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An Evaluation of the ME System Model to Predict Performance of Different Breeds of Feedlot Beef Cattle Fed under Two Different Feeding Periods

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Abstract: In this study, data from Holstein, Brown Swiss, Simmental cattle as European Type (ET) and Boz and Gak as Indigenous Type (IT) grown under feedlot conditions were used to evaluate the ARC, ME system for prediction of beef performance during two different feeding periods. During growing period, the discrepancies between observed and predicted values of daily liveweight gains (OLWG and PLWG) were high and significant ($p<0.05$) for all cattle. OLWGs were underpredicted for IT cattle and those observed values less than 0.9 kg day^{-1}. The Mean-Square Prediction Error (MSPE) of the predictions by the model was 0.03 and 0.007 kg day^{-1} for ET and IT, respectively. During finishing period, the discrepancies between OLWGs and PLWGs were low and were not significant ($p>0.05$) for all cattle except Gak and there were substantial agreement between observed and predicted values for ET. The model tended to underpredict OLWGs of ET while OLWGs were overpredicted for IT and those OLWGs less than 0.6 kg day^{-1}. The MSPE was 0.006 and 0.02 kg day^{-1} for ET and IT, respectively. The accuracy of measurement predictions were within the acceptable range only for OLWGs obtained for ET at finishing period. The results indicated that the model does not provide very close agreement with reality for prediction of LWG for IT cattle.

Key words: Beef production, modelling, metabolisable energy system, performance, prediction

INTRODUCTION

The basic concept of Metabolisable Energy (ME) system described by ARC (1984) has been widely accepted and further revised by AFRC (1993). However, it has not been generally used as a practical method of rationing ruminants. This results partly from its complexity but also from the fact that it allows only prediction of performance from given energy input. As a result, formulation of diets is cumbersome and time consuming since it involves an iterative procedure (Harkins *et al*., 1974). Models that predict production responses in cattle resulting from differences in level of nutrition are based on partitioning ME intake between maintenance and growth or production functions (ARC, 1984; CSIRO, 1990; NRC, 2000).

Net Energy System for ruminants based on the ME system enables a non-iterative approach to be used in the formulation of rations. There is, however, clearly a need for more reliable and precise estimates of performance of cattle fed in different situations and in any practical application of the system (Newbold, 1987). Moreover, the net energy system is also based on comparative slaughter experiments to determine the energy requirements of beef cattle and the net energy value of the food (Henrique *et al*., 2005).

Predictive models, ranging from simplified representations (such as the energy and protein systems for ruminants) to more complex dynamic models have tended to be empirical representations and as such have limited application situations outside those in which the data sets were collected (France *et al.*, 1987). For a system model to be accepted and used with confidence, it should be demonstrated that it is capable of representing the actual system under a wide range of environmental conditions with a reasonable degree of accuracy (Williams and Jenkins, 2003).

There is some debate that the system to specify the energy requirements of ruminants can be used to predict the performance of growing animals, because the ME requirements of growing cattle depend on the ME concentration of the ration and it is not well suited to the formulation of rations to produce specified daily liveweight gains (Glen, 1985). It was indicated by Yan *et al.* (2002) that the feeding level is very important for correction of ME and developed regression equations to predict dietary ME and Digestible Energy (DE) concentration for cattle at any production feeding level using dietary ME and DE concentrations determined at maintenance.

This experiment was designed to evaluate the prediction ability of ME model based on ARC equations in order to estimate the Holstein, Brown Swiss, Simmental cattle as European Type (ET) and Boz and Gak as Indigenous Type (IT) cattle performance during both growing and finishing period under feedlot and to examine the application of the system model in situations outside those in which the data sets were collected.

MATERIALS AND METHODS

This experiment was conducted at the Suleyman Demirel University Research Farm in Isparta Province in Turkey. The study included 100 animals in total and 10 Holstein, 7 Simmental, 26 Brown Swiss (ET), 12 Boz, 45 Gak (IT) calves, all breeds were approximately six months old and had an average body weight of 140 kg. The animals were kept in feedlots with four pens. Each pen contained mixed breeds of 25 animals. The experiment commenced on the 12th of July, 2002, for a duration of 7 months, ending on the 11th of February, 2003. First 3 months of feeding was considered as growing and the rest as finishing period.

Animals were initially weighed at the beginning of the experiment and were divided into groups according to their weights. Each group was weighed and monitored on a fortnightly basis.

Diets (sugar beet bulb and dried hay as roughage and ground barley and cotton seed meal as concentrates) were provided to obtain a target LWG of 1 kg day^{-1} and designed according to live weight change of the animals during both feeding periods.

Prediction of Live Weight Gain Based on the Energy System (Energy Model, EM)

Excel Spreadsheets were used for prediction of LWG.

The System used to specify the energy requirements of growing cattle was outlined by ARC (1984) and fully described by the MAFF (1987). To formulate a requirement in terms of metabolizable energy the Net Energy (NE) requirement must be ascertained together with the efficiency with which dietary Metabolizable Energy (ME) is used to satisfy that requirement (MAFF, 1987). Net energy was calculated using the following equations.

For Maintenance (E_m)

Metabolizable energy requirement of the animals for maintenance was calculated from the net energy required for fasting metabolism. Metabolizable energy required for maintenance (E_m) and can be expressed as:

$$E_m = 5.67 + 0.061\ W \qquad (1)$$

Where:

E_m = Maintenance allowance (MJ day^{-1})

W = Live weight (kg)

The efficiency with which ME is used for maintenance (k_m) was calculated from the energy concentration (M/D) of the ration, using the equation;

$$k_m = 0.55 + 0.061\ M/D \qquad (2)$$

Where:

k_m = The efficiency of utilisation of ME for maintenance

M/D = Energy concentration of the ration (MJ/kgDM)

However, since over a range of ME concentrations (M/D) varies from 8 to 14 MJ/kgDM, k_m varies from 0.68 to 0.77 and therefore an average value of 0.72 for the efficiency of utilisation of ME was assumed. Therefore, Eq. 1 can be rearranged as:

$$E_m = \frac{(5.67 + 0.061W)}{k_m} \qquad (3)$$

Substitution of k_m into Eq. 3 results in the following equation:

$$E_m = \frac{(5.67 + 0.061W)}{0.72} \qquad (4)$$

Then Eq. 4 can be expressed as follows:

$$E_m = 7.88 + 0.085\ W \qquad (5)$$

For Production (MEP)

The metabolizable energy available for production was obtained by deducting the ME allowance for maintenance (E_m) from the total Metabolizable Energy Intake (MEI).

$$MEP = MEI - E_m \qquad (6)$$

Substituting E_m in Eq. 5 into 6 yields the following equation:

$$MEP = MEI - (7.88 + 0.85\ W) \qquad (7)$$

Calculation of Predicted Live Weight Gain

The energy available for growth (E_g) is obtained from the ME available for production (MEP). The efficiency with which ME is utilised for production (k_g) is a function of the ME concentration of the dietary dry matter (M/D), which is expressed as:

$$k_g = 0.0435\ M/D \qquad (8)$$

Accordingly E_g is described by the following equation:

$$E_g = \text{MEP} \times k_g \tag{9}$$

Substituting MEP and k_g into Eq. 9 results in the following equation:

$$E_g = \text{MEI} - (7.88 + 0.085\ \text{W}) \times 0.0435\ \text{M/D} \tag{10}$$

The liveweight gain (LWG) which can be achieved from the stored energy (E_g) is dependent upon the energy value of the gain (EV_g). The net energy stored for gain (E_g) is the energy content of that gain and is the product of the weight of the gain (LWG) and its energy value (EV_g).

$$\text{LWG} = \frac{E_g}{EV_g} \tag{11}$$

For cattle, the energy value of gain (EV_g) is related to the liveweight in kg (W) and the energy stored in MJ (E_g) and was calculated using the following equation:

$$EV_g = 6.28 + 0.3\ E_g + 0.0188\ \text{W} \tag{12}$$

By substituting EV_g from Eq. 12 into 11 the following equation was obtained.

$$\text{LWG} = \frac{E_g}{6.28 + 0.3E_g + 0.0188\text{W}} \tag{13}$$

Finally, substituting E_g from Eq. 10 into 13 provides an equation to calculate liveweight gains (kg day^{-1}) for growing and fattening cattle from a given intake of ME (MEI), the animals body weight (W) and ME concentration of the ration (M/D).

$$\text{LWG} = \frac{\text{MEI} - (7.88 + 0.085\text{W}) \times 0.0435\text{M}/\text{D}}{\left[6.28 + 0.3\left[\text{MEI} - (7.88 + 0.085\text{W}) \times 0.0435\text{M}/\text{D}\right] + 0.0188\text{W}\right]} \tag{14}$$

Statistical Analysis

The difference between actual and predicted LWGs was examined by Students't test, using the statistical package program MINITAB v.13 for windows (MINITAB, 2001). The observed and predicted LWGs were also compared using the Mean-Square Prediction Error (MSPE):

$$\text{MSPE} = \frac{1}{n}\sum_{i=1}^{n}(\text{Oi-Pi})^2$$

Where:

n = The number of pairs of observed and predicted values being compared

i = (1, 2, 3,……, n)

Oi = The observed LWGs with ith variable

Pi = The predicted LWGs with ith variable

The MSPE can be considered as the sum of three components described by Rook *et al*. (1990).

$$\mathrm{MSPE} = (\bar{O} - \bar{P})^2 + S_P^2\,(1 - b)^2 + (1 - r^2)S_O^2$$

Where, S_O^2 and S_P^2 are the variances of the observed and predicted LWGs, respectively. $\bar{O}$ and $\bar{P}$ are the means of the observed and predicted LWGs, b is the slope of the regression of observed values on predicted and r is the correlation coefficient between O and P.

RESULTS AND DISCUSSION

The statistical significant differences between observed and predicted daily LWGs by the model together with R^2 values, MSPE and its proportions and descriptive statistics are shown for all breed types at growing and finishing period in Table 1.

LWGs of Holsteins were underpredicted for all observed values (Fig. 1) both during growing and finishing periods. As can be shown from Table 1, although there were significant ($p<0.05$) differences between observed and predicted values during the growing period (0.893 and 0.739 kg day^{-1}, respectively) differences were insignificant ($p>0.05$) during the finishing period for Holsteins (1.026 and 0.974 kg day^{-1}, respectively).

The MSPEs of the predictions by the model were 0.025 and 0.006 kg day^{-1} for growing and finishing periods, respectively. During the finishing period the model had a greater proportion of error derived from random than other components (Table 1). A small proportion of line as a component of MSPE indicated that the error derived from line was substantially low and there was a minimal variation between predicted and observed LWGs. However, during growing period the model had a greater error derived from bias than other components and there was a big variation between predicted and observed LWGs.

While there were statistically significant ($p<0.05$) differences between observed and predicted values during growing period of Simmentals (0.938 and 0.766 kg day^{-1}, respectively) there were no significant ($p>0.05$) differences during finishing period (1.124 and 1.056 kg day^{-1}, respectively) (Table 1).

Table 1: Differences between observed and predicted daily LWGs by the model together with R^2 values, MSPE and its proportions and descriptive statistics for all breeds

									Proportions of MSPE		
Breeds	Period		LWG	SE	R^2	r	Mean Bias	MSPE	Bias	Line	Random
Holstein	Growing	Observed	0.893^{a}	0.032							
(n = 10)		Predicted	0.739^{b}	0.025	0.84	0.92	-0.154±0.09	0.025	0.940	0.005	0.055
	Finishing	Observed	1.026^{a}	0.033							
		Predicted	0.974^{a}	0.029	0.69	0.83	-0.051±0.09	0.006	0.462	0.004	0.534
Simmental	Growing	Observed	0.938^{a}	0.027							
(n = 7)		Predicted	0.766^{b}	0.019	0.94	0.97	-0.173±0.07	0.030	0.980	0.010	0.010
	Finishing	Observed	1.124^{a}	0.036							
		Predicted	1.056^{a}	0.034	0.60	0.78	-0.068±0.11	0.008	0.540	0.030	0.420
B. Swiss	Growing	Observed	0.865^{a}	0.027							
(n = 26)		Predicted	0.733^{b}	0.020	0.89	0.94	-0.132±0.07	0.025	0.880	0.040	0.080
	Finishing	Observed	0.958^{a}	0.028							
		Predicted	0.918^{a}	0.024	0.86	0.93	-0.039±0.07	0.004	0.360	0.020	0.620
Boz	Growing	Observed	0.603^{a}	0.041							
(n = 12)		Predicted	0.551^{a}	0.036	0.80	0.89	-0.051±0.11	0.007	0.420	0.000	0.580
	Finishing	Observed	0.782^{a}	0.047							
		Predicted	0.856^{a}	0.025	0.56	0.75	0.073±0.11	0.020	0.280	0.060	0.660
GAK	Growing	Observed	0.561^{a}	0.017							
(n = 45)		Predicted	0.502^{b}	0.013	0.55	0.74	-0.061±0.04	0.010	0.350	0.000	0.650
	Finishing	Observed	0.682^{a}	0.023							
		Predicted	0.763^{b}	0.022	0.58	0.57	0.081±0.06	0.020	0.380	0.000	0.620

*: Means with the same superscripts are not statistically significant ($p>0.05$)

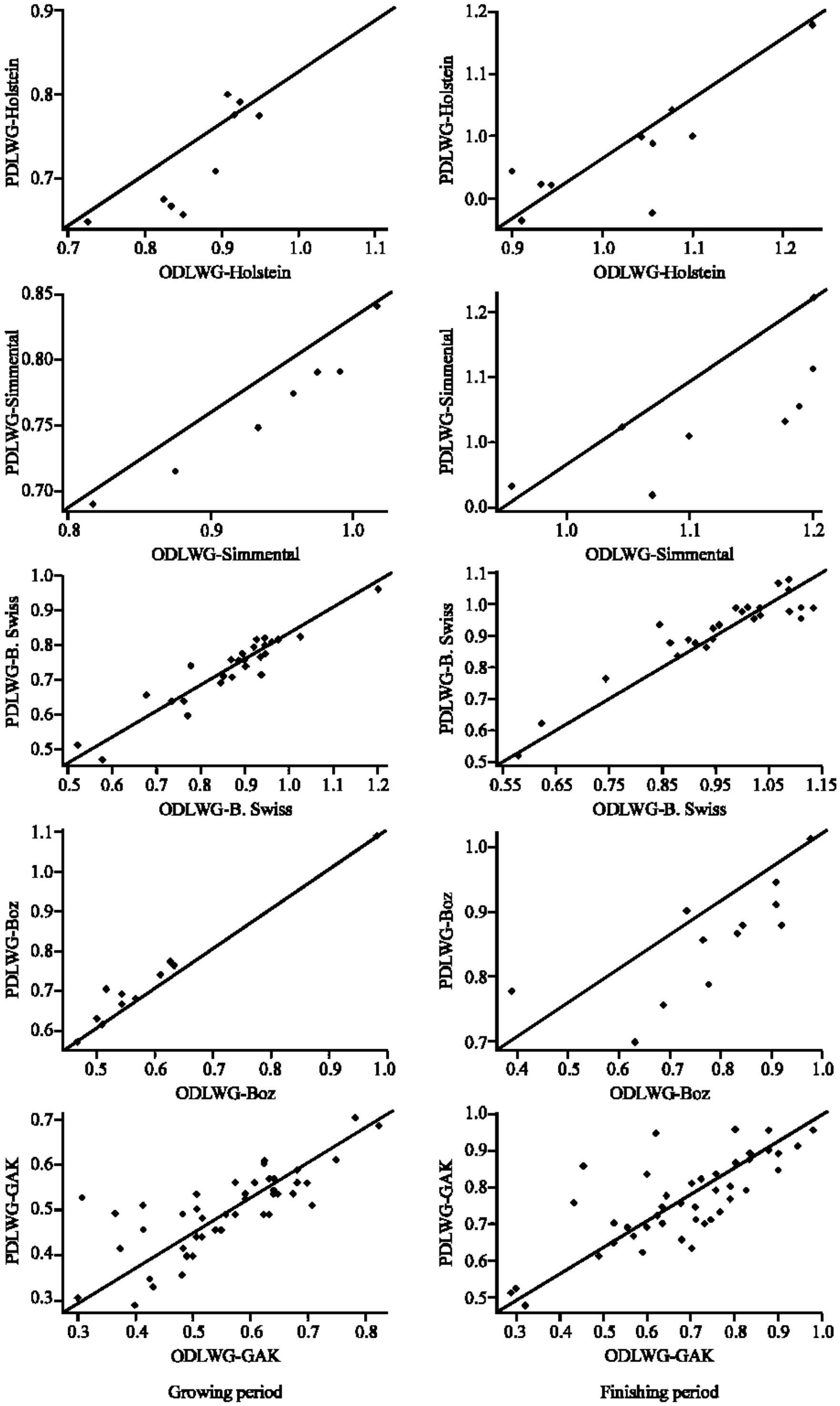

Fig. 1: The predicted LWGs are plotted against observed LWGs for data set. The straight line represents the line of unity and the best prediction

LWGs of Simmentals were underpredicted for all observed values. The MSPEs of the predictions by the model were 0.030 and 0.009 kg day^{-1} for growing and finishing periods, respectively. Underpredictions were smaller during finishing than growing period. The model had a greater proportion of error derived from bias than other components during growing period and a small proportion of random indicated that the error derived from random was substantially low and there was a big variation between predicted and observed LWGs. However, during finishing period the model had a greater proportion of error derived from both bias and random than line component. A small proportion of line indicated that the error derived from line was low and there was a minimal variation between observed and predicted LWGs.

Although there were significant ($p<0.05$) differences between observed and predicted values obtained during growing period of Brown Swiss cattle (0.865 and 0.733 kg day^{-1}, respectively) the differences were insignificant ($p<0.05$) during finishing period (0.958 and 0.918 kg day^{-1}, respectively) (Table 1).

LWGs of Brown Swiss cattle were underpredicted for all observed values. The MSPEs of the predictions by the model were 0.025 and 0.004 kg day^{-1} for both growing and finishing periods, respectively. The model had a greater proportion of error derived from bias and random during growing and finishing periods, respectively than other components. The error derived from line was low for both periods and there was a minimal variation between predicted and observed LWGs only during finishing periods.

There were no significant ($p>0.05$) differences between observed and predicted values in data set of Boz breed cattle both during growing period (0.603 and 0.551 kg day^{-1}, respectively) and finishing period (0.782 and 0.856 kg day^{-1}, respectively).

LWGs of Boz cattle were underpredicted for the observed values obtained during growing period. However, they were overpredicted during the finishing period (Fig. 1). The model had a greater proportion of error derived from random than other components for both feeding periods. A small proportion of line showed that the error derived from line was substantially low and there was a minimal variation between predicted and observed LWGs in both feeding periods. The MSPEs of the predictions by the model were 0.007 and approximately 0.02 kg day^{-1} for growing and finishing periods, respectively (Table 1).

There were significant ($p<0.05$) differences between observed and predicted values in data set of Gak breed cattle both during growing (0.561 and 0.502 kg day^{-1}, respectively) and finishing periods (0.682 and 0.763 kg day^{-1}, respectively).

LWGs of Gak cattle were underpredicted for the observed values obtained during growing period. However, they were overpredicted during the finishing period (Fig. 1). The MSPEs of the predictions by the model were 0.01 and approximately 0.02 kg day^{-1} for growing and finishing periods, respectively.

Results also indicated that higher correlation coefficients (r) and R^2 values were obtained during both feeding period of ET cattle than those of IT cattle. Similarly, r and R^2 values were higher for growing period than finishing period in both type of cattle. Furthermore, error derived from random was greater than other components during finishing period for all breeds except Gak. However, bias was greater during growing period of ET breeds than those of IT breeds.

The accuracy of the model can be evaluated according to components of Mean Square Prediction Error (MSPE) as a proportion of the mean observed LWG in the experiment.

The MSPE can be divided into three components due to mean bias (or mean deviation $(\bar{P}-\bar{O})$ of the prediction); line bias (or deviation of the slope (b) of the regression of O on P from unity) and the random variation about this regression line. A positive mean bias indicates that the equations are generally overestimating relative to observed values while negative mean bias indicating underestimation (Table 1).

Rook *et al*. (1990) indicated that mean bias generally shows differences between estimation and test data while a large line bias is representative of underlying weakness in the structure of models.

In growing period of all breed types (except Gak), the highest proportional contribution to the MSPE of the model predictions was made by the bias, the line bias component being the least, followed by that of the random error of the data about the regression line in the data set. The highest proportional contribution of bias of the data to the MSPE in the model could be due to the poor calculation of energy requirements especially for ET cattle.

In finishing period of all breed types, the highest proportional contribution to the MSPE of the model predictions was made by the random error of the data about the regression line in the data set, the line bias component being the least, followed by that of bias. The highest proportional contribution of random error of the data to the MSPE in the model could be attributed to the calculations of ME concentrations. They are themselves dependent on the predictions of ME supply of the silage and concentrates (Neal *et al*., 1988). This result is also supported by Yan *et al*. (2002) who took into account the dietary forage proportion and the rate of depression of energy digestibility associated with increasing feeding level being reduced with increasing dietary forage proportion.

Bozkurt and Ap Dewi (2001) indicated that the general trend in the model based on the ARC prediction equations was for the slope of the regression of observed on predicted values to be more than unity at low observed values in which LWGs were overpredicted and to be less than unity at high observed values in which LWGs were underpredicted. However, in the present study the general trend in the model was that the slope of regression was less than unity for ET cattle at both growing and finishing period in which LWGs were underpredicted and to be close to or more than unity IT cattle at finishing period in which LWGs were overpredicted. Furthermore, underpredictions were smaller and not statistically significant ($p>0.05$) during finishing period than growing period of all ET cattle. This could be due to the fact that they reached their actual mature size at the end of finishing period while IT cattle were late maturing cattle. Similarly, Williams and Jenkins (2003) argued that the response for Simmental and Charolais crossbreds was similar, with Simmental being greater at 50% of mature weight. The ME prediction for body weight gain for Hereford-Angus crossbreds decreased at a faster rate than Simmental and Charolais crossbreds as proportion of mature weight increased.

The poor ability of the model to predict performance of IT cattle in the present study in which LWGs were consistently underpredicted, could be attributed to underestimation of ME values and thus low metabolizable energy concentrations M/D. Laboratory methods of evaluating the feedstuffs used could be one of the major factors contributing to the errors of prediction.

In contrast to work done by Bozkurt and Ap Dewi (2001), the model underpredicted LWGs at growing period. This could be attributed to an under estimate of the energy available for LWG.

Ellis *et al*. (2006) pointed out that NRC (1996, 2000) values may be slightly too low and that the corresponding ARC predicted efficiencies may be too high on the basis of expected and found liveweight gains in the feedlot cattle. On the average the NRC predicted live weight gains were 6% lower than actual values obtained, whereas the ARC predicted values were approximately 26% higher than the actual values obtained.

Bozkurt and Ap Dewi (2001) and Hirooka and Yamada (1989) compared energy model predictions of weight gain with those observed in a range of experiments and found that, on average, the model overpredicted LWG by 17% and by about 15%, respectively, which was not in close agreement with the findings of the present study in which the model underpredicted LWGs by also 17% for ET cattle (18% for Holstein and Simmental and 15% for Brown-Swiss) and 5% for the same type of cattle (6% for Holstein and Simmental and 4% for Brown-Swiss) during both growing and finishing period, respectively, but 10% for IT cattle (9 and 11% for Boz and Gak, respectively) only during growing and overpredicted LWGs by approximately 10% for IT cattle (9 and 12% for Boz and Gak, respectively) only during finishing period.

It was also suggested by Newbold *et al*. (1986) and Yan *et al*. (2002) that discrepancies between predicted and observed LWG might be due to lack of response to amino acid supply, several of which may be closely co-limiting to growth. This might me the case in this study since discrepancies were higher for both type of cattle during growing period.

The practical implications of over and under-predictions by the model should be taken into consideration in their practical application. Over-prediction might suggest that there was a surplus of feed offered, resulting in a delay in reaching the target LW. With under-prediction, the rations would include more concentrates than necessary, resulting in incurred higher total feed costs.

Metabolizable Energy System outlined by the ARC (1984) enables a non-repetitious approach in the ration formulations. The method is suitable to be used in linear programming for growing cattle. However, there is a clearly a need for more reliable and precise estimates of, or means of predicting the degradability of different protein sources fed in different situation and in any practical application of the system (Newbold, 1987; Henrique *et al*., 2005; Williams and Jenkins, 2003).

In conclusion, ME system proposed by ARC (1984) and revised by AFRC (1993) allows the energy system of growing cattle to be represented in all substantial respects (for maintenance and production). The differences between the predicted and observed LWG values are very small in relation to their practical significance, the accuracy of measurement and error of experimentation and predictions were within the acceptable range for the measured outputs for the finishing period data of all breeds (except Gak) examined in this study.

Although the model based on the energy system may have limitations due to the empirically derived equations, the data presented in this study indicated that the model provides very close agreement with reality for prediction of liveweight gain of both breeds especially for ET cattle at the end of finishing period.

Therefore, liveweight gains can be predicted by the ARC (1984) and AFRC (1993) ME system with confidence and flexibility because the acceptable agreement and the close relationship between observed and predicted LWG gives general support to energy model both to be manipulated with confidence to provide predictions of live-weight gain of European type of cattle fed under local feedlot conditions in order for beef producers to decide when to market cattle for slaughter and also to be used as decision support tool. However, there is still a need for further investigations especially for indigenous breeds fed under local conditions.

REFERENCES

AFRC (Agricultural and Food Research Council), 1993. Energy and Protein Requirements of Ruminants. CAB International, Wallingford, Oxon, UK.

ARC (Agricultural Research Council), 1984. The Nutrient Requirements of Ruminant Livestock. Supplement No. 1. Commonwealth Agricultural Bureaux, Slough.

Bozkurt, Y. and I. Ap Dewi, 2001. An evaluation of equations based on metabolizable energy and ARC protein schemes to predict liveweight gain of housed beef cattle. Suranaree J. Sci. Technol., 8 (1): 15-30.

CSIRO, 1990. Feeding Standards for Australian Livestock, Ruminants. CSIRO Publications, East Melbourne, Victoria, Australia.

Ellis, J.L., F. Qiao and J.P. Cant, 2006. Prediction of dry matter intake throughout lactation in a dynamic model of dairy cow performance. J. Dairy Sci., 89: 1558-1570.

France, J., M. Gill, J.H.M. Thornley and P. England, 1987. A model of nutrient utilization and body composition in beef cattle. Anim. Prod., 44 (2): 374-385.

Glen, J.J., 1985. Approximations in the variable net energy system for ruminants. Anim. Prod., 41: 235-238.

Harkins, J., R.A. Edwards and P. McDonald, 1974. A new energy system for ruminants. Anim. Prod., 19: 141-148.

Henrique, D.S., R.A.M. Vieira, P.A.M. Malafaia, M.C. Mancini and A.L. Gonçalves, 2005. Estimation of the total efficiency of metabolizable energy utilization for maintenance and growth by cattle in tropical conditions. R. Bras. Zootec., 34 (3): 1006-1016.

Hirooka, H. and Y. Yamada, 1989. A comparison of simulation models based on ARC metabolizable energy system and NRC net energy system with special reference to growing steers. Asian-Aust. J. Anim. Sci., 2: 599-605.

MAFF., 1987. Energy allowances and feeding systems for ruminants. Ministry of Agriculture, Fisheries and Food. Reference Book, 433. Her Majesty's Stationery Office, London.

MINITAB., 2001. Statistical Package v. 13. Minitab Inc. USA.

Neal, StC.D.H., M. Gill, J. France, A. Spedding and S. Marsden, 1988. An evaluation of prediction equations incorporated in a computer program to ration beef cattle. Anim. Prod., 46 (1): 169-179.

Newbold, J.R., P.C. Garnsworthy, P.J. Buttery, D.J.A. Cole and W. Haresign, 1986. Effect of oestradiol-17β implantation on responses of Friesian steers to ungraded dietary protein concentration. Anim. Prod., 42: 440 (Abstr.).

Newbold, J.R., 1987. Nutrient Requirements of Intensively-Reared Beef Cattle. In: Recent Advances in Animal Nutrition, Haresign, W. and D.J.A. Cole (Eds.). Butterworths, London, pp: 143-171.

NRC (National Research Council), 1996. Nutrient Requirements of Beef Cattle. 7th Edn. National Research Council, National Academy of Science, National Academy Press, 2101 Constitution Ave., Washington, DC., 20318.

NRC (National Research Council), 2000. Nutrient Requirements of Beef Cattle. 8th Edn. National Research Council, National Academy of Science, National Academy Press, 2101 Constitution Ave., Washington, DC., 20318.

Rook, A.J., M.S. Dhanoa and M. Gill, 1990. Prediction of the voluntary intake of grass silages by beef cattle. 3. Precision of alternative prediction models. Anim. Prod., 50: 455-466.

Williams, C.B. and T.G. Jenkins, 2003. Adynamic model of metabolizable energy utilization in growing and mature cattle. II. Metabolizable energy utilization for gain. J. Anim. Sci., 81: 1382-1389.

Yan, T., R.E. Agnew and F.G. Gordon, 2002. The combined effects of animal species (sheep versus cattle) and level of feeding on digestible and metabolisable energy concentrations in grassbased diets of cattle. Anim. Sci., 75: (1) 141-151.