Session NCSH2.6
Mail:ybozkurt@ziraat.sdu.edu.tr

Performance Prediction Using ARC, ME System for Different Breeds Of Beef Cattle Fed With Two Different Feeding Periods Grown Under Feedlot Conditions

Y. Bozkurt [1] and S. Ozkaya
Suleyman Demirel University, Faculty of Agriculture, Department of Animal Science, Isparta, Turkey, 32260.

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 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. The Mean-Square Prediction Error (MSPE) of the predictions by the model was 0.03 and 0.007 kg/day 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. The MSPE was 0.006 and 0.02 kg/day 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, Energy system, performance, prediction
[1]**Corresponding Author:** Y. Bozkurt, Suleyman Demirel University, Faculty of Agriculture, Department of Animal Science, Isparta, Turkey, 32260, Tel: +90 246 2114650, Fax: +90 246 2371693, E-mail: ybozkurt@ziraat.sdu.edu.tr

INTRODUCTION

It is generally agreed that the energy evaluation of foods for ruminants should be based on net energy rather than a digestible energy method. Moe and Tyrell [1] have reviewed recent net energy systems proposed by Lofgreen and Garrett [2], Blaxter [3], Schiemann et al. [4] and Moe et al. [5]. That of Blaxter [3] as outlined in Agricultural Research Council, ARC [6] is probably the most sophisticated; taking into account variations in feeding level and the efficiency of utilization of metabolizable energy for different functions and food.

Although the basic concept of this system has been widely accepted, 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 [7].

A simplified Net Energy System for ruminants is described. It is based on the Metabolizable Energy System outlined by the ARC [6] and enables a non-iterative approach to be used in the formulation of rations. The method is suitable for use in linear programming work and is illustrated, with appropriate tables, for growing cattle. 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 [8].

Predictive models, ranging from simplified representations (such as the energy and protein systems for ruminants adopted in the United Kingdom and in the United States [6-9]) to more complex dynamic models such as those of Graham et al. [10], Newton and Edelsten [11], Forbes [12-13] and Geisler and Neal [14], have tended to be empirical representations and as such have limited application situations outside those in which the data sets were collected [15].

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 metabolizable energy (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 live weight gains (DLWGs) [16].

This experiment was designed to evaluate the prediction ability of ARC equations in order to estimate the Brown-Swiss cattle performance grown under feedlot conditions in Turkey 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. The present study included 11 Holstein, 8 Simmental, 26 Brown Swiss, 12 Boz, 47 Gak calves, all specimens 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 ten animals. The experiment commenced on the 12th of July, 2000, for a duration of 7 months, ending on 11th of February, 2001.

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 and designed according to live weight change of the animals.

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 [6] and fully described by the Ministry of Agriculture, Fisheries and Food, MAFF [17]. 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 [17]. 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:

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

Where E_m= Maintenance allowance (MJ/day), W= Live weight in 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;

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

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, equation 1 can be rearranged as:-

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

Substitution of k_m into equation 3 results in the following equation:-

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

Then equation 4 can be expressed as follows:-

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

For Production (MEP): The metabolizable energy available for production was obtained by deducting the ME allowance for maintenance (Em) from the total metabolizable energy intake (MEI).

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

Substituting E_m in equation 5 into equation 6 yields the following equation:-

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

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:-

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

Accordingly E_g is described by the following equation:-

$$E_g = MEP \times k_g \qquad (9)$$

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

$$E_g = MEI - (7.88 + 0.085W) \times 0.0435M/D \qquad (10)$$

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).

$$LWG = \frac{E_g}{EV_g} \qquad (11)$$

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:-

$$EV_g = 6.28 + 0.3E_g + 0.0188W \qquad (12)$$

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

$$LWG = \frac{E_g}{6.28 + 0.3E_g + 0.0188W} \qquad (13)$$

Finally, substituting E_g from equation 10 into equation 13 provides an equation to calculate liveweight gains (kg/day) 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).

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

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 [18]. The “observed” and “predicted” LWGs were also compared using the Mean-Square Prediction Error (MSPE):

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

Where n is the number of pairs of observed and predicted values being compared.

i = (1, 2, 3,……, n)
O_i is the observed LWGs with ith variable.
P_i is the predicted LWGs with ith variable.
The MSPE can be considered as the sum of three components described by Rook et al. [19].

$$MSPE = (\overline{O} - \overline{P})^2 + S^2{}_P(1-b)^2 + (1-r^2)S^2{}_O$$

Where, S_O^2 and S_P^2 are the variances of the observed and predicted LWGs respectively. $\overline{O}$ and $\overline{P}$ 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

The statistical significant difference between observed DLWGs and predicted DLWGs by the model and descriptive statistics are shown for Holstein at "growing" and "finishing" period in Table 1.

Breeds	Period		LWG	s.e.	R^2	r	Mean Bias	MSPE	Proportions of MSPE		
Holstein (n=10)	Growing	Observed	0.893[a]	0.032					***Bias***	***Line***	***Random***
		Predicted	0.739[b]	0.025	0.84	0.92	-0.154±0.085	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±0.092	0.006	0.462	0.004	0.534
Simmental (n=7)	Growing	Observed	0.938[a]	0.027							
		Predicted	0.766[b]	0.019	0.94	0.97	-0.173±0.073	0.030	0.98	0.01	0.01
	Finishing	Observed	1.124[a]	0.036							
		Predicted	1.056[a]	0.034	0.60	0.78	-0.068±0.109	0.008	0.54	0.03	0.42
B. Swiss (n=26)	Growing	Observed	0.865[a]	0.027							
		Predicted	0.733[b]	0.020	0.89	0.94	-0.132±0.068	0.025	0.88	0.04	0.08
	Finishing	Observed	0.958[a]	0.028							
		Predicted	0.918[a]	0.024	0.86	0.93	-0.039±0.074	0.004	0.36	0.02	0.62
Boz (n=12)	Growing	Observed	0.603[a]	0.041							
		Predicted	0.551[a]	0.036	0.80	0.89	-0.051±0.113	0.007	0.42	0.00	0.58
	Finishing	Observed	0.782[a]	0.047							
		Predicted	0.856[a]	0.025	0.56	0.75	0.073±0.112	0.02	0.28	0.06	0.66
GAK (n=45)	Growing	Observed	0.561[a]	0.017							
		Predicted	0.502[b]	0.013	0.55	0.74	-0.061±0.043	0.01	0.35	0.00	0.65
	Finishing	Observed	0.682[a]	0.023							
		Predicted	0.763[b]	0.022	0.58	0.57	0.081±0.0574	0.02	0.38	0.00	0.62

As can be observed from Table 1 below, although there were significant (P <0.05) differences between observed and predicted values during the growing period (0.893 kg/day and 0.739 kg/day respectively) differences were insignificant (P >0.05) during the finishing period for Holsteins (1.026 kg/day and 0.974 kg/day respectively).

LWGs of Holsteins were underpredicted for all observed values (Figure 1) both during growing and finishing periods. The MSPEs of the predictions by the model were 0.025 and 0.006 kg/day for growing and finishing periods respectively. The contributions of components to MSPE; the values of bias, line and random error are also shown in Table 1. During the finishing period the model had a greater proportion of error derived from random than other components. A small proportion of line as a component of MSPE showed 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 significant (P <0.05) differences between observed and predicted values during growing period of Simmentals (0.938 kg/day and 0.766 kg/day respectively) there were no significant ($P > 0.05$) differences during finishing period (1.124 kg/day and 1.056kg/day respectively).

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 for growing and finishing periods respectively. The model had a greater proportion of error derived from bias than other components during growing period. 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 as a component of MSPE showed that the error derived from line was substantially low and there was a minimal variation between predicted and observed LWGs.

Although there were significant ($P < 0.05$) differences between observed and predicted values obtained during growing period of Brown Swiss cattle (0.865 kg/day and 0.733 kg/day respectively) the differences were insignificant ($P < 0.05$) during finishing period (0.958kg/day and 0.918 kg/day respectively).

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 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 substantially low for both periods and there was a minimal variation between predicted and observed LWGs only during finishing periods.

The statistical significant difference between observed DLWG and predicted DLWG by the model and descriptive statistics are shown for Boz at growing and finishing period in Table 1.

There were no significant ($P > 0.05$) differences between observed and predicted values in data set of Boz breed cattle both during growing period (0.603kg/day and 0.551 kg/day respectively) and finishing period (0.782kg/day and 0.856 kg/day respectively).

LWGs of Boz cattle were underpredicted for the observed values obtained during growing period. However, LWGs were overpredicted during the finishing period (Figure 1). The model had a greater proportion of error derived from random than other components for both feeding periods. A small proportion of line as a component of MSPE 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 for growing and finishing periods respectively.

The statistical significant difference between observed DLWG and predicted DLWG by the model and descriptive statistics are shown for GAK at the growing and finishing period in Table 1.

There were significant ($P < 0.05$) differences between observed and predicted values in data set of Gak breed cattle both during growing (0.561kg/day and 0.502kg/day respectively) and finishing periods (0.682kg/day and 0.763 kg/day respectively).

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

In this data set, the model had a greater proportion of error derived from random than other components for both feeding periods. A small proportion of line as a component of MSPE 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.

DISCUSSION

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 ($\overline{P}$-$\overline{O}$) 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. [19] 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.

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 [20].

Bozkurt and Ap Dewi [21] 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 at low observed values in which LWGs were underpredicted and to be close to or more than unity at high observed values in which LWGs were overpredicted.

The poor ability of the model to predict performance 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 [21] the model under predicted LWGs at low rates of observed gains. This could be attributed to an under estimate of the energy available for LWG.

Neal et al. [20] were incorporated into a computer program designed to be used by livestock advisors for on-farm rationing of beef cattle that equations for the prediction of forage dry-matter intake, ME, rumen degradable protein and undegradable protein, based on those in the current ARC system. The predictions of silage intake and live weight gain are compared with experimental data.

Burroughs et al. [22] pointed out that NRC 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 [21] and Hirooka and Yamada [23] 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 energy model underpredicted LWG by 11.6%.

Metabolizable Energy System outlined by the ARC [6] 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 [8].

It was also suggested by Newbold et al. [24] 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.

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.

In conclusion ME system proposed by ARC 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 data 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 live-weight gain.

Therefore, liveweight gains can be predicted by the ARC [6] 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 to be manipulated with confidence to provide predictions of live-weight gain of pure-bred cattle fed under local conditions. However, there is still a need for further investigations for other European breeds fed under local conditions.

REFERENCES

1. Moe, P.W. and H.F. Tyrell, 1973. The Rationale of Various Energy Systems for Ruminants. *J. Anim. Sci. 37:183-189.*
2. Lofgreen, C.P. and W.N. Garrett, 1968. A System for Expressing Net Energy Requirements and Feed Values for Growing and Finishing Beef Cattle. *J. Anim. Sci. 27:793-806.*
3. Blaxter, K.L., 1962. The Energy Metabolism of Ruminants. Hutchinson, London.
4. Schiemann, R., K. Nehring, L. Hoffman, W. Jentsch and A. Chudy, 1971. Energetische Futterbewertung and Energienormen. VEB Deutscher Landwirtschaft-sverlag, Berlin.
5. Moe, P.W., W.P. Flatt and H.F. Tyrell, 1972. Net Energy Values of Feeds for Lactation. *J. Anim. Sci. 55:945-958.*
6. AGRICULTURAL RESEARCH COUNCIL, 1984. The Nutrient Requirements of Ruminant Livestock. Supplement No. 1. Commonwealth Agricultural Bureaux, Slough.
7. Harkins, J., R.A. Edwards and P. McDonald, 1974. A New Energy System for Ruminants. *Anim. Prod. 19:141-148.*
8. Newbold, J.R., 1987. Nutrient Requirements of intensively–reared Beef Cattle. In recent Advances in Animal Nutrition. 1987, pp. 143-171. ed. Haresign, W. and Cole, D.J.A., Butterworths, London.
9. NATIONAL RESEARCH COUNCIL, 1996. Nutrient Requirements of Beef Cattle 7th Edition, 1996. National Research Council, National Academy of Science, National Academy Press, 2101 Constitution Ave., Washington, D.C. 20318

10. Graham, N. J.L.McC. Black, G.J. Faichney and G.W. Arnold, 1976. Simulation of Growth and Production in Sheep – Model 1: a computer program to estimate energy and nitrogen utilisation, body composition and empty live weight change, day by day for sheep of any age. *Agricultural Systems 1:113-138.*
11. Newton, J.E. and P.R. Edelsten, 1976. A Model of the Effect of Nutrition on Litter Size and Weight in the Pregnant Ewe. *Agricultural Systems 1:185-199.*
12. Forbes, J.M., 1977. Interrelationships between Physical and Metabolic Control of Voluntary Food Intake in fattening, Pregnant and Lactating Sheep: a model. *Anim. Prod. 24:91-101.*
13. Forbes, J.M., 1977. Development of A model of voluntary Food Intake and Energy Balance in Lactating Cows. *Anim. Prod. 24:203-214.*
14. Geisler, P.A. and H. Neal, 1979. A Model fort he Effects of Energy Nutrition on the Pregnant Ewe. *Anim. Prod. 29:357-369.*
15. 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. 44:374-385.*
16. Glen, J.J., 1985. Approximations in the Variable Net Energy System for Ruminants. *Anim. Prod. 41: 235-238.*
17. MAFF., 1987. Energy allowances and feeding systems for ruminants. Ministry of Agriculture, Fisheries and Food. Reference book, 433. Her Majesty's Stationery Office, London.
18. MINITAB., 2001. Statistical Package v. 13. Minitab Inc. USA
19. 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.*
20. 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. 46:169-179.*
21. 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. 8:15-30.*
22. Burroughs, W., M.A. Fowler and S.A. Adeyanju, 1970. Net Energy Evaluation for Beef Cattle Rations Compared with Evaluation by Metabolizable Energy Measurements. *J. Anim. Sci. 30:450-454.*
23. 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-Australasain J. Anim. Sci. 2: 599-605.*
24. Newbold, J.R., P.C. Garnsworthy, P.J. Buttery, D.J.A. Cole and W. Haresign, (1986). Effect of oestradiol-17ß implantation on responses of Friesian steers to ungraded dietary protein concentration. *Anim. Prod. 42: 440 (Abstr.).*

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