Energy and protein nutrition of early-weaned pigs. 1. Effect of energy intake and energy: protein on growth, efficiency and nitrogen utilization of pigs between 8–32 d

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1. The effect of energy and protein intake on the growth, food efficiency and nitrogen retention of artificially-reared pigs was studied over three 8 d periods between 8–32 d of age in an experiment employing a 5×3×2 factorial design. The factors were initial energy:N value (I; 250, 355, 460, 565 or 670 kJ/g N), rate of increase of I at 8 d intervals (0, 12·5 or 25 %) and plane of nutrition (three times daily to appetite or 75 % of this intake).

2. The range of energy:N values was obtained by formulating five diets based on dried skim milk, lactose and casein and feeding appropriate combinations of two diets. The diets, which were pelleted, contained 100 g maize oil/kg and the gross energy content was approximately 20 MJ/kg.

3. N digestibility was high at all three age intervals, reaching 0·99 on the diet containing the highest dietary crude protein (N × 6·25) level. Metabolic faecal N excretion was found to be 1·1 g/kg dry matter (DM) intake.

4. Growth rate, feed conversion ratio (kg food intake/kg wt gain; FCR), N retention (NR) and the proportion of digested N retained (NR: apparent digested N (ADN)) were significantly ($P < 0·001$) affected by I values at all age intervals and the responses were quadratic. Response curves were calculated by the least squares method and optimum values of I determined for each of the criteria.

A constant energy:N value of approximately 400 kJ/g N was indicated by growth, FCR and NR optima but the NR:ADN value fell from 0·77 for the 8–16 d period to 0·60 for the 24–32 d period at this I value. It is concluded that a suitable compromise would be an I value of 470 kJ/g N increasing by 10 %/week.

5. There was a significant interaction between plane of nutrition and I values on FCR between 16–24 d ($P < 0·001$) and 8–32 d ($P < 0·01$) indicating that FCR was better at high protein levels and worse at low protein levels when the diets were fed on the lower plane of nutrition.

Although information on the nutrition and management of early-weaned pigs has been published (Lucas & Lodge, 1961; Alexander, 1969; Martin & Van der Hyde, 1969; Braude *et al.* 1970; Eddie & McCracken, 1972; Jones, 1972) relatively few detailed studies of the energy and protein requirements, during the first 4 or 5 weeks of life, under optimal conditions of environment and at acceptable levels of growth, have been reported.

To provide a basis for diet formulation it is desirable to obtain information on the effects of protein and energy intake on growth, feed conversion ratio (kg feed/kg gain), nitrogen retention (NR) and the proportion of N intake retained. When the study to be described was undertaken the most comprehensive information on the protein requirements of piglets was that of Manners & McCrea (1962, 1963). They used synthetic diets in which the

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main protein source was casein and took growth rate as the criterion of performance. They found that the crude protein (N×6·25; CP) requirement of piglets from 2 to 28 d of age was 250 g CP/kg on a low-fat diet and 310 g CP/kg on a diet containing 210 g fat/kg. With diets based on dried skim milk or casein it is probable that the major factor influencing the dietary protein requirement is the fat, and hence the energy, content of the diets used. Consequently it would seem preferable to express dietary requirements for protein in relation to energy. From the chemical composition of the diets used by Manners & McCrea (1962, 1963) the optimal energy:N value for growth can be estimated as 460 kJ/g N.

Analysis of the results of three experiments with pigs (Kirchgessner & Kellner, 1972; Kellner & Kirchgessner, 1973; Muller *et al.* 1974) led Muller & Kirchgessner (1974) to conclude that a diet containing 260 g CP/kg was optimal for growth over the 4–12 kg live-weight range but that N retention was maximum at higher CP levels than this. The energy content of the diets was approximately 19·7 MJ/kg so this CP content corresponds to an energy:N value of 470 kJ/g N.

Recently, Newport (1979) reported the results of an experiment using piglets between 2 and 28 d of age and diets containing from 150 to 270 g CP/kg and 290 g fat/kg. Examination of his results indicates that there was a curvilinear improvement in growth rate and feed conversion ratio (kg food intake/kg weight gain; FCR) up to 270 g CP/kg which corresponds to an energy:N value of 580 kJ/g N. In contrast to the results of Muller & Kirchgessner (1974) N retention appeared to be maximal at 240 g CP/kg. Newport (1979) has suggested that a larger-scale experiment over a wider range of dietary CP level might permit a better estimate of the response in performance to level of CP in the diet. Furthermore, Braude *et al.* (1970) have pointed out that there is rapid decrease in protein retention, expressed as a percentage of live weight, between 2 and 28 d. It would seem probable that the optimal energy:protein value would change so rapidly during the first 4 or 5 weeks as to justify a progressive change in the protein level of the diet for early-weaned pigs.

In order to test this hypothesis and obtain fundamental information on the interaction of N and energy intake on the growth and development of young pigs, studies were made on 150 pigs over the period 8–32 d using a wide range of protein levels and two scales of energy intake. This paper describes the management aspects of the experiment and presents assessments of performance using the four criteria discussed previously, at three stages of growth between 8 and 32 d. Preliminary reports have already been presented (Eddie & McCracken, 1973; McCracken & Eddie, 1973).

EXPERIMENTAL

Design and treatments

The design was a 5×3×2 factorial replicated five times, the factors being respectively initial energy:N value (I) at 8 d (250, 355, 460, 565 or 670 kJ/g N), rate (R) of increase of I at 16 and 24 d (0, 12·5 or 25%) and plane of nutrition (PN) (100 or 75% of appetite). Based on previous experience (Eddie & McCracken, 1972) appetite was defined as a gross energy intake of 3 MJ at 2 kg live weight rising linearly to 15 MJ at 12 kg live weight. Each replicate used a block of thirty-six pigs, six of which were slaughtered at 8 d for carcass analysis. The minimum number of litters was used to provide the pigs for a block eliminating extremely heavy or light pigs so that the weight range within a block was as small as possible. Sows were batch-farrowed to provide sufficient pigs for a block within a 48 h period. At 8 d the pigs within each block were randomized to the treatments. The experimental period was divided into three phases each of 8 d and changes in the energy:N value were instituted abruptly at 16 and 24 d of age.

Management

Piglets from a hysterectomy-derived, Large White × Landrace herd were weaned at 2 d and transferred to individual metabolism cages in a room capable of accommodating thirty-six pigs. The temperature of the room was 30 ± 1° at 2 d of age decreasing 1° every 4 d to 23 ± 1° at 30 d, age being determined by the youngest pigs in the block.

Pigs were fed three times daily at 09.00, 16.00 and 24.00 hours throughout the experiment. From 2 to 5 d they were given a liquid diet of reconstituted spray-dried whole milk increasing to a level of 60 g dry matter (DM)/kg live weight per d. At 5 d, diet no. 3 (Table 1) was introduced and the liquid milk intake reduced so that by 7 d pigs were eating only dry food.

They were weighed at weaning, 5 d, 8 d and thereafter at 4 d intervals. Between weighings the body-weights were estimated on a daily basis and the appropriate food allowance for each pig was calculated according to the linear scale described above.

Water was provided at each feeding time and the drinking troughs were changed daily. During the pre-experimental period the water allowance was five times the DM intake. During the experimental period the water allowance was related to the energy:N value to take account of the high urea excretion on the high-protein diets. The levels offered were respectively eight, seven, six, five and four times the DM intake for the five increasing levels of I. Despite considerable spillage by some pigs water was continuously available on all treatments.

Diet composition

The experimental design required twenty-one different diets with energy:N values ranging from 250 to 1000 kJ/g N. Five basic diets were prepared and the other energy:N values obtained by feeding a combination of two diets. In order to minimize problems of food spillage the diets were pelleted using a 4·5 mm die. Water was admixed prior to pelleting to reduce the DM content to approximately 890 g/kg. This value was adjusted with individual diets in an attempt to produce pellets of uniform hardness. The composition and analysis of the five basic diets used are given in Table 1. The diets were formulated to be as similar in gross energy content as possible and to contain approximately 100 g fat/kg since this level of fat was considered to be appropriate to commercial practice and had been found to produce a mixture suitable for pelleting. Due to the high level of casein required to obtain the low energy:N value it was necessary to allow the gross energy content of this diet to be approximately 10% higher than that of the other diets used. The diets were stored in sealed plastic bags and the DM contents were measured at the beginning of each replicate for the computation of the feeding scales.

Balance procedures

Collections of faeces and urine were made throughout the experiment but within each 8 d balance period the output for the first 3 d was kept separate from that for the subsequent 5 d. It was assumed that after 3 d the faecal and urinary excretion would be representative of the intake after changes in the protein content of the feed. Faeces were collected at each feeding time and stored at +4°. The urine was collected into M-sulphuric acid. The nylon mesh which separated the faeces from the urine was sprayed with 0·05 M-sulphuric acid after each faeces collection and the collecting funnel was sprayed each morning. A proportion of the daily urine output was retained and the bulked portions for each pig were stored at +4°.

Spilt food, unless contaminated with urine, was returned to the trough several times daily. Feed troughs were scraped out only at the beginning and end of the three 5 d collection periods. In this way food wastage was minimized. Contaminated waste food was collected

Table 1. *Composition (g/kg) and analysis of the five basic diets used in the experiment*

	1	2	3	4	5
Dried skim milk	466·8	669·0	542·0	401·3	265·9
Lactose	—	109·4	300·0	415·2	530·5
Dried whole milk	—	14·3	39·1	54·3	69·1
Maize oil	79·5	99·0	97·9	96·3	96·0
Casein	446·0	99·0	—	—	—
Trace minerals–vitamins*	5·0	5·0	5·0	5·0	5·0
Ground limestone	1·7	2·0	—	—	—
Dicalcium orthophosphate	1·0	2·3	16·0	27·9	33·5
Crude protein (nitrogen × 6·25) (g/kg DM)	585·5	347·6	218·4	168·8	117·4
Gross energy (MJ/kg DM)	22·46	20·69	19·71	19·25	19·14
Energy: N (kJ/g N)	240	372	564	713	1019

DM, dry matter.

* The trace mineral–vitamin mixture supplied (mg/kg): iron 140, copper 15, zinc 100, manganese 30, cobalt 2, iodine 0·4, nicotinic acid 15, α-tocopheryl acetate 10, ascorbic acid 200, choline chloride 1000, *myo*-inositol 160, *p*-aminobenzoic acid 20, menadione 2·0, ergosterol 25 μg/kg.

and held at +4° until the end of a balance period when it was combined with trough scrapings and dried at 100°. It was assumed that the composition of the waste food corresponded to that of the mixed diets offered.

Analysis of food and excreta

The DM content of the five basic diets was determined in a forced-draught oven at 100°. CP was determined by the macro-Kjeldahl method, ether extract (40–60° b.p. petroleum spirit) by the Soxhlet method and mineral content by ashing at 450° in a muffle furnace. Due to the small amounts of faeces obtained in some collections it was not possible to determine the N content of the fresh material. The bulked faeces were therefore freeze-dried to constant weight, ground and sampled for N determination by the macro-Kjeldahl method.

Urinary N was measured on 10 ml portions of fresh urine by the macro-Kjeldahl method. The gross energy content of the food was measured using an adiabatic bomb calorimeter.

Statistical analysis

The results for each 8 or 5 d period and for the total period were analysed separately by analysis of variance. A significant interaction arose in the initial live-weight as an artefact of the randomization and a number of analyses were repeated using initial weight as a covariate. Least squares curvilinear regressions were calculated with the inclusion of appropriate qualitative factors to test for parallelism and coincidence in respect of energy intake and rate of change of I, for the four criteria of performance in relation to the energy: N value.

RESULTS

Final live-weight (Table 2) was significantly affected by plane of nutrition (PN) ($P < 0·001$), I ($P < 0·001$) and R (rate of increase of I) ($P < 0·01$). The effect of I was significantly quadratic with a maximum point. There was a significant ($P < 0·05$) PN × R interaction at 8, 16 and 24 d. Covariance analysis of live weight at 16 and 24 d using initial live weight as the covariate confirmed that this interaction was entirely due to the initial randomization. At 32 d the PN × R interaction was not significant but there was a significant ($P < 0·01$) interaction between R and I (linear) due to an improvement in performance with increasing

Table 2. *Live weight (kg) of piglets at* 8, 16, 24 *and* 32 *d as affected by initial energy:nitrogen value (kJ/g N;I)* (250, 355, 460, 565 or 670), *rate of increase of I (R)/8 d period* (0, 12·5 or 25%) *and plane of nutrition (PN) (high PN or low PN)*†

(Five blocks of thirty piglets per block five animals/mean)

Age (d)	PN ...	High					Low					df	SE of a mean
	I ... / R (% of I/8 d period)	250	355	460	565	670	250	355	460	565	670		
8	0‡	1·96	2·06	2·02	2·16	2·02	1·94	1·98	1·86	1·96	1·92		
	12·5‡	2·06	2·10	1·84	1·96	1·78	2·14	2·08	2·26	2·02	2·10	113	0·106
	25‡	1·91	1·88	1·98	1·92	2·06	2·00	2·16	1·90	1·94	2·04		
16	0‡	3·30	3·88	3·72	3·24	3·16	2·88	3·34	3·08	3·12	2·80		
	12·5‡	3·36	3·79	3·42	3·08	2·64	3·30	3·52	3·64	3·02	3·22	113	0·214
	25‡	2·93	3·70	3·56	3·04	3·20	3·24	3·58	3·08	2·88	2·96		
24	0	5·78	6·60	6·66	5·88	5·32	4·64	5·52	5·06	4·92	4·00		
	12·5	6·04	6·73	6·22	5·38	4·28	5·44	5·88	5·84	4·66	4·62	113	0·345
	25	5·36	6·60	6·16	4·88	4·78	5·30	6·00	4·78	4·20	4·10		
32	0	8·04	9·64	9·76	8·86	7·56	6·78	7·10	7·47	7·18	5·64		
	12·5	8·70	9·17	9·26	7·92	6·14	7·68	8·56	8·00	5·88	5·88	112	0·423
	25	8·05	9·54	8·32	7·04	6·46	7·18	8·30	6·64	5·62	5·06		

Statistical significance

Age (d)	Qualitative effects: PN	R	PN×R	I	I×PN	I×R	Quantitative responses: I_l	I_q	PN×I_l	PN×I_q	R×I_l	R×I_q
8	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS
16	*	NS	*	***	NS	NS	**	***	NS	NS	NS	NS
24	***	NS	*	***	NS	NS	***	***	NS	NS	NS	NS
32	***	**	NS	***	NS	**	***	***	NS	NS	**	NS

NS, not significant.
† For details, see text.
‡ While the actual treatments applied did not vary between values for R until after the 16th day of age, the means of individual groups of animals and analysis of variance have been presented for completeness.
l, linear; q, quadratic.
* $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.

value of R at low values of I and vice versa at high values of I. Covariance analysis of live-weight at 16 and 24 d using initial live-weight as the covariate indicated that the I×R interaction was also significant ($P < 0.01$) at 24 d. This pattern was confirmed by the growth rate results where the R×I (linear) interaction was significant for 16–24 d ($P < 0.01$) and for 24–32 d ($P < 0.001$). Similarly, increasing values of R caused significant effects on growth rate for 16–24 d ($P < 0.01$) and 24–32 d ($P < 0.001$). PN and I produced highly-significant responses in growth rate ($P < 0.001$) at all ages.

Because of the differences in gross energy content of the diets, FCR (kg feed/kg gain) as determined could not be used as a direct basis for comparison. Accordingly all values (Table 3) were corrected to a mean energy content of 18 MJ gross energy/kg air dry diet (900 g DM/kg) which was close to the mean energy value of the five experimental diets.

PN had no significant effect on FCR but there was a significant quadratic effect due to I ($P < 0.001$) in all three periods and for 8–32 d and a significant effect of R ($P < 0.001$) for 16–24, 24–32 and 8–32 d. There was also a significant R×I (linear) interaction for 16–24 d ($P < 0.001$), 24–32 d ($P < 0.05$) and 8–32 d ($P < 0.001$). For 16–24 d there was a highly significant PN×I (linear) interaction ($P < 0.001$) but this did not reach significance for 24–32 d. However, results for the 24–32 d period are subject to a greater extent of variation, due mainly to a scour problem encountered in the fourth replicate which gave rise to four additional missing values. Over the complete period from 8–32 d the PN×I interaction was significant ($P < 0.01$) indicating an increased response of FCR to I on the low PN compared with the high PN.

The apparent digestibility of nitrogen (ADN) (Table 4) was unaffected by energy intake during any of the periods studied but was significantly reduced ($P < 0.001$) by increasing I and by R. Between 27–32 d and over the total balance period there was a significant quadratic component ($P < 0.05$) due to I. There was a significant R×I (linear) interaction for the 19–24 d balance period ($P < 0.01$) and over the complete experimental period ($P < 0.05$).

NR (Table 5) was higher on the high PN at 11–16 d ($P < 0.01$), and at 19–24 and 27–32 d ($P < 0.001$) and was significantly ($P < 0.001$) affected by I at all ages. There was a quadratic response to I at 11–16 d ($P < 0.01$) and in the two later periods ($P < 0.001$). Between 11–16 d when the actual treatments did not vary between rates of increase, there was no significant difference in NR between the three groups but there was a significant response to R for 19–24 d ($P < 0.01$) and 27–32 d ($P < 0.001$). There were no significant PN×I or PN×R interactions indicating that the higher energy intake only increased protein retention and did not affect the shape of the response curve. There was, however, a significant R×I (linear) interaction for 19–24 d ($P < 0.01$) and for 27–32 d ($P < 0.001$).

Maximum NR increased from approximately 6 g/d for 11–16 d to over 11 g/d for 19–24 d on the treatments giving maximum performance but no further improvement occurred for 27–32 d. The proportion of ADN retained (Table 6) rose rapidly with increases in I and R to a plateau at a value approximately 0.90, the effects in all three periods being highly significant ($P < 0.001$). There was also a significant R×I (linear) interaction ($P < 0.001$) for 19–24 and 27–32 d. PN had no significant effect on the proportion retained for 11–16 and 19–24 d. There was a significant ($P < 0.05$) increase of approximately 3% on the low PN for 27–32 d.

DISCUSSION

The value of the results obtained in this type of experiment is very dependent on the health of the experimental animals. Only one scour outbreak had a serious effect on the results. This occurred during the last 4 d period of the fourth replicate and involved six pigs. Four pigs were actually lighter at 32 d than at 28 d and were treated as missing values in the

Table 3. *Mean Feed Conversion Ratio*† (*kg feed/kg gain*) *of piglets between various ages as affected by initial energy:nitrogen value* (*kJ/g N; I*) (250, 355, 460, 565 *or* 670), *rate of increase of I* (*R*)/8 *d period* (0, 12·5 *or* 25%) *and plane of nutrition* (*PN*) (*high PN or low PN*)‡

(Five blocks of thirty piglets per block five animals/mean)

Age interval (d)	PN ... / I ... / R (% of I/8 d period)	High 250	High 355	High 460	High 565	High 670	Low 250	Low 355	Low 460	Low 565	Low 670	df	SE of a mean
8–16	0§	0·81	0·70	0·82	1·11	1·00	0·98	0·75	0·74	0·91	1·21		
	12·5§	0·86	0·78	0·79	1·06	1·03	0·89	0·77	0·85	0·93	0·98	112	0·053
	25§	0·97	0·73	0·79	0·96	1·09	0·83	0·75	0·80	0·92	1·02		
16–24	0	0·87	0·93	0·91	0·91	1·03	0·86	0·82	0·88	0·91	1·25		
	12·5	0·86	0·88	0·89	0·97	1·13	0·83	0·82	0·87	0·99	1·21	113	0·034
	25	0·86	0·91	0·95	1·07	1·31	0·85	0·83	1·00	1·13	1·35		
24–32	0	1·21	1·04	1·21	1·16	1·26	1·01	1·16	0·99	1·08	1·20		
	12·5	1·17	1·34	1·18	1·19	1·41	1·08	1·06	1·13	1·25	1·52	103	0·060
	25	1·15	1·26	1·32	1·39	1·65	1·07	1·29	1·25	1·47	1·73		
8–32	0	1·01	0·91	1·00	1·03	1·11	0·94	0·92	0·89	0·98	1·20		
	12·5	0·98	1·04	0·96	1·07	1·25	0·93	0·90	0·93	1·14	1·26	112	0·027
	25	0·99	0·99	1·09	1·18	1·36	0·98	0·95	1·04	1·19	1·40		

Statistical significance

Age (d)	Qualitative effects: PN	R	PN×R	I	I×PN	I×R	Quantitative responses: I_l	I_q	PN×I_l	PN×I_q	R×I_l	R×I_q
8–16	NS	—	—	***	NS	—	***	***	NS	NS	—	—
16–24	NS	***	NS	***	***	***	***	***	***	*	***	NS
24–32	NS	***	NS	***	NS	*	***	***	*	NS	*	NS
8–32	NS	***	NS	***	**	***	***	***	**	NS	***	NS

NS, not significant.
† Adjusted to a mean value of 18 MJ gross energy/kg air dry diet.
‡ For details, see text.
§ While the actual treatments applied did not vary between values for R until after the 16th day of age, the means of individual groups of five animals and analysis of variance have been presented for completeness.
l, linear; q, quadratic.
* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Table 4. *Digestibility of nitrogen by piglets between 11–16 d, 19–24 d, 27–32 d and 8–32 d as affected by initial energy: nitrogen value (kJ/g N; I) (250, 355, 460, 565 or 670), rate of increase of I (R)/8 d period (0, 12·5 or 25%) and plane of nutrition (PN) (high PN or low PN)*†

(Five blocks of thirty piglets per block five animals/mean)

Age interval (d)	PN … / I … / R (% of I/8 d period)	High 250	High 355	High 460	High 565	High 670	Low 250	Low 355	Low 460	Low 565	Low 670	df	SE of a mean
11–16	0‡	0·990	0·982	0·975	0·958	0·968	0·982	0·988	0·969	0·974	0·972		
	12·5‡	0·986	0·985	0·977	0·970	0·957	0·986	0·982	0·975	0·968	0·971	113	0·0049
	25‡	0·983	0·986	0·976	0·970	0·964	0·990	0·978	0·972	0·962	0·961		
19–24	0	0·990	0·985	0·976	0·977	0·969	0·991	0·985	0·980	0·980	0·962		
	12·5	0·988	0·984	0·979	0·972	0·964	0·988	0·982	0·982	0·970	0·964	112	0·0039
	25	0·991	0·986	0·967	0·952	0·941	0·987	0·983	0·970	0·967	0·953		
27–32	0	0·988	0·983	0·985	0·966	0·948	0·994	0·988	0·979	0·975	0·961		
	12·5	0·986	0·980	0·968	0·956	0·949	0·985	0·981	0·963	0·954	0·929	102	0·0065
	25	0·981	0·978	0·949	0·954	0·937	0·980	0·973	0·971	0·947	0·926		
8–32	0	0·988	0·984	0·980	0·969	0·961	0·991	0·986	0·977	0·976	0·964		
	12·5	0·987	0·983	0·975	0·966	0·958	0·987	0·982	0·974	0·967	0·955	102	0·0028
	25	0·987	0·984	0·965	0·958	0·946	0·986	0·979	0·971	0·959	0·948		

Statistical significance

Age (d)	Qualitative effects: PN	R	PN×R	I	I×PN	I×R	Quantitative responses: I_l	I_q	PN×I_l	PN×I_q	R×I_l	R×I_q
11–16	NS	NS	NS	***	NS	NS	***	NS	NS	NS	NS	NS
19–24	NS	***	NS	***	NS	**	***	NS	NS	NS	**	NS
27–32	NS	***	NS	***	NS	NS	***	*	NS	NS	NS	NS
8–32	NS	***	NS	***	NS	*	***	*	NS	NS	*	NS

NS, not significant.

† For details, see text.

‡ While the actual treatments applied did not vary between values for R until after the 16th day of age, the means of individual groups of five animals and analysis of variance have been presented for completeness.

l, linear; q, quadratic.

* $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.

Table 5. *Nitrogen retention (g/d) of piglets between* 11–16 *d,* 19–24 *d and* 27–32 *d as affected by initial energy:nitrogen value (kJ/g N; I)* (250, 355, 460, 565 *or* 670), *rate of increase of I (R)/8 d period* (0, 12·5 *or* 25%) *and plane of nutrition (PN) (high PN or low PN)*†

(Five blocks of thirty piglets per block five animals/mean)

Age interval (d)	PN ... / I ... / R (% of I/8 d period)	High 250	High 355	High 460	High 565	High 670	Low 250	Low 355	Low 460	Low 565	Low 670	df	SE of a mean
11–16	0‡	5·12	6·08	5·94	3·80	3·61	3·97	5·04	4·09	4·02	3·11		
	12·5‡	5·62	6·18	5·73	4·10	3·07	4·94	5·27	5·16	3·49	3·35	112	0·63
	25‡	5·07	6·82	5·08	4·05	3·70	4·82	5·12	4·08	3·10	2·89		
19–24	0	9·72	11·23	10·69	8·84	6·77	6·16	7·20	7·01	6·26	4·51		
	12·5	11·03	10·40	9·46	7·57	5·04	8·26	7·95	7·62	5·21	4·43	113	0·67
	25	9·83	10·57	8·59	5·34	5·06	7·51	8·31	6·03	4·42	3·65		
27–32	0	8·89	10·46	11·76	10·28	7·26	8·35	7·76	8·85	7·94	5·80		
	12·5	10·67	8·88	10·12	7·70	5·72	8·76	9·87	8·06	4·67	4·20	108	1·04
	25	10·00	10·73	7·64	6·90	5·14	8·82	8·57	6·53	4·60	3·06		

Statistical significance

Age (d)	Qualitative effects: PN	R	PN×R	I	I×PN	I×R	Quantitative responses: I_l	I_q	PN×I_l	PN×I_q	R×I_l	R×I_q
11–16	**	NS	NS	***	NS	NS	***	**	NS	NS	NS	NS
19–24	***	**	NS	***	NS	**	***	***	NS	NS	**	NS
27–32	***	***	NS	***	NS	***	***	***	NS	NS	***	NS

NS, not significant.
† For details, see text.
‡ While the actual treatments applied did not vary between values for R until after the 16th day of age, the means of individual groups of five animals and analysis of variance have been presented for completeness.
l, linear; q, quadratic.
** $P < 0.01$, *** $P < 0.001$.

Table 6. *Nitrogen retention as proportion of apparent digestible nitrogen (ADN) intake of piglets between* 11–16 *d*, 19–24 *d and* 27–32 *d as affected by initial energy:nitrogen value (kJ/g N; I)* (250, 355, 460, 565 *or* 670), *rate of increase of I (R)/8 d period* (0, 12·5 *or* 25%) *and plane of nutrition (PN) (high PN or low PN)*†

(Five blocks of thirty piglets per block five animals/mean)

Age interval (d)	PN ...	High					Low					df	SE of a mean
	I ... / R (% of I/8 d period)	250	355	460	565	670	250	355	460	565	670		
11–16	0‡	0·517	0·740	0·837	0·845	0·904	0·443	0·708	0·852	0·905	0·904		
	12·5‡	0·514	0·716	0·877	0·904	0·853	0·490	0·723	0·871	0·873	0·896	112	0·033
	25‡	0·457	0·729	0·843	0·900	0·888	0·498	0·728	0·768	0·884	0·900		
19–24	0	0·453	0·648	0·760	0·871	0·889	0·454	0·628	0·790	0·880	0·897		
	12·5	0·559	0·645	0·808	0·892	0·892	0·541	0·700	0·845	0·887	0·859	113	0·024
	25	0·611	0·729	0·861	0·851	0·891	0·556	0·779	0·877	0·898	0·897		
27–32	0	0·345	0·516	0·642	0·789	0·841	0·419	0·522	0·708	0·815	0·881		
	12·5	0·532	0·568	0·748	0·814	0·858	0·510	0·666	0·806	0·783	0·831	111	0·037
	25	0·576	0·695	0·781	0·855	0·872	0·564	0·735	0·865	0·876	0·807		

Statistical significance

Age (d)	Qualitative effects						Quantitative responses					
	PN	R	PN × R	I	I × PN	I × R	I_l	I_q	PN × I_l	PN × I_q	R × I_l	R × I_q
11–16	NS	NS	NS	***	NS	NS	***	***	NS	NS	NS	NS
19–24	NS	***	NS	***	NS	***	***	***	NS	NS	***	NS
27–32	*	***	NS	***	NS	***	***	***	NS	NS	***	NS

NS, not significant.

† For details, see text.

‡ While the actual treatments applied did not vary vetween rates of increase until after the 16th day of age, the means of individual groups of five animals and analysis of variance have been presented for completeness.

l, linear; q, quadratic.

* $P < 0·05$, *** $P < 0·001$.

growth and FCR results. One pig in the second replicate died as a result of a twisted bowel and two pigs in the fifth replicate were discarded at 12 d due to severe scour and loss of body-weight. In all instances where scour occurred during a balance period missing values were calculated. There was no apparent relationship between treatment and the incidence of scour.

The live-weight results (Table 2) show that performance was excellent in comparison with results reported in the literature for suckled and artificially-reared pigs (Manners & McCrea, 1962, 1963; Wood & Groves, 1965; Braude *et al.* 1970; Kirchgessner & Kellner, 1972; Klatt & Wullbrandt, 1975; Wangsness & Soroka, 1978; Newport, 1979) with the pigs on the best treatments averaging over 9·5 kg on the high PN and 8·5 kg on the low PN at 32 d.

The feeding scale employed was similar to one which had previously been found to be close to the *ad lib.* intake of pigs reared under similar conditions on liquid diets (Eddie & McCracken, 1972) and was somewhat lower than the scale adopted by Braude & Newport (1973) using high-fat diets. In the present experiment some food refusals occurred during the first period but between 16–24 d most pigs cleared up all their food. During the final period, however, there were consistent food refusals on the high PN and on average intake was only 80% of the amount offered. This indicates that during the final period the extent of restriction imposed on the animals on the low PN was much less than that intended.

A comparison with the results of Braude *et al.* (1970) indicates that the energy intakes achieved in the present experiment on the high PN were similar to those obtained on their scale B and therefore somewhat higher than intakes normally recorded for suckled pigs.

The ADN was high on all diets and reached 0·99 in the diets containing the higher levels of protein, a value similar to that found in diets based on whole milk (Braude *et al.* 1970). Due to the wide range of protein levels employed and the high digestibility of the dietary N it was possible to calculate a value for metabolic faecal N (MFN) excretion (Fig. 1).

The value of 1·07 g MFN/kg DM is similar to the value of 0·86 g/kg calculated from the results of Schneider (1935) for pigs between 24–109 kg live weight.

The value of 11 g/d for NR between 19–24 d was similar to that obtained by Newport (1979) for pigs at 19 d and higher than the retention of 8·4 g/d reported by Bohme *et al.* (1976) for pigs between 23 and 30 d of age which had been weaned at 15 d. NR as a proportion of digested nitrogen (NR:ADN) rose to 0·90 on the diets containing low levels of protein. This value is in close agreement with that reported by Newport (1979). However the results for NR determined from carcass analysis (McCracken *et al.* 1980) show that, despite the elaborate precautions taken to reduce N loss from the excreta, the N balance results appear to over-estimate retention by approximately 15%. Similar problems have been reported by Nehring *et al.* (1957) and by Fuller & Boyne (1971).

One interesting aspect of the results was the significant ($P < 0{\cdot}01$) PN × I interaction on FCR over the experimental period. The mean values of FCR were almost identical on the two planes of intake (1·07 and 1·05 on the high and low plane respectively) but there was an improvement of 6% on the low plane at the optimum energy:N value (0·98 and 0·92 respectively). It would appear that differences in body composition (McCracken *et al.* 1980) more than offset the reduction in energy available for production. Similar effects of restriction have been commonly reported in older pigs (Vanschoubroek *et al.* 1967).

Although it is not possible to assess the differences statistically there appears to be a marked decrease in FCR with increasing age. In the instance of the pigs given a constant energy:N value throughout the experiment the mean values were respectively 0·90, 0·94 and 1·13 for the periods 8–16, 16–24 and 24–32 d. The increase in FCR between 16–24 and 24–32 d was greater on the high PN the mean values for the latter period being 1·18 and 1·09 on the high and low PN respectively. The animals on the high PN increased their mean daily intake by 23% from the second to the third period but growth rate only increased by

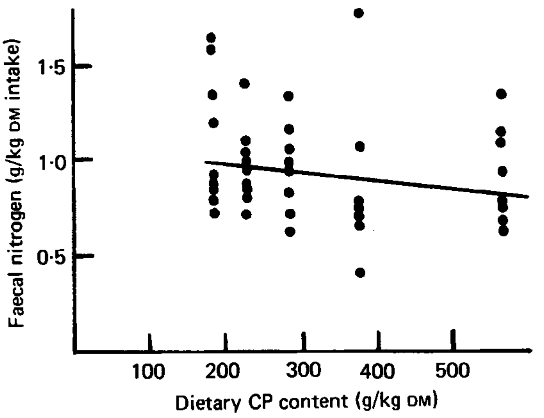

Fig. 1. Faecal nitrogen excretion (g/kg dry matter (DM) intake) of piglets given synthetic diets, containing between 180 and 560 g crude protein (N × 6·25:CP)/kg, in which the main protein source was dried skim milk. Faecal N = 1·070–0·00047 CP.

7% and NR by 3%. Although a complete explanation is not possible in the absence of carcass analysis at the end of each period it appears that the major part of the effect arose from the reduction in the efficiency of NR to which reference has already been made.

Since the main feature of the results was the quadratic effect of I and the I × R interaction, it was possible in the instance of the four criteria examined to calculate response curves of performance *v*. I. These are detailed in Figs. 2 and 3. Apart from the 8–16 d interval when the maximum point of the curve for NR corresponds to 330 kJ/g N the optima derived for growth, FCR and NR during the three periods and for 8–32 d, lie between 385 and 440 kJ/g N (Table 7) when the same diet was fed throughout the experimental period. Progressively lower values of I occur for the other levels of R. However the proportion of digested N retained was maximum at 590, 680 and 950 kJ/g N respectively for the three age intervals.

It is therefore necessary to arrive at a compromise between the factors in order to formulate practical recommendations. However in view of the flat nature of the response curves it will be appreciated that a fairly large change in I may result in a small reduction in performance in relation to any single criterion. The factor most affected by the energy:N value appears to be the NR:ADN value. Fig. 4 illustrates the differences arising in this value over the three N-balance periods. The experimental design did not permit statistical analysis of the differences but they are in general agreement with the decreased efficiency of NR with increasing age reported by Braude *et al.* (1970) and by Newport (1979) and support the hypothesis advanced in the introduction to this paper.

A suitable compromise designed to maintain a relatively high efficiency of utilization of absorbed N during the three periods would appear to be an I value of 470 kJ/g N at 8 d increasing by 10%/week. This would result in reductions of approximately 5% in growth rate and FCR and a somewhat greater reduction in NR in comparison with the maximum values attainable. Alternatively the use of a constant energy:N value of 460 kJ/g N would be acceptable in respect of growth, FCR and NR although wasteful in terms of N utilization. This result is in good agreement with estimates derived from the results of Manners & McCrea (1962, 1963) and Muller & Kirchgessner (1974) but is considerably lower than that calculated from the results of Newport (1979). However an increase in the energy:N value to 500 or 540 kJ/g N only reduces performance by 3–4 and 7–8% respectively. In most instances performance up to 5–6 weeks of age will be of secondary importance to over-all

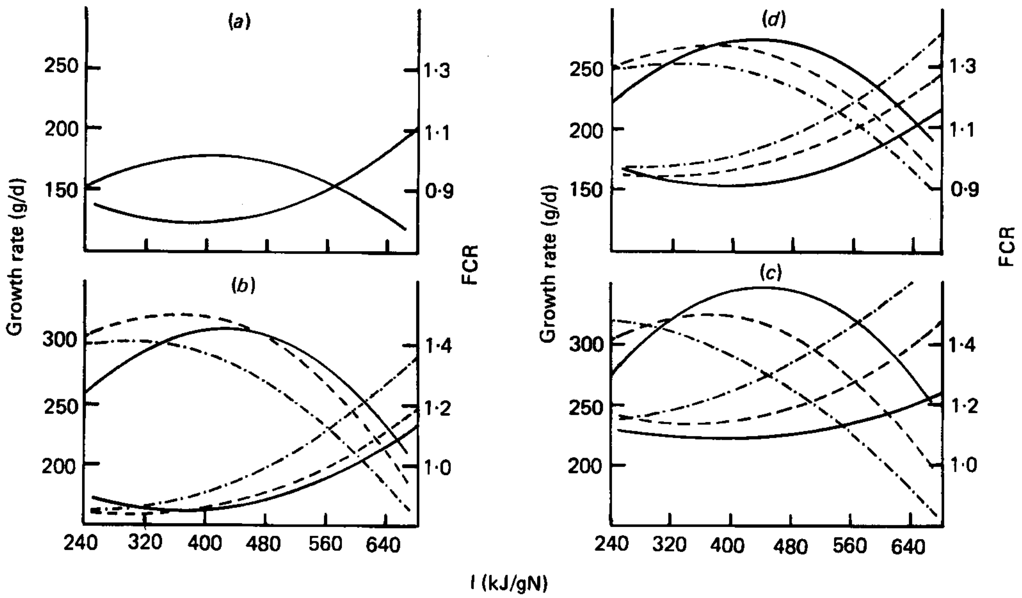

Fig. 2. Response curves of growth rate (g/d) and feed conversion ratio (g food intake/kg weight gain; FCR) in relation to energy:nitrogen value (kJ/g N) in the diet, calculated by least squares regressions (*a*) 8–16 d, (*b*) 16–24 d, (*c*) 24–32 d, (*d*) 8–32 d. (——), constant energy:N value (I); (– – –), I increased by 12·5 % at 16 and 24 d; (–·–·–), I increased by 25 % at 16 and 24 d.

Growth rate (g/d):	8–16 d	$Y = 27{\cdot}749+0{\cdot}7415X-0{\cdot}000908X^2$,
	16–24 d	$Y = 8{\cdot}495+1{\cdot}434X-0{\cdot}001698X^2$,
		$Y = 128{\cdot}379+1{\cdot}078X-0{\cdot}001491X^2$,
		$Y = 206{\cdot}584+0{\cdot}626X-0{\cdot}001046X^2$,
	24–32 d	$Y = -7{\cdot}157+1{\cdot}614X-0{\cdot}001843X^2$,
		$Y = 136{\cdot}088+1{\cdot}022X-0{\cdot}001391X^2$,
		$Y = 295{\cdot}483+0{\cdot}2625X-0{\cdot}000691X^2$,
	8–32 d	$Y = 7{\cdot}729+1{\cdot}3145X-0{\cdot}001520X^2$,
		$Y = 115{\cdot}716+0{\cdot}8516X-0{\cdot}001169X^2$,
		$Y = 148{\cdot}185+0{\cdot}6522X-0{\cdot}000986X^2$.
FCR:	8–16 d	$Y = 1{\cdot}356-0{\cdot}00290X+0{\cdot}000003742X^2$,
(air-dry basis,	16–24 d	$Y = 1{\cdot}216-0{\cdot}002035X+0{\cdot}000002812X^2$,
18 MJ/kg at		$Y = 1{\cdot}122-0{\cdot}001782X+0{\cdot}000002748X^2$,
900 g dry matter		$Y = 1{\cdot}065-0{\cdot}001578X+0{\cdot}000002936X^2$,
/kg)	24–32 d	$Y = 1{\cdot}343-0{\cdot}001327X+0{\cdot}000001711X^2$,
		$Y = 1{\cdot}499-0{\cdot}002120X+0{\cdot}000003035X^2$,
		$Y = 1{\cdot}177-0{\cdot}000630X+0{\cdot}000002051X^2$,
	8–32 d	$Y = 1{\cdot}362-0{\cdot}002277X+0{\cdot}000002934X^2$,
		$Y = 1{\cdot}163-0{\cdot}001384X+0{\cdot}000002271X^2$,
		$Y = 1{\cdot}251-0{\cdot}001826X+0{\cdot}000003040X^2$.

performance up to 30 kg or even to 80 kg live weight. In this respect the results of Wyllie *et al.* (1969), who found that 3-week-weaned pigs given high-starter-protein levels were less efficient during the 24–90 kg period than those given low-starter-protein levels, are of considerable interest.

The long-term effects of the energy and protein nutrition in the early stages of growth obviously merit further attention. In the meantime the results presented in this paper provide a basis for the assessment of energy and protein requirements of the early-weaned

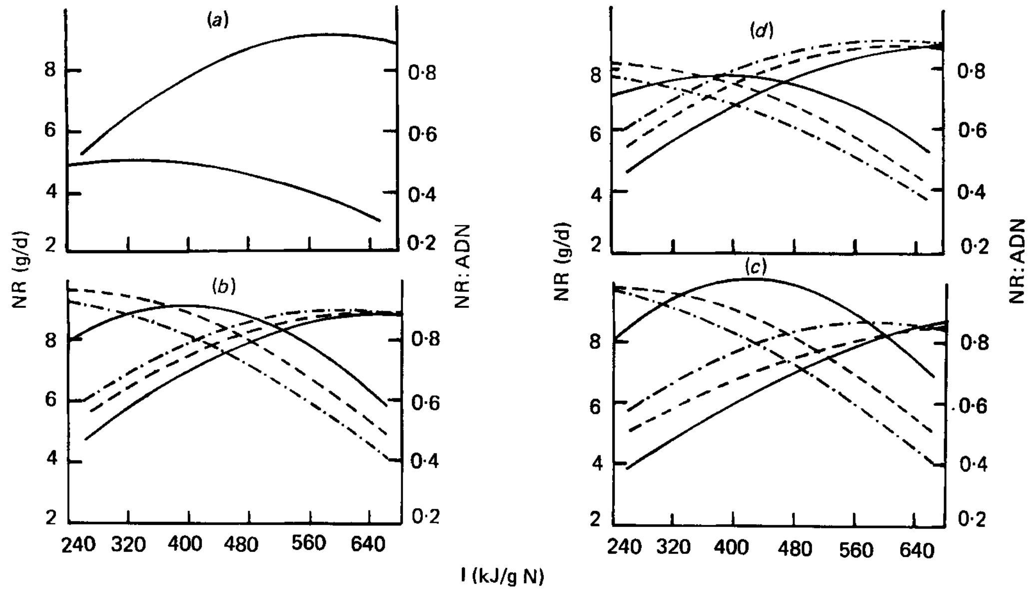

Fig. 3. Response curves of nitrogen retention (g/d; NR): apparent digested N (ADN) (NR:ADN) in relation to initial energy:N value (I) ratio in the diet, calculated from least squares regressions. (*a*) 11–16 d, (*b*) 19–24 d, (*c*) 27–32 d, (*d*) 8–32 d. (——), Constant energy:N; (---), I increased by 12·5% at 16 and 24 d; (-·-·-), I increased by 25% at 16 and 24 d.

NR (g/d):	11–16 d	$Y = 2{\cdot}998+0{\cdot}01370X-0{\cdot}00002034X^2$,
	19–24 d	$Y = 1{\cdot}544+0{\cdot}03788X-0{\cdot}00004766X^2$,
		$Y = 8{\cdot}418+0{\cdot}01134X-0{\cdot}00002540X^2$,
		$Y = 9{\cdot}162+0{\cdot}00472X-0{\cdot}00001884X^2$,
	27–32 d	$Y = 0{\cdot}001+0{\cdot}04724X-0{\cdot}00005568X^2$,
		$Y = 7{\cdot}996+0{\cdot}01428X-0{\cdot}00002868X^2$,
		$Y = 10{\cdot}420+0{\cdot}00144X-0{\cdot}00001666X^2$,
	8–32 d	$Y = 2{\cdot}904+0{\cdot}02548X-0{\cdot}00003330X^2$,
		$Y = 7{\cdot}229+0{\cdot}00868X-0{\cdot}00002030X^2$,
		$Y = 7{\cdot}712+0{\cdot}00412X-0{\cdot}00001566X^2$.
NR:ADN:	11–16 d	$Y = -0{\cdot}3272+0{\cdot}004155X-0{\cdot}000003506X^2$,
	19–24 d	$Y = -0{\cdot}2232+0{\cdot}003292X-0{\cdot}000002416X^2$,
		$Y = -0{\cdot}0700+0{\cdot}003014X-0{\cdot}000002372X^2$,
		$Y = -0{\cdot}0404+0{\cdot}003175X-0{\cdot}000002679X^2$,
	27–32 d	$Y = -0{\cdot}1277+0{\cdot}002299X-0{\cdot}000001209X^2$,
		$Y = +0{\cdot}0808+0{\cdot}001974X-0{\cdot}000001231X^2$,
		$Y = -0{\cdot}0694+0{\cdot}003219X-0{\cdot}000002766X^2$,
	8–32 d	$Y = -0{\cdot}1761+0{\cdot}003092X-0{\cdot}000002256X^2$,
		$Y = -0{\cdot}0383+0{\cdot}002874X-0{\cdot}000002256X^2$,
		$Y = +0{\cdot}0431+0{\cdot}002768X-0{\cdot}000002256X^2$.

pig in a range of management situations and for further studies on diets containing lower-quality-protein sources.

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Table 7. *Values of initial energy:nitrogen value (kJ/g N; I) for optimum growth, food conversion ratio (FCR), N retention (NR) and NR:apparent digestibility of N (ADN) calculated from response curves*

Age interval (d)	Rate of increase of I	Growth	FCR	NR	NR:ADN
8–16	0	410	390	330	590
16–24	0	420	360	400	680
	12·5	360	325	< 250	635
	25	300	270	< 250	590
24–32	0	440	390	425	950
	12·5	365	350	250	800
	25	< 250	< 250	< 250	580
8–32	0	430	390	385	685
	12·5	365	305	< 250	635
	25	330	300	< 250	615

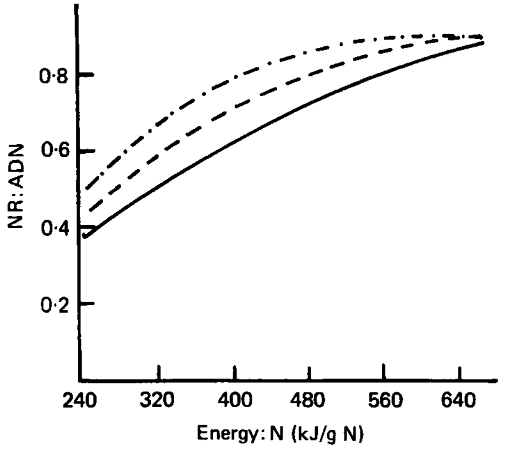

Fig. 4. Effect of energy:nitrogen value (kJ/g N) and age on the proportion of digested N retained (nitrogen retention:apparent digestible N) by piglets. (–·–·–), 11–16 d; (–––), 19–24 d; (——), 27–32 d of age.

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