure of Van Soest et al. (1991).

4.2.3 Indirect calorimetry procedure

Oxygen (O_2) consumption and production of carbon dioxide (CO_2) and *methane (CH_4) were measured by ventilated flow-through method using head hood* chamber, open-circuit indirect calorimetry system (Suzuki et al., 2008a), during the last 3 days of the 6-day total collection period and the last 2 days of the 5-day fasting period. The gas exchange respiration calorimetry system was designed for individual animals to be comfortable standing or lying down in stanchions with feed and water available in their head hood. The calorimetry system was designed such that air could be drawn inside the hoods.

The calorimetry system consisted of a head hood, flow cell (Thermal flow cell FWH-N-S, NIPPON FLOW CELL Co., Ltd., Japan), O_2 analyzer (Xentra 4100, Servomex Pcl., UK), CO_2 analyzer (Infra-red gas analyzer, VIA 510, HORIBA, Japan) and CH_4 analyzer (Infra-red gas analyzer, VIA 510, HORIBA, Japan). Gas analyzers were calibrated against certified gases (TAKACHIHO CHEMICAL INDUSTRIAL Co., Ltd., Japan), with known gas concentrations every days in collection periods at 9:00 a.m. Details of this equipment are described by Suzuki et al. (2008a).

The respiration measurements were conducted for 23.30 hours each day, from 09.30 a.m. on the start day to 09.00 a.m. of the next day. The respiratory gas exchange volumes (liter, l) from 23.30 hours were converted into gas exchange volumes per hour, then gas exchange volumes per 24 hours were calculated. The data-recording software TESTPOINT (Capital Equipment Corporation, Billerica, Massachusetts, USA) was used to record data, and was set up to record data every 0.5 second continuously. The system also allowed measurement of the concentration of ambient O_2, CO_2 and CH_4. The calorimetry system was calibrated by the CO_2 injection method (by releasing a weighed amount of CO_2 gas into the system).

4.2.4 Calculations of energy utilization

Digestible energy (DE) was calculated by subtracting total fecal energy losses from GE intake. The energy lost as CH_4 was calculated as the total CH_4 produced in liters per day (heat of combustion $CH_4 = 39.5$ kJ/l) (Brouwer, 1965). ME was calculated by subtracting total energy losses in urine and CH_4 from DE. Retained energy (RE) was calculated as the difference between ME intake and total heat production (HP).

Total heat production (HP) was determined by indirect calorimetry from the respiration gas exchanges using Brouwer's (1965) equation: HP (kJ/d) = $16.18\ O_2 + 5.02\ CO_2 - 2.17\ CH_4 - 5.99\ N$, where O_2, CO_2, and CH_4 represent volume of O2 consumed, CO_2 and CH_4 produced (l) and N is the quantity of urinary nitrogen excreted (g).

The ME requirement for maintenance (ME_m) and fasting HP (FHP) were estimated using the simple linear regression method according to ARC (1980).

All data sets of energy retention were regressed on metabolizable energy intake. Thus, the linear equation was obtained to estimate ME needed for zero retention as MEm and energy retained at zero MEI as FHP (ARC, 1980).

4.2.5 The digestibility of nutrients and energy content of feedstuffs

The digestibility of nutrients and energy content of each feedstuff were calculated by difference method following Schneider and Flatt (1975) and Pond et al. (2005).

4.2.6 Eating behavior observations

Eating behaviors were observed following method of Krause et al. (2002). Eating and ruminating behaviors were monitored visually by trained staff for a 24-h period during the collection period. Eating and ruminating activities were noted every 5 min, and each activity was assumed to persist for the entire 5-min interval. To estimate the time spent eating per kilogram of DMI, NDF intake (NDFI) and ADF intake (ADFI), the actual intake for that day was used. A period of rumination was defined as at least 5 min of rumination occurring after at least 5 min without ruminating activity. Total time spent chewing was calculated as the total time spent eating and ruminating. To register water intake, individual drinking cups with direct-reading flow meters were used which allowed a minimum water measurement of 10 ml.

4.2.7 Statistical analysis

All data were tested by ANOVA and differences among treatments were tested by using the LSMEANS and STDERR statement in PROC GLM. Mean separation was determined using the PDIFF statement in PROC GLM with a $P < 0.05$ significance level (SAS, 1996). The original model included the effects of cattle, period, and diet in a 4 x 4 Latin Square Design according to the following statistical model:

$$\mathbf{Y_{ijk} = \mu + A_i + P_j + T_k + E_{ijk}}$$

where $\mathbf{A_i}$ = steer 1, 2, 3 and 4

$\mathbf{P_j}$ = experimental period1, 2, 3 and 4

$\mathbf{T_k}$ = dietary treatment 1, 2, 3 and 4

$\mathbf{E_{ijk}}$ = residual error.

Regression analysis was computed using the PROC REG procedure of SAS (1996).

4.3 Results and discussion

4.3.1 Chemical compositions

Chemical compositions of feedstuffs and dietary treatments are shown in Table 4.1 and Table 4.2. The CP content in dietary treatments was similar among diets as expected, since dietary treatments were formulated as iso-nitrogenous feed. The EE content in those 4 dietary treatments ranged from 0.30 to 1.14 % of DM.

The NDF content in T1 treatment which consisted of mostly of Pangola grass hay was 72.32 % of DM. On the other hand, NDF content in T2, T3, and T4 treatments was 37.68, 38.53 and 35.80 % of DM, respectively, showing a lower (but similar) content when these dietary treatments are containing cassava chip, brewery waste or cassava pulp. The ADF content in T1 treatment was 38.92 % of DM. Again, the ADF content in T2, T3 and T4 treatments (19.88, 20.18, and 21.42 % of DM, respectively) were similar. Gross energy content varied within a narrow range among dietary treatments, depending in part on the energy content in feedstuffs and the ratio of feedstuffs in the rations. GE content in T1, T2, T3 and T4 treatments was 16.83, 16.47, 17.54 and 16.16 MJ/kg DM, respectively.

Table 4.1 Chemical composition of feedstuffs

Items	**Feedstuffs**			
	Pangola	**Cassava chip**	**Brewery waste**	**Cassava pulp**
Chemical composition, %[1]				
DM	87.27	86.17	87.68	84.94
	-----------------------% of DM-----------------------			
OM	92.67	96.98	95.32	93.62
CP	3.37	2.32	32.74	2.19
EE	1.15	0.22	9.5	0.04
NFE	55.41	91.23	37.62	79.18
CF	32.74	3.22	15.46	12.22
NDF	73.27	14.34	57.91	31.78
ADF	39.43	7.04	29.98	21.13
ADL	5.32	2.39	8.02	6.52
GE (MJ/kg)	17.06	16.53	22.43	16.24

[1] DM, dry matter; OM, organic matter; CP, crude protein; EE, ether extracts; NFE, nitrogen free extracts; CF, crude fiber; NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin; GE, gross energy; DE, digestible energy; ME, metabolizable energy

Table 4.2 Feed formulation, chemical composition and energy of dietary treatments

Items	Dietary treatments			
	T1	T2	T3	T4
Ingredients, % of DM				
Pangola	98.69	40.00	30.00	20.00
Cassava chip	-	58.34	54.81	21.12
Brewery waste	-	-	15.00	-
Cassava pulp	-	-	-	57.00
Urea	1.31	1.66	0.19	1.88
Chemical composition, %[1]				
DM	87.43	86.83	86.75	85.94
OM[2]	92.77	95.31	95.45	94.26
CP[2]	7.06	7.44	7.73	7.78
EE[2]	1.14	0.59	1.89	0.30
NFE[2]	52.26	72.31	71.92	71.99
CF[2]	32.31	14.98	13.91	14.19
NDF[2]	72.32	37.68	38.53	35.80
NDF from forage, % in ration	72.32	29.31	21.98	14.65
NDF from non-forage, % in ration	0.00	8.37	16.55	21.14
NDF from non-forage/ NDF from forage, %	0.00	28.56	75.30	144.30
GE (MJ/kg)	16.83	16.47	17.54	16.16

[1] DM, dry matter; OM, organic matter; CP, crude protein; EE, ether extracts; NFE, nitrogen free extracts; CF, crude fiber; NDF, neutral detergent fiber
[2] per cent of DM

4.3.2 Feed, nutrients and energy intake

The animals BW and feed intake are shown in Table 4.3. Dry matter intake (DMI) of 4 dietary treatments (ranging from 1.26 to 1.34 % of BW) was lower than the expected DMI of 1.5 % of BW that cattle were fed approaching the maintenance level of feed intake. That result might be because of the variation of DM in feedstuffs. However, DMI express as percent of BW and metabolic BW ($BW^{0.75}$), showed no difference among dietary treatments. On the basis of $BW^{0.75}$, OM intake was highest ($P < 0.01$) in T3 treatment, but there were no differences among T1, T2, and T4 treatments.

Although the rations were formulated as iso-nitrogenous, crude protein intake on the basis of $BW^{0.75}$ was highest ($P < 0.01$) in cattle fed T4 treatment, but there were no differences between T1 and T3 treatments.

The NDF intake in units of $BW^{0.75}$ varied among treatments, being highest ($P < 0.01$) in T1 treatment consisting almost completely of Pangola grass hay.

Cattle fed T1 treatment showed a different ($P < 0.01$) NDF intake from those cattle fed the other 3 dietary treatments. The inclusion of cassava chip, cassava pulp or brewery waste in the rations may be a reason for lower NDF intake for cattle fed T2, T3 and T4 diets.

The GE content of dietary treatments based on actual feed intake (Table 4.3) varied among treatments according to the GE content in the feedstuffs and ratio of those feedstuffs in rations, ranging from 16.08 to 17.56 MJ/kg DM. The DE and ME content in T1 dietary treatment that consisted almost entirely of Pangola grass hay was lowest (8.20 and 6.32 MJ DE/kg DM, respectively) ($P < 0.01$) when compared to other treatments (T2, T3 and T4) that contained cassava chip, brewery waste or cassava pulp. These tropical feedstuffs mixed in the rations can improve DE content (ranging from 11.37 to 11.74 MJ/kg DM) and ME content (ranging from 9.10 to 9.76 MJ/kg DM) of Pangola grass hay-based diets. The limitation of ME content in diets and the restricted feeding level in the present study might be the causes of the negative energy balance of animals.

Energy intake (Table 4.3), GE intake (ranging from 36.47 to 42.78 MJ/d) and DE intake (ranging from 9.92 to 28.59 MJ/d) were varied among treatments. The ME intake was lowest ($P < 0.01$) in T1 (15.34 MJ/d) when cattle were fed almost entirely on Pangola grass hay, whereas ME intake improved in T2, T3, and T4 (21.62, 23.72 and 22.51 MJ/d, respectively) when diets were mixed with concentrate feed sources and there were not significant differences among those three treatments. Although the level of DM intake of cattle in this study (ranging from 1.26 to 1.34 % BW, which were expected to approximate the maintenance level of feed intake) is less than previous work of Kawashima et al. (2000) in which Thai native steers (live weight range 162-168 kg) were fed 1.7 % of BW of DM, these levels of DM intake provided ME intake ranging from 19.41 to 27.06 MJ/d. Cammell et al. (1993) conducted an experiment to examine energy utilization in cattle offered a forage diet at near- and sub-maintenance level of feeding reported that, Friesian steers (live weight range from 258 to 275 kg) fed at 0.75 or 1.25 of the maintenance (M) dry matter intake produced ME intake 23.60 or 38.58 MJ/d, respectively. These data indicate that ME intake depends on either level of DM intake or ME content in ration.

Table 4.3 Body weight, energy content of dietary treatment, feed and nutrient intake, and energy intake of Thai native beef cattle in dietary treatments periods and fasting periods

Items[1]	Dietary treatment					*P* value	SE[2]
	T1	T2	T3	T4	Fasting		
Number of animal, head	4	4	4	4	4		
Body weight (kg)							
Average weight	191.70	186.40	182.73	180.40	182.20	-	-
Energy content[3] (MJ/kg DM)							
Gross energy	16.79^{b}	16.41^{c}	17.56^{a}	16.08^{d}	-	<0.001	0.003
Digestible energy	8.20^{c}	11.37^{b}	11.74^{a}	11.59^{ab}	-	<0.001	0.097
Metabolizable energy	6.32^{c}	9.10^{b}	9.76^{a}	9.76^{a}	-	<0.001	0.158
Feed and nutrient intake							
DM intake (kg/d)	2.43^{a}	2.38^{a}	2.44^{a}	2.27^{b}	-	0.025	0.030
DM intake (%of BW)	1.27	1.28	1.34	1.26	-	0.060	0.017
DM intake (g/kg $BW^{0.75}$)	47.14	47.15	49.01	46.00	-	0.058	0.593
OM intake (g/kg $BW^{0.75}$)	43.25^{b}	44.13^{b}	46.85^{a}	42.51^{b}	-	0.006	0.552
CP intake (g/kg $BW^{0.75}$)	3.52^{c}	3.94^{b}	3.56^{c}	4.29^{a}	-	<0.001	0.043
NDF intake (g/kg $BW^{0.75}$)	31.53^{a}	17.14^{c}	18.03^{b}	16.62^{c}	-	<0.001	0.256
Energy intake (MJ/d)							
Gross energy	40.76^{b}	39.07^{b}	42.78^{a}	36.47^{c}	-	<0.001	0.491
Digestible energy	19.92^{c}	27.06^{ab}	28.59^{a}	26.35^{b}	-	<0.001	0.549
Metabolizable energy	15.34^{b}	21.62^{a}	23.72^{a}	22.51^{a}	-	<0.001	0.610

[1]: DM, dry matter; OM, organic matter; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; GE, Gross energy; DE, Digestible energy; ME, Metabolizable energy; OM, organic matter

[2]: SE, standard error; $^{a, b, c, d, e}$ Means with different superscripts among treatments significantly differ (P<0.05).

[3]: Energy content determined from actual feed intake

4.3.3 Energy utilization

The partitioning of GE intake determined by animal calorimetry on $BW^{0.75}$ basis is shown in Table 4.4. GE intake varied among treatments. There was no difference ($P > 0.05$) in GE intake between cattle fed T1 and T2, but it was lowest in cattle fed T4 diet and highest in cattle fed T3 diet. The DE intake was lowest ($P < 0.01$) in cattle fed T1 diet which consisted almost entirely of Pangola grass hay. The highest ($P < 0.01$) DE intake was in cattle fed T3 diet, whereas DE intake of cattle fed T2 and T4 diets was intermediate. The MEI was lowest ($P < 0.01$) in cattle fed T1 (298 kJ/kg $BW^{0.75}$/d). When cassava chip, brewery waste or cassava pulp were included in the T2, T3 or T4 dietary treatments, compared to T1 dietary treatments, it was observed that MEI increased significantly (ranged from 429 to 479 kJ/kg $BW^{0.75}$/d). Data suggest that these tropical feedstuffs mixed with Pangola grass hay-based diet could improve the ME intake of Thai native cattle. Nevertheless, the level of improvement depends on type and amount of those feedstuffs in the ration.

Energy loss into feces and urine excretion, except for fasting animals, was lowest ($P < 0.01$) in cattle fed T4 diet. On the other hand, cattle fed a diet consisting almost entirely of Pangola grass hay (T1) recorded the highest ($P < 0.01$) energy loss into feces and urine in comparison to other groups. As a result, the lowest DE and ME intake took place in cattle fed T1 diet. Cattle fed T2 and T3 diets lost energy in feces and urine at a moderate level.

Methane production was lower ($P < 0.01$) in cattle fed T1 and T4 diet (71 and 66 kJ/kg $BW^{0.75}$/d, respectively) in comparison to the other two groups. Although T1 diet was higher in NDF content (lower available carbohydrate) than others, methane loss was lower than T2 and T3 diets (94 and 86 kJ/kg $BW^{0.75}$/d, respectively) which were lower in NDF content. As Johnson and Johnson (1995) suggested, when highly available carbohydrates are fed at limited intakes, high fractional methane losses occur, whereas, at high intakes of highly digestible diets, low fractional methane losses occur. Compared to the experiment of Kawashima et al. (2000) studying energy metabolism of Thai native cattle, and finding that cattle given Ruzi grass hay with different levels of soybean meal, with DM intake at 1.7 % of BW showed energy loss as methane ranging from 38 to 55 kJ/kg $BW^{0.75}$/d, this study shows a slightly higher figure. The lower of feeding level in this experiment and the difference of available carbohydrate in diets might cause the difference.

Even though there were variations in ME intake, energy loss in terms of feces and urine excretion and methane production, HP of cattle was not significantly different among dietary treatments. However, cattle fed almost all Pangola grass hay (T1) were slightly higher in HP than other groups which were fed mixed diets with other feedstuffs.

Energy balance in terms of energy retention. Cattle DM intake ranged between 1.26 to 1.34 % of BW, lower than the expected near-maintenance level as discussed above. However, negative energy retentions occurred, as shown in cattle fed T1, T2, T3 and T4 rations which retained energy at -126, -56, -11 and -37 kJ/kg BW$^{0.75}$/d, respectively. From the results, reducing the amount of Pangola grass hay in diets and replacing with cassava chip, brewery waste or cassava pulp increased energy retentions of cattle significantly. Because of the low ME content of the low quality Pangola grass hay in this study with resticted feeding, feeding Pangola grass hay solely or as the greater part of a mixed ration could not supply enough energy to meet maintenance requirements. Supplementation or replacing with these tropical feedstuffs could improve the energy balance for Thai native cattle.

Table 4.4 Body weight and energy balance of Thai native beef cattle in feeding dietary treatment periods and fasting periods

Treatment	T1	T2	T3	T4	Fasting	SEM[1]
Number of animal, head	4	4	4	4	4	
Average body weight, kg	191.70	186.40	182.73	180.40	182.20	-
Energy balance, kJ/kg BW$^{0.75}$						
Gross energy (GE) intake	792^{b}	774^{b}	860^{a}	740^{c}	-	9.59
Digestible energy (DE) intake	386^{c}	536^{b}	575^{a}	534^{b}	-	9.99
Metabolizable energy (ME) intake	298^{c}	429^{b}	479^{a}	456^{ab}	-	11.86
Feces excretion	405^{a}	238^{c}	285^{b}	206^{d}	35	3.68
Urine excretion	18^{a}	14^{b}	12^{c}	12^{c}	13	0.50
Methane production	70^{b}	93^{a}	84^{a}	65^{b}	3	3.26
Heat production	424^{b}	485^{a}	490^{a}	493^{a}	281	7.34
Energy retention	-126^{c}	-56^{b}	-11^{a}	-37^{ab}	-281	11.74

[1] SEM, standard error of the mean

$^{a, b, c, d, e}$ means with different superscripts among treatments significantly differ (P<0.05).

4.3.4 Partition of energy

Energy utilization of diets (Table 4.5) in terms of energy digestibility or the ratio of DE to GE, the T1 diet that consisted almost entirely of Pangola grass hay only was 0.49. This value was significantly lower ($P < 0.01$) than others. When Pangola grass hay was replaced with concentrate feedstuffs in T2, T3 and T4 diets, energy efficiency was 0.69, 0.67 and 0.72, respectively. This suggests that replacing Pangola grass hay with concentrate feedstuffs could improve energy digestibility. It is different from a study with goats (Bava et al., 2001) that substituted concentrate feed stuff or non-forage fiber sources for fiber sources from forage offered *ad libitum*. They found that energy digestibility decreased when roughage was replaced with non-forage fiber sources. Similarly with ARC (1980) which notes that the depression of digestibility is slightly greater in sheep than that in cattle.

Energy metabolizability or ratio of ME to GE (Table 4.5), showed a similar tendency to energy digestibility. T1 diet (0.38), in comparison to the other three groups, was the lowest ($P < 0.01$) in metabolizability, and T2 and T3 diet (0.56 both) were moderate, whereas T4 diet (0.62) was the highest. Except for T4 diet, this is a slightly lower metabolizability than previous work. Kirkpatrick et al. (1997) observed that metabolizability of silage-based diets varied from 0.58 to 0.69 in beef cattle given different forage: concentrate ratios at restricted intake. Dawson and Steen (1998) studied the estimation of energy requirements in beef cattle and sheep. They also reviewed the metabolizability of the silage-based rations from several works. They found ME to GE ratio ranged from 0.58 to 0.70 in cattle and from 0.61 to 0.72 in sheep. This data suggests that given the low nutritive value of Pangola grass hay, it is necessary to supply other concentrate feedstuffs to improve metabolizability.

Table 4.5 Body weight, energy intake and energy efficiency of Thai native beef cattle in dietary treatment periods and fasting period

Items[1]	Dietary treatment					*P* value	SE[2]
	T1	T2	T3	T4	Fasting		
Animal	$n = 4$	$n = 4$	$n = 4$	$n = 4$	$n = 4$		
Body weight (kg)							
Average weight	191.70	186.40	182.73	180.40	182.20	-	-
Energy intake (MJ/d)							
Gross energy	40.76^{b}	39.07^{b}	42.78^{a}	36.47^{c}	-	<0.001	0.491
Digestible energy	19.92^{c}	27.06^{ab}	28.59^{a}	26.35^{b}	-	<0.001	0.549
Metabolizable energy	15.34^{b}	21.62^{a}	23.72^{a}	22.51^{a}	-	<0.001	0.610
Energy efficiency							
DE/GE	0.49^{d}	0.69^{b}	0.67^{c}	0.72^{a}	-	<0.001	0.006
ME/GE	0.38^{c}	0.56^{b}	0.56^{b}	0.62^{a}	-	<0.001	0.010
Methane energy/GE	0.09^{b}	0.12^{a}	0.10^{b}	0.09^{b}	-	0.013	0.005
Urine energy/GE	0.02^{a}	0.02^{a}	0.01^{b}	0.02^{a}	-	0.004	0.001
ME/DE	0.77^{c}	0.80^{b}	0.83^{a}	0.85^{a}	-	0.001	0.007
Heat production/GE	0.63	0.62	0.57	0.61	-	0.679	0.036

The proportion of methane energy losses to GE (Table 4.5) was higher ($P < 0.05$) in cattle fed T2 diet (0.12) in comparison to the other three groups. A similar pattern occurred with the proportion of methane energy losses to OM intake. These results may be because of higher available carbohydrate from cassava chip (about 58 % as in diet DM) with restricted feed intake as discussed regarding methane production above. Methane losses in this experiment ranged from 9 to 12 % of GE intake. These results are slightly higher than Kirkpatrick et al. (1997) where Charolais crossbred steers given different forage: concentrate ratio at restricted intake, resulted in methane energy losses which varied from 5 to 8 % of GE.

The higher proportion of methane energy losses to GE in this experiment might be because of not only the different breed of cattle but also the different source of feed. Thus, this experiment used Pangola grass hay and tropical feed sources, whereas Kirkpatrick et al. (1997) used grass silage and cereal-based concentrates to formulate the rations. Nevertheless, observed values in the present study agree with the literature review of Johnson and Johnson (1995) that methane emissions from cattle vary from approximately 2 to 12 % of GE intake. However, methane energy losses as a percentage of DE intake, ranged from 13 to 18 %, which are higher than reported by Van Soest (1994) who stated that methane losses average about 5 to 12 % of DE. The different result might be due to the difference in feed sources.

Proportional loss of energy in urine or urine energy losses to GE ratio was lower ($P < 0.01$) in cattle fed T3 than cattle fed the other 3 diets. Blaxter (1989) stated that the proportional loss of energy in urine varied less between animal species but was greater with higher protein diets. He showed the energy losses in urine of cattle given 40 % hay with 60 % grain was 2.7 kJ/100 kJ of feed. Data in this study are slightly lower, thus, 2.2, 1.8, 1.3, and 1.6 kJ/100 kJ of feed for cattle fed T1, T2, T3, and T4 diet, respectively (Table 4.5 showing value as ratio, i.e. 0.02, 0.02, 0.01, and 0.02, respectively). These results are very similar to Kawashima (2000) who reported that Thai native cattle fed different levels of CP content in the diets had proportional loss of energy in urine ranging from 1.4 to 2.5 kJ/100 kJ of feed. In the present experiment, the variation of proportional loss of energy in urine may be due to the different source of CP, thus, urea or brewery waste in the ration.

As a result, T1 diet produced the lowest efficiency of DE (0.77). On the other hand, T3 and T4 diets recorded less in energy losses into urine (both of two diets), and less energy losses in methane (T4 diets). Thus, T3 and T4 diets were greatest in efficiency of DE (0.83 and 0.85, respectively). Compared to T1 dietary treatment, it was found that energy utilization efficiency in terms of ME to DE was improved in T2, T3 and T4 diets, where concentrate feedstuffs were mixed into a Pangola grass hay based-diet.

The ratios of HP to GE intake were not different ($P > 0.05$) among treatments. The values ranged from 0.57 to 0.63. As MEI of cattle in this study were approaching or were at sub-maintenance levels, the work of Blaxter (1989) is relevant, which shows in his literature reviewed that many animal species e.g. human, sheep, and cattle show depressed minimal metabolism (fasting metabolic rate) when they were subjected to under-nutrition conditions. In addition, ARC (1980) stated that below maintenance increments of metabolizable energy of particular diets are used with one constant of efficiency in promoting energy retention. Therefore, the HP and ratio of HP to GE intake of cattle fed those 4 treatments were consistent.

In the present study, therefore, cattle fed different diets at near- or sub-maintenance levels were not affected in terms of heat production or energy efficiency as ratio of HP to GE intake, but were affected in energy efficiency in terms of digestibility, metabolizability, methane energy to GE, urine energy to GE, and ME to DE.

4.3.5 Digestibility and metabolizable energy content of Pangola grass hay, cassava chip, cassava pulp and brewery waste

Nutrient digestibility and ME values of each feedstuff was determined following by-difference methodology. Total digestible nutrients (TDN) of Pangola grass hay, cassava chip, brewery waste, and cassava pulp was 48.65, 82.19, 58.91 and 71.52 % respectively. The ME content was 6.42, 12.01, 10.07 and 10.89 MJ/ kg DM, respectively.

The ME content of cassava chip was the highest followed by cassava pulp (Table 4.6). It might be because these feedstuffs contained higher soluble carbohydrates and lower fiber when compared to Pangola grass hay or brewery waste. The ME content of cassava chip in this study is slightly lower than that reported by Holzer et al. (1997) (12.80 MJ/ kg DM). However, it is higher than the calculated ME in the study of Suksombat et al. (2006) (10.04 MJ/ kg DM). The ME content of cassava pulp in this study is also higher than that reported by Suksombat et al. (2006) who observed calculated ME as 9.75 MJ/ kg DM. The ME content of Pangola grass hay is lower than previous studies by Chaokaur et al. (2008a) (3.3 % CP, ME = 7.29 MJ/ kg DM) and Suzuki et al. (2008a). The latter author found that ME content of high quality Pangola grass hay (9.5 % CP) was 7.99 MJ/ kg DM.

Metabolizability of the gross energy of feed (q) is defined as the ME of a diet divided by the gross energy (GE) and q at maintenance is q_m. The q_m of feeds used in this study are shown in Table 4.6. The q_m of cassava chip was the highest, followed by cassava pulp. Pangola grass hay showed lower q_m than that observed by Chaokaur et al. (2008a) and Suzuki et al. (2008a) who found that q_m of Pangola grass hay was 0.46 and 0.43, respectively.

Table 4.6 Digestibility, energy content and metabolizability of feedstuffs

Items	Feedstuffs			
	Pangola	Cassava chip	Brewery waste	Cassava pulp
Digestibility, %				
DM	48.83	83.05	40.73	73.62
OM	54.91	89.39	29.28	82.10
CP	56.33	63.64	33.89	63.84
NDF	54.17	32.99	33.25	54.95
ADF	55.75	30.61	39.06	57.98
ADL	20.11	30.84	50.81	54.84
TDN, %	48.65	82.19	58.91	71.52
Energy content, MJ/kg				
GE	17.06	16.53	22.43	16.24
DE	8.20	14.54	7.92	12.17
ME	6.29	12.01	7.02	10.89
Metabolizability (q_m= ME/GE)	0.37	0.73	0.31	0.67

[1] DM, dry matter; OM, organic matter; CP, crude protein; EE, ether extracts; NFE, nitrogen free extracts; CF, crude fiber; NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin; GE, gross energy; DE, digestible energy; ME, metabolizable energy

4.3.6 Energy intake and methane production

The DEI and MEI were lowest ($P < 0.05$) in cattle fed T1 (Table 4.7). The inclusion of cassava chip (T2), brewery waste (T3) or cassava pulp (T4) in Pangola grass hay-based diets can improve DEI and MEI of Thai native cattle ($P < 0.05$)

Methane production was lower ($P < 0.05$) in cattle fed T1 and T4 diet (70 and 65 kJ/kg $BW^{0.75}$/d, respectively) in comparison to the other two groups. Although T1 diet was higher in NDF content (lower available carbohydrate) than others, methane loss was lower than T2 and T3 diets (93 and 84 kJ/kg $BW^{0.75}$/d, respectively) which were also lower in NDF content (higher available carbohydrate). As Johnson and Johnson (1995) state; when highly available carbohydrates are fed at limited intakes, high fractional methane losses occur, whereas, at high intakes of highly digestible diets, low fractional methane losses occur. Although NDF content in the group of Pangola grass hay mixed with other feedstuffs (T2, T3 and T4) were similar, ratios of non-forage NDF the rations were different. In these three Pangola grass hay based dietary treatments, data suggest that methane production decreased as the proportion of NDF from Pangola grass hay decreased. Therefore, the efficiency of energy utilization in terms of reducing methane energy loss would be improved by reducing roughage or the ratio of NDF from roughage in diets while the NDF content is maintained at the same level.

Table 4.7 Body weight, energy intake, heat production and methane production of Thai native beef cattle in dietary treatments

Treatment	T1	T2	T3	T4	SEM[1]
Number of animal, head	4	4	4	4	
Average body weight, kg	191.70	186.40	182.73	180.40	-
Energy intake, kJ/kg $BW^{0.75}$					
Gross energy (GE)	792^{b}	774^{b}	860^{a}	740^{c}	9.59
Digestible energy (DE)	386^{c}	536^{b}	575^{a}	534^{b}	9.99
Metabolizable energy (ME)	298^{c}	429^{b}	479^{a}	456^{ab}	11.86
Heat production	424^{b}	485^{a}	490^{a}	493^{a}	7.34
Methane production					
L/day	92.62^{bc}	120.25^{a}	108.96^{ab}	82.80^{c}	5.79
MJ/day	3.66^{bc}	4.75^{a}	4.30^{ab}	3.27^{c}	0.23
kJ/kg $BW^{0.75}$	70^{b}	93^{a}	84^{a}	65^{b}	3.26
Methane/GE intake	0.09^{b}	0.12^{a}	0.10^{ab}	0.09^{b}	0.01
L/kg OM intake	40.58^{b}	52.16^{a}	45.59^{ab}	38.32^{b}	2.09
L/kg NDF intake	52.21^{c}	128.84^{a}	110.58^{b}	99.20^{b}	5.14

[1] SEM, standard error of the mean

$^{a, b, c, d, e}$ means with different superscripts among treatments significantly differ ($P<0.05$)

Comparing the methane production to previous work by Kawashima et al. (2000) who studied energy metabolism of Thai native cattle fed Ruzi grass hay with different levels of soybean meal, with energy lost as methane ranging between 38 to 55 kJ/kg $BW^{0.75}$/d, this study records a rather higher loss rate (ranging between 65 to 93 kJ/kg $BW^{0.75}$/d). However, almost all the diets here have a lower level of CP content than in the work of Kawashima et al. (2000). The feeding level in this experiment and the difference of available carbohydrate in diets might cause the difference.

Compared to Brahman cattle, the ratio of methane production to GE intake of Thai native cattle fed the Pangola grass hay-based diet in this study (range between 0.09 to 0.12) agrees with Suzuki et al. (2008a) who found that Brahman steers fed Pangola grass hay (9.5 %CP and 74.6 % NDF) lost energy in the form of methane at 0.097 of the GE intake. Also, this value is acceptable when compared with Brahman heifers fed tropical feed such as Angleton grass (2.4 %CP and 75.3 % NDF) and Rhodes grass (8.9 %CP and 71.8 % NDF) where energy loss in the form of methane was 0.104 and 0.114 of the GE intake, respectively (Kurihara et al., 1999). Nevertheless, this study fed cattle at near- or sub-maintenance level of feed intake, therefore, further study is needed to evaluate the effect of the ratio of roughage fed at above maintenance levels.

4.3.7 Metabolizable energy requirement for maintenance (ME_m), ME utilization efficiency for maintenance (k_m) and fasting heat production (FHP)

A highly significant linear relationship of regressing MEI against ER was obtained, ER = 0.616 $_{(SE = 0.074)}$ MEI - 313.831 $_{(SE = 31.028)}$, [$R^2 = 0.822$, $P = 0.0001$, RSD = 5.400, n = 16] (see also Figure 4.1). Thus, an estimate of FHP and ME_m was 314 and 509 kJ/kg $BW^{0.75}$/d, respectively. Results suggest that ME utilization efficiency for maintenance (k_m; $k_m = FHP/ME_m$) of Thai native cattle is 0.616. The estimated FHP in this study (314 kJ/kg $BW^{0.75}$/d) is similar to FHP reported by ARC (1980) (319 kJ/kg $BW^{0.75}$/d). The actual FHP (281 kJ/kg $BW^{0.75}$/d) determined by indirect calorimetry from the respiration gas exchanges in fasting animals was 10 % lower than estimated FHP (314 kJ/kg $BW^{0.75}$/d) which was determined by the linear relationship of regressing MEI against ER. The lower actual FHP of this study might be due to negative energy retention (sub- maintenance of MEI) before fasting as suggested by Blaxter (1989) who proposed that in fasting metabolism decreases after sub- maintenance feeding.

Even though some negative energy balances were observed in the present experiment, the energy requirement for maintenance can still be found by regression method, in a similar manner as Cammell et al. (1993) who arranged dietary treatments for cattle at near- and sub-maintenance levels of feeding. Cammell et al. (1993) fed Friesian steers (live weight range 258-275 kg) at 0.25, 0.5, 0.75 or 1.25 of the maintenance (M). From that arrangement, energy retentions of cattle ranged between -261 to 114 kJ/kg $BW^{0.75}$/d.

Metabolizable energy requirement for maintenance of Thai native beef cattle in the present study is higher than previously reported by Kawashima et al. (2000). Although Kawashima et al. (2000) investigated ME_m of Thai native cattle, with a reported value of 245 kJ/kg $BW^{0.75}$/d, this value is dramatically different from the NRC (2000) suggestion. Data of Kawashima et al. (2000) could be an under-estimated value because indirect calorimeters with face-mask were used, which cannot measure the gas exchange continuously. Their measurements were conducted 6 times per day, each 6 to 10 min. Thus, it could not continuously determine energy loss into CH_4 and HP and may be a reason for lower estimation of ME_m compared to the present study. By contrast, the present study was conducted with a new system of indirect calorimeters with ventilated hood (head box) which is improved and established by Suzuki et al. (2008a). Compared to the face-mask system, the new system offers more advantages in conducting the gas exchange measurements all day, even during eating and ruminating and is less stressful for cattle. However, gases produced from the lower gut could not be measured.

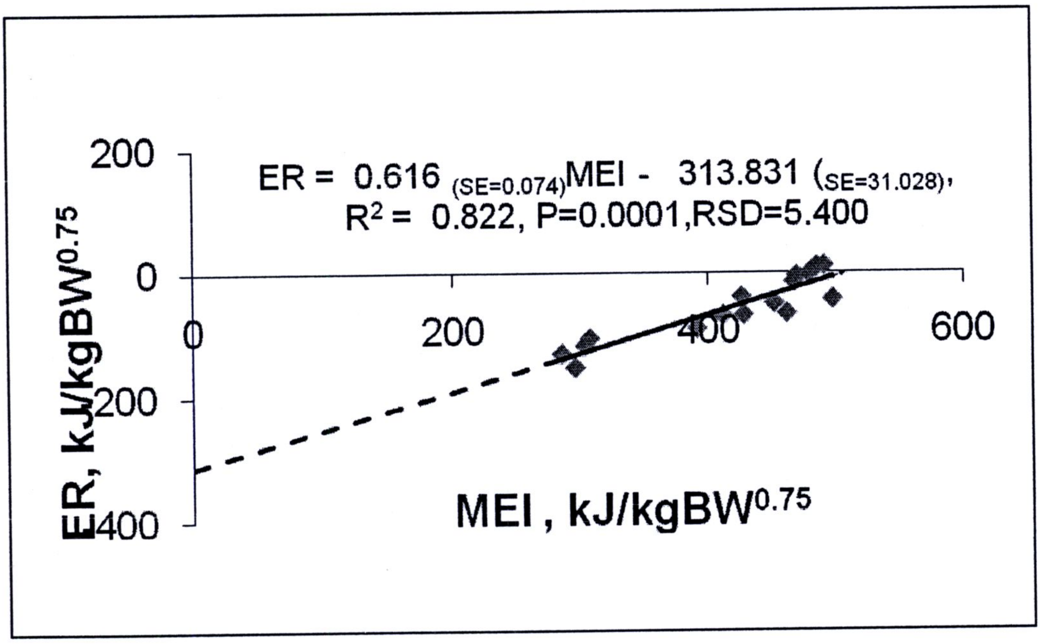

Figure 4.1 The relationship between metabolizable energy intake and energy retention.

The comparison in ME_m among breeds of cattle is shown in Table 4.8 showing data obtained from various methods. When Brahman cattle in different studies are compared with studies done in Thailand (T. Suzuki, National Agricultural Research Center for Agriculture, Kyushu, Okinawa Region, Kumamoto 861-1192, Japan, personal communication; Chaokaur et al., 2007) and USA (Ferrell and Jenkins, 1998b) which used the same method, it is found that ME_m of Brahman cattle is not much different across the studies (on average 3.7 % differ). Compared to Hereford steers in Europe (Derno et al. 2005), the growing Hereford steer (416 kJ/kg BW$^{0.75}$/d) has lower ME_m than Thai native cattle (509 kJ/kg BW0.75/d).

The lack of appropriate feeding standards and nutritive values of feedstuffs are some of the main constraints for the further development of ruminant production in Thailand. The establishment of proper feeding management for cattle has been urged for the sustainable development of animal production in the region. However, the type of cattle and feed resources available in the country are different from those in temperate countries and cattle in the tropics tend to be fed with low quality diets. The information obtained from the present study will be useful in solving these problems. However, for Thailand and this region, this information is only the first step in determining metabolizable energy requirement of Thai native cattle and metabolizable energy utilization of feedstuffs because there is a very limited body of experimental data. As the literature shows, there is variation in metabolizable energy requirements according to breed, state of maturity and body size of cattle. Therefore, more data should be accumulated in order to define the ME_m value of Thai native cattle to use as a recommendation.

Table 4.8 Comparison of metabolizable energy requirement for maintenance (ME_m) of cattle

Breed	Sex	State	BW, kg	ME_m, kJ/kgBW$^{0.75}$/d	Method[1]	Sources
Thai Native cattle	Steer	Mature	185	509	ICH; RE ra MEI	This study
Thai Native cattle	Steer	Mature	163	245	ICF; RE ra MEI	Kawashima et al. (2000)
Kedah Kelantan	bulls	Growing	149	335	TOH; RE ra MEI	Liang and Young (1995)
Brahman	Steer	Mature	370	377	ICF; RE raM EI	Kawashima et al. (2000)
Brahman	Steer	Mature	370	488	ICH; RE ra MEI	T. Suzuki [2]
Brahman	Steer	Mature	373	458	ICH; RE ra MEI	Chaokaur et al. (2007)
Brahman	Dry cow	Mature	499	410	FT; BWC ra MEI	Solis et al. (1988)
Brahman crossbred	Steer	Growing	313	501	ICH; RE ra MEI	Ferrell and Jerkins (1998b)
Hereford	Steer	Growing	286	416	ICH;RE ra MEI	Derno et al. (2005)
Holstein friesian	Cow	Lactating	542 to 663	610	ICH; RE ra MEI	Kirkland and Gordon (1999)
Jersey	Dry cow	Mature	504	630	FT; BWC ra MEI	Solis et al. (1988)

[1] Method of respiration gas measurement; IC, indirect calorimetry, ICH, indirect calorimetry head hood; ICF, indirect calorimetry face mask; FT, feeding trial; BWC, BW change; TOH= titrated water (TOH) dilution; RE ra MEI= retained energy regressed against MEI.

[2] National Agricultural Research Center for Agriculture, Kyushu, Okinawa Region, Kumamoto 861-1192, Japan, personal communication

4.3.8 Nitrogen Balance

Nitrogen balance data are shown in Table 4.9. Nitrogen intake of cattle fed dietary treatments varied from 30.43 to 35.46 g/d. It was highest in cattle fed T4 diet but lowest in cattle fed T1 and T3. This range of N intake is lower than Chaokaur et al. (2009) and Yan et al. (2007) studies where cattle consumed N ranging from 61.86 to 136.01 g/d and 73 to 316 g/d, respectively. The lower N intake in the present study is because cattle were offered a restricted feeding level while those Chaokaur et al. (2009) and Yan et al. (2007) were offered diets at production feeding levels. But it is similar to Kamiya et al. (2006) who determined nitrogen utilization of Thai native cattle fed solely Ruzi grass hay (6.7 % CP). They found that the cattle consumed 36.9 g/d of nitrogen and retained nitrogen at 13.9 % of nitrogen intake. Based on $BW^{0.75}$, N intake of Thai native cattle fed almost entirely Pangola grass hay mixed with urea (T1) in this study (0.59 g/ kg $BW^{0.75}$) is slightly lower than Kamiya et al. (2006) (0.68 g/ kg $BW^{0.75}$). Consequently, the N retention (0.05 g/ kg $BW^{0.75}$) was slightly lower than Kamiya et al. (2006) (0.10 g/ kg $BW^{0.75}$). The low nitrogen intake in the present study is because the experiment was designed to feed cattle at near-maintenance level. Results suggest that this level of nitrogen intake could maintain a positive retained nitrogen value, which indicates an adequate nitrogen intake for maintenance for Thai native cattle at body weight about 185 kg.

Table 4.9 Nitrogen metabolism in Thai native beef cattle fed dietary treatments

Items	Dietary treatments				P value	SE$^{1)}$
	T1	T2	T3	T4		
Animal	*n = 4*	*n = 4*	*n = 4*	*n = 4*		
Nitrogen balance						
Nitrogen intake (NI) (g/d)	30.43^{c}	32.99^{b}	30.87^{c}	35.46^{a}	<0.001	0.37
Fecal N (g/d)	13.24^{b}	12.38^{b}	18.17^{a}	12.78^{a}	<0.001	0.56
Fecal N (% of NI)	43.55^{b}	37.42^{c}	58.51^{a}	36.16^{c}	<0.001	1.62
Urinary N (g/d)	14.72^{a}	11.42^{b}	6.152^{c}	12.96^{ab}	<0.001	0.69
Urinary N (% of NI)	48.45^{a}	34.66^{b}	19.84^{c}	36.36^{b}	<0.001	2.14
Nitrogen retention (g/d)	2.47^{b}	9.20^{a}	6.55^{a}	9.73^{a}	0.004	1.09
Nitrogen retention (% of NI)	8.01^{b}	27.93^{a}	21.66^{a}	27.49^{a}	0.016	3.29
Nitrogen balance (g/kgBW$^{0.75}$)						
Nitrogen intake	0.59^{d}	0.65^{b}	0.62^{c}	0.72^{a}	<0.001	0.01
Fecal N loss	0.26^{b}	0.24^{b}	0.36^{a}	0.26^{b}	<0.001	0.01
Urine N excretion	0.29^{a}	0.23^{b}	0.12^{c}	0.26^{ab}	<0.001	0.01
Nitrogen retention	0.05^{b}	0.18^{a}	0.14^{a}	0.20^{a}	0.001	0.02

$^{1)}$: SE, standard error

$^{a, b, c, d, e}$: Means with different superscripts among treatments significantly differ ($P<0.05$).

Fecal N loss was highest in cattle fed T3, followed by T1 diet. Results suggest that fecal N production depends on feed quality which affects feed digestibility and utilization. As a result, the CP digestibility of T1 and T3 diets were lower than the other two diets. Fecal N production of Thai native cattle fed solely Ruzi grass hay in the Kamiya et al. (2006) experiment (54.2 % of N intake) was dramatically higher than cattle fed Pangola grass hay with urea (T1) in this study because Ruzi grass hay in the Kamiya et al. (2006) experiment had lower CP digestibility (45.8 %) than that of Pangola grass hay (56.3 %) in this study. Even though N intake of cattle in the present study is lower than that of Chaokaur et al. (2009) and Yan et al. (2007) studies, where cattle consumed N ranging from 61.86 to 136.01 g/d and 73 to 316 g/d, respectively, the range of fecal N loss in the present study agrees with Chaokaur et al. (2009) who found that the fecal N loss of Brahman cattle fed various energy levels ranged from 35.31 to 39.72 % of N intake. It also agrees with the finding of Yan et al. (2007) that beef cattle lost fecal N in the range from 22.3 to 52.6 % of N intake. Yan et al. (2007) found that N lost was related positively with DMI and energy intake (GE, DE, and ME). Chaokaur et al. (2009) observed a similar pattern that fecal N production increased linearly when ME intake was increased.

For N excretion in terms of urine, based on $BW^{0.75}$, fugures for Thai native cattle in this study (ranging from 0.12 to 0.29 g/ kg $BW^{0.75}$) was comparable to the study of Kawashima et al. (2000) (ranged from 0.074 to 0.333 g/ kg $BW^{0.75}$) where Thai native cattle (BW 165 kg) were fed solely Ruzi grass hay (2.2 % CP) or Ruzi grass hay plus various levels of soybean meal (8.5, 17.1 and 25.7 % DM in rations). It also agrees with the investigation of Kamiya et al. (2006) (0.22 g/ kg $BW^{0.75}$) where Thai native cattle (BW 205 kg) were fed solely Ruzi grass hay (6.7 % CP). It is slightly lower than that of Brahman cattle fed various levels of ME intake in experiment of Chaokaur et al. (2009) (ranging from 0.28 to 0.38 g/ kg $BW^{0.75}$). This variation may relate to many factors such as type or quality of feed, level of intake and digestibility of feed.

Urinary N excretion both in unit of g/d and % of N intake was highest in cattle fed T1 diet. It might be because T1 diet consisted almost completely of Pangola grass hay mixed with urea. Van Soest (1994) stated that diets low in soluble carbohydrates and high in mature plant cell wall carbohydrates limit non protein nitrogen (NPN) use because of the low energy content and slow rate of digestion of the carbohydrate. Furthermore, NH_3-N production is absorbed and lost from the rumen into the blood, followed by its conversion to urea and excretion in the urine, therefore limiting the available energy for ruminal microbes to couple with degraded urea as NH_3-N to use as a nitrogen source for microbial protein synthesis.

By contrast to T1, urinary N excretion (as % of N intake) was lower in cattle fed T2, T3 and T4 diet. Similar results were observed on the basis of metabolic body weight ($BW^{0.75}$). These Pangola grass hay based diets mixed with urea, cassava chip, brewery waste or cassava pulp can decrease urinary N excretion. This manipulation can replaced feeding high quality protein source such as soybean meal. In the work of Kawashima et al. (2000) where Thai native cattle (BW 165 kg) were fed solely Ruzi grass hay (2.2 % CP) or Ruzi grass hay plus various levels of soybean meal (8.5, 17.1 and 25.7 % DM in rations), they found that cattle fed solely Ruzi grass hay recorded negative N retention (-0.114 g/kg BW$^{0.75}$) while cattle fed Ruzi grass hay plus various levels of soybean meal showed positive N retention (0.100, 0.341 and 0.688 g/kg BW$^{0.75}$, respectively). The data of the present study indicate that using urea as a N source in rations needs an available energy source for ruminal microbes to utilize NH_3-N degrading from urea. The addition of rapidly degradable carbohydrate promotes utilization of urea. In this instance carbohydrate and nitrogen become synchronized, with greatly improved microbial efficiency (Van Soest, 1994). Otherwise, N from urea would be lost as N excretion in urine.

With respect to results of this study, Thai native cattle offered this level of N intake could maintain positive N retention. Thai native cattle fed mainly Pangola grass hay improved their N retention when urea was supplemented with adequate available energy sources such as cassava chip, brewery waste or cassava pulp.

4.3.9 Eating behaviors

The dietary treatments were formulated as different sources and levels of fiber (Table 4.10). Thus, fiber in T1 diet was all from Pangola grass hay (forage fiber source), and the other three diets were mixed with cassava chip, brewery waste or cassava pulp (non-forage fiber sources). These three diets were formulated to a similar total NDF content but to different ratios of NDF from non-forage fiber sources to NDF from a forage source. Those different factors are hypothesized as accounting for the differences in eating behavior in Thai native cattle.

1) Water consumption

Water consumption in liter (l)/d and l/kg BW were observed in the same pattern (Table 4.10). Thus, cattle fed T3 diet consumed a smaller volume of water than others (11.25 l/d). The volume of water consumption ranged from 11.25 to 15.25 l/d and 0.06 to 0.08 l/kg BW. These ranges are slightly lower than the observation by Kamiya et al. (2006) that Thai native cattle (205 kg BW) fed solely Ruzi grass hay *ad libitum* consumed 21 l/d or 0.10 l/kg BW of water. Nevertheless, there was a difference in level of intake between experiments. Restricting feed intake to 1.5 % of BW was conducted in this study, whereas, Kamiya et al. (2006) fed *ad libitum* with slightly bigger animals. This might be the cause for different water consumption. Compared to water consumption of Hereford steers (338 kg BW) (Luginbuhl et al., 2000), the range of water consumption (0.06 to 0.08 L/kg BW) in the present study is similar to that of steers fed *ad libitum* grass hay but higher than that of steers fed *ad libitum* grass silage (0.065 and 0.031 L/kg BW). Luginbuhl et al. (2000) found that steers fed hay consumed a greater quantity of water from the water supply than steers fed silage. By contrast, total water intake (water consumed from the water supply and water ingested as part of the feed) was greater for steers fed silage than for those fed hay. However, total water intake/kg DMI ingested did not differ between treatments. These data indicate that body size of animal, level of intake or characteristic of the diet have an effect on water consumption of cattle.

Table 4.10 Water consumption and eating behavior in Thai native beef cattle fed dietary treatments

Items	Dietary treatments				P	SE1)
	T1	T2	T3	T4		
NDF content in ration, %	72.32	37.68	38.53	35.80	-	-
NDF from forage, % in ration	72.32	29.31	21.98	14.65	-	-
NDF from non-forage, % in ration	0.00	8.37	16.55	21.14	-	-
NDF from non-forage/NDF from forage,%	0.00	28.56	75.30	144.30	-	-
Water consumption						
l/d	15.25^{a}	15.25^{a}	11.25^{b}	14.00^{a}	0.023	0.718
l/kg BW	0.08^{a}	0.08^{a}	0.06^{b}	0.08^{a}	0.032	0.004
Eating and ruminating behavior2)						
Feed intake time, min/d	105.00	117.50	88.75	166.25	0.085	17.589
Ruminating time, min/d	370.00^{a}	250.00^{b}	235.25^{b}	202.50^{c}	<0.001	8.223
Total chewing time, min/d	475.00^{a}	367.50^{b}	324.00^{b}	368.75^{b}	0.013	21.721
Ruminating time /DMI, min/ kg	153.75^{a}	105.75^{a}	97.25^{ab}	85.75^{b}	<0.001	3.556
Ruminating time /NDFI, min/ kg	213.25^{d}	274.00^{a}	247.25^{b}	230.50^{c}	<0.001	4.376
Ruminating time /ADFI, min/ kg	396.50^{c}	519.00^{a}	471.75^{b}	401.25^{c}	<0.001	8.614
Total chewing time /DMI, min/ kg	197.38^{a}	154.05^{b}	134.13^{b}	154.68^{b}	0.004	6.977
Total chewing time /NDFI, min/ kg	273.68^{c}	399.55^{ab}	340.80^{b}	416.73^{a}	0.007	19.379
Total chewing time /ADFI, min/ kg	508.60^{b}	756.38^{a}	649.88^{a}	725.23^{a}	0.010	35.234

1): SE, standard error

2): DMI, NDFI and ADFI = DM, NDF and ADF intake, respectively

$^{a, b, c, d, e}$: Means with different superscripts among treatments significantly differ ($P<0.05$).

2) Eating and ruminating behavior

Eating behavior data are also shown in Table 4.10. Significant differences of feed intake time were not found. It might be because of high variation among individual animal eating behavior. However, cattle fed T4 diet tended to spend more time eating. More than a half of this ration was mixed with cassava pulp. Cattle fed this diet might need more time to consume the fine particles of cassava pulp.

The physical difference of feeds also influences ruminating time. Cattle fed T1 diet took the longest time for ruminating ($P<0.001$) while cattle fed T4 ration spent the shortest time for ruminating. Ruminating time in the present study ranged from 202.5 to 370.0 min/d or approximately 3.37 to 6.17 h/d. Susenbeth et al. (1998) stated that when animals are given *ad libitum* diets containing a high proportion of roughage, the time that cattle spend for eating and ruminating amounts to 13 to 17 h/d. The capacity of ruminants for mechanically reducing feed particle size can be a limiting factor for feed intake (Susenbeth et al., 1998). The lower range of ruminating time in the present experiment may be because the experiment was restricting feed intake of cattle to near-maintenance level.

In terms of total chewing time, summation of eating time and ruminating time, it was found that total chewing time of cattle fed T1 diet was dramatically higher than cattle fed T2, T3 and T4 where Pangola based diets were mixed with cassava chip, brewery waste or cassava pulp. Even though T2, T3 and T4 were different in non-forage NDF content but similar in NDF content, the total chewing time of cattle fed T2, T3 and T4 were not different ($P > 0.05$). In terms of energy utilization, Susenbeth et al. (1998) found that energy requirements for eating and ruminating per day ranged in total from 8.3 to 11.0 MJ/d and from 0.8 to 2.4 MJ/kg of DM ingested. This energy increased when roughage quality decreased. Susenbeth et al. (1998) showed that the energy required for the activity associated with eating and ruminating can account for one-third of the ME in low-quality roughages, which leads to a significant reduction in the proportion of ME available for maintenance and production. This fact might be responsible for the lower efficiency of the utilization of ME, especially of low-quality roughages.

Differences in dietary treatments affected ruminating behavior in terms of ruminating time/DMI. Thus, ruminating time/DMI of cattle fed T4 diet was decreased when NDF from non-forage fiber sources was replaced at 144.27 % of NDF from forage fiber, compared with cattle fed T1 and T2 diet (0 and 28.54 % NDF from non-forage replaced, respectively) , but it was not different from cattle fed T3 diet (75.27 % NDF from non-forage replaced).

Replacing Pangola grass hay with cassava chip, brewery waste or cassava pulp in the rations more clearly decreases total chewing time/DMI following the reduced NDF content in those rations. By contrast, the ruminating time and total chewing time to fiber (NDF and ADF) intake ratio moved in the opposite direction to that of DMI. The ratio of ruminating time/NDFI, ruminating time/ADFI, total chewing time/NDFI and total chewing time/ADFI showed the same trend. Thus, cattle fed T2 T3 and T4 ration had greater ruminating time/NDFI, total chewing time/NDFI and total chewing time/ADFI than cattle fed T1 diet, even though there was no difference in ruminating time/ADFI between cattle fed T1 and T4 diet. The range of both total chewing time/NDFI and ruminating time/NDFI in the present experiment are greater than the experiment of Luginbuhl et al. (2000), where Hereford steers fed *ad libitum* grass hay (207.2 and 198.6 min/kg NDFI, respectively) or grass silage (125.0 and 128.4 min/kg NDFI, respectively). Restricted feeding in the present study causes NDFI to be lower which resulted in the higher value for total chewing time/NDFI and ruminating time/NDFI.

In the relationship of fiber intake with energy utilization, Susenbeth et al. (2004) determined the energy requirement for chewing in cattle for feedstuffs differing in ruminal degradability, particle size, and type of conservation. They found that heat production does not strongly depend on fiber intake; on the contrary, heat production per gram of barley NDF was similar to the roughages. The number of chews or time spent for ingestion seems to be the main determinant of the energy requirement for ingestion.

These data indicate that replacing Pangola grass hay with cassava chip, brewery waste or cassava decreased total NDF content in the rations and altered the ratio of non-forage fiber to forage fiber. Decreasing Pangola grass hay in the ration decreased total chewing time and ruminating time/DMI but increased time spent chewing per fiber intake. However, the present study assigned cattle to a limited feed intake approaching maintenance level, and therefore, the eating behavior of Thai native cattle at higher levels of intake should be further investigated.

4.3.10 Ruminal Fermentation

Ruminal fermentation parameters such as ruminal pH, NH_3-N and TVFAs are important indicators of the effect of feed on ruminal function. The data are shown in Table 4.11. Ruminal fluid pH was not affected ($P > 0.05$) by the difference of dietary treatment at any time post-feeding. It tended to decrease after feeding in every treatment with the time-averaged value ranging from 7.08-7.21 (see also Figure 4.2).

Ruminal fluid NH_3-N concentration was not different among treatments at 0 (before feeding) and 6 hour post-feeding. But the difference was observed at 3 hour post-feeding. Thus, ruminal fluid NH_3-N of cattle fed T3 diet (0.74 mg %) was lowest compared with the other three treatments (Figure 4.3). The same result was observed in the time-averaged value. The observed result might be because of the lowest proportion of urea and the CP digestibility in T3 ration. On the other hand, cattle fed T1, T2 and T4 were greater in ruminal fluid NH_3-N. Those three diets were mixed with a higher proportion of urea which easily degrades to be NH_3-N in rumen.

Table 4.11 Ruminal fluid pH, ammonia nitrogen (NH_3-N) and total volatile fatty acids (TVFAs) concentration at 0, 3 and 6 hour (h) post-feeding in Thai native beef cattle fed dietary treatments

Items	Dietary treatments				P value	SE$^{1)}$
	T1	T2	T3	T4		
Ruminal fluid pH						
h0	7.43	7.27	7.25	7.41	0.586	0.108
h3	7.13	7.16	6.96	7.14	0.294	0.075
h6	7.06	7.05	7.03	7.07	0.996	0.111
Average	7.21	7.16	7.08	7.21	0.596	0.073
Ruminal fluid NH_3-N concentration, mg %						
h0	0.88	0.86	0.70	1.08	0.054	0.074
h3	2.02^{a}	2.49^{a}	0.74^{b}	2.18^{a}	0.019	0.282
h6	0.86	1.01	0.70	1.39	0.242	0.220
Average	1.25^{a}	1.46^{a}	0.71^{b}	1.55^{a}	0.024	0.144
Ruminal fluid TVFAs concentration, mM						
h0	63.67	80.52	74.06	75.58	0.296	5.686
h3	78.00	89.05	86.18	103.64	0.182	7.117
h6	86.58	91.85	102.26	95.78	0.862	13.359
Average	76.08	87.14	87.50	91.67	0.571	7.805

$^{1)}$: SE, standard error

$^{a, b, c, d, e}$: Means with different superscripts among treatments significantly differ ($P<0.05$).

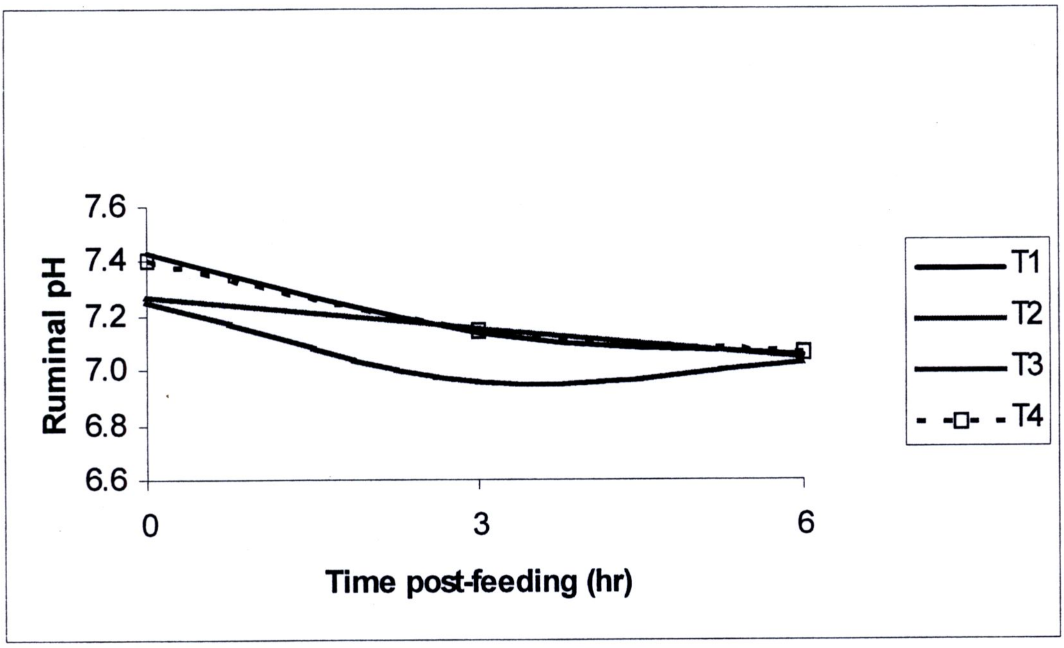

Figure 4.2 Effect of dietary treatment on ruminal pH at 0, 3 and 6 hr post-feeding.

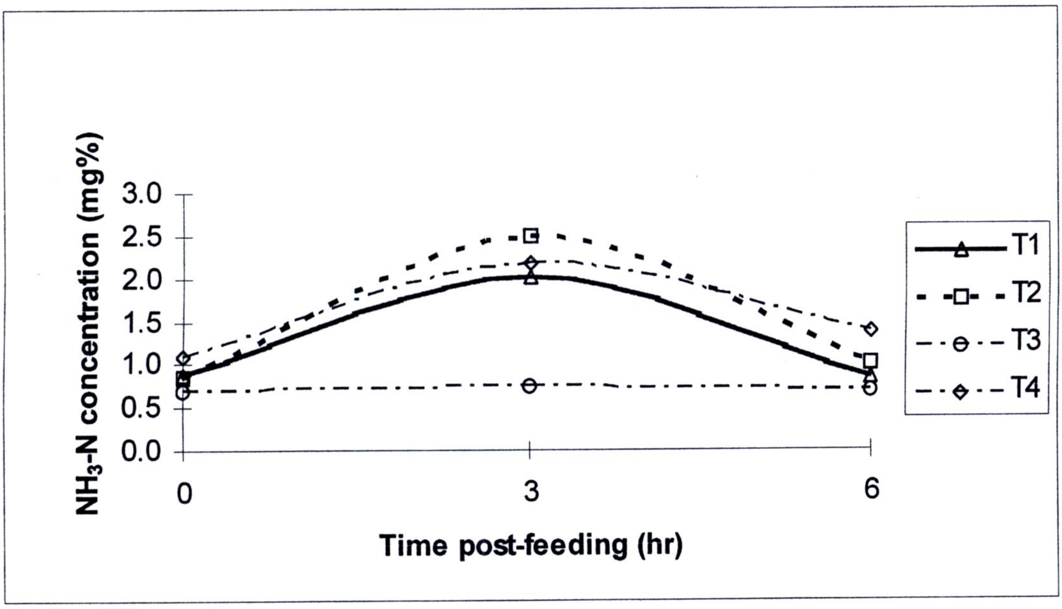

Figure 4.3 Effect of dietary treatment on ruminal NH_3-N concentration (mg %) at 0, 3 and 6 hr post-feeding.

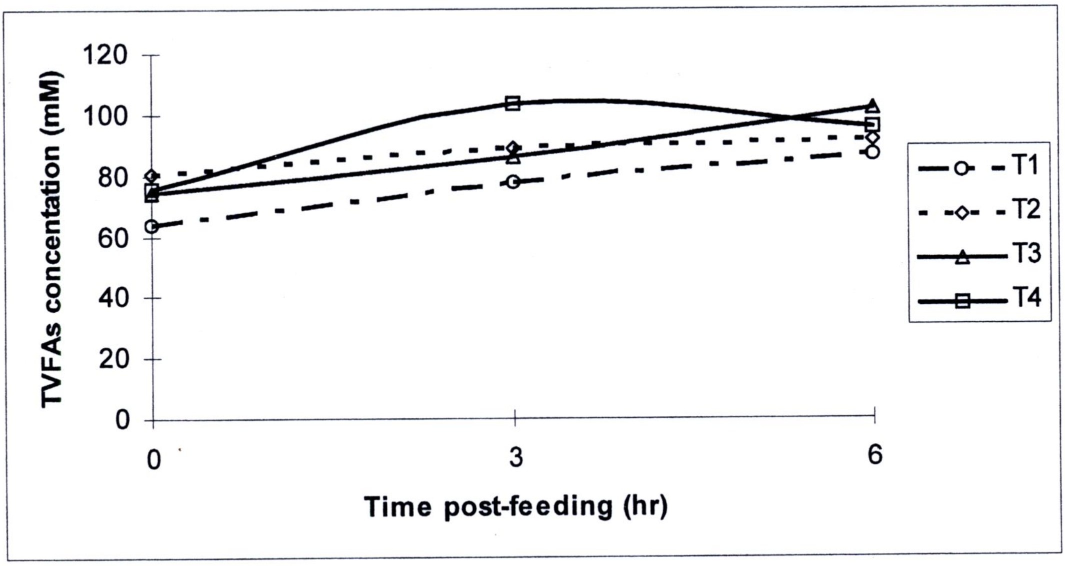

Figure 4.4 Effect of dietary treatment on ruminal total volatile fatty acid (TVFAs) concentration (mM) at 0, 3 and 6 hr post-feeding.

Ruminal fluid TVFAs concentration was not significantly different among treatments at any time of feeding duration and on the time-averaged value. At 3 hour post feeding, however, in cattle fed T4 diet TVFAs tended to a higher concentration than other, whereas, cattle fed T3 diet tend to higher in TVFAs at 6 hour post feeding. In all treatments, however, TVFAs concentration tended to increase after feeding with the time-averaged value ranged from 76.08 to 91.67 mM (see also Figure 4.4).

As the result of eating behavior above, there was almost no effect on ruminal fermentation. Ruminal NH_3-N might be affected by the urea proportion and CP digestibility.

4.4 Conclusion

Based on this experimental data, Thai native cattle fed Pangola grass hay mixed with urea, cassava chip, brewery waste or cassava pulp at about 1.5 % BW did not receive enough energy to meet maintenance. Supplementation or replacement with concentrate or agro-industrial by-product tropical feedstuffs, such as cassava chip, cassava pulp or brewery waste, can improve the energy balance for Thai native beef cattle. Results suggest that estimated FHP and ME_m of Thai native beef cattle is

314 and 509 kJ/kg $BW^{0.75}$/d, respectively, and ME utilization efficiency for maintenance (k_m; $k_m = FHP/ME_m$) is 0.616.

Using the indirect calorimetry procedure with Thai native beef cattle yielded the data for nutrient digestibility and metabolizable energy content of each feedstuff. Nutrient digestibility and ME values of feedstuffs were determined following by-difference methodology. Total digestible nutrients (TDN) of Pangola grass hay, cassava chip, brewery waste, and cassava pulp was 48.65, 82.19, 58.91 and 71.52 % respectively. The ME content was was 6.42, 12.01, 10.07 and 10.89 MJ/ kg DM, respectively.

Feeding cassava chip, cassava pulp or brewery waste with Pangola grass hay-based diets at maintenance level can improve N retention in Thai native beef cattle. Decreasing Pangola grass hay in the ration decreased NDF content in the rations but increased time spent chewing per fiber intake, even though total chewing time and ruminating time per DMI were decreased. There was almost no effect on ruminal fermentation, except for ruminal NH_3-N, which might have been affected by the urea proportion and CP digestibility. However, this experiment fed animals at about 1.5 % of BW which is near-maintenance level. Feeding these feedstuffs at production level to investigate the detailed effect on digestibility, eating behaviors and ruminal fermentations is needed.