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Prediction of Dry Matter Intake in Lactating Holstein Dairy Cows Offered High Levels of Concentrate

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ABSTRACT : Accurate estimation of dry matter intake (DMI) is a prerequisite to meet animal performance targets without penalizing animal health and the environment. The objective of the current study was to evaluate some of the existing models in order to predict DMI when lactating dairy cows were offered a total mixed ration containing a high level of concentrates and locally produced agricultural by-products. Six popular models were chosen for DMI prediction (Brown et al., 1977; Rayburn and Fox, 1993; Agriculture Forestry and Fisheries Research Council Secretariat, 1999; National Research Council (NRC), 2001; Cornell Net Carbohydrate and Protein System (CNCPS), Fox et al., 2003; Fuentes-Pila et al., 2003). Databases for DMI comparison were constructed from two different sources: i) 12 commercial farm investigations and ii) a controlled dairy cow experiment. The model evaluation was performed using two different methods: i) linear regression analysis and ii) mean square error prediction analysis. In the commercial farm investigation, DMI predicted by Fuentes-Pila et al. (2003) was the most accurate when compared with the actual mean DMI, whilst the CNCPS prediction showed larger mean bias (difference between mean predicted and mean observed values). Similar results were observed in the controlled dairy cow experiment where the mean bias by Fuentes-Pila et al. (2003) was the smallest of all six chosen models. The more accurate prediction by Fuentes-Pila et al. (2003) could be attributed to the inclusion of dietary factors, particularly fiber as these factors were not considered in some models (i.e. NRC, 2001; CNCPS (Fox et al., 2003)). Linear regression analysis had little meaningful biological significance when evaluating models for prediction of DMI in this study. Further research is required to improve the accuracy of the models, and may recommend more mechanistic approaches to investigate feedstuffs (common to the Asian region), animal genotype, environmental conditions and their interaction, as the majority of the models employed are based on empirical approaches. (**Key Words :** DM Intake, Prediction, Model, Lactation, Dairy Cow)

INTRODUCTION

Ruminants need to be fed according to their nutrient requirements to achieve their optimum performance in terms of milk and meat production. However, providing an adequate amount of nutrients in terms of energy and protein to dairy cows is a challenging task due to many complex factors. Accurate estimation of dry matter intake (DMI) is a prerequisite for the formulation of diets to optimize milk production without compromising animal welfare (National Research Council, 2001). As such, this will contribute towards more sustainable production methods, and in particular, efficient use of nutrients, e.g. nitrogen, which has an impact on the environmental footprint.

In the past, most intake prediction equations relied upon the live weight of the animal and its current level of productivity. These approaches are of concern as they do not take into consideration forage composition or the nature of any concentrate fed (Beever, 1993). This is particularly the case with the equations proposed by the Agricultural Research Council (ARC, 1980), National Research Council (NRC, 2001) and the Agriculture Forestry and Fisheries Research Council Secretariat (AFFRCS, 1999). Further consideration such as environmental factors were included in the model suggested by Cornell Net Carbohydrate and Protein System (CNCPS; Fox et al., 2003). The composition of feedstuffs was taken into account in the equations proposed by others (Brown et al., 1977; Rayburn and Fox, 1993; Fuentes-Pila et al., 2003). Roseler et al. (1997) partitioned factors that could mediate effects into live weight (17%), milk yield (45%), feed offered and herd management (22%), body condition score (5%) and climatic

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Table 1. Equations employed for dry matter intake (DMI) prediction in lactating Holstein dairy cows during this study

Model [1]	Reference
$DMI = \exp(0.5198+0.000675\times BW+0.33922\ \ln(MY)+0.09927\times FY-0.000827$ $\times DIM+0.14807\times \ln(DIM)+0.01800\times(0.78\times RADF-0.000557\times(0.79\times RADF)^2)$	Brown et al. (1977)
$DMI\ (\text{for}\ DIM <84) = 0.0117\times BW60.0749\times DIM+0.281\times FCM$	Rayburn and Fox (1993)
$DMI\ (\text{for}\ DIM >70) = 0.023\times BW+0.0201\times DIM+0.286\times FCM-0.0979\times RNDF$	
$DMI = (2.9810+0.00905\times FBW+0.41055\times FCM)$ $\times(0.73406+0.056491\times WOL-0.004321\times WOL^2+0.000115\times WOL^3)$	AFFRCS (1999)
$DMI = (-0.293+0.372\times FCM+0.0968\times BW^{0.75})\times(1-\exp(-0.192\times(WIM+3.67)))$	NRC (2001)
$DMI = (0.0185\times FBW+0.305\times FCM\times TEMP1\times MUD1)\times Lag$	CNCPS (Fox et al., 2003)
$DMI = 548.0294-111.7076\times \ln(BW)+1.4024\times BW^{0.75}-4.4128\times \ln(MY)+3.7496\times FY+11.7684$ $\times PY+3.8327\ \ln(MOL)+0.0043\times RADF^2+0.7589\times RNDF-0.0101\times RNDF^2-0.1367\times RCP$	Fuentes-Pila et al. (2003)

[1] Definitions: MY = Milk yield (kg/d); FY = Milk fat yield (kg/d); PY = Milk protein yield (kg/d); MOL = Month of lactation, variable whose value is equal to 1 for the first month, 2 for the second one, 3 for the third one and 4 for the remaining months of lactation; RADF = Ration acid-detergent fiber (% of DM); RNDF = Ration neutral-detergent fiber (% of DM); RCP = Ration crude protein (% of DM); WIM = Weeks in milk; FBW = Full body weight (kg); FCM = 4% fat corrected milk (kg/d); TEMP = Temperature adjustment factor for DMI; MUD = Mud adjustment factor for DMI; Lag = Adjustment factor for DMI during early lactation; WOL = Week of lactation.

factors (10%). With advances in computerized models, the accuracy of the prediction has been improved, recognizing factors such as: types of feed offered, level of feeding, ration formulation, quality of feed, body condition, stage of lactation, reproduction and climate (Mazumder and Kumagai, 2006).

Dairy production systems in some Asian countries are often intensive and rely heavily on imported feedstuffs. Korean Feeding Standard for Dairy Cattle (Ministry of Agriculture and Forestry, 2002) reported that more than 60% of diets offered to dairy cows are based on imported concentrates and agricultural by-products in order to improve the overall efficiency of economic productivity. In part, this situation is attributable to poor production of good quality forage per unit area and the costs of production of such forage. Hence, the supply of good quality forage, vital for ruminant production, is not as stable as in Western European or North American countries. Therefore, the aim of this study was to evaluate existing models in order to predict DMI when lactating cows were offered high concentrate-based diets containing agricultural by-products.

MATERIALS AND METHODS

Dry matter intake prediction models

Six equations to predict DMI were chosen and are presented in Table 1. Both AFFRCS (1999) and NRC (2001) models estimate DMI using only animal factors such as body weight, milk yield and days in milk, whilst CNCPS (Fox et al., 2003) includes environmental factors such as ambient temperature. The chemical composition of feedstuffs, such as crude protein (CP), neutral detergent fiber (NDF) and acid detergent fiber (ADF), as well as animal productivity, were particularly important for the other equations employed (Brown et al., 1977; Rayburn and Fox, 1993; Fuentes-Pila et al., 2003) (Table 1).

Data collection from commercial dairy farms

The data collected contained a total of 430 lactating Holstein cows from 12 different commercial dairy farms in the Gyeonggi Province, Republic of Korea. Collection was conducted by visiting the farms regularly once a month for 6 months from December 2003 to May 2004. Commercial dairy cow concentrates were supplied by a computer-based concentrates feeder according to production level of each cow. Home-made total mixed rations (TMR), consisting primarily of a roughage or a commercial TMR were offered to cows twice a day (between 8:00 to 10:00 and 16:00 to 18:00 depending on individual farm). Cows were all free-stall housed with fermented sawdust bedding. Among the survey group cows were discounted from data collection if they were either more than 500 days in milk (DIM), yielded on average less than 10 kg milk/day or had somatic cell count (SCC) of more than 500,000 cells/ml. In the surveyed farms, commercial concentrate, commercial TMR (dry or wet), cracked corn, beet pulp, brewer's grain, cottonseed, corn silage, alfalfa hay, Klein grass hay, Bermuda grass hay, tall fescue grass hay, timothy grass hay, orchard grass hay, oat hay and rice straw were used to formulate the feed (see Table 2 for the chemical composition of individual feed ingredients), and the chemical analysis of nutrients in the diets for the 12 farms is shown in Table 3.

Body weight, body condition score (BCS), the average amount of TMR supplied, and the amount of concentrate feeds fed to individual cows were monitored by regular monthly visits. Parity, days in milk, monthly average milk yield (MY), milk fat, milk protein, total solid (TS), milk urea nitrogen content (MUN) and SCC were available from the database of the Korean Animal Improvement Association (Seoul, Republic of Korea).

Animal experiment for the model evaluation

To examine the DMI of Holstein lactating cows under more controlled conditions, 24 lactating Holstein cows

Table 2. Chemical composition of individual feed ingredients used in the commercial farm investigation (% of DM unless otherwise stated)

	DM (%)	CP	EE[2]	Ash	NDF	ADF	ADL[3]	NDICP[4]	ADICP[5]
ConcentrateA[1]	89.3	21.7	3.49	4.14	26.9	11.9	3.31	2.87	0.42
ConcentrateB[1]	90.7	16.9	14.3	3.08	20.9	7.00	1.77	1.84	0.27
TMR1-wet[1]	62.0	15.5	5.44	8.51	45.9	33.0	4.66	3.13	0.52
TMR2-wet[1]	71.5	16.2	4.11	4.56	39.3	22.7	6.01	2.96	0.76
TMR3-dry	87.5	12.7	4.52	9.58	54.7	38.7	6.25	1.89	0.47
By-pass fat	95.0	-	98.3	1.00	-	-	-	-	-
Cottonseed	90.4	20.9	18.4	4.13	44.4	34.2	13.4	1.94	1.13
Wheat bran	87.8	16.5	4.01	4.85	41.5	12.3	3.87	3.36	0.65
Beetpulp	87.9	9.89	1.23	6.03	47.8	31.2	2.68	5.80	0.74
Brewers grain (wet)	20.9	22.7	6.65	3.84	33.4	15.8	7.11	9.59	2.75
Alfalfa hay	89.8	18.5	2.13	9.43	42.5	35.3	12.6	3.04	1.36
Oat hay	90.7	7.84	2.49	6.53	57.6	39.1	8.40	1.40	0.58
Orchard grass hay	90.7	8.90	2.70	8.82	60.9	39.7	9.55	3.26	0.61
Klein grass hay	93.1	11.3	1.67	8.77	70.1	41.2	5.46	5.53	1.56
Bermuda grass hay	91.7	9.64	1.90	7.76	66.6	37.2	7.45	4.41	0.97
Tall fescue hay	90.5	6.28	1.03	5.87	63.0	44.1	5.46	5.53	1.56
Timothy hay	91.2	8.20	2.27	7.08	61.7	38.2	5.60	2.50	0.72
Sugarcane	84.4	10.8	2.00	7.00	69.1	41.6	5.90	7.40	1.10
Wheat straw	90.9	3.82	1.57	7.78	74.6	52.8	12.6	2.36	1.84
Rice straw	91.3	4.82	1.46	16.4	63.9	43.3	4.62	1.28	0.29
Corn silage	30.5	8.08	2.77	4.00	52.3	33.7	4.62	1.29	0.64

[1] Chemical composition was estimated at Konkuk University. [2] EE = Ether extract. [3] ADL = Acid detergent lignin. [4] NDICP = Neutral detergent insoluble crude protein. [5] ADICP = Acid detergent insoluble crude protein.

housed on fermented sawdust (Paju Research Farm, Konkuk University, Gyeonggi Province, Republic of Korea) were used in a completely randomised design regardless of lactation cycle. The experiment was conducted for a total of 23 days in February 2005 and also in April to May 2005. For 2 weeks prior to the initiation of the experiment, cows were adapted to individual electronic feeding gates (American Calan Inc., North-wood, NH, USA) and to experimental diets. Animal feed was supplied as a TMR containing commercial dairy concentrates, cracked corn, wheat bran, cottonseed, alfalfa hay, rye straw and Sudan grass silage. The chemical composition of the diets is presented in Table 4. The body weights of the cows were measured on the first and last day of each experimental period and mean values are presented (Table 5). Milking was performed using a tandem parlor system (DeLaval, Sweden) twice a day at 04:00 and 16:00 and milk yields were recorded by in-parlor milk meters (α-Laval, DeLaval, Sweden). The diets were offered at 10:00 and 17:00 in two equal portions at 110% of the previous day's intake level; the refusals were measured the next day at 09:00 and individual feed intake assessed. Observed mean milk yield and milk composition, body weight, parity, BCS, DIM and days pregnant are presented in Table 5.

Environmental conditions

During the collection of commercial farm and animal experimental data, information on average daily temperature, maximum and minimum temperatures, relative humidity and wind speed were available from the Korean Meteorological Administration (Seoul, Republic of Korea). These are presented in Table 3 for the commercial farm survey period and in Table 5 for the controlled experiment.

Chemical analysis

The DM, ash, CP, ether extract (EE), ADF and acid detergent lignin (ADL) contents of the feed samples from both the commercial farm data and the animal experiment were analyzed by Association of Official Analytical Chemists (1990) methods. NDF was analyzed according to the method of Mertens (2002) and neutral detergent insoluble crude protein (NDICP) and acid detergent insoluble crude protein (ADICP) were analyzed according to the methods of Licitra et al. (1996). Milk composition was analyzed using an automatic milk composition analyzer (MilkoScan, System 4300, Foss Electric, Denmark).

Model evaluation, calculation and statistical analysis

The differences between observed and predicted DMI values from the commercial farm survey and the animal experiment were validated by the paired t-test procedure using SAS Software 8.02 version (SAS Institute, 2001). Model evaluation included a rigorous statistical component and in this study two different methods were used to evaluate the accuracy of predicted values. Firstly, a linear regression analysis, which is often used to evaluate predictions regressing actual values on predicted responses. Secondly, root mean square prediction error analysis was

Table 3. Animal performance and chemical composition of milk and diets (in % of DM unless otherwise stated) in the commercial farm investigation

Item	Values[1]
Number of observations	1,177
Animal description	
Body weight (kg)	614±32.7
Parity	2.4±1.51
Body condition score	3.1±0.26
Days in milking	183±115.4
Milk production and its chemical composition	
Yield (kg/d)	31.9±9.01
Fat (%)	4.08±0.623
Protein (%)	3.27±0.367
Urea nitrogen (mg/100 ml)	16.3±3.58
Total solids (%)	8.8±0.41
Somatic cell count (10^3 cells/ml)	104±101.1
Chemical composition of diets (% of DM)	
Dry matter (%)	78.9±6.67
Crude protein	16.4±0.94
Ether extract	3.9±0.31
Ash	5.5±0.59
Non fiber carbohydrate	37.3±1.96
Neutral-detergent fiber	41.0±2.57
Forage NDF	20.2±4.19
Acid detergent fiber	24.5±2.34
Acid detergent lignin	5.6±0.41
Proportion of concentrates	65±6.9
Rumen degradable protein[2]	9.9±0.70
Rumen undegradable protein[2]	6.5±0.61
Net energy lactation[2] (Mcal/kg DM)	1.5±0.04
Environmental conditions	
Mean temperature (°C)	3.3±2.77
Wind speed (km/h)	6.9±0.67
Relative humidity (%)	58±3.6

[1] Mean±standard deviation except for the number of observations.
[2] The values were estimated by NRC nutrient requirements of dairy cattle program (2001, version 1.0).

used, as advocated by some authors (Kohn et al., 1998; Dhanoa et al., 1999; Chaves et al., 2006) who have shown that a measure of how well model predictions fit observed data can be calculated as the root mean square prediction error (RMSPE):

$$\text{RMSPE} = \sqrt{\frac{\sum(\text{predicted - observed})^2}{\text{number of observations}}}$$

This term is the square root of the estimate of variance of observed values about the predicted values. The RMSPE can be partitioned in many different ways to identify systematic problems with models (Kohn et al., 1998) and was divided into two terms in this study: the mean bias and the residual error. The mean bias represents the average inaccuracy of model predictions across all data and the

Table 4. Diet formulation (TMR) and chemical composition of the experimental diet (in % of DM unless otherwise stated) used in the dairy cow experiment

Item	Values
Ingredients (% of total)	
Concentrate[1]	28.9
Corn, cracked	9.6
Wheat bran	6.9
Cotton seed	3.9
Alfalfa hay	10.4
Perennial ryegrass straw	1.7
Sudan grass silage	38.5
Total	100.0
Chemical composition of diets (% of DM)	
Dry matter (%)	62.5
Crude protein	16.4
Ether extract	3.6
Ash	7.9
Non fiber carbohydrate	38.8
Neutral-detergent fiber	36.8
Forage NDF	16.8
Acid detergent fiber	19.5
Acid detergent lignin	5.9
Proportion of concentrates	69.7
Rumen degradable protein[2]	11.4
Rumen undegradable protein[2]	4.9
Net energy lactation[1] (Mcal/kg DM)	1.5

[1] Individual ingredients of concentrate (% of DM): Corn cracked (37), wheat (8.7), Molasses (4), lupinseed (14.8), soybean meal (9), corn gluten meal (3), coconut meal (5), palm meal (3), wheat bran (11), limestone (2.9), dicalcium phosphate (0.5), salt (0.5) and vitamin mixture (0.6).
[2] The values were estimated by NRC nutrient requirements of dairy cattle program (2001, version 1.0).

residual error was defined as the remaining error in model prediction after accounting for the mean bias. The residual error is also referred to as prediction error excluding mean bias.

$$\text{Mean bias} = \frac{\sum(\text{predicted} - \text{observed})}{\text{number of observations}}$$

$$\text{Residual error} = \sqrt{\text{RMSPE}^2 - (\textit{mean}\ \text{bias})^2}$$

As a summary measure of the relative degree of deviation, either mean bias or RMSPE can be used (Chaves et al., 2006).

RESULTS AND DISCUSSION

DMI prediction from the commercial farm investigation

Mean prediction of DMI based on six model simulations compared with actual observed values from the commercial farm surveys with 430 lactating dairy cows are presented in Table 6. The actual mean DMI of 12

Table 5. Animal performance, milk composition and environmental conditions in the dairy cow experiment[1]

Item	Values[2]
Number of observations	548
Animal description	
Body weight (kg)	643±83.0
Body condition score	2.8±0.45
Parity	2.7±1.30
Days in milking (days)	181±77.9
Days in pregnancy (days)	106±26.0
Milk production and its chemical composition	
Yield (kg/d)	29.5±6.31
Fat (%)	3.77±0.810
Protein (%)	3.40±0.299
Urea nitrogen (mg/100 ml)	18.2±2.04
Total solid (%)	13.3±1.63
Somatic cell count (10^3 cells/ml)	215±344.3
Environmental conditions	
Mean temperature (°C)	9.0±9.13
Wind speed (km/h)	9.5±3.26
Relative humidity (%)	59±12.6

[1] Data set was constructed from 24 Holstein lactating cows.
[2] Mean±standard deviation except for the number of observations.

commercial farms over a 6-month period was 24.0 kg/d (±0.10 SE). In general, all models under-predicted mean DMI except for the one proposed by Fuentes-Pila et al. (2003). The CNCPS model (Fox et al., 2003) estimated the DMI at 13% lower than the observed value whilst Fuentes-Pila et al. (2003) most closely predicted the actual DMI when compared with the observed mean value.

When the model evaluation was conducted with the linear regression method, predicted values were significantly correlated with actual values for all models ($p<0.001$, Table 6), although R^2 values varied substantially and were particularly low for the models by Rayburn and Fox (1993) ($R^2 = 0.07$) and Fuentes-Pila et al. (2003) ($R^2 = 0.10$). However, the slopes of the regression lines from all six models were significantly different from the theoretical value of 1.0 and unexplained sources of variation (i.e. high values of RSD) were observed (Table 6). It is common to find in the literature that models relevant to feeding lactating dairy cows are evaluated by regression of observed values against predicted responses (i.e. DMI in the current study, Ingvartsen, 1994). However, the data provided by simple regression analysis can be ambiguous in testing the null hypothesis and lack sensitivity (Mitchell, 1997; Dhanoa et al., 1999; St-Pierre, 2001), and thus are not able to provide a reliable interpretation of these relationships (Chaves et al., 2006). Indeed, regression equations (Table 6) with various ranges of slopes and intercepts larger than zero have little biological meaning, even though they all appeared to be statistically significant.

When model predictions were tested using measures of deviation, mean bias was significantly different from zero for DMI for all models proposed (Table 6), suggesting that model predictions were not as accurate as expected. In Table 6, residual error terms represent the error in prediction after accounting for the mean bias (see Materials and Methods) and this was highest with the model by Fuentes-Pila et al. (2003), although the mean bias was the least for this model among the six models employed. However, despite a larger mean bias, the residual error was relatively small in the model prediction of the CNCPS (Fox et al., 2003).

DMI prediction from the dairy cow experiment

Table 7 shows the observed and predicted DMI values from the dairy cow experiment conducted in the Konkuk University Research Farm. The actual mean DMI was 25.7

Table 6. Comparison between the observed and predicted dry matter intakes investigated during the commercial farms survey evaluated by six different models

Model	Observed ±SE[1]	Predicted ±SE[1]	Linear regression method: Intercept ±SE	Slope ±SE	RSD[3]	R^2	p	RMSPE method: Mean bias[4]	Residual error[5]	RMSPE[6]	p[7]
Brown et al. (1977)	24.0 ±0.10	23.4 ±0.08	9.74 ±0.470	0.57 ±0.019	2.20	0.42	***	-0.65	2.62	2.70	***
Rayburn and Fox (1993)	24.0 ±0.10	22.8 ±0.08	17.55 ±0.541	0.22 ±0.022	2.53	0.07	***	-1.29	3.62	3.85	***
AFFRCS (1999)	24.0 ±0.10	21.2 ±0.10	3.19 ±0.474	0.75 ±0.020	2.22	0.56	***	-2.81	2.37	3.68	***
NRC (2001)	24.0 ±0.10	22.6 ±0.09	10.28 ±0.548	0.51 ±0.023	2.56	0.30	***	-1.43	3.03	3.35	***
CNCPS (Fox et al., 2003)	24.0 ±0.10	20.8 ±0.08	7.88 ±0.445	0.54 ±0.018	2.08	0.42	***	-3.20	2.58	4.11	***
Fuentes-Pila et al. (2003)	24.0 ±0.10	24.3 ±0.09	16.97 ±0.629	0.30 ±0.026	2.94	0.10	***	0.22	3.74	3.74	*

[1] Mean value±standard error (SE). [2] R^2 = Adjusted R square. [3] Residual standard deviation.
[4] Mean predicted minus mean actual. [5] Model prediction excluding that due to the mean bias. [6] Root mean square prediction error.
[7] *, ** and *** for $p<0.05$, $p<0.01$ and $p<0.001$, respectively.

Table 7. Comparison between the observed and predicted dry matter intakes in the controlled animal experiment evaluated by six different models

Model	Observed ±SE[1]	Predicted ±SE[1]	Linear regression method: Intercept ±SE	Slope ±SE	RSD[3]	R^2	p	RMSPE method: Mean bias[4]	Residual error[5]	RMSPE[6]	p[7]
Brown et al. (1977)	25.7 ±0.19	22.0 ±0.11	14.38 ±0.552	0.29 ±0.021	2.15	0.26	***	-3.74	3.74	5.29	***
Rayburn and Fox (1993)	25.7 ±0.19	23.1 ±0.12	14.01 ±0.637	0.35 ±0.024	2.48	0.28	***	-2.60	3.74	4.56	***
AFFRCS (1999)	25.7 ±0.19	20.4 ±0.12	11.89 ±0.634	0.33 ±0.024	2.47	0.25	***	-5.30	3.81	6.53	***
NRC (2001)	25.7 ±0.19	22.5 ±0.12	13.18 ±0.605	0.36 ±0.023	2.36	0.31	***	-3.20	3.63	4.84	***
CNCPS (Fox et al., 2003)	25.7 ±0.19	19.9 ±0.16	11.84 ±0.878	0.32 ±0.034	3.42	0.14	***	-5.76	4.53	7.32	***
Fuentes-Pila et al. (2003)	25.7 ±0.19	24.9 ±0.17	12.34 ±0.854	0.49 ±0.033	3.33	0.29	***	-0.82	4.00	4.08	***

[1] Mean value±standard error (SE). [2] R^2 = Adjusted R square. [3] Residual standard deviation.
[4] Mean predicted minus mean actual. [5] Model prediction excluding that due to the mean bias. [6] Root mean square prediction error.
[7] *, ** and *** for p<0.05, p<0.01 and p<0.001, respectively.

kg/day (±0.19 SE). As seen in the previous commercial farm dataset, wide variation existed in the predicted DMI values, ranging from 19.9 to 24.9 kg/day, and all models again under-predicted observed DMI. The mean value predicted by Fuentes-Pila et al. (2003) was the closest to the actual DMI value, whilst there was some 22% difference between observed and predicted value by the CNCPS model (Fox et al., 2003). Although linear regression analyses of observed against predicted values were all significant (p<0.001), interpretation of the results was rather unreliable due to the low R^2 values, explaining only limited variation in DMI (Table 7). The RMSPE analysis provided more accurate interpretation of the predicted values; for example, as a component by RMSPE analysis, mean bias from all six models were statistically significant from zero, again indicating the inaccuracy of all of the models (Table 7). Interestingly, unlike in the commercial farm survey the CNCPS model (Fox et al., 2003) expressed the greatest residual error (4.53) among the six models, showing the existence of some potential error even after accounting for mean bias.

Apart from those used in the current study, numerous other models have been recommended in the literature for the accurate prediction of DMI in the ruminant animal (see review by Ingvartsen, 1994). Many of these models were developed based on single or multiple regression techniques using empirical data, which made it difficult to improve the accuracy unless a new set of data became available (Ingvartsen, 1994; Forbes, 1995). Ingvartsen (1994) in a substantial review of DMI prediction concluded that animal and food factors (especially parity, stage of lactation, and an expression of live weight, i.e. metabolic live weight) should be more carefully considered to make better predictions. Some reported energy-corrected milk yield rather than milk yield as the primary factor in their DMI prediction equation (Mazumder and Kumagai, 2006) whilst others suggested that introduction of lipostatic feedback mechanisms into the prediction equation should improve body weight and DMI prediction (Ellis et al., 2006). Without doubt, the major reason for this interest is the impact that feed intake has on animal performance.

Of all six models, the model proposed by Fuentes-Pila et al. (2003) predicted DMI closely on both the commercial farm investigation and the dairy cow experiment. One possible reason could be the consideration of the function of individual feedstuffs with regards to effective NDF and/or ADF consumption by dairy cows as also seen in the equation by Brown et al. (1977). Many researchers suggested that NDF could be the most important factor to estimate the range of DMI as it is a major factor in gut-fill (Waldo, 1986; Mertens, 1994). Mertens (1997) also summarized the importance of NDF in the dairy ration in relation to animal health and performance especially, where the ratios of forage:concentrate are concerned. Thus, inclusion of NDF (and/or ADF) as a factor to estimate DMI may improve the accuracy of the model. It should be noted that the larger residual error of this model prediction compared with those from the other models (Tables 6 and 7) would suggest that accurate prediction of mean values does not necessarily demonstrate good predictability in the current study (Chaves et al., 2006).

On the other hand, a poor prediction in terms of mean bias by the CNCPS model (Fox et al., 2003) was notable, and perhaps unexpected as this equation has been evaluated frequently and robustly, and widely adopted in many other countries (i.e. Chiou et al., 2006) as a feeding standard for animal production. Chaves et al. (2006) discussed that there might be potential to predict DMI inaccurately with a model such as CNCPS as it is a requirement system, not a response system, of which the distinctiveness was further reviewed in the study of St-Pierre and Thraen (1999). For instance, DMI prediction is based on the input of milk production, of which the level and the composition are used to calculate the energy and nutrients required. However, factors that affect production responses such as feeding value and animal responses are not accounted for in the model (i.e. Sunagawa et al., 2007), and inability to explain nutrient partitioning between the various productive processes can be attributed to poor DMI prediction (Chaves et al., 2006). Lanzas et al. (2007) proposed that inclusion of dietary factors in DMI prediction is necessary in their recent revision for CNCPS feed carbohydrate fractionation scheme for formulating rations for ruminants. Instead, the results predicted by the AFFRCS (1999) model in Table 6 showed the least residual error, indicating better predictability in terms of DMI, although mean bias from both evaluations were relatively large.

In the present study, we did not compare high concentrate-based diets with forage-based ones in DMI prediction. However, it is also speculated that feeding more than 65% of concentrate is not that common, especially in Western European countries where a forage-based feeding system, either fresh or conserved, plays an important role in the dairy production system. Hence, we suggest that high concentrate-based feeding systems might contribute towards bias to predict DMI with chosen models in this study.

Further research is needed to identify the issues raised above and much attention has to be paid to developing a modified or new model to predict DMI more accurately for lactating dairy cows reared in Asian countries. As a consequence of variation in individual feedstuffs, which are often caused by constraints in cereal trading and also the use of locally-produced agricultural by-products, an accurate estimation of DMI will always be a challenging task. To achieve this goal, more mechanistic approaches, rather than simple empirical associations, are recommended for investigating diet and animal interactions under non-standard environmental conditions, animals or feeds (Kohn et al., 1998; Martin and Sauvant, 2007). Any improvement will help producers to achieve productivity and profitability goals and, in the end, will contribute to the overall efficiency and sustainability of the ruminant agricultural industry especially in Asian countries.

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