ADVANCES IN THE MEASUREMENT OF METABOLIZABLE ENERGY IN POULTRY FEEDSTUFFS

D. J. Farrell,* E. Thomson*, K. du Preez** and J. P. Hayes**

SUMMARY

Four different methods (Dual Semi-quick (DSQ), Conventional and Sibbald's and Farrell's rapid) were used to measure in adult roosters the apparent metabolizable energy (AME) and true metabolizable energy (TME) of 4 corn-based diets with bran inclusions of 0-60%. Daily food intakes were 75g (or ad libitum), 35g and 10g. AME values were not different at the two highest levels of intake between the DSQ, Conventional and Farrell methods, but were depressed at 10g. Sibbald's method often gave lower values than other methods particularly at the lowest intake. The linear relationships between food intake and excreta energy yielded intercept values of 14 to 38 kJ/d for 3 methods, but Sibbald's yielded much higher intercepts. A linear model may not be the most appropriate fit to the data. Removal of the lowest food intakes yielded linear regression equations with zero intercept values for the two continuous feeding methods, i.e. there was no endogenous excreta (EEL). For the two methods using a single feed input of feed intercepts were always positive. This helps to explain why Hartel (1986) observed no EEL using a continuous feeding method. Correction to AME for endogenous and metabolic excreta to obtain TME tended to increase values for all diets with decreasing level of intake. For Sibbald's method TME values were independent of level of feeding but there was wide variation among the data. The effect of correcting AME to nitrogen balance was to give AME_n values that were more consistent between diets and reduced differences between methods. For the Conventional method differences between the 3 levels of intake on all diets were removed. There is reason to be concerned about the many different ME values obtained using the Sibbald method compared to the three other methods and the basis for correcting for endogenous excreta. It is concluded that because of the uncertainty of EEL values and their variation due to circumstances the AME system should be retained.

INTRCDUCTION

There has been considerable debate on the relative merits of current methods used to measure the metabolizable energy (ME) of poultry feedstuffs (see Farrell 1981, 1982, 1987; McNab and Fisher 1982; Sibbald 1982, 1985; Fisher 1987). This has stemmed, in part from the validity of measuring, in a true metabolizable energy (TME) assay (Sibbald 1976), the endogenous unrinary and metabolic faecal excreta (EEL) of starved birds, then using the mean value obtained to correct for EEL of fed birds (du Preez et al. 1981; Farrell 1981). As a consequence of this debate there has been much recent research compiled by Sibbald (1986) on the measurement of the ME of poultry feedstuffs and diets.

A recent study by Hartel (1986) has cast some doubt on the existence of endogenous excreta voided by continuously-fed birds. Unpublished (C. Fisher personal communication, 1987) and published work (Johnson 1987) appear to support Hartel's findings. This has raised questions about the basis of the TME assay (Sibbald 1976) in which EEL is measured in starved birds in order

*Department of Biochemistry, Microbiology & Nutrition, University of New England, Armidale NSW 2351, Australia

**Department of Poultry Science, Stellenbosch University, Stellenbosch 7600, Republic of South Africa

to correct these components in similar birds force-fed small amounts of a feedstuff. Hartel (1986) concluded that in continuously-fed birds the AME and TME values of a feedstuff must be the same. Recent correspondence in British Poultry Science between Sibbald and Wolynetz (1987) and Hartel (1987) has done little to clarify the situation. However, Dale (1988), in a survey of ME data found that for maize and soybean meal average values for AME_n and TME_n, determined at the University of Georgia and by Agriculture Canada were the same and identical to those used by the poultry industry in the United States.

There are several assays used to measure the ME of a feedstuff; these range from the conventional method (Hill and Anderson 1958; Sibbald and Slinger 1963) to rapid methods (Sibbald 1976; Farrell 1978) and a semi-rapid method (Du Preez et al. 1986). Some of these methods use birds that have been starved prior to feeding, while in others the birds are fed continuously.

Age of bird is another confounding factor. It has been shown by Mollah et al (1983) and Johnson (1987) that adult birds generally give a significantly higher ME value than young chickens offered the same diet or ingredient. For example, Farrell et al (1988) measured the apparent metabolizable energy (AME) of 13 samples of wheat with chickens and adult roosters and reported a nitrogen (n) corrected mean AME_n of 13.35 $\pm$ 0.08 MJ/kg for chickens. This was lower ($P<0.05$) than 13.92 $\pm$ 0.07 MJ/kg for cockerels. A sample of feather meal gave substantially higher ME values for adult cockerels than for chickens (Pesti et al. 1988a).

The purpose of the present study was to compare four methods of measuring ME, and to determine if endogenous excreta is an artefact related to method of determination. If endogenous excreta does exist, is it influenced by the nature of the diet and by feeding level?

MATERIALS AND METHODS

Adult cockerels (Amber Link) weighing about 3.3 kg (range 2.8-3.8) were used throughout the study. Five birds were offered one of four diets in which 0, 20, 40 or 60% wheat bran was added to a basal diet of 98% corn and 2% minerals and vitamins.

There were three nominal levels of feeding, ad libitum, 35 and 10 g/d. In the rapid method (Farrell 1978) and TME method (Sibbald 1986) birds were offered 75g of feed, or forcefed that amount in three portions over 2h (TME) rather than fed ad libitum.

The four methods of measurement were:

1. the Conventional method in which birds were accustomed to the diet and level of feeding for 4d, then a total collection of excreta was made for the next 5d;

2. the Dual Semi-quick (DSQ) method of Du Preez et al (1986) in which the birds were starved for 16h and then accustomed to the diet and level of feeding for 1d followed by a total collection of excreta for 3d;

3. the TME method followed the procedure outlined by Sibbald (1986);

4. the Rapid method of Farrell (1977, 1978) with modifications (D.J. Farrell and A. Choice unpublished results), in which birds, trained to consume their daily, cold-pelleted feed allowance in 1 h, were starved for 32 h then given a fixed amount of feed. Excreta were collected for the next 42h.

The design of the experiment was 4 methods x 4 diets x 3 levels of intake using 5 birds per treatment. Data were analysed using analysis of variance and regression analysis. Differences between means were tested the Least Significance Test (LSD) (Steel and Torrie 1960).

Endogenous excreta were determined on 5 starved birds, each force-fed 30g/d of dextrose, and excreta collected for 48h. Excreta were dried in a forced-draft oven at 70°C for 24h. Gross energy and nitrogen (N) content of finely-milled feed and excreta were determined in an automatic bomb calorimeter (Digital Data Systems CP500) and using a macro Kjeldahl procedure, respectively. Correction of ME values to N balance were based on a factor of 36.5 MJ/kg N.

To determine if the relationship between excreta energy and food intake is linear, 16 individual starved crossbred cockerels were fed a commercial crumbled, layer diet in increasing amounts from 5 to 65g per bird. Excreta were collected for the next 42h.

RESULTS

Daily EEL loss of the birds receiving dextrose was on average 54 kJ/per bird, and endogenous N loss was 0.773g/bird. The values are similar to those reported by Dale and Fuller (1984) and Askbrant (1988) and were used to make the appropriate corrections from apparent to true ME values and to N equilibrium for TME_n. For the Farrell method, excreta collection was for 42h post feeding. Correction for EEL was adjusted accordingly where necessary.

TABLE1 Overall means (MJ/kg)

Method	AME	AME_n	TME	TME_n
DSQ	11.64	12.19	13.86	13.25
Conventional	11.37	12.09	13.66	13.15
Sibbald	9.06	10.56	14.17	13.00
Farrell	11.49	11.80	15.44	13.69
LSD (P<0.05)	0.221	0.185	0.219	0.177
Diet				
1	12.44	13.17	15.96	14.76
2	11.18	11.93	14.58	13.55
3	10.57	11.29	13.95	12.91
4	9.39	10.25	12.82	11.86
LSD (P<0.05)	0.221	0.185	0.219	0.177
Intake (g/d)				
75 (or ad lib)	12.24	12.19	13.23	12.66
35	11.73	12.13	13.96	13.17
10	8.71	10.66	15.85	13.98
LSD (P<0.05)	0.191	0.160	0.190	0.153

The crude protein (%) contents were 9.5, 10.4, 10.8 and 11.9 for Diets 1, 2, 3 and 4 respectively. Birds force-fed 75g of diet or trained to consume their feed allowance in one hour achieved these intakes on all diets. Birds on methods (DSQ and Conventional) that allowed unrestricted intakes consumed more than the nominal 75g/d particularly on diets with the lower inclusions of, or no wheat bran. Analysis of variance showed that there was a' significant ($P<0.01$) difference among the 48 treatments of 5 birds. Shown in Table 1 are the main effects and individual means in Table 2. ME values are on an 'as fed' basis.

There were highly significant ($P<0.01$) effects of assay method, diet and level of feeding. There were significant interactions ($P<0.01$) between assay method x diet, assay method x level of feeding, and diet x level of feeding for each of the four energy systems used.

As would be expected, with increasing amounts of wheat bran in the diet, ME values declined (Table 1). At the highest level, feed intake was always maintained above 70g/d per bird even when the diet contained 60% wheat bran. For DSQ, Conventional and Farrell methods mean AME and TME , values were in excellent agreement (Table 1). Values for TME and TME increased within a diet with decreasing food intake on the two single feeding methods. ME values for diets, methods and systems are given in Table 2.

Apparent metabolizable energy

For the Conventional, DSQ and Farrell methods, generally there was no difference ($P>0.05$) in AME values at the two highest levels of intake on the 4 diets, On Diets 2-4, for the three intakes using Sibbald's method, values declined significantly as feed intake declined. At the 10g/d intakes, AME values were consistently reduced ($P<0.05$) irrespective of method of measurement.

Variation among replicate birds tended to increase as the inclusion of bran increased, and as the level of feeding declined. At the two lowest levels of intake, Sibbald's AME values were generally lower than those for other methods and they were substantially lower at 10g/d with high variation among birds. Diet 4, at 10g/d, yielded an AME value of 0.86 MJ/kg using Sibbald's method compared to 8-9 MJ/kg with other methods. As indicated by high SEM there was much variation at the lowest level of feed intake (10g/d). This probably reflected the high and variable EEL among birds. The decline in AME values was much more noticeable with Sibbald's method and at the lowest intakes, these values were unusually low even compared with Farrell's values.

True metabolizable energy

The correction to AME for EEL was, with minor exceptions, to increase values for all diets with decreasing level of intake. Substantial increases were observed at 10g/d intakes using the Farrell method, and to a lesser extent using the Sibbald method. The majority of increases were significant ($P<0.05$) on the former method but generally not so on the latter, mainly due to high variation among birds. There were some noticeable differences between assay methods; Farrell's method tended to give values significantly higher than others at the same feed intake.

Apparent metabolizable energy corrected to nitrogen balance

The overall result was to reduce differences within diets due to level of feeding, At the two higher feed intakes. AME values were reduced or unchanged compared to corresponding AME values, while at the low intake values were increased. But this depended to some extent on the diet, since crude protein increased gradually from Diet 1 to Diet 4. For Sibbald's

TABLE 2 Metabolizable energy (+SEM) of four diets measured using two ME systems corrected to nitrogen equilibrum or not and using four assay methods.

	Intake (g/d)	Apparent metabolizable energy system			
		DSQ	Conventional	Sibbald	Farrell
Diet 1 (0% bran)	75	13.86	13.58	13.25	13.85
	35	13.77	13.31	12.38	13.41
	10	10.99	11.18	7.72	11.96
Diet 2 (20% bran)	75	12.62	12.78	12.27	12.86
	35	12.60	12.29	10.58	12.10
	10	10.78	10.35	5.20	9.73
Diet 3 (40% bran)	75	12.36	11.54	11.43	12.04
	35	12.03	11.75	9.74	11.61
	10	9.76	9.91	5.49	9.16
Diet 4 (60% bran)	75	11.07	10.52	10.53	11.32
	35	11.30	10.84	9.31	10.67
	10	8.56	8.44	0.86	9.22
LSD = 0.765 (P<0.05)					
		True metabolizable energy system			
Diet 1 (0% bran)	75	14.45	14.14	14.69	15.04
	35	15.29	14.87	15.46	16.07
	10	15.36	15.86	18.52	19.39
Diet 2 (20% bran)	75	13.30	13.33	13.71	14.12
	35	14.10	13.86	13.67	14.96
	10	15.25	14.98	16.00	17.68
Diet 3 (40% bran)	75	13.03	12.14	12.87	13.26
	35	13.54	13.36	12.82	14.26
	10	14.23	14.58	16.29	17.05
Diet 4 (60% bran)	75	11.83	11.16	11.97	12.60
	35	12.84	12.42	12.39	13.45
	10	13.06	13.20	11.66	17.34
LSD = 0.759 (P<0.05)					
		Apparent metabolizable energy system corrected to AMEn			
Diet 1 (0% bran)	75	13.74	13.48	13.42	13.72
	35	13.90	13.55	13.20	13.44
	10	12.88	12.81	11.18	12.91
Diet 2 (20% bran)	75	12.50	12.63	12.36	12.75
	35	12.70	12.74	11.51	12.36
	10	12.07	12.32	8.50	10.74
Diet 3 (40% bran)	75	12.29	11.44	11.50	11.91
	35	12.50	11.97	10.52	11.65
	10	11.08	11.50	8.85	10.32
Diet 4 (60% bran)	75	11.06	10.51	10.67	11.16
	35	11.47	11.52	10.10	10.86
	10	10.13	10.60	4.93	10.03
LSD = 0.641 (P<0.05)					
		True Metabolizable Energy System corrected to TMEn			
Diet 1 (0% bran)	75	14.01	13.74	14.12	14.28
	35	14.63	14.31	14.68	14.71
	10	14.97	15.04	16.33	16.26
Diet 2 (20% bran)	75	12.81	12.88	13.05	13.35
	35	13.43	13.49	12.98	13.74
	10	14.21	14.53	13.66	15.54
Diet 3 (40% bran)	75	12.60	11.72	12.19	12.48
	35	13.22	12.74	12.00	12.93
	10	13.21	13.73	14.00	14.09
Diet 4 (60% bran)	75	11.43	10.81	11.36	11.76
	35	12.22	11.87	11.57	12.18
	10	12.26	12.87	10.08	13.91
LSD = 0.612 (P<0.05)					

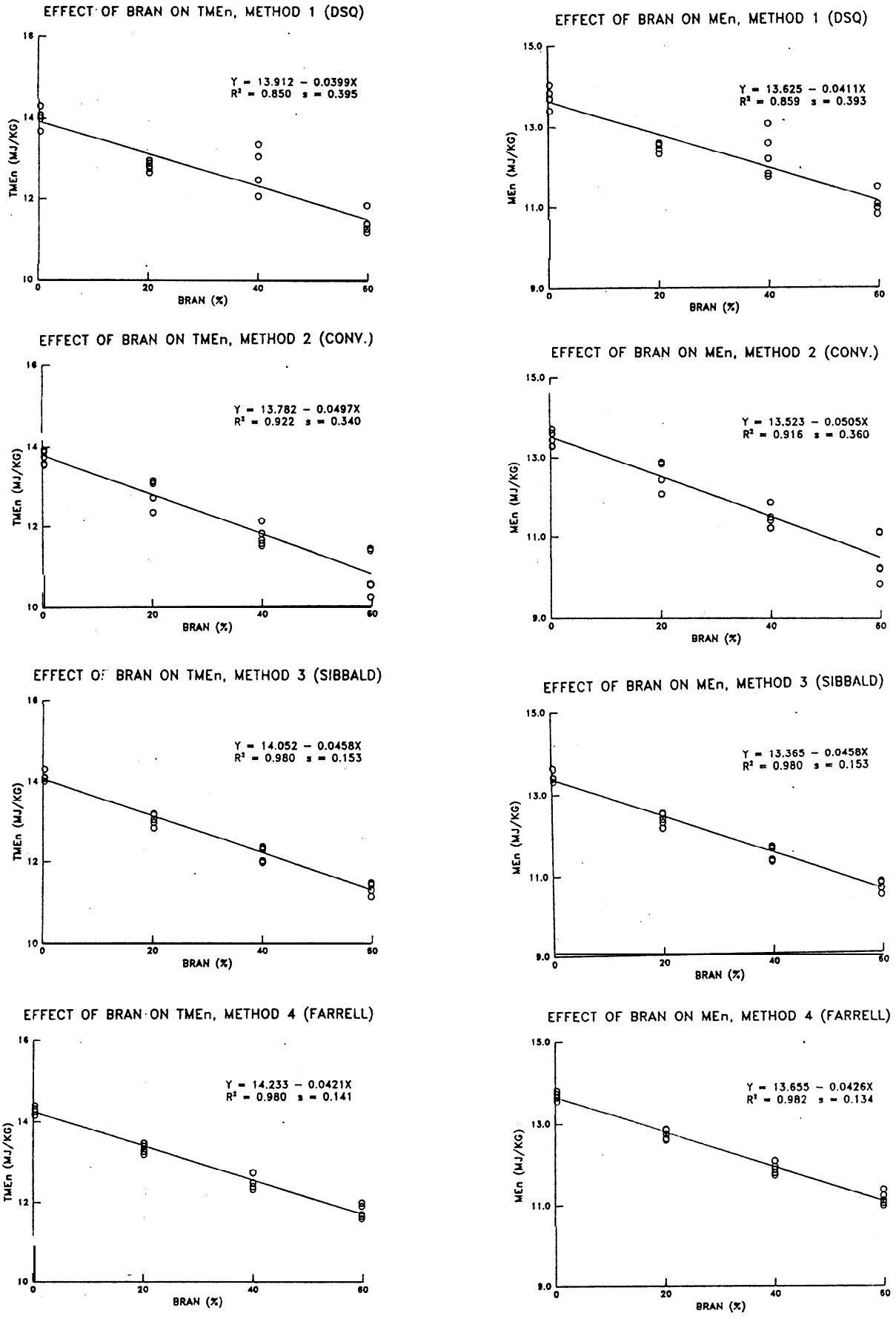

Fig. 1 Examples of relationships between TME$_n$ or ME$_n$ (MJ/kg) and bran (%) inclusion in the diet. Values for bran and the basal diet are given for all four assay methods in Table 3.

method, correction to N balance consistently increased AME_n values compared to AME, and differences due to level of feeding were reduced.

True metabolizable energy corrected to nitrogen balance

Correction to N balance was according to Sibbald (1982). Mean daily N excretion was unusually high at 0.773 g but so too was the liveweight of the roosters used here. Compared with TME, values for TME_n were consistently reduced, and there was a tendency towards fewer significant differences between assay methods and means. For the Sibbald method there were differences ($P<0.05$) between level of feeding for Diet 3 only, but for Farrell's method N correction did not reduce differences between diets to any extent compared with corresponding TME values. For the two continuous feeding methods differences between diets persisted.

Significant ($P<0.01$) regression equations were computed relating energy concentration (MJ/kg) and wheat bran content (%) of the diet at the two highest levels of intake for the four system. This allowed calculation of ME values for the basal diet (0g bran/kg diet) and for bran at a calculated inclusion of 1000g of bran/kg diet. Data are given in Table 3. Again there was a tendency for TME and TME_n values to be higher for the 35g/d intakes than for the 75g or ad libitum intakes irrespective of method. The lower level of feeding did not geneally depress AME or AME_n values for the continuous feeding methods. Examples of these relationships are shown in Fig. 1.

TABLE 3 Calculated energy values for bran and maize using regression analysis of energy concentration (MJ/kg) and level of bran inclusion in the diet (%) at the two highest feeding levels.

Ingredient	intake (g/d)	DSQ	Conventional	Sibbald	Farrell
			Apparent Metabolizable energy		
Maize	75 or ad libitum	13.8	13.7	13.2	13.7
	35	13.6	13.2	12.0	13.3
Bran	75 or ad libitum	9.5	8.4	8.7	9.6
	35	9.6	9.3	7.1	8.9
			True metabolizable energy		
Maize	75 or ad libitum	14.4	14.2	14.7	15.0
	35	15.1	14.8	15.1	16.0
Bran	75 or ad libitum	10.3	9.1	10.2	10.8
	35	11.2	10.9	10.1	11.7
			Apparent metabolizable energy corrected to AME_n		
Maize	75 or ad libitum	13.6	13.5	13.4	13.7
	35	13.8	13.5	12.9	13.4
Bran	75 or ad libitum	9.5	8.4	8.8	9.4
	35	9.7	10.0	7.7	9.2
			True metabolizable energy corrected to TME_n		
Maize	75 or ad libitum	13.9	13.8	14.0	14.2
	35	14.5	14.3	14.4	14.7
Bran	75 or ad libitum	9.9	8.8	9.5	10.0
	35	10.8	10.3	9.2	10.5

Shown in Table 4 are linear regression equations relating feed intake and excreta output. The intercept values (EEL) are all positive and reasonably consistent between DSQ, Conventional and Farrell methods. There does not appear to be a consistent effect of diet on EEL. In 3 out of 4 of the diets for the DSQ, Conventional and Sibbald methods the linear model was not the most significant ($P<0.05$) fit to the data.

Endogenous excreta were calculated by dividing the intercept values by the number of days the birds were offered food or force-fed (Table 4). However it could be argued that for the Sibbald method the intercept values should be divided by 2 because collection was made over two days and by 1.75 for the Farrell method. These values are also given in Table 4. Since intakes at the two lower levels were more or less fixed at 10g and 35g/day, these regressions may not be the most appropriate to test for non linearity. Values obtained using the Sibbald method gave higher EEL than the other three methods even when adjusted to a daily basis. This was in part due to the fact that on diet 4 at 10g intake, roosters were often voiding 8 to 10g of dry excreta per bird. This would tend to increase substantially the intercept value. Coefficients for X for each diet increased consistently with increasing bran inclusion (1 to 4), and for each diet there is reasonable agreement among methods (Table 4).

TABLE 4 Regression of feed intake (X, g) and excreta energy (Y, kJ) using all 15 observations for each equation

	Equation	R^2	RSD	Endogenous excreta		
DSQ	Diet 1 Y = 93.7 + 1.96X,	0.941,	54.5	31.2*		(1)
	Diet 2 Y = 60.3 + 3.64X,	0.991,	31.9	20.1		(2)
	Diet 3 Y = 84.7 + 3.93X,	0.967,	73.3	28.2		(3)
	Diet 4 Y = 73.8 + 5.30X,	0.989,	44.9	24.6		(4)
Conven-	Diet 1 Y = 143.0 + 2.29X,	0.977,	70.0	28.6		(5)
tional	Diet 2 Y = 159.0 + 3.42X,	0.977,	103.4	31.8		(6)
	Diet 3 Y = 63.2 + 4.85X,	0.990,	92.2	12.6		(7)
	Diet 4 Y = 98.0 + 5.91X,	0.978,	176.1	19.6		(8)
Sibbald	Diet 1 Y = 62.5 + 2.12X,	0.951,	13.8	62.5	31.3**	(9)
	Diet 2 Y = 88.2 + 3.16X,	0.964,	17.6	88.2	44.1	(10)
	Diet 3 Y = 78.2 + 4.19X,	0.986,	14.6	78.2	39.1	(11)
	Diet 4 Y = 104.5 + 4.83X,	0.990,	14.2	104.5	52.2	(12)
Farrell	Diet 1 Y = 28.9 + 2.00X,	0.978,	8.8	28.9	16.5	(13)
	Diet 2 Y = 44.5 + 3.09X,	0.968,	15.9	44.5	25.4	(14)
	Diet 3 Y = 37.6 + 4.04X,	0.994,	9.1	37.6	21.5	(15)
	Diet 4 Y = 31.9 + 5.07X,	0.996,	8.8	31.9	18.2	(16)

*kJ/bird per day on feed. **Corrected to number of days during which excreta were collected.

Shown in Fig. 2A is the result of feeding a standard layer diet in incremental amounts of approximately 5g to 65g per bird. There was a significant improvement in RSD and coefficient of determination (R^2) when a

cubic relationship ($P<0.025$) was fitted to the data. Compared to a linear fit R^2 increased from 0.96 to 0.98 and RSD was reduced from 11.9 to 9.8.

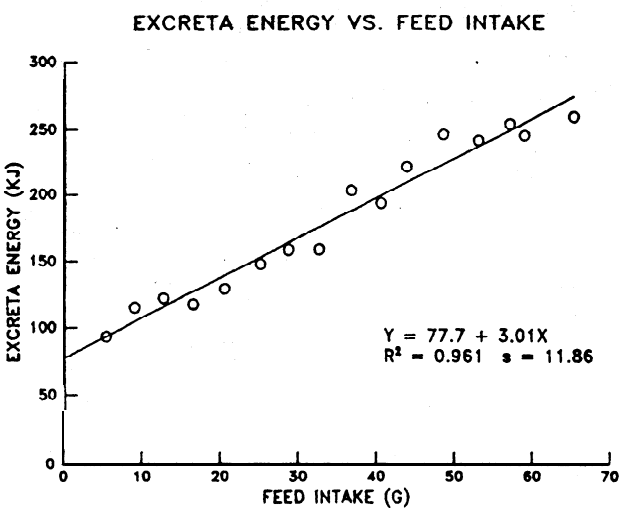

Fig. 2A The linear relationship between excreta energy (y) and food intake (x)

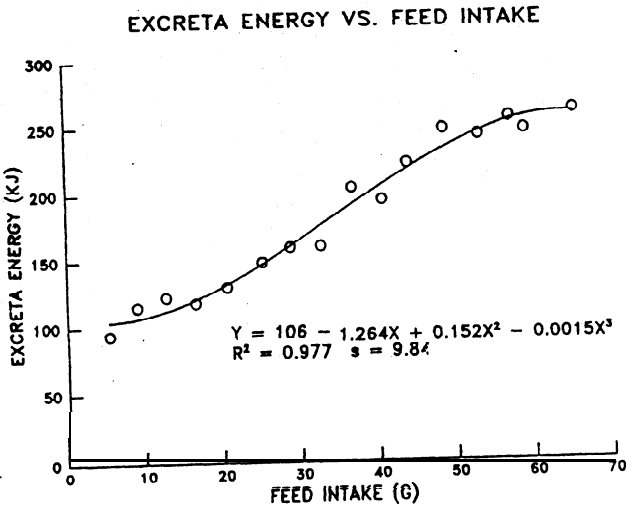

Fig. 2B The quadratic relationship between excreta energy (y) and food intake (x)

In the present study, the relationships between AME and food intake was asymptotic for the DSQ and Conventional methods, although variation about the line tended to increase with increasing concentrations of bran inclusion. The curves for the four diets had the same shape ($P>0.05$) but different displacements ($P<0.05$). A constant value was normally reached at an intake of about 35g/day.

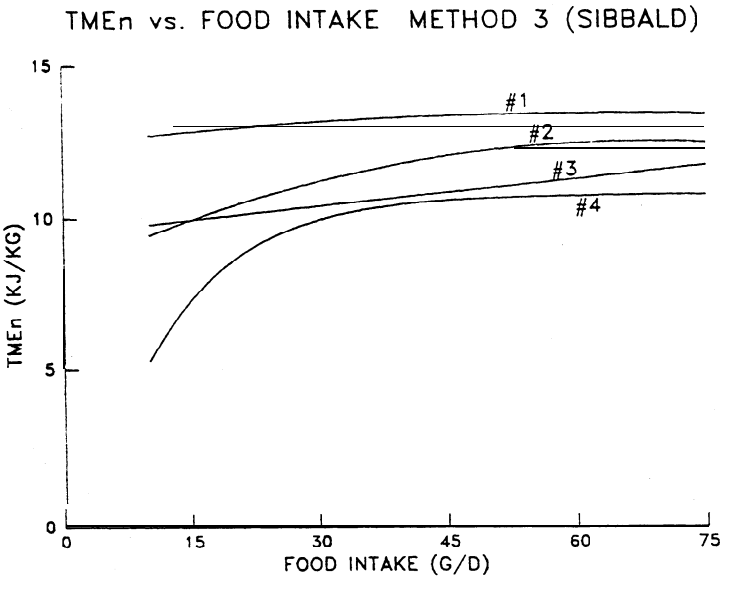

Fig. 3 The relationship between TME_n (Y) and food intake (X) of the four diets (1-4) using Sibbald's assay method. Equation for

Diet 1 is $Y = 11.0 + 0.092\ X - 0.00079\ X^2$, RSD = 1.15, $R^2 = 0.32$

Diet 2 is $Y = 8.3 + 0.124\ X - 0.00091\ X^2$, RSD = 0.63, $R^2 = 0.83$

Diet 3 is $Y = 9.2 + 0.0521\ X - 0.00026\ X^2$, RSD = 0.47, $R^2 = 0.79$

Diet 4 is $Y = 10.8 - 14.10e^{-0.09395X}$, RSD = 0.65

For TMEn a constant value was not observed that was independent of intake (Fig. 3). This occurred irrespective of method. There was generally an increase in values with increasing food intake but diet 4 reached a constant value. At the lowest level of intake values tended to vary greatly. A similar decline in TME values with increasing level of intake was reported for broiler chickens by Johnson and Eason (1986).

DISCUSSION

A pleasing feature of these results is the consistent AME and AME_n values between the DSQ, Conventional and Farrell methods, irrespective of diet or feed consumption (see also Longe and Tona 1988). Criticism has been levelled at the Farrell method (Jonsson and McNab 1983; Sibbald 1985) because several workers were unable to obtain satisfactory feed intakes, consequently AME values were depressed. Had these workers (Schang and Hamilton 1982) trained their roosters to consume their daily maintenance feed allowance according to recommendations in the original procedure and pelleted the experimental diets (Farrell 1977; 1978), such difficulties would probably not have arisen. In the present experiment, training of birds took up to 6 weeks (the normal time), and birds consumed all feed offered irrespective of diet. Expertise, within the two research groups in the use of the various methods for determining metabolizable energy was combined here.

The good agreement for AME and AMEn for each diet across assay methods (Table 2) suggests that all of the excreta were collected from birds irrespective of method. Thus collection time on the single feeding methods was adequate.

Furthermore, using adult cockerels and at the two highest levels of intake, correction to AME_n for the DSQ, Conventional and Farrell methods seems to be unwarranted (Tables 2 and 3). It is our contention that correction to nitrogen equilibruim is not necessary (see Farrell 1981; 1982). Although Sibbald and Morse (1983) argued that such a correction was important to reduce variation, McNab and Blair (1988) report that it seldom improved the precision of their assay. In the present study nitrogen correction reduced only marginally variation as indicated by LSD values (Table 2) . The additional time and expense of undertaking nitrogen analysis detracts from the original concept of a low-cost rapid ME assay (Sibbald 1976; Farrell 1978).

Values calculated for the maize and bran (Table 3) using regression analysis also underpin the reliability of AME and AMEn although the Sibbald's method tended to yield lower values at intakes of 35g/d. Using this method of calculation, TME and TMEn also provided similar values across methods at each level of intake. However the consistent increase in mean TME and TME_n with decreasing food intake (Table 1) again indicates that EEL is not independent of level of feeding.

Theoretically, the relationship between AME (Y,MJ/kg) and food intake (x,g/day) is of the form $Y = A + BR^x$ where $R = e^{-(-k)}$ (Guillaume and Summers 1970; Sibbald 1975). The basis of this relationship is that at low intakes EEL makes a disproportionate contribution to excreta voided thereby depressing AME and AMEn values for the same ingredient (Table 1). Only at high intakes are AME values relatively constant. Correction to excreta voided for EEL should give a constant ME irrespective of amount of feed consumed. The underlying assumption is that EEL is independent of the feed and a single

correction value may be applied at all levels of intake. It is clear that at intakes of 10g/day and irrespective of diet,, both AME and AME_n values were depressed using Sibbald's method even compared with Farrell's method (Table 2). Correction for EEL to these diets gave consistently elevated TME and TME_n values with decreasing intake on all methods but it was less consistent using Sibbalds' method. This indicates that EEL may be influenced by the nature of the diet (Tanesaca and Sell 1981; Siriwan et. al. 1989) and by level of intake (Table 1) as suggested by Farrell (1981) and found by Hartel (1986) (see his Table 16). This supports the contention that a single correction value for EEL is not appropriate, Recently McNab and Blair (1988) have recommended force-feeding 50g of food per adult cockerel.

A basic assumption in the TME assay is that the relationship between feed intake and excreta output is linear (Sibbald 1975) which was clearly not the case (Fig. 2A, B), and that the intercept value gives EEL at zero food intake. These intercepts were all positive (Table 3) and with the exception of equations 9-12, EEL values are within a normal range but lower than the 54 kJ when our starved birds were force-fed 30g dextrose. These findings are contrary to those of Hartel (1986) who reported some significant negative intercepts and others which did not differ from zero (Hartels' Table 3) using his continuous feeding method (CAM). Hartel (1986) found that intercepts were consistently positive using Sibbald's force-feeding method but Hartels' findings are not surprising. In his Experiment 1, using CAM the lowest level of intake for roosters was 80g/day and for broilers 60g/day; in Experiment 2, corresponding intakes were 20-100g and 20-80g respectively. Under the circumstances extropolation to zero intake to obtain EEL will likely be imprecise as indicated by the impossible situation of Hartels' significant negative intercepts. On the other hand intakes on Hartels' force-feeding assay were from 0 to 60 or 40g/day. In some instances, actual intakes were much lower eg, 5g/bird. It is not clear from Hartels' discussion whether excreta energy at zero intakes were also included in the regression equations but close examination of Fig. 1 in his paper suggests that they were. Since starved birds void some excreta, this would bias the regression by forcing a positive intercept (see Farrell 1981) and therefore give significant EEL.

Johnson (1987) has also reported intercept values of continuously-fed broilers that did not differ from zero. Again his lowest level of intake was 20g/day with high variation (SEM) about the mean of -0.4 (±44.8) and 8.2 (±71.1) and large residual standard deviations (RSD) about-regression lines of 76 and 121 respectively. These values can be compared with intercepts of 81.8 (±10.8, RSD=20) for broilers and 98.6 (±7.5, RSD=17) for roosters fed once by Johnson (1987) using a rapid method similar to that of Farrell (1978).

Removal of the lowest values (10g/d) from regressions in Table 3 and thus calculating the equations using the remaining 10 values yielded highly significant ($P<0.01$) regressions with $R^2>0.93$. Intercepts gave lower and sometimes negative EEL for the two continuous-feeding methods (Table 5) but no intercept value differed ($P>0.05$) from zero ie. no EEL voided. For the two methods (Sibbald and Farrell) requiring a single input of feed, regressions were also highly significant ($P<0.01$) with $R^2> 0.93$ but in this case all changes were small and intercepts were significantly different from zero and there was no indication of an EEL intercept close to zero or negative. Examples of regression lines for the four methods for Diets 1 and 3 with and

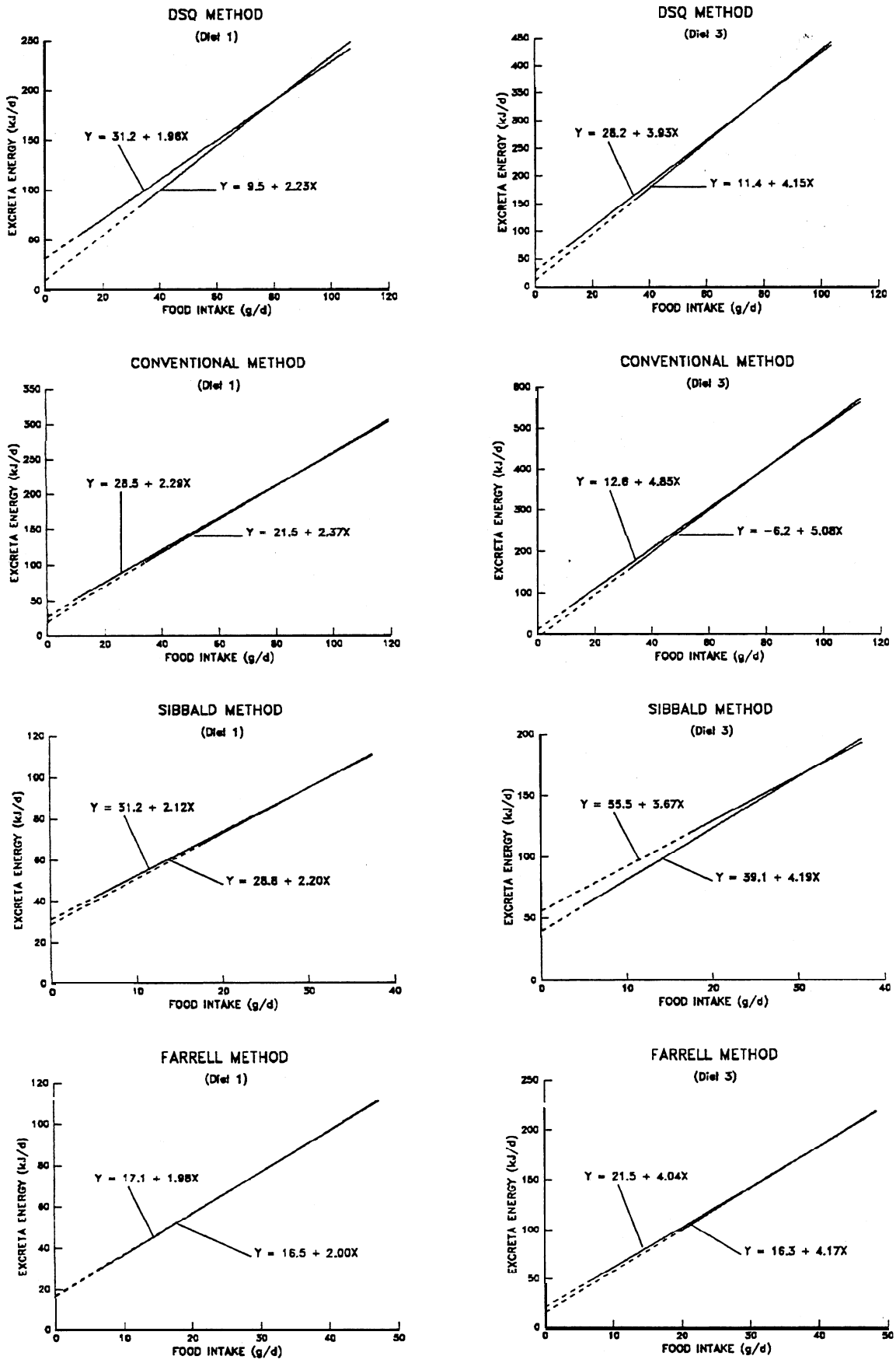

Fig. 4 The relationship between excreta energy and food intake for Diets 1 and 3 for four assay methods with and without the 5 lowest intakes. Extrapolation to zero food intake is shown with broken lines.

without the 10g intake are shown in Fig. 4. For the Farrell and Sibbald method food intake has been adjusted to 24 h to provide EEL on a daily basis.

These results may help to explain why Hartel (1986) and Johnson (1987) found no EEL on their continuous-feeding methods where extrapolation to zero food intake was made from the lowest intake of 20 or 80 g per day in their experiments. Moreover the lack of a large effect of feeding level on AME values using the DSQ and the Conventional feeding methods (Table 2) strongly suggests that EEL is comparatively low because at only 10g/day, depression in ME values was quite small (see also Hartels' Table 13). This is contrary to the EEL values observed in Table 4 and supports the contention that a linear model as used in Table 4 is probably not the most appropriate fit to the data as shown in Fig. 2A, B. This is contrary to the original findings of Sibbald (1975) in his Fig. 2 and may reflect variation about his regression line. The R^2 was 0.97 for 46 DF. Furthermore the intercept value was 'forced' by at least 10 values from birds offered no food. In addition it is common practice in the TME assay to remove excreta weights from data sets with weights more than one standard deviation from the mean (Pesti et al 1988b). This may well be not justified and will influence the line of best fit to data.

Not only is there evidence that EEL is influenced by the nature of the diet (Farrell 1982; Raharjo and Farrell 1984; Siriwan et al 1989), it also appears to be related to the amount of food consumed by the bird. Dale and Fuller (1982) concluded "that endogenous excreta energy is inversely related to caloric intake in roosters in negative energy balance". This is to be expected, In theory as the amount of food consumed decreases, the bird will be required to meet more of its protein and energy needs from tissue catabolism. Hence maximum EEL would be expected during starvation and minimum when food intake equals or exceeds energy and protein needs with a progressive change in EEL between these two extremes. For a 3 kg adult cockerel maintenance food needs would be about 90-100g per day. Providing a bird with 30g of dextrose per day will meet only 30-40% of daily energy needs, it still has to meet its entire N needs from tissue catabolism. Had a linear relationship been used for data in Fig. 2A to estimate EEL, a value of 78 kJ would have been obtained rather than 106 kJ found. On a daily basis these values would be 44.6 and 60.6 kJ respectively. Furthermore given a single input of food irrespective of quantity, birds are likely to be catabolizing increasing amounts of tissue reserves after 20-24 h. By collecting excreta for 42-48 h following a single input of feed, substantial amounts of EEL are produced. It is not surprising therefore that consistent significant, positive intercepts are observed for the Sibbald and Farrell method's and these were not reduced substantially when the lowest intakes were eliminated from the regression calculations (Table 5). Differences in EEL between the Farrell and Sibbald methods (Table 5) likely stem from differences in starvation period prior to feeding. In the former method 32 h is used. This was shown to be sufficient to evacuate the tract satisfactorily on a predominantly maize-based diet (Farrell 1978) as used here. Starvation prior to feeding was for 48 h using the Sibbald method and recommended by McNab and Blair (1988).

Another feature of these results (Table 2) is the similar AME and AME_n values observed at 75g (or ad libitum intakes) and 35g/day. This is contrary to previous concepts in which a depression in ME values would be predicted at an intake of 35g/day for adult cockerels of around 3kg bodyweight (Guillaume

Table 5 Intercept values (± SD) from linear regressions with (+) or without (-) the 5 lowest food (10g/d) intakes to calculate endogenous excreta (EEL) (kJ/d)*

Diet	DSQ (-)	DSQ (+)	Conventional (-)	Conventional (+)	Sibbald (-)	Sibbald (+)	Farrell (-)	Farrell (+)
1	9.4** (14.4)	31.2 (7.9)	21.4** (11.6)	28.6 (5.9)	28.8 (4.3)	31.3 (3.2)	17.1 (5.6)	19.3 (2.4)
2	2.2** (8.9)	20.1 (4.9)	30.2** (19.0)	31.8 (8.8)	55.4 (8.7)	44.1 (4.2)	25.4 (7.5)	25.4 (3.7)
3	11.4** (22.8)	28.2 (10.9)	-6.2** (13.4)	12.6** (7.9)	55.5 (4.2)	39.1 (3.3)	16.3 (4.4)	21.5 (2.5)
4	-13.0** (3.2)	24.6 (7.2)	-1.8** (27.4)	19.6** (13.3)	40.1 (5.5)	52.1 (3.3)	22.4 (4.6)	18.2 (2.4)

*Values are divided by the number of days on experiment.
**Intercepts not different (P>0.05) from zero.

and Summers 1970; Sibbald and Wolynetz 1985) but is in agreement with the results of Hill and Anderson (1958) and Potter et. al. (1960) . Correction to TME in the Sibbald method theoretically removes significant (P>0.05) differences between feeding level but clearly this was not the case (Fig. 3).

The data of Jonsson and McNab (1983) in which chickens and laying hens were given 9 diets containing 0 to 800g grass meal/kg diet is unconvincing. Although these workers regressed ME against grass meal inclusion and obtained a negative linear regression (Fig. 2) there is much variation in their data as is evident by the R^2 values; it was therefore not surprising that alternative fits to the data were not statistically significant. However Jonsson and McNab's (1983) data for TME and TME gave almost identical values for diets containing 200, 300 and 400g of grass meal (Table 2). Similar TME values were also observed for inclusions of 500, 600 and 700g grass meal/kg. AME_n values were indentical for diets containing 300 and 400g grass meal/kg and those with 600, 700 and 800g (Fig. 1). Such discrepancies and variation are unexplainable, were not mentioned in the paper and do not allow general conclusions to be drawn from these findings (McNab and Blair 1988). A second criticism of the data of Jonsson and McNab (1985) is their inclusion of excreta output of starved birds in linear regressions relating feed intake and excreta energy. Apart from the fact that such inclusions 'force' the intercept through or close to the mean EEL, had these zero intakes not been included quite different intercepts would have been found. For the basal diet these intercepts appear to be much higher than found (Fig. 3A) and for the diet containing 600g grass meal/kg, the intercept value would have been highly negative (Fig. 3C).

The results presented here cast serious doubt on the validity of the TME assay for measuring food energy values "because the magnitude of the actual EEL is unknown" (Hartel 1986) and "assays should be judged on how well food intake and endogenous energy losses (EEL) can be measured ....." (McNab and Blair 1988). Unless a reliable technique can be established in which EEL is

identified as part of the total excreta voided from a given input of food then the assay should be discarded, Data presented here (Table 2 & 3) supports the contention that the apparent metabolizable energy system should be retained and that the DSQ, Conventional and Farrell methods can give consistent, similar and reliable AME values.

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