The effects of environmental temperature on the growth and metabolism of pigs given different amounts of food

1. Nitrogen metabolism, growth and body composition

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1. Twelve castrated male pigs were kept at each of three temperatures and given food at one of three levels of intake. The temperatures and daily food intakes (expressed as $g/kg^{0.73}$) were 23° (80, 100, 120), 13° (100, 120, 140), 3–5° (120, 140, 160). Growth and nitrogen metabolism were measured during growth from 20 kg live weight until slaughter at 90 kg live weight, when the body contents of N and fat were estimated.

2. Growth rate increased with each unit of daily food intake (1 $g/kg^{0.73}$ live weight) by 7·73 ± 0·74 g/d. This value did not vary significantly with temperature. Daily growth rate was depressed by 17·8 ± 2·3 g for each 1° fall of temperature.

3. Daily N retention estimated by the balance method exceeded by 2·59 g/d that estimated by the comparative slaughter technique. Both results led to the same conclusion, which echoed that found with growth rate, that there was no significant effect of temperature on the response of N retention to increasing food intake. Taking the mean of the two estimates, N retention at a constant food intake fell by 0·38 ± 0·055 g/d for each 1° fall of temperature.

4. The N content of the ingesta-free carcass at slaughter fell with each increase in daily food intake by 0·007 ± 0·002 %, and the fat content rose correspondingly by 0·116 ± 0·027 %. These regressions did not vary significantly with temperature. When considered at a constant food intake, body composition did not alter significantly with temperature.

The primary influence of environmental temperature on the growth of animals is by way of their heat exchanges. Exposure to cold, by causing the animal to increase its heat production, diverts nutrients from anabolic to oxidative metabolism. The particular nutrients that are utilized for thermoregulatory heat production will have repercussions not only on nutrient requirements at different temperatures, but also on the rate of growth and on body composition. In particular, because of the central importance of protein metabolism in growth, the question arises of the extent to which protein katabolism is accelerated in pigs exposed to cold. In an earlier experiment (Fuller, 1965) young pigs, fed *ad lib.*, used their dietary nitrogen with constant efficiency at all temperatures between 10 and 30°. In that experiment pigs, at any given weight, ate progressively more food, the lower was the temperature.

In contrast, Piatkowski (1958) and Moustgaard, Nielsen & Sørensen (1959) reported that pigs kept at different temperatures, but given the same amount of food, retained less N in cold than in thermally neutral environments.

There are reasons for expecting that the effect of temperature on N metabolism will vary according to the amount of food the animal is given. The first of these can be illustrated by taking the extreme case in which the food supply is reduced to the maintenance level. In this stuation, only a small fraction of the protein consumed will be retained; the greater part will contribute to the animal's energy needs. Because this maintenance energy requirement varies with environmental temperature, so must also the amount of N retained at a given, low food intake.

The second reason is that, as the food intake is increased, the total heat production increases proportionately, at a rate which is defined by the heat increment of the particular diet. Work with sheep (Graham, Wainman, Blaxter & Armstrong, 1959) has shown that this heat can 'replace' at least some of the thermoregulatory heat produced specifically in response to cold exposure.

These two considerations lead one to expect an interaction between environmental temperature and feed intake in their effects on the pig's metabolism and growth. Experimental evidence for such interactions exists. For example, Lucas & Calder (1955) reported that pigs kept in an uninsulated stone building grew more slowly in winter than in summer when on a low plane of nutrition, but that on a high plane this difference disappeared.

With this background, the experiment to be described was designed to investigate the extent and nature of the interrelation between temperature and food intake, as it affects various facets of the growth of pigs.

EXPERIMENTAL

Design of the experiment. At each of three temperatures, pigs were given food according to one of three scales, which increased with body-weight. This nine-treatment design was replicated four times, with a total of thirty-six pigs. The experiment began when the pigs weighed 20 kg and ended when they weighed 90 kg. In the choice of temperatures, the aim was to provide three environments, the warmest of which would be within the thermoneutral zone of pigs throughout the experiment, and the coldest permanently below the critical temperature of all pigs. For this purpose temperatures of 23 and 3° were chosen. The intermediate temperature was set at 13°, which was judged to be below the zone of thermoneutrality of a 20 kg pig, but probably about equal to its critical temperature by the time it weighed 90 kg. After the first replicate, the lowest temperature was increased to 5° for reasons which will be given later.

The choice of feeding levels was governed by two considerations. First, in order to show clearly the effects of increasing food intake, and to establish the presence or absence of an interaction with temperature, the ratio of the highest to the lowest feed intake at any one temperature should be large—of the order of 1·5:1. If the same quantities of food were to be given at all temperatures, the greatest of them could clearly be no more than a pig at 23° would voluntarily and reliably consume. This was found by preliminary experience to be about 120 g/kg$^{0.73}$.d. The lowest feeding level would therefore be 80 g/kg$^{0.73}$.d. This quantity of feed was estimated to be hardly sufficient to maintain a pig at 3°.

This led to the second consideration, which concerned the interpretation of the results if pigs at the different temperatures grew at different rates, as would occur if the same feeding levels were used at all temperatures. One of the responses to be examined was the change of body composition, which is closely allied to growth rate, and in the analysis of these results the effects of temperature would have been confounded with those of slower growth *per se*.

These considerations seemed to preclude an orthogonal design, and suggested that, for each downward step of temperature, the daily food intake should be increased by an amount sufficient to give equal growth at all temperatures. A preliminary estimate of this requirement was 2 g/kg$^{0.73}$ per °C, and the results showed that this value was approximately correct. The resulting design, in terms of the food intake at each temperature, is shown in Table 1.

Table 1. *Planned food intakes at the different temperatures*

(The food intakes actually achieved by the pigs are given in parentheses)

	Food intake (g/kg$^{0.73}$.d)		
Feeding level	At 5°*	At 13°	At 23°
High	160 (156·2)	140 (135·8)	120 (116·3)
Medium	140 (137·6)	120 (117·7)	100 (95·8)
Low	120 (117·0)	100 (98·3)	80 (78·7)

* 3° in replicate 1.

Table 2. *Composition of the diets*

	Replicate 1		Replicates 2–4	
Diet	1 (Start–50 kg live weight)	2 (50 kg live weight–end)	A (Start–50 kg live weight)	B (50 kg live weight–end)
	Percentage of diet			
Component				
Ground barley	84·6	92·0	72·5	77·5
Wheat offal	—	—	10·0	10·0
White fish meal	15·4	8·0	7·5	5·0
Soya-bean meal	—	—	10·0	7·5
	100·0	100·0	100·0	100·0
	kg/1000 kg			
Supplements				
Steamed bone flour	—	—	2·23	2·68
Mineral–vitamin mixture*	1·10	1·00	2·23	2·23
Copper sulphate, $5H_2O$	0·76	0·76	—	—
Zinc carbonate	0·15	0·15	—	—
	mg/1000 kg			
Vitamin B_{12}	—	2·44	—	—
Average analysis				
Protein (N × 6·25) (%)	18·5	13·3	17·3	14·0
kcal/kg	—	—	3850	3792
Ash	5·6	3·9	4·2	3·6
Ether extractives	2·3	1·9	2·1	2·3

* Parkhill No. 2 (Isaac-Spencer and Co. Ltd, Aberdeen), supplying, per 1000 kg diet, vitamin A 4×10^6 i.u., cholecalciferol 1×10^6 i.u., riboflavin 2 g, DL-calcium pantothenate 10 g, nicotinic acid 10 g, cyanocobalamin 5 mg, vitamin K (menaphthone) 5 g, Cu 200 g, Zn 100 g, Mn 30 g, Fe 60 g, Co 0·9 g, I 1 g.

Diets. Although the effects of temperature may differ according to the kind of food the pig is given, such interactions were beyond the scope of this experiment. The diets used were intended to represent those used in current standard practice. In the first replicate, simple diets (1 and 2) based on barley and fish meal were used; their

compositions are given in Table 2. For later replicates, diets were formulated which conformed to the then newly published ARC recommendations (Agricultural Research Council, 1967). The compositions of these diets are also given in Table 2.

Environmental conditions. Three simple temperature-controlled rooms were made within existing buildings. Each room measured approximately 3 m × 3·5 m. Its walls and ceiling were insulated with a 7 cm thickness of glass fibre, and its floor with a 7 cm thickness of expanded polystyrene beneath the wooden floor. This high degree of insulation was to ensure that radiant temperature would not differ significantly from air temperature, so that the environmental conditions could be specified more exactly.

The cold room (3 or 5°) was equipped with a low-temperature refrigeration plant with ample capacity to maintain the required temperature at all times of the year. The hot room (23°) was fitted with a 3 kW fan heater and the third room with a medium-temperature air-conditioning unit to which two 1 kW electric elements had been added. This room could be maintained at 13° whether the outside temperature was below or above this. To prevent over-shooting when outside temperature was close to 13°, one of the 1 kW elements was left on with the refrigerator removing the surplus heat. The temperatures were controlled by bimetallic thermostats acting through hot-wire vacuum switches.

Each chamber was ventilated by an 11 cm diam. fan delivering approximately 1·4 m^3/min. The air movement within each chamber was created by the fan of the temperature-control equipment, which ran continuously. Measurements made with a kata-thermometer at the places occupied by the pigs gave the air movement in the three environments as: 5° room, 70–80 cm/s; medium room, 40–45 cm/s; hot room, 45–55 cm/s.

The temperatures at various sites within each room were recorded continuously by thermocouples connected to a potentiometric recorder. Any deviation of temperature from that desired could therefore be observed and rectified quickly. These records may be summarized by saying that the temperatures recorded, excluding the short periods when the doors were open, were almost always within 1° of the stated temperatures, and usually within 0·6°. Humidity was not controlled but the generous ventilation ensured no great increase of absolute humidity over that of outdoor air.

Animals. In the first replicate of the experiment, pigs from the Institute's Large White herd were used. The experiment was then interrupted by the establishment at the Institute of a minimal disease herd. For the second replicate, Landrace pigs were used. They were produced by hysterectomy and reared as described by Robertson, Jones, Fuller & Elsley (1970).

The third and fourth replicates comprised Large White × (Landrace × Large White) pigs which were born naturally.

All pigs were males, castrated at about 3 weeks of age.

Measurements made. In all replicates the losses of N in faeces and urine were estimated throughout. For this purpose, the experiment was divided into seven periods, each spanning a weight interval of 10 kg. Growth rate and food conversion ratio (FCR) were also recorded. At the end of the experiment, when the animal was estimated to have a fasted weight of 90 kg, it was slaughtered. In replicates 2, 3 and 4

the carcasses were minced and sampled and their contents of water, fat and N determined. Samples of fat were taken from seven sites and their iodine values, and in some instances fatty acid composition, were determined. These results will be given in the following paper of this series.

In addition, in the last two replicates, measurements were made of the animals' energy utilization. The details of the calorimetric procedures and the results of the energy metabolism experiments will be given in the third paper of this series.

Six pigs were slaughtered at a weight of 20 kg to estimate the composition of the animals at the start of the experiment. From these values and from the determined N and fat contents of the carcasses of the experimental pigs, estimates were made of the average rates of N and of fat deposition.

Experimental procedure. Each animal was put into a metabolism cage in the appropriate environmental room when it weighed about 17 kg and it remained there throughout the experiment. The metabolism cages were made of tubular steel, with sides of 25 mm × 25 mm wire mesh, and floors of 76 mm × 12 mm × 3 mm diam. wire mesh. The cages were adjusted frequently in both length and width, allowing a lying area of 250 mm × 630 mm when the pigs weighed 20 kg, increasing to 500 mm × 1150 mm when they reached 90 kg. The construction of the cage, being of wire mesh, clearly afforded the animal the minimum of isolation from the climatic environment of the room at large.

On 3 alternate days every week, each animal was weighed in order to decide the amount of food it would receive until it was weighed again. Each day's feed was given in two equal portions at 08.00 hours and at 16.00 hours with 2·5 l water per kg feed. No other water was given.

Faeces were voided direct into plastic bins containing enough sulphuric acid (0·1 N) to cover them. Urine was collected by a square funnel 500 mm × 500 mm into a container to which 10 ml of urine preservative (12·5 g $HgCl_2$, 87·5 g $K_2Cr_2O_7$ and 100 ml 36 N-H_2SO_4 per l) were added. The urine funnel was covered with Terylene gauze to prevent contamination of the urine by any solid material (food, hair or faeces) accidentally falling into the funnel. Food spilt as the pig ate was caught on a tray immediately below the feeding-trough, and was added to the next feed. The urine funnel and the cage floor were washed daily with ~ 200 ml 0·1 N-H_2SO_4.

Estimation of the losses of N as skin and hair. Food particles, which were mixed with hair and skin debris, were collected from the gauze and accumulated together with similarly mixed material swept up from the floor around the cage. The N content of these mixed residues was determined, and from this value the contribution of hair and skin debris to the mixed residues was estimated by assuming it to be a mixture of a skin component containing 15·8% N and a food component, the N content of which was also known. The weight of hair + shed skin (H) was then estimated as

$$H = \frac{R\,(N_r - N_f)}{0{\cdot}158 - N_f},$$

where R = total weight of mixed residues, and N_r and N_f are the N contents of the residues and of food respectively, expressed as proportions.

Procedure for slaughter and carcass analysis. After an overnight fast, the pigs were killed with a captive bolt pistol. They were suspended by the hind legs and bled by severing the major blood vessels of the neck. The alimentary tracts were removed, weighed, emptied and reweighed. The entire animal was then ground through a mincer with a 4·8 mm diam. screen and the minced material was mixed by machine. A primary sample of about 1200 g of minced material was freeze-dried. Secondary samples of freeze-dried material were further comminuted in an electric coffee mill before analysis. About 60 g of this material were extracted with diethyl ether in a large Soxhlet apparatus. This scale of operation was found necessary to obtain satisfactory duplication.

RESULTS

Appearance and behaviour of the animals. During the first 2 weeks or so of the experiment, pigs in the cold environment, whether 3 or 5°, shivered visibly for much of the time. Later, shivering disappeared. Four weeks after the first replicate had begun, the pigs on the high and low feed intakes in the cold environment suffered rectal prolapses. These were treated surgically, but without success, and the animals were discarded. Whether or not this was an effect of the cold is not known; no such effect of cold seems to have been reported. We have noted, however, that pigs in metabolism cages seem more prone to rectal prolapse than penned animals. In later replicates, when the lowest temperature was increased to 5°, there were no health problems.

Food intake. The food consumed by the animals was slightly less than the intended intakes. This was primarily due to the fact that the feed was allocated for a period of 2 or 3 d on the basis of the animal's weight at the start of that period, rather than on its mean weight during the period. The mean quantities of food consumed are given in Table 1. The general mean for the whole experiment was 117·1 $g/kg^{0.73}.d$ and it is to this value that the results have been adjusted in the covariance analyses.

Differences between replicates. In most of the measurements made, there were considerable differences between the first and subsequent replicates. This may be illustrated by the mean growth rates in the four replicates, which were 477, 608, 616 and 625 g/d (SE of difference = ±32 g). Similar differences were recorded in FCR. These differences no doubt reflect the change to a minimal disease herd and the genetic change which accompanied it.

The inferior growth of the pigs in the first replicate was reflected in their N retention, which had a mean value of 13·5 g/d. In the following replicates, the values were 16·9, 18·4 and 17·4 g/d. In the analysis of the results, there were, however, no significant differences between replicates in the regressions of these variables on food intake, indicating that the pattern of change was similar in all replicates.

Growth rate during the whole experiment. To illustrate the pattern of response to food intake and temperature which was found in this experiment, Fig. 1 shows the mean growth rate corresponding to each temperature and food intake. A similar pattern appeared in the results of the N retention studies.

The mean food intakes and growth rates at each temperature are given in Table 3.

The coefficient of the regression equation relating growth rate to food intake did not vary significantly with temperature; daily growth rate increased by 7·73 ± 0·74 g per g/kg$^{0·73}$ increase in daily food intake. The growth rates at the different temperatures, adjusted to a common food intake of 117 g/kg$^{0·73}$.d, are also given in Table 3. The effect of temperature on the adjusted growth rates was the same over each temperature interval, and amounted to −17·8 g/°C fall of temperature.

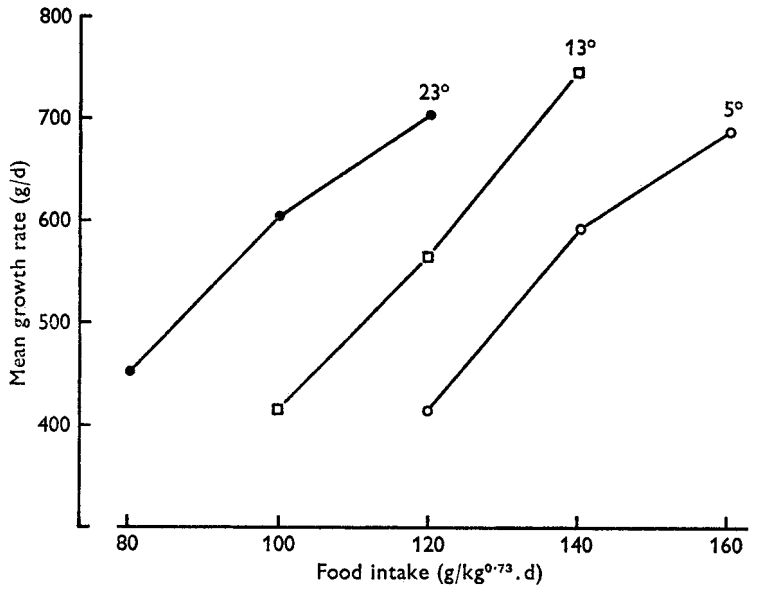

Fig. 1. Effect of increasing food intake on the mean growth rate throughout the experiment of pigs at different environmental temperatures.

Table 3. *Effect of temperature on growth rate and food conversion ratio of pigs between 20 and 90 kg body-weight, both for the mean food intake at that temperature, and when adjusted to a common food intake*

	At 3–5°	At 13°	At 23°	SE of differences between: Adjacent temperatures	SE of differences between: Extreme temperatures
Food intake (g/kg$^{0·73}$.d)	136·9	117·1	96·9	—	—
Growth rate (g/d)	566	591	587	49	49
Adjusted to intake of 117 g/kg$^{0·73}$.d	412	590	742	33	42
Food conversion ratio (g food/g live-wt gain)	4·34	3·58	2·98	0·18	0·18
Adjusted to intake of 117 g/kg$^{0·73}$.d	4·51	3·58	2·81	0·19	0·25

Growth rate at different body-weights. Because the relative effect of a given environment alters as the pig gets bigger, the growth of each pig was divided into two phases: 25–50 and 50–85 kg. Growth rates in each phase were then examined separately. The regression of growth rate on daily food intake did not vary with temperature in either

period, nor did it differ significantly between the two periods. When the effects of food intake were eliminated by covariance, the daily growth rate of the small pigs was seen to fall with temperature by $22{\cdot}3 \pm 1{\cdot}9$ g/°C, whereas for the large pigs the corresponding value was $9{\cdot}5 \pm 2{\cdot}1$ g/°C.

FCR. FCR, calculated as g food consumed per g live-weight gain, showed a tendency to fall with increasing intake. The regression coefficient was $-0{\cdot}0085 \pm 0{\cdot}0044$, which just failed to reach significance at the 5% level. The mean values of FCR at each temperature, both at the mean food intakes at those temperatures and when adjusted to a common food intake, are given in Table 3.

When adjusted to a common food intake, FCR increased by 0·077 units per °C between 23 and 13°, and by 0·109 units per °C between 13 and 5°.

Digestibility of N. The general mean value for N digestibility was 82·0%. There was no consistent pattern of change in digestibility with increasing body-weight, except that in period 4, immediately after the change of diet, N digestibility fell to 80·6%, but recovered in the next period.

The mean values of N digestibility and of its change with increasing food intake at each temperature are given in Table 4. N digestibility fell with increasing food intake at each temperature, but this effect was only significant at 5 and 13°. The pooled regression for the two lower temperatures was $-0{\cdot}090 \pm 0{\cdot}021$. If this coefficient was used to adjust the N digestibilities at 5 and 13° to a common food intake, all effect of temperature disappeared. At 23°, however, because the regression coefficient was not significant, it is not possible to say whether the higher digestibility at that temperature was attributable to the lower food intake, or to the higher temperature itself.

Loss of N as skin and hair. The estimates of the quantities of N lost as hair and skin debris in each period were highly variable, as might be expected both from the difficulty of collecting the material, and from the approximations involved in estimating contamination by food. Even so, statistical analysis showed that there were significant differences between treatments ($P < 0{\cdot}01$). Skin N loss increased with the weight of the animal ($P < 0{\cdot}001$), as might be expected, but this effect varied considerably between replicates. There was a significant ($P < 0{\cdot}001$) linear regression of daily skin N loss on daily food intake, which did not differ between temperatures. However, the magnitude of this effect differed significantly ($P < 0{\cdot}05$) between replicates, and in adjusting the values to a mean food intake of 117 g/kg$^{0{\cdot}73}$.d, the separate regression coefficients appropriate to each replicate were used.

The adjusted mean values at each temperature are given in Table 4. It is clear that the daily loss of N increased with temperature, and was significantly higher at 23° than at the lower temperatures.

N retention. The average daily N retention of each pig throughout the experiment was estimated both by the N balance method and by the comparative slaughter technique. To distinguish between the two they will be called 'daily N balance' and 'daily body N gain', respectively. The changes in daily N balance with increasing body-weight are shown in Fig. 2. It can be seen that from 20 to 50 kg, when the pigs were eating diet A, N balance increased with body-weight by approximately 0·7 g/d for

each 10 kg increase in body-weight. In the period following the change of diet it fell, reflecting both the lesser protein content of the diet and the lower digestibility of N in this period. It reached a maximum at 65 kg, thereafter declining by approximately 0·7 g/d with each 10 kg increase in body-weight up to 90 kg.

Table 4. *Nitrogen metabolism of pigs at* 5, 13 *and* 23°

(Mean values at each temperature are given both as observed and when adjusted to a common food intake of 117 g/kg$^{0·73}$.d, using the appropriate residual regression)

	At 5°	At 13°	At 23°	SE of difference between: Adjacent temperatures	SE of difference between: Extreme temperatures
Mean food intake (g/kg$^{0·73}$.d)	137	117	97		
Nitrogen digestibility					
Apparent digestibility of N (%)	80·3	82·1	83·6	0·84	0·840
Regression coefficient of N digestibility on food intake (%/g.kg$^{0·73}$.d)	−0·093 ± 0·030	−0·087 ± 0·031	−0·011 ± 0·031	—	—
Adjusted N digestibility (%)	82·2	82·1	83·4	0·76	0·97
Daily loss of N as hair and skin debris					
Mean skin N loss (g/d)	0·39	0·34	0·41	0·080	0·080
Adjusted skin N loss (g/d)	0·24	0·34	0·52	0·058	0·075
Daily N retention					
N balance (g/d)*	16·9	17·7	18·0	1·69	1·69
Body N gain (g/d)†	14·1	15·4	15·2	1·61	1·61
Adjusted N balance (g/d)*	13·7	17·6	21·4	0·86	1·11
Adjusted body N gain (g/d)†	11·6	15·4	17·8	1·26	1·62
Daily N balance per kg$^{0·73}$					
N balance/kg$^{0·73}$ (g/d)	0·92	0·95	0·98	0·081	0·081
Adjusted N balance/kg$^{0·73}$ (g/d)	0·73	0·94	1·15	0·052	0·068

Daily N balance per kg$^{0·73}$ in relation to food intake and body-wt

	Food intake (g/kg$^{0·73}$.d)	At 5°	At 13°	At 23°
Mean N balance/ kg$^{0·73}$ (g/d)‡	80	—	—	0·827 (−0·108)
	100	—	0·793 (−0·088)	0·999 (−0·148)
	120	0·753 (−0·053)	0·965 (−0·128)	1·171 (−0·188)
	140	0·925 (−0·093)	1·137 (−0·168)	—
	160	1·097 (−0·133)	—	—

* Daily N retention estimated by the balance technique.
† Daily N retention estimated by the comparative slaughter technique.
‡ These values correspond to a weight of 55 kg; in parentheses are the changes in this value corresponding to an increase of 10 kg in body-weight.

The effects of temperature and food intake on this pattern are described below, where N balance is expressed in relation to body-weight.

Daily N balance increased with food intake by 0·165 ± 0·018 g per g/kg$^{0·73}$.d. The corresponding regression of daily body N gain was 0·128 ± 0·029. Neither of these regressions varied significantly with temperature, nor did they differ between replicates. The rate of increase of body N gain with increasing daily food intake tended to be less at the higher food intakes, but this effect did not approach statistical

significance. Both these estimates of N retention are given in Table 4, with the mean food intakes at those temperatures. The same values adjusted to a common food intake of 117 g/kg$^{0.73}$.d are also given. Because estimates of body N gain were made only in replicates 2, 3 and 4, only the corresponding values for N balance are given in this table.

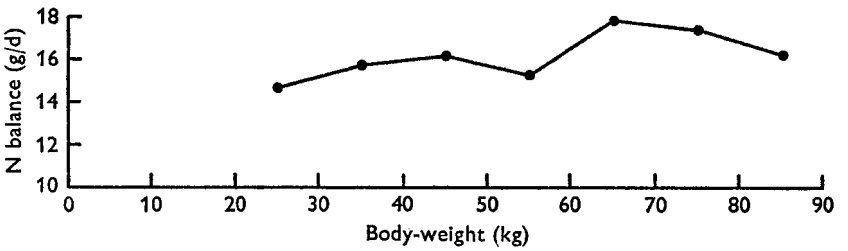

Fig. 2. Effect of increasing body-weight on the mean daily nitrogen balance of pigs for all environmental temperatures.

N balance in relation to body-weight. To analyse the changes in daily N balance with increasing body-weight, daily N balance was also expressed per kg$^{0.73}$. Because N retention is closely related to N intake and because the pigs were fed in proportion to the 0·73 power of their weight, it might be expected that this approach would reveal the most consistent patterns of change with increasing body-weight.

In replicate 1, the mean value of N retention/kg$^{0.73}$ was 0·83 g/d, considerably lower ($P < 0.001$) than in subsequent replicates, in which the mean values were 0·96, 1·00 and 0·99. However, the treatment × replicate interaction was not significant, indicating that the effects of temperature and food intake were similar in all replicates.

At a weight of 55 kg, the mean weight of pigs during the experiment, N retention/kg$^{0.73}$ increased with daily food intake. For each increase in feeding level (20 g/kg$^{0.73}$.d), N retention increased by 0·712 ± 0·024 g/kg$^{0.73}$.d. This regression, which did not vary significantly with temperature, was used to adjust N retention to a common food intake of 117 g/kg$^{0.73}$.d. These adjusted values are given in Table 4. The mean values for each treatment, adjusted to the intended food intakes, are also given in Table 4.

N retention per kg$^{0.73}$ fell with increasing body-weight, at a rate which increased both with daily food intake and with temperature, giving rise to significant treatment × period interactions ($P < 0.001$).

The magnitude of this change was expressed as the fall in N retention corresponding to a 10 kg increase in weight. These values (adjusted to the intended food intakes) are also given in Table 4. From this table the N retention at any temperature, feed intake and body-weight may be calculated.

Body composition at 90 kg. The effect of increasing daily food intake was to reduce the percentage of N in the ingesta-free body by 0·007 ± 0·002 % per g/kg$^{0.73}$.d. This highly significant ($P < 0.001$) residual regression did not vary with temperature or between replicates. When the mean values of % N at each temperature were adjusted by means of this regression to a common daily food intake, there were no significant differences between temperatures (Table 5).

The content of ether-extractable fat in the carcasses of the pigs at slaughter was measured in replicates 2, 3 and 4 and was expressed as a percentage of ingesta-free body-weight. The fat content expressed in this way did not vary significantly between replicates. There was a small but highly significant ($P < 0.001$) effect of increasing daily food intake which did not vary with temperature, or between replicates. The increase in fat content associated with 1 g increase in daily food intake per $kg^{0.73}$ was 0.116 ± 0.027, or 2·32% per unit change of feed level. The mean percentage of fat in pigs at each temperature is given in Table 5. When these values were adjusted to a common daily food intake, there were no significant differences between temperatures.

Table 5. *Percentages of nitrogen and of ether-extractable fat in the ingesta-free bodies of pigs kept at different environmental temperatures*

	At 5°	At 13°	At 23°	SE of differences between: Adjacent temperatures	SE of differences between: Extreme temperatures
Food intake ($g/kg^{0.73}.d$)	136·4	117·4	96·7	—	—
N in ingesta-free body (%)	2·36	2·5	2·57	0·093	0·093
Fat in ingesta-free body (%)	28·6	28·0	24·2	1·46	1·46
Adjusted to a food intake of 117 $g/kg^{0.73}.d$					
N(%)	2·5	2·5	2·42	0·076	0·096
Fat (%)	26·3	27·9	26·5	1·15	1·49

Table 6. *Mean daily fat deposition of pigs at three environmental temperatures, both for the mean food intake at those temperatures and when adjusted to a common food intake*

	At 5°	At 13°	At 23°	SE of differences between: Adjacent temperatures	SE of differences between: Extreme temperatures
Mean food intake ($g/kg^{0.73}.d$)	136	117	97	—	—
Daily fat deposition (g)	208·1	204·4	169·3	30·8	30·8
Adjusted to a food intake of 117 $g/kg^{0.73}.d$	146·4	203·4	234·5	10·3	13·2

Daily fat deposition. From estimates of net carcass fat gain and the number of days spent on the experiment, average daily fat deposition was estimated for each animal in the last three replicates.

There was a significant linear regression ($P < 0.001$) of daily fat deposition on daily food intake which did not differ significantly at the different temperatures. Daily fat deposition increased with daily food intake by 3.18 ± 0.24 g per $g/kg^{0.73}.d$. This pooled regression was used to adjust the values to the common intake of 117 $g/kg^{0.73}.d$. After adjustment, there were significant differences between temperatures ($P < 0.001$) in daily fat deposition. These values are given in Table 6.

DISCUSSION

It was expected from previous work, mentioned on p. 259, that there would be differences in the effect of increasing food intake at different temperatures, yet the most striking feature of these results is the absence of any evidence of an interaction between temperature and food intake. Certainly, it must be admitted, the animals involved were few and variable, encompassing as they did a range of genotypes and a changing health status. However, the experiment was intended to caricature, rather than to reproduce exactly, the conditions met in practice, and for this reason the temperatures and feeding levels were chosen to span a wide range. If, in these circumstances, no significant interaction could be detected, then it is likely that within the range of conditions met in practice the effects of any interaction which may exist will be slight. The effects of cold and of a low food intake may thus be regarded as essentially additive. In terms of growth rate and N retention, their equivalence may be calculated. Growth rate, for example, fell by 17·8 g/d per °C fall of temperature. It also fell with decreasing food intake by 7·73 g/d per $g/kg^{0.73}$.d. A change in temperature of 1° was therefore equivalent to a reduction in food intake of 2·3 $g/kg^{0.73}$.d. Thus, in the original design of the experiment, for each downward step of temperature (10°) the food intake should have been increased by 23 g rather than 20 g to give equal growth rates. To give equal daily N retention, an increment of 25 or 26 g (according to the method of estimating N retention) was required.

Table 7. *Comparison of the effects of cold on the growth rate of pigs in this and other experiments*

Wt of pig (kg)	Temperature range (°C)	Rate of fall of growth rate over this range (g/d.°C)	Source of values
40–90	8–15	8·6	Moustgaard *et al.* (1959)
	3–15	12·5	
30–110	5–20	11·6	Siegl (1960)
30–90	5–14	14·6	Comberg (1959)
70	4–16	17·5	Heitman, Kelly & Bond (1958)
20–90	5–13	17·8	Present experiment

It is interesting to note that growth rate changed with temperature at the same rate between 5 and 13° as between 13 and 23°. This implies that the temperature, or range of temperature, allowing the maximum growth rate of the caged pig lies at or above 23°. This is considerably higher than the lower limit of the range of temperature which is optimum for the growth of pigs housed normally. In this connexion, the rate of fall of growth rate with decreasing temperature, which was 17·8 g/d.°C, is also higher than that found in more practical circumstances. Table 7 compares the effects of temperature on pig growth found by several workers. Apart from the results of Heitman *et al.* (1958) which were obtained in a psychrometric room, the other values are substantially lower than that found here. The most probable cause of the greater severity of cold is the lack of any shelter afforded by the metabolism cages. In addition,

the lowest temperature was accompanied by the highest rate of air movement, and it is likely that this factor further reduced the effective temperature of the environment.

The effects of temperature and food intake on N retention were essentially the same as on growth rate, by whichever means the N retention was estimated. Taking the mean value of the two results, daily N retention was reduced by $0{\cdot}38 \pm 0{\cdot}055$ g for each 1° fall of temperature. From Piatkowski's (1958) results with five different diets, values for reduction in daily N retention, ranging from 0·1 to 0·9 g N/d.°C can be calculated, but there seems to be no relation between the composition of the diet and the magnitude of the temperature effect. His mean value was 0·56. Moustgaard *et al.* (1959) found that between 15 and 8° daily N retention fell by 1·31 and 1·22 g/°C for pigs on two different diets. When one of these diets was also given at 3°, the further fall was only 0·05 g/°C. The results in the literature are seen to be inconsistent, both within and between individual experiments, and we have at present no information on the way that the effect of temperature on N retention may be expected to change with the composition of the diet.

Table 8. *Comparison, in pigs, of the total retention of nitrogen estimated by the balance technique with that obtained by the comparative slaughter technique*

(The values are the general means for each replicate. The number of pigs is given in parentheses after the value)

Replicate	2	3	4
Body N of initial pig (g)	522 (1)	543 (1)	409 (3)
Mean final N of experimental pigs (g)	1969 (9)	2104 (9)	2201 (8)
Mean body N gain (g)	1447 (9)	1561 (9)	1792 (8)
Mean N balance (g)	1932 (9)	1785 (9)	1929 (8)
Difference	485 (9)	224 (9)	137 (8)

Some mention must be made of the discrepancy between our two separate estimates of N retention. The mean values of each estimate are given in Table 8. These results show what has generally been found by other workers, which is that balance methods give higher estimates of retention than those derived by comparative slaughter (see review by Duncan, 1966). With small laboratory animals, the two methods can, with extreme care, be made to agree to an extent which demonstrates that the errors involved lie purely in technique and not in any unknown metabolic route of N loss. With larger animals, the technical problems increase greatly, and with pigs discrepancies of a magnitude similar to ours were reported by Schiemann, Jentsch, Klippel, Schmidt, Trela & Tscheschmedschiew (1962). Much closer agreement was obtained by Harnisch & Becker (1958) in experiments specifically intended to investigate this subject, and a systematic error of only 2 % is reported by Oslage (1965), though he gives no details. In our results, there was a tendency in some groups for the discrepancy to increase with an increase in daily food intake; in general, however, this effect was not significant.

Whichever result was used, however, the same conclusion was reached; namely, that there was no significant interaction between temperature and food intake in their effects on N retention.

There is conflicting evidence in the literature on the effects of temperature on the

fatness of pigs at slaughter. Lucas (1956) concluded that the slower growth of pigs in the cold was likely to lead to leaner carcasses, and this was confirmed by results of his own experiments which he reports. The same result was obtained with young pigs fed *ad lib.* (Fuller, 1965). On the other hand, Moustgaard *et al.* (1959) found no change in the percentage of fat in pigs over the temperature range 23–8°, but between 8 and 3° the fat content of the body increased from 26 to 37%. There were, however, only two or three pigs at each temperature. In our experiment, the effect of temperature on the percentage of fat was small, and there was virtually no difference in fatness at the extreme temperatures when adjusted to a common food intake, even though the growth rate was reduced by 330 g/d. It is interesting to calculate from the results what change in body fatness would be expected had this retardation of growth been achieved by a reduction of food intake rather than of temperature. It was found that, for each 1 g increase in daily food intake per $kg^{0.73}$, growth rate increased by 7·73 g/d and body fat increased by 0·116 percentage units. Therefore the expected reduction in body fat content is $0{\cdot}116 \times 330/7{\cdot}73 = 5{\cdot}0$ percentage units.

This can best be illustrated by making a comparison from the original values. The pig given the high food intake at 23° (120 $g/kg^{0.73}$) contained 26·1% fat. The pig given the same daily food intake at 5° had 26·9% fat, whereas the pig at 23° whose growth was similarly slowed, but by a reduction of food intake, had only 22·3% of fat. These results suggest that, whereas slow growth achieved by a reduction in food intake is associated with a decreased fatness, that produced by cold is not.

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