Enteric Methane Emission, Energetic Efficiency and Energy Requirements for the Maintenance of Beef Cattle in the Tropics

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Abstract

This study was conducted to determine the energy balance of beef cattle by indirect animal calorimetry utilizing a ventilated head box respiration system. Fifteen native Thai bulls were randomly allocated to one of three dietary metabolizable energy intake (MEI) levels (1.1 × maintenance, 1.5 × maintenance and 1.9 × maintenance) in a completely randomized design for a 116 day feeding trial. Animals were allocated to individual metabolic cages for the determination of digestibility and energy balance. Heat production was determined from oxygen consumption, carbon dioxide and methane production. The results showed that dry matter, organic matter and crude protein intake were increased ($P < 0.01$), but digestibility of all nutrients, except neutral detergent fiber, was not significantly affected ($P > 0.05$) by MEI levels. The energy loss in feces and urine (% of gross energy intake) were not different ($P > 0.05$); however, enteric methane conversion rate (% of methane energy loss per gross energy intake) and heat energy production loss (% gross energy intake) were linearly decreased ($P < 0.01$) with increasing MEI levels. Methane conversion rates ranged from 8.4 to 10.0% and appeared to have been underestimated by the Intergovernmental Panel on Climate Change 6.5% default values set for cattle fed low quality crop residues and by-products. The estimate of metabolizable energy requirements for maintenance was measured using linear regression analysis derived for native Thai cattle was 520 kilojoules per kilogram of metabolic body weight per day. Increased dietary intake levels reduced enteric methane emissions in beef cattle fed on tropical feedstuffs. The results of the present study indicated that greater dietary intake feeding strategy in cattle fed above the maintenance level resulted in improved energetic efficiency utilization, and thus improved energy retention because of the reduction of enteric methane energy emission and heat production.

Discipline: Animal industry
Additional key words: cattle, energy requirements, enteric methane, tropical

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This paper reports results obtained in the international project on "Establishment of feeding standard of beef cattle and feedstuff database in Indochina." The Japan International Research Center for Agricultural Sciences, Department of Livestock Development, Ministry of Agriculture and Cooperatives, Thailand, and Khon Kaen University took responsibility for all subjects picked up in the project, implemented main subjects jointly and managed the project. Since it is essential to construct a regional research cooperation network for the efficient achievement of the targets, other research organizations such as Mahasarakham University, Ubon Ratchatanee University, Rajamangala University of Technology-Isan, Suranaree University of Technology, Chiang Mai University, Maejo University, Prince of Songkla University, National University of Laos, Lao PDR, and Royal University of Agriculture, Cambodia were also involved in the project. The project was implemented during the five-year period from 2006 to March 2011.
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Introduction

The Food and Agriculture Organization of the United Nations (FAO) reported that enteric fermentation is the single largest global source of anthropogenic methane, a greenhouse gas emission, contributing to climate change and responsible for 29% of global emissions. Of the 7.1 Gt CO_2-eq. emitted from the livestock sector, 40%, or 2.7 Gt CO_2-eq, are from enteric fermentation according to a life cycle assessment (Gerber *et al.* 2013). Overall cattle and buffalo populations in developing countries are four times higher than in developed countries; however, lower meat production indicates that ruminant production efficiency in the developing countries is poor based on numbers of cattle and buffalo populations in developing countries. It is expected that methane production may be four times that of developed countries. However, the expected demand for ruminant livestock products, especially meat and milk, has been increasing annually due to human population and economic growth, particularly in developing countries.

Feeding systems which do not consider that nutrient deficiencies and/or imbalances may result in failure to meet animal production performance expectations, which affect methane emissions (Chuntrakort *et al.* 2014, Chaokaur *et al.* 2015, Johnson and Johnson 1995, Kurihara *et al.* 1999). The feeding guidelines for beef cattle production (Agricultural Research Council (ARC) 1980, Kearl 1982, National Research Council (NRC) 2000) are commonly used to formulate diets and evaluate feeding programs around the world. Reviews of the energy requirements and energetic efficiency in beef cattle are available (Williams and Jenkins 2003a, b, Ferrell and Oltjen 2008).

Native Thai cattle, Zebu (*Bos indicus*) and Brahman crossbreds are the predominant breeds used in beef production in Thailand. They have a smaller mature body size and grow at a slower rate compared to European breeds of cattle (*Bos taurus*). They have been raised, however, under more diverse conditions and are considered to be well adapted to heat stress, disease and low quality feeds of the humid tropical zone. Most Thai native beef cattle are from small-holder farmers, who need to improve beef production efficiency. They require information on appropriate feeding programs for sustainable production development. The feeding systems are normally based on pasture and crop residues that are often deficient in protein and energy and/or other major nutritional factors, limiting animal production. Recently, Nitipot *et al.* (2009) conducted a meta-analysis of data and suggested that metabolizable energy for maintenance of native Thai beef cattle was lower than for *Bos taurus*. However, research on the energy metabolism of cattle in humid tropical condition is still scarce. The Intergovernmental Panel on Climate Change (IPCC) guidelines for a Tier 2 approach set a default value of 6.5% for the proportion of methane energy emission to gross energy intake (methane emissions rate), chosen on the basis of limited data from *B. indicus* (Chuntrakort *et al.* 2014, Chaokaur *et al.* 2015, Gerber *et al.* 2013, IPCC 2006, Kurihara *et al.* 1999, Steinfeld *et al.* 2006). Nutritional feeding guidelines of native beef cattle have not been well defined because of a paucity of information on energy utilization. Therefore, this study aimed at determining the energy partition and requirements for the maintenance of native Thai beef cattle.

Materials and methods

The experiment was conducted at the Khon Kaen Animal Nutrition Research and Development Center, Khon Kaen province, Thailand (latitude 16.34°N, longitude 102.82°E) from October 2008 to January 2009. Agro climatological data indicated an average temperature of 25.3 ± 1.9°C, an average relative humidity of 67.2 ± 1.9%, and an average temperature-humidity index (THI) of 74.0 ± 12.9. All animal-related procedures were in accordance with the Guide for the Care and Use of Experimental Animals (Curtis and Nimz 1988) with the permission of Khon Kaen University.

1. Animals and experimental design

Fifteen native Thai beef cattle bulls, with an average body weight of 268 ± 26 kg and aged 23 months were individually housed in stalls with free access to drinking water and mineral block. In the adaptation period, they were fed a diet at 1.5 × maintenance.

Animals were randomly allocated to one of three dietary treatments in a completely randomized design (5 replications). Treatments were the levels of ME intake according to the working Committee of Thai Feeding Standards for Ruminant (WTSR) (2008) recommendation of metabolizable energy requirements for maintenance (M = 484 kilojoules (kJ) per kilogram (kg) of metabolic body weight ($BW^{0.75}$) per day (d) ($kJ \cdot kgBW^{-0.75} \cdot d^{-1}$) is as follows; T1 = 1.1 × maintenance (1.1M), T2 = 1.5 × maintenance (1.5M) and T3 = 1.9 × maintenance (1.9M). The feed formulation of the experimental diet consisted of 32% Guinea hay, 32% cassava chip, 18% rice bran, 7% soybean meal, 6% palm meal, 4% coconut meal, 0.5% urea and 0.5% mineral (dry matter basis) (Table 1).

The animals were fed twice daily at 0900 h and 1600 h. They were allowed an adaptation period of 30 days before the 86-day collection of feeding experiment data. The animals were weighed every two weeks in the morning (0800 h) before feeding and body weight (BW) was used to determine the metabolic body weight ($BW^{0.75}$) for the calculation of the daily feed allocation for the following two weeks.

2. Gas exchange measurement

During the energy balance trial, animals were moved to respiration chambers. The oxygen consumption, carbon dioxide and methane production of each animal were measured using an open-circuit indirect respiration calorimetry system with ventilated flow-through method employing a head hood chamber for 3-day collection. The details of the method were determined according to the procedure of Suzuki *et al.* (2008). The system consisted of a head hood and flow meter with thermal flow cell (NIPPON FLOW CELL Co., Ltd., Japan, model FWH-N-S), which was used to record flow rate and total volume of air flowing out from the respiration chamber. The collected samples of outflow and incoming air were analyzed for oxygen using a dual chamber paramagnetic oxygen analyzer (Servomex-Pcl., UK, model Xentra 4100), and an infrared gas analyzer (HORIBA, Japan, model VIA 510) was used for the analysis of carbon dioxide and methane. The temperature and humidity of out flowing air were recorded electronically (ESPEC MIC CORP, Japan, model RS-12). The gas analyzers were calibrated against certified gases (TAKACHIHO CHEMICAL INDUSTRIAL Co., Ltd, Japan), with known gas concentrations once per day. These measurements were conducted for 23.30 hours each day, from 0930 h to 0900 h of the next day. The data recording program used TEST-POINT® software. The system also allowed measurement of the concentration of ambient oxygen. The calorimetry system was calibrated by the CO_2 injection method by releasing a measured amount of CO_2 gas into the system.

Heat production (HP, kilojoules per day, kJ/d) was calculated from oxygen consumption, carbon dioxide and methane emission with correction for urinary nitrogen (N) loss by the equation according to Brouwer (1965) as follows:

$$HP\ (kJ/d) = 16.18O_2 + 5.02CO_2 - 2.17CH_4 - 5.99N$$

where, O_2 represents the volume of oxygen consumed in liters (L), CO_2 by carbon dioxide production in liters, CH_4 represents the methane emission in liters and N represents urinary nitrogen excretion in grams.

Table 1. Feed formulation (dry matter basis), analyzed chemical composition and energy content of the experimental diet fed to native Thai cattle

Item	Amount
Ingredient, %	
Guinea grass hay	32.0
Cassava chip	32.0
Rice bran	18.0
Soybean meal	7.0
Coconut meal	4.0
Palm kernel cake	6.0
Urea	0.5
Mineral mixed	0.5
Chemical composition, %	
Crude protein	10.6
Crude ash	7.3
Organic matter	92.7
Ether extracts	3.5
Neutral detergent fiber	36.3
Acid detergent fiber	21.7
Energy content, megajoules/kilogram	
Gross energy	17.7
Digestible energy	13.1
Metabolizable energy	10.3

3. Sampling and analytical methods

Samples of feed offered (1 kilogram, kg), feed refused (1 kilogram, kg), feces (1 kilogram, kg) and urine (500 milliliters, mL) from the individual animals were collected daily in the morning (0900 h) for 7 days (d) and stored at -18˚C. Urine was collected in buckets containing sufficient H_2SO_4 (20% v/v; 200 mL) to maintain pH at < 3. Samples were thawed and aliquots pooled for each animal at the end of the 7-day collection period, mixed thoroughly and subsamples (2.5 kg of feed, 2.5 kg of feed refusal and 2.5 kg of feces collected) of feed offered, feed refused and feces were dried in a forced-air oven at 60°C for 72 h and ground to pass through a 1-mm screen. The urine samples during the 7-day collection period were mixed well and stored at -18˚C until analysis.

The dry matter (DM), crude protein (CP), ether extracts (EE), crude fiber (CF), and ash contents of the feed, feed refusals, and feces were determined following procedures described by the Association of Official Analytical Chemists AOAC (1990). The nitrogen (N) content of urine was determined following the described methods (AOAC) (1990). The gross energy (GE) contents of feed, feces, feed refusal and urine were determined in a Shimadzu auto-calculating bomb calorimeter (SHIMADZU CA-4PJ, SHIMADZU Corporation, Japan). Neutral detergent fiber (NDF) was determined following Van Soest *et al.* (1991). Acid detergent fiber (ADF) was determined following Goering and Van Soest (1970).

Digestible energy (DE) was computed from the GE of feed intake and feces. MEI was calculated as the difference between GE intake and energy loss in feces, urine and methane energy emission.

4. Statistical analysis

All data were analyzed using the general linear models procedure according to the following completely randomized design model: $Y_{ij} = \mu + T_i + \varepsilon_{ij}$, where Y_{ij} = observed data, μ = overall mean, T_i = effect of dietary treatment, and ε_{ij} = error. Polynomial contrasts were used to determine the influence of increasing energy intake, and treatment means were compared by Duncan's New Multiple Range Test (SAS, 1996). Significance was shown at $P < 0.05$ unless otherwise noted.

Results and discussion

1. Intake and digestibility

Feed intake and digestibility are shown in Table 2. Dry matter intake (kilograms of dry matter per day, kgDM/d) was significant ($P < 0.01$) with an increasing level of MEI. Feed intake on basis of percent of body weight and metabolic body weight for cattle fed 1.5M and 1.9M was greater ($P < 0.01$) than that of cattle fed 1.1M; however, no differences were observed between these 2 treatments (1.5M and 1.9M). The results indicated that voluntary feed intake of native cattle fed a tropical feedstuff-based diet in this experiment was maximized at not greater than 1.7% of BW.

Apparent digestibility of all nutrients except for NDF was not significantly affected by differences of MEI ($P >$ 0.05). Digestibility of NDF was reduced with increasing levels of MEI ($P < 0.05$). These results indicated that the ability to digest fiber of tropical feed did not improve by increasing energy intake levels in native Thai cattle. Digestibility in the rumen is the result of the inverse relationship between digestion and passage rates, and passage rate is positively correlated with DM intake (Van Soest, 1994). Therefore, the lesser DMI of cattle on a restricted intake level likely resulted in a slower passage rate and greater digestibility of the diet. These findings are similar to those reported by Gabel *et al.* (2003), who found that digestibility of DM and all specific measures of dietary components declined significantly in cows as the nutrition level increased, and that digestibility of energy decreased by 4.1% for each increase in nutrition level. This is in contrast to the suggestion of Bartlett *et al.* (2006) and Sauvant and Giger-Reverdin (2007), who found that increased feeding level could improve diet digestibility in ruminants in a temperate zone. These differences may be dependent upon the amount and source of fiber used in the experiment. The results from this study, however, were similar to Chaokaur *et al.* (2007)

Table 2. Feed intake, nutrient intake and digestibility of diets in native Thai cattle

Item	Levels of energy feeding[1/]			SEM[2/]	Polynomial contrast[3/]	
	1.1M	1.5M	1.9M		L	Q
Dry matter feed intake						
Kilograms per day	3.5[c]	4.9[b]	5.5[a]	0.14	< 0.01	0.03
% of Body weight	1.3[b]	1.7[a]	1.7[a]	0.02	< 0.01	< 0.01
Grams per kilogram metabolic body weight	52.3[b]	70.7[a]	73.7[a]	0.99	< 0.01	< 0.01
Nutrient intake, kilograms per day						
Organic matter	3.1[c]	4.5[b]	5.1[a]	0.14	< 0.01	0.03
Crude protein	0.3[c]	0.5[b]	0.6[a]	0.02	< 0.01	0.29
Ether extracts	0.1[b]	0.2[a]	0.2[a]	0.01	< 0.01	0.28
Neutral detergent fiber	1.2[b]	1.8[a]	1.7[a]	0.11	< 0.05	0.06
Acid detergent fiber	0.7[b]	1.1[a]	1.0[a]	0.07	< 0.05	0.07
Digestibility, %						
Dry matter	71.5	69.8	71.6	0.88	0.94	0.14
Organic matter	76.0	73.4	75.1	0.89	0.47	0.10
Crude protein	66.1	63.2	67.0	1.78	0.72	0.15
Neutral detergent fiber	52.2[a]	49.6[ab]	44.1[b]	2.04	0.02	0.58
Acid detergent fiber	45.2	43.6	38.4	3.64	0.21	0.69
Ether extracts	87.3	80.0	86.2	3.65	0.84	0.18

[a,b,c] within a row, means without a common superscript letter differ ($P < 0.05$); [1/]M, metabolizable energy requirements for maintenance (M = 484 kilojoules per kilogram of metabolic body weight per day ($kJ \cdot kgBW^{-0.75} \cdot d^{-1}$); [2/]Standard error of treatment mean, n = 5; [3/]Probability of polynomial contrast significant, L = linear, Q = quadratic

and Chaokaur *et al.* (2015) for Brahman cattle fed under the tropical condition. They reported increased feeding energy level with decreased NDF digestibility. The current findings indicated that increased feeding level did not improve nutrient digestibility. Similarly, Hindrichsen *et al.* (2003) and Pittroff *et al.* (2006) reported that an increased intake of forage resulted in decreased digestion of OM and NDF. Moreover, this study was in good agreement with the report of O'Mara *et al.* (1999) and Woods *et al.* (1999), who found that NDF digestibility decreased when energy intake increased from maintenance level.

2. Energy utilization and methane emission

Energy partitions and energy efficiencies are shown in Table 3. The results reflect the experience of this study that increased levels of energy resulted in greater GE intake, DE

Table 3. Energy intake, energy partition (feces excretion, urine excretion, methane production, heat production and energy retention) and energy metabolizability of native Thai cattle [1/]

	Levels of energy feeding				Polynomial contrast	
Item	1.1M	1.5M	1.9M	SEM	L	Q
Number of animals, cattle	*n = 5*	*n = 5*	*n = 5*			
Energy intake						
GE intake (GEI), MJ/d	60.0^{c}	86.8^{b}	96.8^{a}	2.65	0.01	0.03
GE intake, $kJ\cdot kgBW^{-0.75}\cdot d^{-1}$	926.1^{b}	1251.8^{a}	1303.2^{a}	17.73	< 0.01	< 0.01
DE intake, $kJ\cdot kgBW^{-0.75}\cdot d^{-1}$	679.7^{c}	884.6^{b}	945.0^{a}	14.44	< 0.01	< 0.01
ME intake, $kJ\cdot kgBW^{-0.75}\cdot d^{-1}$	568.1^{c}	753.0^{b}	812.3^{a}	12.56	< 0.01	< 0.01
Feces excretion						
Feces, kgDM/d	1.0^{b}	1.5^{a}	1.6^{a}	0.07	< 0.01	0.03
Feces energy, MJ/d	16.0^{b}	25.5^{a}	26.6^{a}	1.17	< 0.01	0.02
Feces energy, $kJ\cdot kgBW^{-0.75}\cdot d^{-1}$	246.4^{b}	367.2^{a}	358.1^{a}	12.02	< 0.01	< 0.01
Feces energy/GEI,%	26.6	29.3	27.4	0.95	0.55	0.08
Urine excretion						
Urine volume, L/d	5.6	6.7	4.4	1.18	0.49	0.26
Urine energy, MJ/d	1.2	1.6	1.7	0.16	0.07	0.37
Urine energy, $kJ\cdot kgBW^{-0.75}\cdot d^{-1}$	19.2	23.7	22.9	2.32	0.29	0.36
Urine energy/GEI, %	2.1	1.9	1.7	0.18	0.24	0.96
Methane emission						
Methane production, L/d	150.8^{b}	189.7^{ab}	206.6^{a}	12.77	0.02	0.50
Methane production, L/kgOMI	48.2^{a}	41.61^{ab}	40.3^{b}	2.11	0.03	0.33
Methane production, L/kgNDFI	122.9	106.3	121.6	6.28	0.88	0.07
Methane energy, MJ/d	6.0^{b}	7.5^{ab}	8.2^{a}	0.51	0.02	0.51
Methane energy,$kJ\cdot kgBW^{-0.75}\cdot d^{-1}$	92.4^{b}	107.8^{a}	109.9^{a}	6.11	0.07	0.39
Methane energy/GEI, %	10.0^{a}	8.6^{ab}	8.4^{b}	0.44	0.03	0.32
Heat production						
Heat energy, MJ/d	35.1^{b}	45.0^{a}	48.7^{a}	1.58	< 0.01	0.15
Heat energy, $kJ\cdot kgBW^{-0.75}\cdot d^{-1}$	543.3^{b}	647.5^{a}	656.0^{a}	15.8	< 0.01	0.04
Heat energy/GEI, %	58.7^{a}	51.7^{b}	50.4^{b}	1.53	< 0.01	0.17
Energy retention, $kJ\cdot kgBW^{-0.75}\cdot d^{-1}$	24.8^{b}	105.5^{a}	156.3^{a}	19.77	< 0.01	0.55
Energy metabolizability						
DE/GE	0.73	0.71	0.73	0.01	0.60	0.11
ME/GE	0.61	0.60	0.63	0.01	0.33	0.15
ME/DE	0.84	0.85	0.86	0.01	0.05	0.61

[a,b,c] Within a row, means without a common superscript letter differ ($P < 0.05$); [1/]M, metabolizable energy requirements for maintenance (M = 484 kilojoules per kilogram of metabolic body weight per day ($kJ\cdot kgBW^{-0.75}\cdot d^{-1}$); Standard error of treatment mean, n = 5; Probability of polynomial contrast significant, L = linear,Q = quadratic; BW, body weight; $BW^{0.75}$, metabolic weight; GE, gross energy; DE, Digestible energy; ME, Metabolizable energy; kgDM, kilogram of dry matter intake per day; MJ/d, megajoule per day; L/d, liter per day; kgOMI, kilogram of organic matter intake; kgNDFI, kilogram of neutral detergent fiber intake.

intake and ME intake ($P < 0.01$) (Table 3). Energy excretion in feces (kJ·kgBW$^{-0.75}$·d^{-1}) was linearly increased ($P < 0.01$); however, energy loss in feces per GE intake trended to increase ($P < 0.08$) with increasing level of MEI. Energy loss in urine and urine volume were not different ($P > 0.05$) in all treatments.

Enteric methane emission (ranged from 150.8 to 206.6 liters per day (L/d) or 6.0 to 8.2 megajoules per day (MJ/d) and increased linearly ($P < 0.05$) with increasing level of MEI; however, methane emission (liters per kilogram of organic matter intake), methane energy loss per GEI (term of methane conversion rate) and heat energy loss per GEI were reduced ($P < 0.01$) with increasing level of MEI. These findings indicate that increased energy intake may reduce the methane conversion rate in cattle fed under tropical feeding system condition. The results are similar to those reported by Yan *et al.* (2002), Gabel *et al.* (2003) and Chaokaur *et al.* (2015), who found that increased feeding level can reduce energy loss in methane as a proportion of gross energy intake.

The methane conversion rate from this study ranged from 8.4% to 10.0%, which was in the range of the figure reported by Johnson and Johnson (1995), who suggested that energy loss as methane from cattle ranged from 2 to 12% of GEI. This finding showed a relatively greater enteric emissions rate because of the greater fiber content feeding system for cattle in the tropical developing countries when compared with the beef cattle production system in the temperate zone (Johnson and Ward 1996, Lassey 2007, Staerfl *et al.* 2012). Our result, however, was in good agreement with the report of other researchers in the tropics (Suzuki *et al.* 2008), who found that the methane conversion rate of cattle fed Pangola grass hay was 9.7%. Krishna *et al.* (1978) also estimated the methane conversion rate of 9.0% in Indian cattle fed above the maintenance diet. The present work also supports the report of Chaokaur *et al.* (2007, 2015), who found that the methane conversion rate was reduced from 11.5% to 8.0% when MEI was increased from the maintenance level to *ad libitum* in Brahman cattle fed diets in the tropical zone. Several reports suggested that methane conversion rates of cattle in the tropics are greater than in the temperate zone (Chuntrakort *et al.* 2014, Chaokaur *et al.* 2007, Chaokaur *et al.* 2015, Kurihara *et al.* 1999, Suzuki *et al.* 2008). The IPCC (2006) default value of 6.5% appears to underestimate methane emissions from native Thai cattle fed with a range of tropical feeds and feeding systems.

Heat production loss per GEI was linearly reduced ($P < 0.01$) with increasing level of MEI. Energy retention was also greater ($P < 0.01$) with increasing level of energy intake. This increase was due mainly to the increase of energy intake and the difference of energy partition ratio between maintenance and growth when a higher energy intake above maintenance level was offered.

The ratios of DE to GE and ME to GE were not different ($P > 0.05$) in all treatments. The ratio of ME to DE from this study, however, (range from 0.84 to 0.86) was improved by increased level of MEI. By comparison with other breeds, it is found that the ratio of ME to DE from this study was less than Brahman cattle fed a diet containing energy at 1.4M to an *ad libitum* level from the report of Chaokaur *et al.* (2007)(0.86 to 0.88). These values were relatively greater compared to 0.82 of the NRC (2000).

3. Energy requirements for maintenance

All data were constructed and analyzed to determine the requirement for maintenance by regressing energy retention (kJ·kgBW$^{-0.75}$·d^{-1}) against energy intake (kJ·kgBW$^{-0.75}$·d^{-1}). Metabolizable energy for maintenance was estimated by regression analysis as shown in Figure 1. The equation was significant ($P < 0.01$) and the proportion of variation accounted for was high (simple coefficient of determination; $r^2 = 0.6992$). Metabolizable energy for maintenance of native Thai cattle as derived was 519.8 ± 9.26 kJ·kgBW$^{-0.75}$·d^{-1}. The metabolizable energy for maintenance of native Thai cattle from the recommendation of WTSR (2008) was 484 kJ·kgBW$^{-0.75}$·d^{-1} and was reported by Nitipot *et al.* (2009) at 509 kJ·kgBW$^{-0.75}$·d^{-1}. A range of data is available in the literature for the ME_m of *Bos taurus* and *Bos indicus* (Table 4). In addition, the metabolizable energy requirements for maintenance from this study were greater than Malaysian Kedah Kelantan cattle from the report of Laing and Young (1995) (335 kJ·kgBW$^{-0.75}$·d^{-1}), Brahman crossbreeds from the report of Ferrell and Jenkins (1998) (488 kJ·kgBW$^{-0.75}$·d^{-1}) and Nellore cattle from the report of Tedeschi *et al.* (2002) (498 kJ·kgBW$^{-0.75}$·d^{-1}). The current study results, however, were similar to the recommendation of the ARC (1980) (527 kJ·kgBW$^{-0.75}$·d^{-1}) and NRC (1976) (540 kJ·kgBW$^{-0.75}$·d^{-1}); however, they were less than the report of Dawson and Steen (1998) in *Bos taurus* crossbreeds. Metabolizable energy and net energy for maintenance estimates vary widely and are not yet clarified because there are many factors such as biological type, sex, stage and environmental conditions that influence energy requirements (NRC 2000, Luo *et al.* 2004).

From the obtained equations, the metabolizable energy requirements for maintenance were determined using calculations assuming that maintenance requirements are values at which energy retention is equal to zero (Y-intercept; *a*) and the slope (*b*) is the efficiency of metabolizable energy utilization for maintenance. From the present study, the net energy for maintenance can be estimated by extrapolation to the point of zero metabolizable energy intake. The net energy for maintenance was 259.9 kJ·kgBW$^{-0.75}$·d^{-1}. The results of this study were lower than for Tuli cattle from the report of Ferrell and Jenkins

(1998) (318 kJ·kgBW$^{-0.75}$·d^{-1}) and Nellore cattle from the report of Tedeschi *et al.* (2002) (323 kJ·kgBW$^{-0.75}$·d^{-1}). This finding indicates that native Thai cattle require net energy for maintenance which is lower by 12.07% than for *Bos taurus* cattle from the recommendation of Lofgreen and Garrett (1968) (322 kJ·kgBW$^{-0.75}$·d^{-1}). This finding could support the recommendation of the NRC (2000), which indicated that the net energy for maintenance of *Bos indicus* was 10% lower than *Bos taurus*.

Conclusions

The methane conversion rate appears to be underestimated from the IPCC default values of 6.5%. Increasing levels of offered energy intake resulted in increased energetic efficiency due to decreased energy excretion into feces, urine and methane emission, thus improving beef cattle growth performance under humid tropical conditions. Energy requirements for maintenance of native Thai cattle is suggested to be 520 kJ·kgBW$^{-0.75}$·d^{-1}.

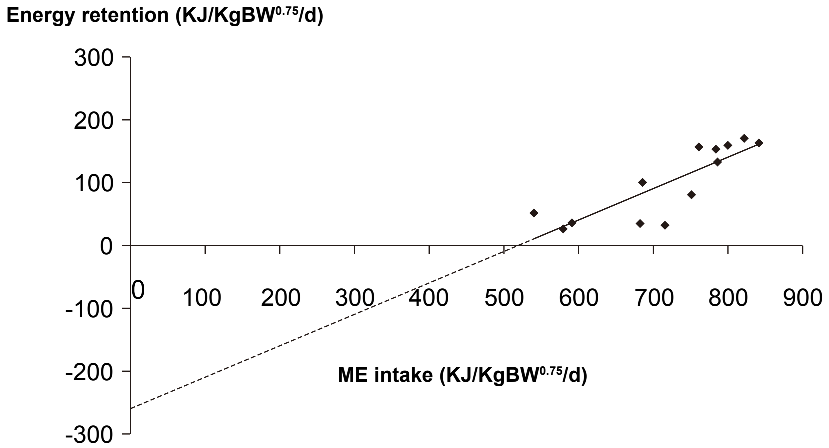

Fig. 1. Relationship between energy retention (ER, kilojoules per kilogram of metabolic body weight per day, kJ·kgBW$^{-0.75}$·d^{-1}) and metabolizable energy intake (MEI, kJ·kgBW$^{-0.75}$·d^{-1}) describes equation, ER = $(-259.88)_{(SE=71.70)} + 0.50ME_{I(SE=0.09)}$ (sample size = 13, simple coefficient of determination (r^2) = 0.70, *P* < 0.01; RSD = 9.26).

Table 4. Metabolizable energy requirements for maintenance of beef cattle

Source	Breed	N[1]	Stage	Sex	BW (kg)	Measured variable[2]	MEm[3]
Ferrell and Jenkin (1998b)	Brahman crossbred	15	Growing	Steer	313	RE; 1	501
	Brahman crossbred	15	Growing	Steer	313	RE; 4	488
Solis et al. (1988)	Brahman	4	Mature	Dry cow	499	BWC; 2	410
	Brahman	4	Mature	Dry cow	499	RE; 3	392
Chaokaur et al.(2007)	Brahman	16	Mature	Steer	373	RE; 4	458
Liang and Young (1995)	Kedah Kelantan	16	Growing	bulls	149	TEG; 5	335
This study	Thai Native	15	Mature	bulls	268	RE; 4	520
Dawson and Steen(1998)	CharolaisxAngus	75	Mature		628	RE; 4	614
NRC (1976)	Beef cattle						540
ARC (1980)	Beef cattle						527
Kearl (1982)	Beef cattle						493

[1]N, number observed. [2]RE, recovered or retained energy; BWC, body weight change; TEG, tissue energy gain; 1, comparative slaughter; 2, feeding trial; 3, deuterium oxide dilution; 4, indirect calorimetry head cage; 5, tritiated water (TOH) dilution. [3]MEm = kJ·kgBW$^{-0.75}$·d^{-1}.

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