CHAPTER V
EXPERIMENT III: METABOLIZABLE ENERGY REQUIREMENT FOR MAINTENANCE AND GAIN OF *Bos indicus* BEEF CATTLE: A META-ANALYSIS

5.1 Introduction

The *Bos indicus* cattle and their crossbreds are commonly used in beef production systems in tropical regions. They possess abilities to withstand hot and humid weather, tolerate intense sunshine, to resist parasites, and to utilize poor quality forages. The NRC (2000) indicated that *Bos indicus* breeds of cattle require about 10% less energy requirement for maintenance than *Bos taurus* cattle. In Thailand, although there have been attempts to evaluate metabolizable energy (ME) requirement for maintenance (ME_m) of Thai native and Brahman beef cattle by the indirect-calorimetry method (Kawashima et al. 2000 and Chaokaur et al., 2007, respectively), these short-term metabolism trials give only ME_m of beef cattle with no information about ME requirement for gain (ME_g). Thus, there is still very limited information to clarify the ME_m and ME_g of *Bos indicus* in tropical conditions to use as feeding recommendations.

Nevertheless, there were previous long-term feeding trials which have been applied to determine beef cattle performance. The metabolism is highly dynamic in terms of energy expenditure. Several studies have been independently conducted to determine energy requirements of *B. indicus* purebreds and their crosses. A meta-analysis of this data is necessary to provide an overall summary, and its interpretation can provide directions for future experiments. Therefore, the objective of this study was to perform a meta-analysis to determine energy requirements for maintenance and growth of beef cattle as classified as global *Bos indicus*, *Bos indicus* raised outside of Thailand, Thai *Bos indicus* (including of Thai native cattle, Thai Brahman and Thai Brahman crossbred), Thai native cattle, Thai Brahman and Thai Brahman crossbred from independent studies that used the feeding trial and indirect-calorimetry method.

5.2 Materials and methods

A database was constructed from feeding trials data to develop equations to predict ME_m and ME_g by using average daily gain (ADG) in beef cattle.

A database of metabolizable energy intake (MEI) used in this analysis was compiled from work involving various methods such as indirect gas exchange respiratory calorimetry and estimation by nutritive values. The estimated MEI by nutritive values were calculated from digestible energy (DE), total digestible nutrients (TDN) and digestible organic matter (DOM) where ME = 0.82DE, DE (Mcal) = $4.4TDN_{(kg)}$ and ME (Mcal) = $3.80DOM_{(kg)}$ following the method of Luo et al. (2004). The MEI and ADG were transformed to be the unit per metabolic body weight ($kgBW^{0.75}$) where MEI as $kJ/kgBW^{0.75}$ and ADG as $g/kgBW^{0.75}$. Cattle datasets were analyzed using a mixed model (St-Pierre, 2001) by SAS (1996) as follows:

$$\mathbf{Y_{ij} = B_o + B_1X_{ij} + s_i^* + b_i^*X_{ij} + e_{ij}}$$

where Y_{ij} = expected outcome for the dependent variable Y observed at level j of the continuous variable X in the study i,

$i = 1, 2,\ldots, n$ studies,

$j = 1, 2,\ldots, n_i$ values,

$B_o + B_1X_{ij}$ = the fixed effect part of model,

$s_i^* + b_i^*X_{ij} + e_{ij}$ = the random effect part of the model.

Because of the limitation of data sources on Brahman cattle, it was not possible to analyze using a mixed model (St-Pierre, 2001), so the datasets were analyzed using a simple regression model (St-Pierre, 2001) by SAS (1996) as follows:

$$\mathbf{Y_i = B_o + B_1X_i + e_i}$$

where Y_i = expected outcome for the dependent variable Y observed at the continuous variable X,

B_o = the intercept,

B_1 = the regressing coefficient of Y on X,

$i = 1, 2,\ldots, 39$, and

e_i = residual error.

The MEI and ADG of *Bos indicus* cattle used in this analysis is composed of 106 datasets and was separated into 6 types of cattle as follows:

Group 1. Global *Bos indicus*; 106 datasets (including datasets of groups 2 to 6)

Group 2. *Bos indicus* raised outside of Thailand; 49 dataset (Zinn et al., 1996; Ferrell and Jenkins, 1998b; Kurihara et al., 1999; Tedeschi et al., 2002; Jenet et al., 2004; Chizzotti et al., 2007b)

Group 3. Thai *Bos indicus*; 57 dataset (including datasets of groups 4 to 6)

Group 4. Thai native cattle; 20 dataset (Bunnakit, 2003; Prajakboonjetsada et al. 2006; Phaowphaisal and Wijitphan, 2006; Sengsa et al. 2006; Tamchan et al, 2007; and this study data in Chapter 3: Experiment II)

Group 5. Thai Brahman; 15 dataset (Prachyalak et al., 2001; Chumpawadee, 2006, and Chaokaur 2009)

Group 6. Thai Brahman crossbred; 22 dataset (Toaburan et al.1995; Boonpuckdee et al., 1997; Bannakit et al., 2006; Chaichaum et al., 2007; Yimmongkol et al., 2007 and Maliwan et al., 2008)

The ADG (g/kg $BW^{0.75}$) was regressed against MEI (kJ/kg $BW^{0.75}$) to obtain linear regression equations as follows; MEI = a + bADG. From the obtained equations, the ME_m was calculated by assuming that maintenance requirement is the value at which ADG is equal to zero (Y-intercept; a), and the slope (b) was assumed to be the ME_g according to the method of Luo et al. (2004). The accuracy of the obtained equations were evaluated by paired t-test (Paul et al., 2003) and the mean proportion bias (MPB, %) and mean prediction error (MPE) (Mandal et al., 2005) were determined for the precision evaluation.

5.3 Results and discussion

Database statistics separated according to the provenance or breed are shown in Table 1. *Bos indicus* used in this analysis were separated into overall *Bos indicus*, *Bos indicus* raised outside of Thailand, Thai *Bos indicus*, Thai native cattle, Thai Brahman and Thai Brahman crossbred. Mean body weight were 317, 376, 268, 212, 262 and 324 kg, respectively. The MEI were 787.26, 179.21, 190.96, 204.86, 155.17 and 194.53, respectively. The ADG were 8.16, 7.43, 9.35, 7.87, 11.42 and 9.27 $g/kgBW^{0.75}$, respectively. It was indicated that *Bos indicus* raised outside of Thailand had a higher mean body weight than Thai *Bos indicus*. *Bos indicus* raised in Thailand and Thai native cattle exhibited the lowest mean body weight when compared to Thai Brahman or Thai Brahman crossbred

Table 5.1 Summary of database for prediction of ME_m and ME_g of global *Bos indicus*, *Bos indicus* outside of Thailand, Thai *Bos indicus*, Thai native cattle, Thai Brahman and Thai Brahman crossbred; means, standard deviation (SD), minimum and maximum value of biological characteristic.

Items	n	mean	SD*	Min.*	Max.*
Global *Bos indicus*					
Average body weight (kg)	106	317.87	104.71	96.00	669.00
Metabolic body weight (kg $BW^{0.75}$)	106	74.50	18.60	30.57	131.47
Metabolizable energy intake (kJ/kg$BW^{0.75}$/d)	106	787.26	184.76	408.00	1137.00
Average daily gain (g/kg$BW^{0.75}$/d)	106	8.46	5.12	-0.23	21.05
***Bos indicus* raised outside of Thailand**					
Average body weight (kg)	49	375.61	85.08	284.00	669.00
Metabolic body weight (kg $BW^{0.75}$)	49	84.95	13.98	69.18	131.47
Metabolizable energy intake (kJ/kg$BW^{0.75}$/d)	49	789.88	179.21	559.00	1137.00
Average daily gain (g/kg$BW^{0.75}$/d)	49	7.43	5.35	-0.23	21.05
Thai *Bos indicus*					
Average body weight (kg)	57	268.23	94.49	96.00	489.00
Metabolic body weight (kg $BW^{0.75}$)	57	65.52	17.43	30.57	104.05
Metabolizable energy intake (kJ/kg$BW^{0.75}$/d)	57	785.02	190.96	408.00	1111.00
Average daily gain (g/kg$BW^{0.75}$/d)	57	9.35	4.78	0.16	19.94
Thai native cattle					
Average body weight (kg)	20	211.95	63.74	96.00	291.00
Metabolic body weight (kg $BW^{0.75}$)	20	55.05	12.83	30.57	70.46
Metabolizable energy intake (kJ/kg$BW^{0.75}$/d)	20	727.90	204.86	418.00	1013.00
Average daily gain (g/kg$BW^{0.75}$/d)	20	7.87	5.05	0.16	15.47
Thai Brahman					
Average body weight (kg)	15	261.73	66.94	189.00	358.00
Metabolic body weight (kg $BW^{0.75}$)	15	64.70	12.44	51.06	82.34
Metabolizable energy intake (kJ/kg$BW^{0.75}$/d)	15	793.60	155.17	459.00	995.00
Average daily gain (g/kg$BW^{0.75}$/d)	15	11.42	5.33	1.00	19.94
Thai Brahman crossbred					
Average body weight (kg)	22	323.82	104.22	171.00	489.00
Metabolic body weight (kg $BW^{0.75}$)	22	75.60	18.63	47.31	104.05
Metabolizable energy intake (kJ/kg$BW^{0.75}$/d)	22	831.09	194.53	408.00	1111.00
Average daily gain (g/kg$BW^{0.75}$/d)	22	9.27	3.70	3.09	16.11

*SD, standard deviation; Max., maximum; Min., minimum

The statistical parameters of obtained equations from analysis are presented in Table 5.2. All equations were statistically significant ($P<0.01$) with the coefficient of determination (R^2) ranging from 0.421 to 0.807. Regressing MEI (kJ/kg $BW^{0.75}$) against ADG (g/kg $BW^{0.75}$) yielded the following equation:

1) Overall *Bos indicus* beef cattle; MEI = 518.85 +3 1.60ADG (n = 106, R^2 = 0.628, RSD = 12.06, $P < 0.001$),

2) *Bos indicus* beef cattle raised outside of Thailand; MEI = 465.37 + 41.18ADG (n = 49, R^2= 0.652, RSD = 17.55, $P < 0.001$),

3) Thai *Bos indicus*; MEI = 545.03 + 25.92ADG (n = 57, R^2= 0.517, RSD = 15.72, $P < 0.001$),

4) Thai native cattle; MEI = 478.77 + 31.30ADG (n = 20, R^2= 0.807, RSD = 17.18, $P < 0.001$),

5) Thai Brahman; MEI = 548.39 + 21.39ADG (n = 15, R^2= 0.503, RSD = 28.24, $P = 0.002$), and

6) Thai Brahman crossbred; MEI = 546.08 + 30.55ADG (n = 22, R^2= 0.421, RSD = 27.39, $P < 0.001$).

The accuracy and precision were evaluated and results are shown in Table 5.3. The accuracy was evaluated by the paired t-test, and all of the obtained equations were non-significantly different ($P > 0.05$) among actual MEI and predicted MEI. It is indicated that the yielded equations can predict the metabolizable energy requirement.

The precision of equations were evaluated by using the mean proportion bias (MPB, %) and mean prediction error (MPE). The MPB of all prediction equations were negatively biased. Results indicate that all of the obtained equations give an under-estimated prediction value. The bias was lowest in the prediction equations of Thai Brahman (1.60 %) while highest in Thai Brahman crossbred (3.00 %). The MPE ranged from 0.11 to 0.19.

Table 5.2 Statistical parameters of obtained equations

Eq.	Response parameter (Y)	Independent parameter (X)	Number of observations observation	Number experiment of study	Parameter estimates				Model statistics		
					Y - intercept	SE	Slope	SE	R^2	RSD	*P*-value
	Global *Bos indicus*										
1	MEI	ADG	106	29	518.85	23.38	31.60	2.37	0.628	12.06	<0.001
	***Bos indicus* raised outside of Thailand**										
2	MEI	ADG	49	13	465.37	30.24	41.48	3.31	0.652	17.55	<0.001
	Thai *Bos indicus*										
3	MEI	ADG	57	16	545.03	34.80	25.92	3.32	0.517	15.72	<0.001
	Thai native cattle										
4	MEI	ADG	20	6	478.77	32.40	31.30	3.49	0.807	17.18	<0.001
	Thai Brahman [2/]										
5	MEI	ADG	15	4	549.39	68.75	21.39	5.49	0.503	28.24	0.002
	Thai Brahman crossbred										
6	MEI	ADG	22	6	546.08	75.35	30.55	7.57	0.421	27.39	<0.001

[1/]MEI, metabolizable energy intake (kJ/ $kgBW^{0.75}$/d); ADG, average daily gain (g/ $kgBW^{0.75}$/d); Y – intercept, metabolizable energy for maintenance (kJ/ $kgBW^{0.75}$/d); SE, standard error; RSD, residual standard deviation

[2/] simple linear regression (general linear model; GLM)

Table 5.3 Prediction accuracy and precision evaluation of obtained equations.

Eq.	Cattle	Actual (A) [1/]	Predicted (P) [1/]	Residual (P-A) [1/]	Paired t-test A vs. P (*P*-value)	Mean proportional bias (%)	Mean Prediction Error
1	**Global *Bos indicus***	787.26±17.95	786.18±15.70	-1.09±12.23	0.93	-2.00	0.16
2	***Bos indicus* raised outside of Thailand**	789.88±25.60	773.62±31.71	-16.25±21.63	0.46	-2.40	0.19
3	**Thai *Bos indicus***	785.02±41.47	787.28±24.12	2.26±27.78	0.89	-2.50	0.15
4	**Thai native cattle**	727.90±45.81	725.08±35.33	-2.82±18.25	0.88	-2.40	0.11
5	**Thai Brahman**	793.60±40.06	793.60±29.40	0.00004687±27.21	1.00	-1.60	0.13
6	**Thai Brahman crossbred**	831.09±41.47	829.42±24.12	-1.67±27.78	0.95	-3.00	0.15

[1/] mean ± standard deviation

It was found that ME_m of global *Bos indicus* beef cattle, *Bos indicus* beef cattle raised outside of Thailand, *Bos indicus* beef cattle raised in Thailand, Thai native cattle, Brahman beef cattle raised in Thailand, and Brahman crossbred beef cattle raised in Thailand was 518.85, 465.37, 454.37, 478.77, 549.39 and 546.08 kJ/kgBW$^{0.75}$/d, respectively and ME_g for 1 g/kgBW$^{0.75}$/d of ADG was 31.60, 41.47, 25.92, 31.30, 21.39 and 30.55 kJ/kgBW$^{0.75}$/d, respectively. Data suggested that ME_m and ME_g are highly variable depending on provenance and breed of *Bos indicus* beef cattle. The high variability might be according to state of maturity and body size of cattle, climatic conditions and available feed resources which effected the animal energy utilization and requirements.

Equation 1 (Figure 5.1) gives the ME_m of overall *Bos indicus* cattle at 518 kJ/kgBW$^{0.75}$/d. which is higher than ARC (1980), Kearl (1982) and NRC (2000) which ranged from 465 to 494 kJ ME/kgBW$^{0.75}$/d. This value is also higher than that of Thai native cattle and Thai Brahman (484 and 486 kJ ME/kgBW$^{0.75}$/d, respectively) as reported by WTSR (2008). But it is similar to the result of Experiment II of this study (Chapter 4) where ME_m of Thai native cattle was 509 kJ/kgBW$^{0.75}$/d. Equation 1 also gives information of ME_g for 1 g/kgBW$^{0.75}$/d as 31.60 kJ ME/kgBW$^{0.75}$/d.

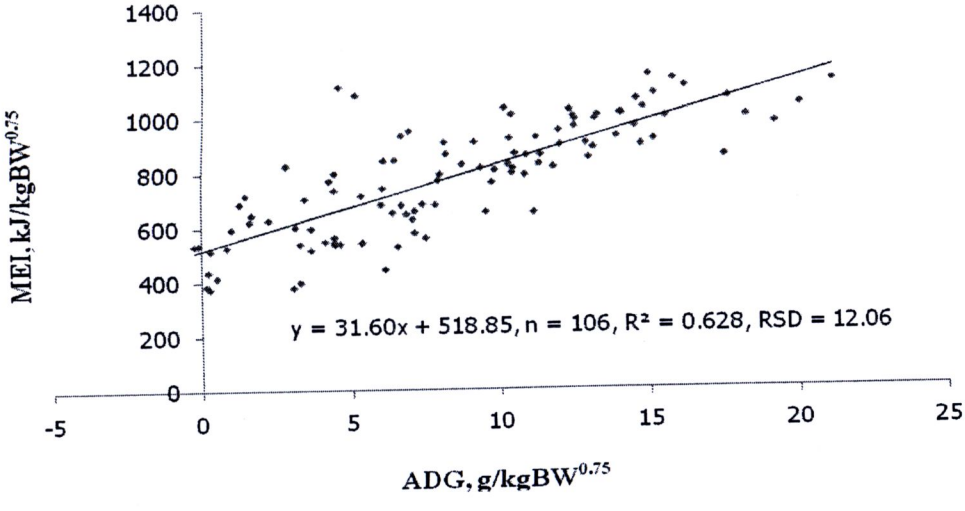

Figure 5.1 Relationship between average daily gain (ADG, g/ kgBW$^{0.75}$/d) and metabolizable energy intake (MEI, kJ/ kgBW$^{0.75}$/d) of global *Bos indicus* under study

Equation 2 (Figure 5.2) gives the ME_m of *Bos indicus* raised outside of Thailand at 465 kJ/kgBW$^{0.75}$/d which is similar to that reported by ARC (1980) and NRC (2000) (465 and 468 kJ/kgBW$^{0.75}$/d, respectively) On the other hand, Equation 3 (Figure 2) gives the ME_m of Thai *Bos indicus* at 545 kJ/kgBW$^{0.75}$/d. Both Equation 2 and 3 also indicate that the ME_g for 1 g/kgBW$^{0.75}$/d of *Bos indicus* raised outside of Thailand and Thai *Bos indicus* were 41.47 and 25.92 kJ ME/kgBW$^{0.75}$/d, respectively.

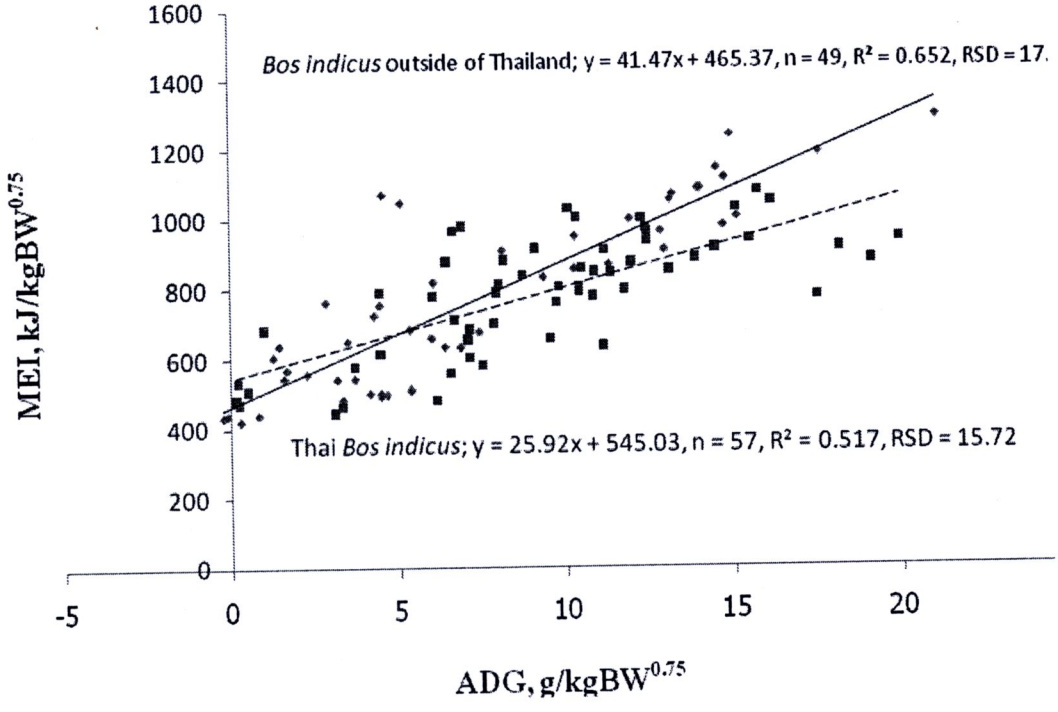

Figure 5.2 Relationship between average daily gain (ADG, g/ kgBW$^{0.75}$/d) and metabolizable energy intake (MEI, kJ/ kgBW$^{0.75}$/d) of *Bos indicus* raised outside of Thailand (♦, solid line) and Thai *Bos indicus* (■, dash line)

Equations 4, 5 and 6 (Figure 5.3) give the ME_m of Thai native cattle, Thai Brahman and Thai Brahman crossbred as 479, 549 and 546 kJ/kgBW$^{0.75}$/d, respectively. It also gives a similar ME_g for 1 g/kgBW$^{0.75}$/d among Thai native cattle and Thai Brahman, thus 31.30 and 30.55 kJ/kgBW$^{0.75}$/d, respectively. But it is lower in Thai Brahman crossbred where ME_g for 1 g/kgBW$^{0.75}$/d was 21.39 kJ/kgBW$^{0.75}$/d.

Note: Appendix II contains extention data applying the above analysis to recommends ME requirements of some beef types considered here.

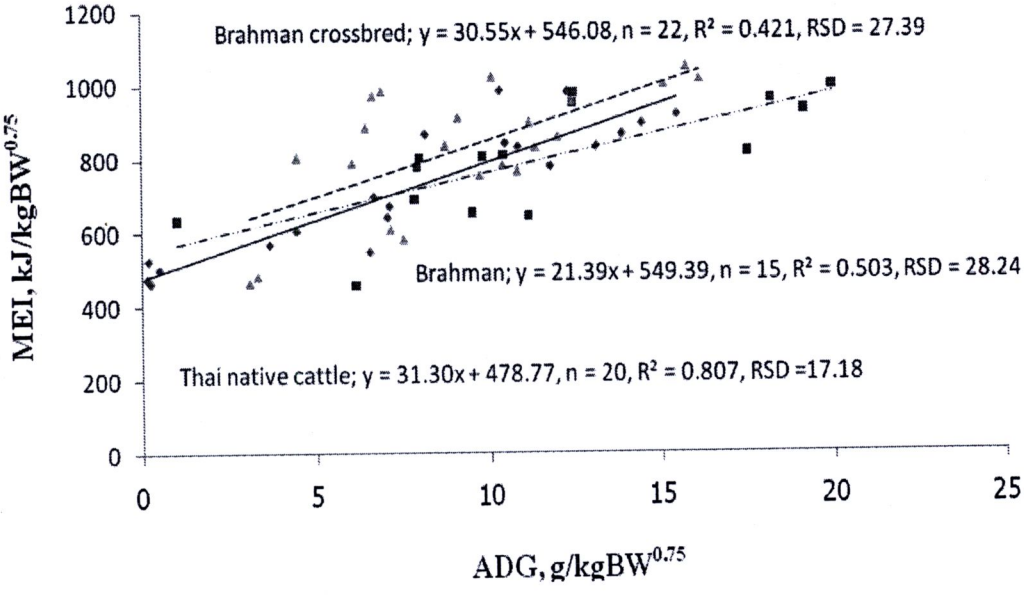

Figure 5.3 Relationship between average daily gain (ADG, g/ $kgBW^{0.75}$/d) and metabolizable energy intake (MEI, kJ/ $kgBW^{0.75}$/d) of Thai native cattle (♦, solid line) Thai Brahman (■, dot-dash line) and Thai Brahman crossbred (▲, dash line)

The ME_m of beef cattle of different breed, stage of growth, sex, body weight and method of determination is shown in Table 5.4. The ME_m of Thai native cattle obtained from this meta-analysis (479 kJ/$kgBW^{0.75}$/d) was similar to the ME_m of Thai native cattle and Thai Brahman cattle in the report of WTSR (2008) (484 and 486 kJ/$kgBW^{0.75}$/d, respectively) where it was determined by the same method. But this value is lower than that of Experiment II of this study (Chapter 4) where ME_m of Thai native cattle was 509 kJ/$kgBW^{0.75}$/d which was found by using indirect respiratory calorimetry. These values of ME_m differ perhaps because of different evaluation methods. The energy retention investigated by using the indirect respiratory calorimetry is usually different from that evaluated by ADG where the animals are in a normal feeding situation. (Luo et al., 2005)

The ME_m of Thai Brahman cattle obtained from this study (549 $kJ/kgBW^{0.75}/d$) is slightly high when compared to the report of WTSR (2008) (486 $kJ/kgBW^{0.75}/d$) which was evaluated with the same method. It is also higher than reported by Chaokaur et al. (2007), Chaokaur et al. (2008b) and Chaokaur et al. (2008c) (458, 454 and 497 $kJ/kgBW^{0.75}/d$, respectively) where it was investigated by using the same method of indirect respiratory calorimetry.

Table 5.4 Metabolizable energy requirement for maintenance (ME_m) of beef cattle of different breed, growing stage, sex, body weight and method of determination

Breeds	Country	Stage	Sex	BW (kg)	Method[a]	ME_m[b]	Sources
Beef cattle						465	ARC (1980)
Beef cattle						494	Kearl (1982)
Beef cattle						468	NRC (2000)
Nellore	Brazil	Growing	Bulls	200	CS; RE ra MEI	494	Tedeschi et al. (2002)
Nellore	Brazil	Growing	Steer	314	CS; RE ra MEI	469	Tedeschi et al. (2002)
Boran crossbred	USA	Growing	Steer	277	CS; RE ra MEI	293	Ferrell and Jenkins (1998b)
Brahman crossbred	USA	Growing	Steer	313	CS; RE ra MEI	488	Ferrell and Jenkins (1998b)
Brahman x Hereford	USA	Mature	Cow	632	CS; RE ra MEI	580	Reid et al. (1991)
Brahman x Angus	USA	Mature	Cow	581	CS; RE ra MEI	598	Reid et al. (1991)
Brahman	USA	Mature	Dry cow	499	D_2O; RE ra MEI	392	Solis et al. (1988)
Brahman	USA	Mature	Dry cow	499	FT; BWC ra MEI	410	Solis et al. (1988)
Brahman	Thailand	Mature	Steer	370	ICH; RE ra MEI	488	T. Suzuki[c]
Brahman	Thailand	Mature	Steer	353	ICM; RE ra MEI	377	Kawashima et al. (2000)
Brahman	Thailand	Mature	Steer	373	ICH; RE ra MEI	458	Chaokaur et al. (2007)
Brahman	Thailand	Mature	Bulls	384	ICH, FT; RE ra MEI	454	Chaokaur et al. (2008b)
Brahman	Thailand	Growing	Bulls	178	ICH, FT; RE ra MEI	497	Chaokaur et al. (2008c)
Brahman	Thailand					486	WTSR (2008)[d]
Thai native cattle	Thailand	Mature	Steer	163	ICM; RE ra MEI	245	Kawashima et al. (2000)
Thai native cattle	Thailand	Mature	Steer	185	ICH; RE ra MEI	509	This study (Chapter3: Experiment II, on page 104)
Thai native cattle	Thailand					484	WTSR (2008)[c]
Kedah Kelantan	Malaysia	Mature and Growing	Bulls	149	TOH; RE ra MEI	335	Liang and Young (1995)

[a]RE, recovered or retained energy; MEI, metabolizable energy intake; ICH, indirect calorimetry head cage; ICM, indirect calorimetry mask; CS, comparative slaughter; TOH, tritiated water (TOH) dilution; D_2O, deuterium oxide dilution; FT, feeding trial; ra, regressed against

[b]ME_m = kJ of ME per $kgBW^{0.75}$ per day

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

[d]The Working Committee of Thai Feeding Standard for Ruminant ;WTSR (2008)

The ME_m of Thai Brahman crossbred cattle obtained from this investigation (546 kJ/kgBW$^{0.75}$/d) is higher than that for Thai Brahman crossbred cattle in USA in the report of Ferrell and Jenkins (1998b) (488 kJ/kgBW$^{0.75}$/d). But it is lower than the ME_m of Brahman-Hereford and Brahman-Angus crossbred (580 and 598 kJ/kgBW$^{0.75}$/d, respectively) reported by Reid et al. (1991). It is possible that the actual ME_m of cattle breeds differs as the species/breed of cattle, climatic conditions and available feed resources are all different; the energy requirements of cattle in Thailand may not be the same as recommended for other zones.

Equations obtained from analysis of the relationship between MEI and ADG enabled evaluation of ME_m and ME_g of *Bos indicus* cattle. However, compared to previous information, it can be seen that energy requirement shows great variation. The variation might be due to the differences in breed, stage of growing, sex, body size, environmental climate, feed quality and the method of evaluation in each investigation.

NRC (2000) details that considerable variation exists in maintenance requirements among cattle germ plasm resources, little difference ME_m exists between steers and heifers but it is higher in bulls than in steers and heifers, the maintenance requirement per unit of size declines with age in cattle, the effects of season have been associated with effects of temperature, and that the season per se may have significant effects on maintenance requirement of cattle. Physiological changes usually associated with acute temperature change include shivering and sweating as well as acute changes in feed and water consumption, respiration rate, heart rate, and activity. It should be noted that animals differ greatly in their behavioral responses and their ability to physiologically adapt to the thermal environment (NRC, 2000). Also, NRC (2000) states that because of differences in procedures and approaches as well as diversity of breeds compared, direct comparisons among available data are difficult and are often tenuous. Thus, these factors should be considered to minimize the variation of investigations and comparisons.

Indeed, the limited database of this study caused a low coefficient of determination in some equations, and more investigation of metabolizable energy requirements of cattle in Thailand is needed to enhance accuracy.

5.4 Conclusions:

Based on this data analysis, it has been found that ME_m of *Bos indicus* beef cattle, *Bos indicus* beef cattle raised outside of Thailand, *Bos indicus* beef cattle raised in Thailand, Thai native cattle, Brahman beef cattle raised in Thailand, and Brahman crossbred beef cattle raised in Thailand is 518.85, 465.37, 454.37, 478.77, 549.39 and 546.08 $kJ/kgBW^{0.75}/d$, respectively and ME_g for 1 $g/kgBW^{0.75}/d$ of ADG was 31.60, 41.47, 25.92, 31.30, 21.39 and 30.55 $kJ/kgBW^{0.75}/d$, respectively. Data suggest that ME_m and ME_g are highly variable among provenances and breed of *Bos indicus* beef cattle.