The effects of energy intake and dietary protein on nitrogen retention, growth performance, body composition and some aspects of energy metabolism of baby pigs

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1. The effects of level of feeding of either a protein-adequate or a protein-deficient diet on nitrogen retention (NR), growth performance, body composition and some aspects of energy utilization in pigs growing from 1·8 to 6·5 kg live weight (LW) were investigated in two experiments.

2. In Expts 1 and 2 piglets were given a protein-adequate diet at four levels of intake (0·93, 1·44, 1·83 and 2·30 MJ gross energy (GE)/kg $LW^{0·75}$ per d) and a protein-deficient diet at five levels of intake (1·14, 1·38, 1·68, 1·95 and 2·30 MJ GE/kg $LW^{0·75}$ per d) respectively.

3. For pigs given the protein-adequate diet (Expt 1) NR was linearly ($P < 0·001$) related to energy intake (EI) and independent of N intake (NI). NR in pigs given the protein-deficient diet (Expt 2) was linearly ($P < 0·001$) related to NI and independent of EI.

4. Average daily LW gain responded linearly to increases in EI in both experiments. However, at equivalent levels of EI pigs given the protein-adequate diet exhibited more rapid and efficient growth than those given the protein-deficient diet. The results also indicated an interaction between the effects of EI and dietary protein content for feed conversion efficiency.

5. Body fat at 6·5 kg LW increased in a curvilinear fashion with increasing EI in both experiments. However, over the range of EI tested (from approximately 1·8 to 4·6 times energy for maintenance) body fat increased by 153% in Expt 1 and by only 27% in Expt 2. Pigs given the protein-deficient diet were also markedly fatter than those given the protein-adequate diet. Body protein at 6·5 kg LW decreased ($P < 0·01$) with increasing EI in Expt 1 but was unaffected by EI in Expt 2.

6. As estimated by multiple regression analysis, the values for the efficiency of energy utilization for protein (k_p) and fat (k_f) deposition were 0·76 and 0·78 respectively in Expt 1 and 0·42 and 0·89 resepctively in Expt 2. The estimates of metabolizable energy required for maintenance were 445 and 532 kJ/kg $LW^{0·75}$ per d for Expts 1 and 2 respectively.

Nitrogen retention (NR) and body composition of the growing animal are known to be influenced by the level of energy intake (EI) and dietary-protein concentration (Breirem & Homb, 1972; Black, 1974). Black & Griffiths (1975) showed that NR in milk-fed lambs given N-deficient diets was linearly related to N intake (NI) and independent of EI. Conversely, when N-adequate diets were given, NR was found to be linearly related to EI and independent of NI.

Support for this biphasic response of NR in pigs is given by the results of Williams (1976) for pigs growing from 1·8 to 6·5 kg live weight (LW) and, for slightly heavier pigs, by the results of McCracken *et al.* (1980). However, because both Williams (1976) and McCracken *et al.* (1980) incorporated only two levels of EI in their experiments they were unable to provide information on the relationship between EI and NR for pigs given N-adequate diets.

Similarly, the response of body composition to change in EI is only poorly defined. This somewhat surprising situation, which was noted by the Agricultural Research Council (1967), exists because in the majority of experiments the levels of EI tested have been too few and not sufficiently dispersed to provide the information required to develop input–output relationships. Research with milk-fed lambs (Black, 1974) further suggests that the influence

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Table 1. *Composition of experimental diets*

Diet	Expt 1	Expt 2
Ingredients (g/kg DM)*		
Ultra-filtered skim-milk powder	524	186
Glucose	234	477
Butterfat	183	224
Soya-bean oil	59	73
Mineral mix†	—	40
Analysis		
Crude protein (N × 6·38; g/kg DM)	359	134
Gross energy (MJ/kg DM)	25·4	24·0
Digestible energy (MJ/kg DM)‡	—	23·3
Metabolizable energy (MJ/kg DM)‡	—	21·7
Apparent digestibility of protein‡	—	0·99
Protein:gross energy (g/MJ)	14·1	5·6
Calcium (g/kg)	9·6	9·9
Phosphorus (g/kg)	5·8	6·0

* The diets used in Expt 1 and 2 were reconstituted with water to contain 200 and 250 g total solids/kg respectively. The following micronutrients were added daily before feeding (mg/pig per d): cholecalciferol 0·12, D-α-tocopherol 31·0, retinol 0·85, menadione 0·06, thiamin 1·50, riboflavin 2·50, nicotinic acid 20·0, pantothenic acid 10·00, pyridoxine 2·50, cyanocabalamin 0·02, biotin 0·08, pteroylmonoglutamic acid 1·00, ascorbic acid 100·0, iron 20·0, zinc 10·0, manganese 4·0, copper 2·0.

† Contained the following compounds (g/kg of mineral mix) excluding water of hydration: Ca lactate 610, $Na_2HPO_4.12H_2O$ 150, KH_2PO_4 225, $MgSo_4.7H_2O$ 25.

‡ Determined from energy and protein contents of faeces and urine collected during a 6 d period from pigs fed at the highest level.

of EI on body composition may be modified by the N adequacy of the diet. However, similar information in unavailable for the pig.

The aims of the two experiments reported here were: (1) to investigate the effects of EI on growth performance, body composition and NR of pigs given a protein-adequate diet between 1·8 and 6·5 kg LW; (2) to see how these effects were modified in pigs given a protein-deficient diet.

In both experiments, NR was determined by comparative slaughter.

EXPERIMENTAL

General

Thirty and eighteen Large White piglets, representing females and entire males, were used in Expts 1 and 2 respectively. In both experiments the piglets were removed from their dams within 24 h of birth. At 1·8 kg LW they were allocated randomly to either an initial slaughter group, comprising six and three piglets in Expts 1 and 2 respectively, or among the dietary treatments. In Expt 1 these treatments consisted of four feeding levels which provided gross energy (GE) intakes of 0·93, 1·44, 1·83 and 2·30 MJ/kg $LW^{0.75}$ per d of a protein-adequate diet. In Expt 2 a protein-deficient diet was given at five different levels corresponding to an EI of 1·14, 1·38, 1·68, 1·95 and 2·30 MJ GE/kg $LW^{0.75}$ per d. In both experiments individual piglets were killed when they attained 6·5 kg LW.

Diets and feeding

The constitutents and analyses of the semi-synthetic diets are given in Table 1. The diet given in Expt 1 was reconstituted to 200 g total solids/kg and was formulated to contain 14·1 g crude protein (CP; N × 6·38)/MJ GE. This protein:energy value was selected to be

slightly in excess of the requirement previously reported for pigs growing from 1·8 to 6·5 kg LW and given diets based on similar ingredients (Williams, 1976).

In Expt 2, the diet contained 250 g total solids/kg and was formulated to provide 5·8 g CP/MJ GE. The latter value was selected to be grossly deficient in relation to the pigs' requirement at this stage of development (Williams, 1976).

Vitamins and minerals were added daily before feeding. The amounts given (see Table 1) were based on the estimates of requirement given by the Agricultural Research Council (1967). Because of the low level of skim-milk powder used in the diet given in Expt 2, additional calcium and phosphorus were added to provide levels in accordance with the Agricultural Research Council's (1967) recommendations.

Before commencement of the dietary treatments at 1·8 kg LW, all pigs were given a liquid diet containing 200 g total solids/kg and 12·1 g CP/MJ GE and were fed at a level calculated to provide 1·5 MJ GE/kg $LW^{0.75}$ per d. During the first 24 h after weaning all pigs were taught to drink from an infant's bottle fitted with a teat and later from a similar teat fixed to the side of each cage and connected by plastic tubing to a reservoir of milk located beneath the level of the teat. During this training period, which lasted between 6 and 24 h, milk was offered hourly. This was followed by thrice daily feeding for the next two days and by twice daily feeding at 08.00 and 16.00 hours thereafter.

The diets were prepared by homogenization using the procedures described by Campbell & Dunkin (1983). The pigs were weighed daily and each pig's feed allowance for the following day was adjusted accordingly.

Slaughter procedure

Following slaughter at both 1·8 and 6·5 kg LW, the contents of the gastrointestinal tract were removed and the eviscerated carcass, blood, internal organs and empty gut were weighed together and stored at −15°. The frozen material was ground to a fine paste with a commercial butcher's mincer, mixed and subsampled for chemical analysis.

Chemical analysis

Dietary ingredients and samples of prepared diets were analysed by the same methods as those described by Campbell & Dunkin (1983).

Carcass dry matter was determined by drying samples (25–30 g) to constant weight in a forced draught oven at 105°. Ash was determined by burning the oven-dry samples in a muffle furnace at 600°. Protein (N × 6·25) was determined on freeze-dried samples using the Kjeldahl technique and fat by extracting freeze-dried samples in chloroform–methanol (2:1 v/v) for 8 h and drying the extract to constant weight (Braude & Newport, 1973).

Energy retained as protein and as fat was calculated from chemical analysis of the carcass material using the factors 24·2 MJ/kg for protein (Jordan & Brown, 1970) and 39·6 MJ/kg for fat (Burlacu *et al.* 1973).

Statistical analysis

The results were analysed by analysis of variance and regression.

RESULTS
Health of animals

No disease problems were encountered in the first experiment. In Expt 2, two litter-mate piglets died and there were some minor scouring problems which were confined to the first 2–4 d after weaning and before the introduction of experimental treatments. Post-mortem examination of the pigs which died revealed a heavy infestation of a rotavirus in the gastrointestinal tracts of both animals. Missing values were calculated for these pigs.

Table 2. *Effects of level of feeding on growth performance and nitrogen retention (NR) of pigs given a protein-adequate diet (Expt 1) or a protein-deficient diet (Expt 2) from 1·8 to 6·5 kg live weight (LW)*

| | Level of feeding (MJ GE/kg LW$^{0·75}$ per d) | | | | |
	0·93	1·44	1·83	2·30	SEM
Expt 1					
Daily LW gain (g)	105^a	182^b	240^c	296^d	6·6*
FCR	0·96^a	0·88^b	0·89^b	0·90^b	0·02*
NR (g/d)	3·8^a	5·3^b	6·4^c	7·9^d	0·07*

| | Level of feeding (MJ GE/kg LW$^{0·75}$ per d) | | | | | |
	1·14	1·38	1·68	1·95	2·30	SEM
Expt 2						
Daily LW gain (g)	88^a	105^b	145^c	182^d	216^e	6·0†
FCR	1·46^a	1·50^a	1·31^b	1·22^{bc}	1·21^c	0·03†
NR (g/d)	1·7^a	2·2^b	2·8^c	3·5^d	4·3^e	0·11†

* 20 degrees of freedom.
† 10 degrees of freedom.
GE, gross energy.
FCR, feed conversion ratio (g dry matter/g LW gain).
$^{a, b, c, d, e}$ Within rows, treatment means followed by different superscripts differed significantly ($P < 0.05$).

Growth performance

The results for growth performance are presented in Table 2. In both experiments there was a highly significant ($P < 0.001$) linear relationship between level of feeding (EI; MJ GE/kg LW$^{0·75}$ per d) and LW gain (LWG; g/d). These relationships were described by the following equations.

Expt 1 (protein-adequate diet):

$$LWG = 139·8 (\pm 2·6) EI - 21·5 \quad (r^2\ 0·902).$$

Expt 2 (protein-deficient diet):

$$LWG = 114·0 (\pm 4·0) EI - 44·6 \quad (r^2\ 0·895).$$

The feed conversion ratio (FCR) in Expt 1 improved ($P < 0.05$) with the first increase in feeding level and remained constant thereafter. In Expt 2, FCR improved ($P < 0.05$) with increasing feed intake up to 1·68 MJ GE/kg LW$^{0·75}$ per d. The values were markedly higher than those for pigs given the protein-adequate diet.

NR

NR increased linearly ($P < 0.01$) with increasing level of feeding in both experiments (Table 2). However, at equivalent levels of EI pigs given the protein-adequate diet deposited N at a faster rate than those given the protein-deficient diet. Regression of NR v. NI revealed a marked difference between experiments in the regression coefficient. The relationships, which were both linear ($P < 0.001$), were:

Expt 1:

$$NR = 0·466 (\pm 0·02) NI + 1·01 \quad (r^2\ 0·92).$$

Table 3. *Effects of energy intake on body composition (g/kg) at 6·5 kg of pigs given a protein-adequate diet (Expt 1) or a protein-deficient diet (Expt 2) between 1·8 and 6·5 kg live weight (LW)*

| | Energy intake (MJ GE/kg LW$^{0·75}$ per d) | | | | |
	0·93	1·44	1·83	2·30	SEM
Expt 1*					
Water	723^a	694^b	672^c	659^d	4·9†
Protein	195^a	182^b	174^c	168^d	1·6†
Fat	57^a	103^b	129^c	144^d	0·9†
Ash	22^a	21^a	25^a	23^a	0·5†

| | Energy intake (MJ GE/kg $^{0·75}$ per d) | | | | | |
	1·14	1·38	1·68	1·95	2·30	SEM
Expt 2*						
Water	658^a	631^b	618^c	609^{cd}	598^d	4·6‡
Protein	136^a	143^a	137^a	139^a	141^a	3·1‡
Fat	174^a	194^b	214^c	219^c	224^c	2·1‡
Ash	32^a	32^a	33^a	33^a	37^a	0·7‡

* The average body composition (g/kg ± SEM) of the six piglets killed at 1·8 kg LW in Expt 1 was, water 735 ± 5·1, protein 185 ± 2·3, fat 49 ± 1·2 and ash 31 ± 0·4. The corresponding values for the three piglets killed at 1·8 kg LW in Expt 2 were 727 ± 5·8, 189 ± 3·1, 54 ± 1·7 and 30 ± 0·6 respectively.

† 20 degrees of freedom.

‡ 10 degrees of freedom.

$^{a, b, c, d}$ Within rows, treatment means with different superscripts are significantly different ($P < 0·01$).

Expt 2:

$$NR = 0·880 \,(\pm 0·05)\,NI - 1·01 \quad (r^2\ 0·89).$$

Body composition

The results for body composition and the rates of deposition of fat and protein are given in Tables 3 and 4 respectively. In Expt 1 the proportion of fat in the empty body increased ($P < 0·01$) in a curvilinear fashion with each increase in EI. The proportions of protein and water in the empty body decreased ($P < 0·01$) with each increase in EI. With the protein-deficient diet, body fat at 6·5 kg LW increased ($P < 0·01$) in a curvilinear fashion with each increase in EI, up to 1·68 MJ GE/kg LW$^{0·75}$ per d, and at the lowest level of EI was higher than that for pigs fed at the highest level of protein in Expt 1. Body water responded in a similar manner but in the opposite direction to body fat, while body protein was not significantly affected by EI.

The rates of deposition of body fat and protein increased linearly ($P < 0·001$) with increasing EI in both experiments (Table 4). However, at all levels of EI, pigs given the protein-adequate diet deposited protein at a faster rate and fat at a slower rate than those given the protein-deficient diet. The fat:protein value of the daily LWG (Table 4) increased ($P < 0·01$) in a curvilinear fashion with each increase in EI in Expt 1 but only up to 1·68 MJ GE/kg LW$^{0·75}$ per d in Expt 2.

Energy retention

Total energy retained (TER) and that retained as fat (FE) and protein (PE) were linearly related to EI in both experiments. The equations describing these relationships, which were all highly significant ($P < 0·001$), are set out in Table 5.

Table 4. *Effect of energy intake on the rate of deposition of fat and protein between 1·8 and 6·5 kg in pigs given a protein-adequate diet (Expt 1) or a protein-deficient diet (Expt 2)*

| | Energy intake (MJ GE/kg LW$^{0.75}$ per d) | | | | |
	0·93	1·44	1·83	2·30	SEM
Expt 1					
Protein (g/d)	23·6[a]	32·8[b]	40·1[c]	48·9[d]	0·75*
Fat (g/d)	7·2[a]	21·8[b]	35·3[c]	53·2[d]	0·36*
Fat:protein	0·28[a]	0·66[b]	0·88[c]	1·09[d]	0·025*

| | Energy intake (MJ GE/kg LW$^{0.75}$ per d) | | | | | |
	1·14	1·38	1·68	1·95	2·30	SEM
Expt 2						
Protein (g/d)	10·4[a]	13·3[b]	17·2[c]	22·1[d]	26·9[e]	1·14†
Fat (g/d)	18·1[a]	24·5[b]	36·9[c]	44·3[d]	56·2[e]	1·47†
Fat:protein	1·73[a]	1·86[b]	2·16[c]	2·09[c]	2·10[c]	0·03†

* 20 degrees of freedom.
† 10 degrees of freedom.
[a, b, c, d, e] Within rows, treatments means with different superscripts are significantly different ($P < 0.01$).

Table 5. *Regression equations of total energy retained (TER; kJ gross energy (GE)/kg live weight (LW)$^{0.75}$ per d) and that retained as protein (PE; kJ GE/kg LW$^{0.75}$ per d) and fat (FE; kJ GE/kg LW$^{0.75}$ per d) on energy intake (kJ GE/kg LW$^{0.75}$ per d) for pigs given a protein-adequate diet (Expt 1) or a protein-deficient diet (Expt 2) between 1·8 and 6·5 kg LW*

Variable	Regression equation	Coefficient of determination
Expt 1		
TER	$Y = 0.633 \, (\pm 0.015) \, X - 312$	0·998
PE	$Y = 0.158 \, (\pm 0.003) \, X + 49.8$	0·996
FE	$Y = 0.475 \, (\pm 0.014) \, X - 364$	0·996
Expt 2		
TER	$Y = 0.596 \, (\pm 0.014) \, X - 350.8$	0·997
PE	$Y = 0.12 \, (\pm 0.002) \, X - 50.2$	0·995
FE	$Y = 0.476 \, (\pm 0.012) \, X - 300.8$	0·994

The partition of TER between fat and protein in Expts 1 and 2 is shown in Figs. 1 and 2 respectively.

The GE requirements for maintenance were estimated by extrapolating TER to zero. The values for Expts 1 and 2 were 492·0 and 588·5 kJ/kg LW$^{0.75}$ per d respectively. Using the metabolizable energy (ME) value determined for the diet given in Expt 2, the corresponding ME requirements for maintenance (ME$_M$) in Expts 1 and 2 were 445 and 532 kJ/kg LW$^{0.75}$ per d respectively. The ME content of the diet given in Expt 2 was also used to determine the relationship between ME available for production (ME$_p$; ME intake $-$ ME$_M$) and FE and
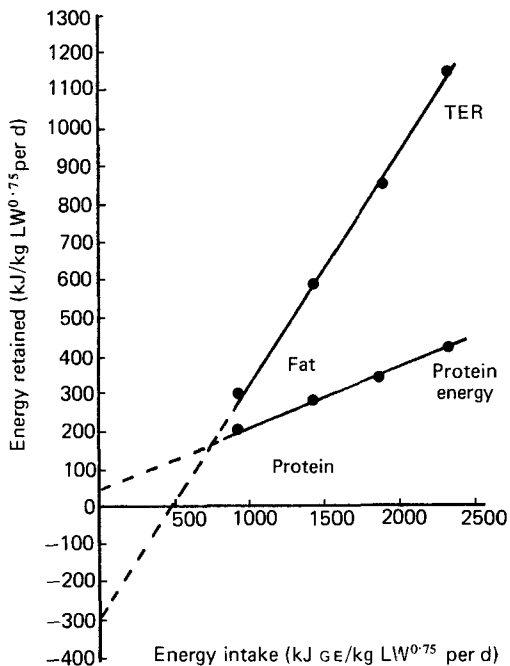
Fig. 1.

Fig. 2.

Fig. 1. Effect of gross energy (GE) intake (kJ/kg live weight (LW$^{0.75}$ per d) between 1·8 and 6·5 kg LW on the partition of total energy retained (TER; kJ/kg LW$^{0.75}$ per d) between fat and protein for pigs given a protein-adequate diet (Expt 1).
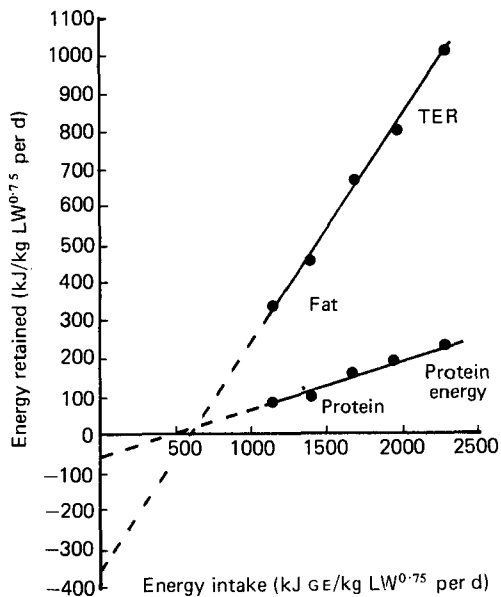
Fig. 2. Effect of gross energy (GE) intake (kJ/kg live weight (LW)$^{0.75}$ per d) between 1·8 and 6·5 kg LW on the partition of total energy retained (TER; kJ/kg LW$^{0.75}$ per d) between fat and protein for pigs given a protein-deficient diet (Expt 2).

PE using the multiple regression equation $ME_p = a\ PE + b\ FE$. The relationships yielded were:

Expt 1:

$$ME_p = 1·32\,(\pm 0·02)\,PE + 1·28\,(\pm 0·06)\,FE \quad (r^2\ 0·99).$$

Expt 2:

$$ME_p = 2·48\,(\pm 0·15)\,PE + 1·12\,(\pm 0·07)\,FE \quad (r^2\ 0·99).$$

Estimates of the efficiency of energy utilization for protein (k_p) and fat (k_f) deposition were estimated from the reciprocals of the regression coefficients. The values for k_p and k_f in Expt 1 were 0·76 and 0·78 respectively and in Expt 2 were 0·42 and 0·89 respectively.

DISCUSSION

Raising the level of intake of the diets fed in either experiment resulted in a linear increase in NR. However, the more rapid deposition of N exhibited at any given level of EI by pigs given the protein-adequate diet (Table 2) and the markedly different value for the regression coefficient for NR on NI suggested that the relative influences of dietary N and energy on NR differed in these two situations.

Because dietary protein was highly digestible (apparent digestibility 0·99), NI was equivalent to N absorbed. Therefore, if the linear improvement in NR was primarily a consequence of the concomitant increase in NI, it follows that the slope of the regression NR v. NI reflects very closely the biological value of the protein. In fact, the regression coefficient for pigs given the protein-deficient diet (0·88) was slightly above the biological value determined for milk protein by Williams (1976) and identical to that reported by Newport (1979). Thus it is probable that in Expt 2, NR was linearly related to NI and independent of EI.

In contrast, the slope of the regression equation for NR v. NI for pigs given the protein-adequate diet (0·466) bore no relationship to the biological value of the protein which was derived from the same batch of milk powder in both experiments. Furthermore, the fitted relationship, although statistically significant, was biologically unsound since the intercept value was considerably greater than zero. We conclude, therefore, that NR in Expt 1 was a function of EI and was independent of NI. Regression of NR (g/d) v. EI (MJ GE/kg LW$^{0·75}$ per d) yielded the highly significant ($P < 0·001$) linear relationship:

$$NR = 2·96\,(\pm 0·012)\,EI + 1·02 \quad (r^2\ 0·927).$$

Taken together, the results of these experiments confirm the existence of separate N- and energy-dependent phases of NR in the baby pig as established previously by Williams (1976). Furthermore, the results show that over the range of feeding levels tested (from approximately 1·8 to 4·6 times energy for maintenance; M) NR in pigs given the protein-adequate diet (Table 2) was linearly related to EI. Similar findings have been reported for rats (Miller & Payne, 1963) as well as for milk-fed calves and lambs (Blaxter & Wood, 1952; Black & Griffiths, 1975). The results of Burlacu et al. (1973) and Fuller et al. (1976) also indicate a linear relationship between EI and NR for older pigs. However, the highest level of EI tested in the experiments of Burlacu et al. (1973) and Fuller et al. (1976) were equivalent to only 3·0 M and 2·5 M respectively. Average daily LWG increased by 182 and 144 % over the range of feeding levels tested in Expts 1 and 2 respectively. The growth rates of pigs fed at the lowest and highest levels in Expt 1 were approximately 50 % less and 50 % more respectively than those reported for sow-reared pigs grown to a similar LW (Manners & McCrae, 1963; Wood & Groves, 1965). The higher level was also similar to that reported for artificially-reared pigs growing between 2 and 28 d and between 8 and 32 d of age by Newport (1979) and McCracken et al. (1980) respectively.

Although the protein:energy value of the diet given in Expt 2 was grossly deficient in relation to requirements (Williams, 1976), the rate of gain exhibited on the highest level of feeding was equal to that of sow-reared pigs grown to similar weight (Wood & Groves, 1965) and was intermediate between those of pigs given the protein-adequate diet at the second and third levels of feeding in Expt 1 (Table 2). However, average feed conversion efficiency in Expt 2 was 62 % poorer than that for pigs given the protein-adequate diet in Expt 1. The results for energy retention (Figs. 1 and 2) showed this was largely a result of pigs given the protein-deficient diet apportioning relatively more of the energy available for growth to fat (and less to protein) than those given the protein-adequate diet. Similar findings have been reported for young pigs by Newport (1979) and McCracken et al. (1980). Our findings also indicate an interaction between the effects of dietary protein and level of feeding on the FCR. In Expt 1, FCR improved by 10 % with the first increase in energy intake and remained constant thereafter. In Expt 2 there was a progressive improvement of 20 % in FCR as EI increased from 1·14 to 1·95 MJ GE/kg LW$^{0·75}$ per d. This was probably attributable to the associated increase in protein intake which, in turn, led to increases in the rates of deposition of protein and water.

The results also indicate an interaction between EI and dietary protein for body

composition. The linearity of the increases in the daily rates of energy deposited both as protein and as fat with unit increase in EI (Figs. 1 and 2) implies a constant ratio between these respective rates. However, whereas in Expt 1 the value of rate of fat deposition:rate of protein deposition in energy gain was 1·8:1, the corresponding value in Expt 2, when protein was limiting, was 2·5:1. However, the overall effect of increasing EI on the fat:protein value of energy gain was curvilinear, approaching an asymptote value equal to the ratios mentioned previously. It appears, therefore, that there is a maximum amount of fat that can be induced in the young pig by raising its EI, and that the maximum increases as the protein adequacy of the diet is reduced.

The results further demonstrate that the level of dietary protein influences the magnitude of the response of body fat to change in EI. Over the range of EI tested in Expt 1 (from approximately 1·8 to 4·6 M) body fat at 6·5 kg LW increased from 57 to 144 g/kg (153%) and was not maximized at the highest level of EI. The lower level of body fat is approximately 40% of that reported for sow-reared pigs of similar LW (Manners & McCrae, 1963; Lodge *et al.* 1978; Whittemore *et al.* 1978). The higher level is in line with that for sow-reared pigs and similar to that reported by Newport (1979) for artificially reared pigs given a high EI between 2 and 28 d of age.

With the protein-deficient diet the deposition of fat exceeded that of protein at the lowest EI tested (approximately 1·8 M) and resulted in a level of body fat at 6·5 kg LW which was 19% above that of pigs given the highest EI in Expt 1 (Table 3). Furthermore, over a similar range of EI as that tested in Expt 1, body fat increased by only 27% and showed no further significant response to increases in EI above 1·68 MJ GE/kg $LW^{0.75}$ per d or approximately 3 M (Table 3). A similar interaction between the effects of EI and dietary protein on body fat content has been predicted for milk-fed lambs (Black, 1974). Our results suggest that for the baby pig the same interaction exists for body protein. In Expt 1 body protein decreased with increasing EI but was unaffected by EI in Expt 2 (Table 3). Combining the results for growth performance (Table 2) and body composition (Table 3) it is evident that although large differences in growth rate can be achieved by altering the EI of either a protein-adequate or a protein-deficient diet, the influence of EI on body composition diminishes as the protein adequacy of the diet is reduced.

The protein adequacy of the diet also markedly affected the partial efficiencies of ME for protein and fat deposition. The estimates of k_p (0·76) and k_f (0·78) derived from Expt 1 are similar to those reported by Kielanowski (1965), Burlacu *et al.* (1973) and McCracken *et al.* (1980) for young pigs given protein-adequate diets and contrast with those obtained when the protein-deficient diet was given. The high value for k_f (0·89) in Expt 2 suggests that a high proportion of dietary fat was incorporated directly into body lipid and is in line with the value reported by Boyd & McCracken (1979) for pigs given high-fat diets. The very low value for k_p (0·42) suggests considerably more energy was required per unit protein deposited than was the situation for pigs given the protein-adequate diet (Expt 1) and is in line with recent findings of Close & Berschauer (1981) who reported a marked deterioration in k_p as dietary protein content was reduced. This low efficiency of energy utilization for protein deposition is possibly associated with an increased rate of protein synthesis in pigs given protein-deficient diets as suggested by the results of Reeds *et al.* (1981).

Although the interdependence of the regression coefficients for protein deposition and fat deposition require that the estimates of k_p be viewed with caution, the present results (and those of Close & Berschauer (1981)) indicate that for the young pig much of the variation in the published values for k_p, which range from 0·48 (Muller & Kirchgessner, 1974) to 0·84 (Close *et al.* 1979), may be attributable to variation in dietary protein content.

Overall, the results indicate that the relative effects of EI and NI on NR and the influence

of EI on the partition of energy between fat and protein are materially affected by the protein status of the diet. They provide support for the view that in determining responses to change in EI it is important to distinguish between situations of protein adequacy and those in which, to varying degree, it is limiting.

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