Artificial rearing of pigs

1. Effect of frequency and level of feeding on performance and digestion of milk proteins

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1. Pigs were weaned from the sow at 2 d of age and reared on a diet of cow's milk supplemented with vitamin D_3 and antibiotics. The effects of four levels and two frequencies of feeding, and the temperature of the environment were studied in relation to the performance of the pigs and the digestion of the milk protein. Pigs fed at the two lower levels received a diet of cow's milk, but at the two higher levels cow's milk was spray-dried and reconstituted to 20% total solids. A comparison was also made between cow's milk and spray-dried reconstituted milk, both fed hourly with 12·5% total solids. The pigs were slaughtered at 28 d of age.

2. No differences in the nutritive value or digestion of the milk protein were found when cow's milk and reconstituted milk were fed with a total solids content of 12·5%.

3. Increasing the level of feeding resulted in a faster growth rate, and some deterioration in the feed conversion efficiency. The growth rate of the pigs from 2 to 28 d of age when fed at a high level greatly exceeded that of sucking pigs reared on the sow. The retention of the dietary nitrogen also improved with increased feed intake. A highly significant inverse linear correlation of N retention with age was found at all levels of feeding. The milk protein was efficiently digested at all levels of feeding.

4. The mortality rate was very low but there appeared to be some association of losses with a high level of feeding during the first few days of life.

5. Feeding hourly compared with feeding twice daily improved the feed conversion efficiency, although the effect on growth rate and N retention was small. The retention of digesta in the stomach appeared to be an important factor in the regulation of the amount of digesta in the small intestine and in the maintenance of digestive efficiency. The stomachs of pigs fed twice daily contained considerably greater amounts of digesta than those of pigs fed at hourly intervals. There was little difference in the amount and composition of digesta in the small intestine and caecum at either frequency of feeding.

6. No differences were found in the performance of the pigs, N retention or the efficiency of digestion of the milk protein when the environmental temperature was maintained either at 20° throughout the experiment, or at 30° gradually reducing to 20° during the first 14 d.

Artificial rearing methods which involve removal of the pigs from the sow soon after birth and rearing them on milk substitutes could have the following advantages over the conventional rearing on the sow: reduction of losses of pigs through control of environment, improvement in their growth rate by making available more nourishment than that supplied by the sow, elimination of lactation and shortening of the reproductive cycle of the sow, thus increasing her productivity by enabling her to produce a larger number of pigs per year. The economic advantages of a successful artificial rearing routine could be considerable.

Earlier work at Shinfield provided basic information on the qualitative and quantitative aspects of milk production by the sow and on the natural method of rearing pigs (Braude, Coates, Henry, Kon, Rowland, Thompson & Walker, 1947; Barber, Braude & Mitchell, 1955*a*). The present series of papers will report investigations on rearing pigs away from the sow and replacing the natural sucking by automatic feeding on substitutes for sow's milk.

In the preliminary studies, homogenized cow's milk was found to support a satisfactory rate of growth of pigs up to 28 d of age and it was used in experiments reported here on the effects of different levels and frequencies of feeding on the performance and on the processes of digestion of cow's milk proteins in the young pig. Some observations were also made on rearing pigs at two different environmental temperatures. The little information there is on these topics in the literature has been reviewed by Braude (1964) and Newport (1968).

EXPERIMENTAL

Animals

Pigs from the Institute's herd of Large Whites were allowed to suck colostrum and were removed from the sow 36–48 h after birth. They were put into individual cages in which they remained until 28 d of age.

Housing and equipment

The animals were housed in a building containing six isolated rearing rooms. The temperature in each room was independently controlled and maintained by heating units situated both under the floor and in ducts through which air was drawn independently into each room from the exterior through a bacteriological filter. A small positive pressure maintained within each room forced the air out through a second duct containing a similar filter. Artificial light was provided continuously but its intensity could be adjusted. The cages and the feeding equipment, which controlled the quantity and frequency of feeding, were described by Braude, Mitchell & Suffolk (1969).

A high environmental temperature is considered essential for baby pigs. Sainsbury (1965) proposed that the air temperature around the baby pig should not be less than 27°, and Mount (1968) stated that the critical temperature of the newborn pig is in the region of 34°. In preliminary studies, pigs were reared in an environment at 30° for the first few days after birth. However, at this temperature blockages in the tubing delivering the milk to the troughs were encountered owing to the souring of the milk. In addition to this difficulty, soured or partly soured milk may lead to digestive upsets in the pigs. The problem of milk souring at this temperature was overcome by providing fresh milk, adding antibiotics, feeding twice daily and wrapping the milk containers with wet muslin to obtain some evaporative cooling. Having ascertained that no such difficulties were encountered when the room temperature was reduced to 20°, this temperature was compared with an initial environmental temperature of 30°. In rooms starting at 30° the temperature was reduced to 27° after 4 d, 24° after 8 d and 20° after 14 d, at which temperature it remained until the end of the experiment.

Between each experiment, the rooms were thoroughly cleaned and then fumigated with formaldehyde for 48 h, at a room temperature of 30°.

Management

Once put in the rearing cages, the pigs quickly adapted themselves to the new environment and within a few hours started to drink the milk from the troughs. When 4 d old, the pigs were injected intramuscularly with 2 ml Imposil (Fisons Pharmaceuticals Ltd, Loughborough), an iron dextran preparation containing 100 mg iron/ml, to guard against anaemia. The pigs were weighed at 14.30 h thrice weekly. The feeding equipment was washed, sterilized twice daily in free-flowing steam at 90–95° for 10 min, and subsequently filled with milk from a bulk store kept at 4°. The pigs were transferred to clean cages twice weekly; all cages were thoroughly cleaned and sterilized in steam before re-use. At the time of changing the cages the floor of each room was washed with phenolic disinfectant. When scouring occurred the pigs were given orally either Framomycin (Crookes Laboratories Ltd, Basingstoke) or Neocreme (Stevenson, Turner and Boyce Ltd, Reading), once daily on 2 consecutive d.

Diets

The diets used were cow's milk and spray-dried cow's milk powder reconstituted with water to contain either 12·5 or 20% total solids. No other water was supplied. The milk powders were good-quality commercial products supplied either by L. E. Pritchitt & Co. Ltd, London, or by Unigate Ltd, London.

Fresh batches of diet were prepared twice weekly. The liquid or reconstituted milk was homogenized at a pressure of 176 kg/cm^2 and pasteurized at 72° for 17 s. Penicillin, Aureomycin (Cyanamid Ltd, London) and vitamin D_3 (100000 i.u./g; Roche Products Ltd, London) were then added, each at the level of 4·5 mg/l, and the milk was stored at 4°.

Scales of feeding

Pigs were given daily an amount of milk solids that was determined by their weight, according to one of the four scales of feeding shown in Fig. 1. Scale A was arbitrarily fixed to give an initial intake of milk solids similar to that received by a pig weighing about 1·5 kg and sucking a well-lactating sow. Scales B, C and D provided progressively greater quantities of nutrients.

Pigs were allotted to a scale at the start of each experiment and the amount of milk to be fed daily was adjusted after each thrice-weekly weighing. Pigs fed twice daily were offered one-third of their daily ration at 10.00 h and two-thirds at 17.00 h.

Plan of experiments

The effects on performance of frequency of feeding and of environmental temperature were studied in Expts 1 and 2 in which pigs were given cow's milk (containing 12·5% total solids) according to scales A and B respectively, and in Expt 3 in which pigs were given reconstituted milk containing 20% total solids according to scale C. In each of these experiments litter-mate pigs were allocated at random to one of the following three treatments: (1) fed at hourly intervals in a room kept initially at 30°; (2) fed at hourly intervals in a room kept at 20° throughout the experiment; (3) fed twice daily in a room kept initially at 30°.

In Expt 4 the nutritive value of liquid cow's milk was compared with that of milk reconstituted from spray-dried milk powder. Litter-mate pigs were fed hourly and received either liquid milk (12·5% total solids) according to scale B, reconstituted milk (12·5% total solids) according to scale B, or reconstituted milk (20% total solids) according to scale D. The volume of diet offered to the pigs was the same for both scales B and D.

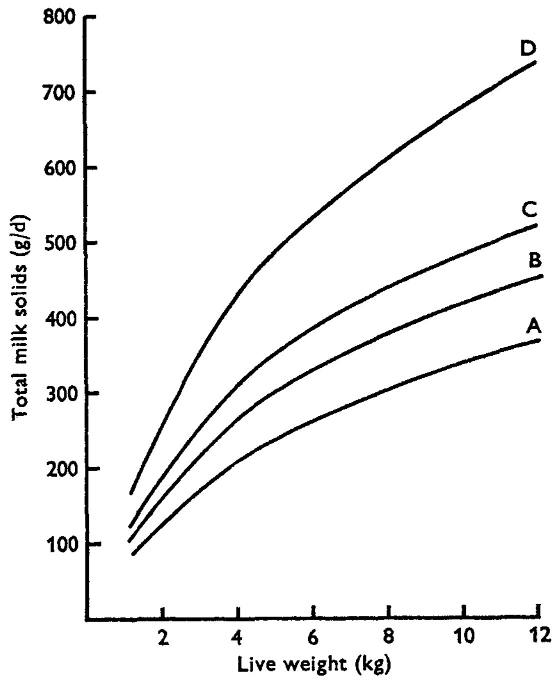

Fig. 1. Levels of feeding of the pigs: scale A used in Expt 1; scale B in Expts 2 and 4; scale C in Expt 3; scale D in Expt 4.

In all experiments, pigs on each treatment were housed in separate rearing rooms, each containing four individual cages. Sixteen pigs were started on each treatment in Expt 1, and twelve pigs on each treatment in the other experiments.

Nitrogen retention

Daily collections of urine and faeces were made from each pig throughout the experimental period unless the pigs were scouring. As far as possible N balances were determined for each pig for four periods each of 6 d, though a shorter collection period, with a minimum of 3 d, was used when scouring interfered. Glacial acetic acid (25 ml) was added daily to the urine-collecting bottle as a preservative. The faeces were homogenized in water before N analysis.

Procedure at slaughter

At 28 d of age the pigs were killed by an intracardiac injection of sodium pentobarbitone. For the study of digestion it was important that all animals were healthy and consuming the diet according to the scale of feeding prescribed; therefore animals showing signs of scouring, or refusing some of their feed on the day of slaughter, were not used.

After opening the body cavity, the stomach was ligated with thread just below the pyloric sphincter and also at the distal end of the œsophagus. The pancreas was then removed and weighed. The stomach was removed and weighed; the contents were then emptied into a beaker and their pH value was determined immediately with a glass electrode. The stomach contents were then centrifuged at 850 ***g*** for 15 min at 5°, and the soluble or 'whey' fraction was decanted off; the residue was termed the insoluble fraction. In the results, the soluble or 'whey' fraction is presented as the amount obtained by centrifugation together with the amount remaining trapped inside the clotted digesta, which was estimated by determining the dry-matter content of the clot. Digesta were washed from the small intestine with 0·9% saline warmed to 37°. Washing was continued until a colourless effluent was obtained. The contents and saline washings from the small intestine were centrifuged at 1350 ***g*** for 20 min at 5°, and the soluble fraction was decanted off. The weights of the empty stomach and small intestine were recorded. The caecum was removed and weighed, its contents were then emptied into a beaker and their pH value was determined immediately. The weight of the empty caecum was recorded. Finally, the liver was removed and weighed. All samples of digesta and organs were kept at −20° until analysed.

Pigs that had been fed at hourly intervals were killed 1 h after the last hourly feed; the time required for the consumption of the last feed at different levels of feeding was usually less than 1 min and was never longer than 5 min. In Expts 1 and 2, the pigs that had been fed twice daily were killed either 1 or 2 h after consuming a feed given at 10.00 h; in Expt 3 all pigs were killed 1 h after finishing their last feed. The mean times required for the consumption of the last feed by the pigs fed twice daily and given milk according to scales A, B and C were 0·5, 1·7 and 3·1 h respectively.

Analytical methods

Dry matter. Samples were dried at 100–105° to a constant weight.

Total N. Digestion was carried out with 2 ml conc. sulphuric acid (AR) and 1·20 g anhydrous potassium sulphate (AR) with 0·05 g yellow mercuric oxide (laboratory grade) as catalyst. Each digest was diluted with distilled water so as to contain 1–15 mg N/100 ml. The N concentration was estimated in the Technicon Autoanalyzer system with alkaline phenate (Technicon Instruments Co. Ltd, Chertsey). The procedure given in the Technicon Methodology Sheet N-3b was followed, except that 1% (w/v) ethylenediaminetetra-acetic acid (AR) was used in the sodium hydroxide solution, and 4% (w/v) sulphuric acid was used as a wash between samples.

Fat. Digesta (5–10 g) were extracted three times with a 1:1 (v/v) mixture of petroleum spirit (b.p. 40–60°) and diethyl ether. The ether extract was evaporated to dryness at 100° and weighed.

Non-protein N. Trichloroacetic acid (TCA) solution (100%, w/v) was added to the sample to give a final TCA concentration of 10% (w/v). The mixture was left at

5° overnight, and the protein precipitate separated by centrifuging at 1350 *g* for 30 min. A portion of the supernatant fraction containing the non-protein N was taken for the estimation of total N.

RESULTS AND DISCUSSION

Performance and mortality

Pigs fed according to scales A, B and C generally drank all the feed offered, whereas those fed according to scale D sometimes refused a portion of it. The initial intake of milk solids provided by scale A was similar to that provided by the lactating sow (Barber *et al.* 1955*a*), although sow's milk has a greater energy content (approx. 590 kcal/100 g milk solids) than cow's milk (535 kcal/100 g milk solids). However, as the pigs grew larger the amount of feed offered became progressively greater than that provided by a lactating sow. The tendency to refuse some feed when milk was offered according to scale D indicated that this level of feeding was close to the appetite of the pigs.

Table 1. *Effect of frequency and level of feeding and environmental temperature on performance from 2 to 28 d of age of pigs given cow's milk with 12·5% solids (CM) or reconstituted spray-dried cow's milk with 20% solids (RM)*

(See p. 504 for scales of feeding)

Treatment no. ...				1	2	3				
Frequency of feeding ...				Hourly	Hourly	Twice daily				
Initial environmental temperature (°C) ...				30	20	30	SEM and treatment differences significant at the 5% level		No. of litters	Difference between litters
Expt no.	Scale of feeding	Type of milk								
1	A	CM	No. pigs	16	14	16	—	—	9	—
			LWG	201	196	185	5·6	1 > 3	—	NS
			FCE	0·81	0·83	0·95	0·014	3 > 1,2	—	NS
2	B	CM	No. pigs	11	12	12	—	—	6	—
			LWG	276	273	263	6·2	NS	—	*
			FCE	0·82	0·82	0·89	0·014	3 > 1,2	—	***
3	C	RM	No. pigs	11	8	10	—	—	6	—
			LWG	297	283	276	9·9	NS	—	**
			FCE	0·89	0·93	1·01	0·014	3 > 1,2	—	***
4	D	RM	No. pigs	12	—	—	—	—	—	—
			LWG	326	—	—	—	—	—	—
			FCE	0·96	—	—	—	—	—	—

LWG, live-weight gain (g/d); FCE, feed conversion efficiency (g milk dry matter/g LWG). The standard error between scales of feeding (vertical comparisons) was 9 for LWG and 0·02 for FCE. They were calculated from the combined residual errors for each experiment. SEM of the treatment means were calculated from the harmonic mean. NS, not significant ($P > 0{\cdot}05$). *$0{\cdot}05 > P > 0{\cdot}01$. **$0{\cdot}01 > P > 0{\cdot}001$. ***$P < 0{\cdot}001$. No. of pigs initially put on experiment were 16/treatment in Expt 1, and 12/treatment in Expts 2–4.

The mean daily live-weight gains and feed conversion efficiencies of pigs completing the experiments are shown in Tables 1 and 2. It is apparent that the higher levels of feeding allowed an increase in the rate of growth of the pigs, though with some reduction in the feed conversion efficiency. The liquid and reconstituted milks of the same total solids content did not differ in their nutritive value when offered to the pigs according to scale B (Expt 4). The growth rate of these pigs was slightly inferior to that achieved in Expt 2. This slight depression in growth may have resulted from a higher 'infection level' in the building due to the presence in other rooms of pigs, fed to scale D, which had a relatively high incidence of scouring.

The rate of gain of the pigs fed according to scale A was similar to that of pigs reared by the sow in the conventional manner. A growth rate until 28 d of age of approx. 175 g/d was calculated from the results of Barber *et al.* (1955*a*), and of approx. 210 and 220 g/d for pigs reared indoors and outdoors respectively (Barber, Braude & Mitchell, 1955*b*). It is evident that, on all higher scales of feeding, a considerably higher growth rate was achieved by artificial rearing than with conventional methods.

Table 2. *Expt* 4. *Performance of pigs given at hourly intervals either cow's milk or milk reconstituted from spray-dried cow's milk powder*

(The total solids content of both diets was 12·5 %, and they were fed to scale B (see Fig. 1))

Treatment no.	1	2	SE of differences
Type of milk	Cow's milk	Reconstituted milk	between treatments*
No. of pigs	12	11	—
Live-weight gain (g/d)	255	242	20
Feed conversion efficiency (g milk dry matter/g gain)	0·85	0·84	0·02

* Neither of the differences between treatments was significant at the 5 % level.

A low mortality rate was found when low or moderate quantities of feed were offered (scales A, B). The mortality rate was higher when scale C was used, and may have been due to overfeeding in the first few days of the experiment. However, on the even higher level of feeding (scale D) in Expt 4, although there was a high incidence of scouring, there were no deaths. The hypothesis that overfeeding results in an increased mortality rate requires further investigation.

Feeding at hourly intervals as compared with twice-daily feeding had no significant effect on live-weight gain, except at the lowest level of feeding, but improved the feed conversion efficiency at all levels of feeding.

There was no effect on performance due to differences in environmental temperatures.

N retention and digestibility

When N retention was expressed either as a percentage of the ingested N or as g/d per kg live weight, significant linear regressions on age were found for each treatment in each experiment (Figs. 2, 3). The decline in N retention with age is in agreement with the findings of Wöhlbier (1928) and Albig (1940). The N retention (g/d per kg live weight) in the first few days of life increased with the level of feeding. However, these higher retentions declined more rapidly with age to give similar values at all levels of feeding at 21–28 d of age. These results indicated that it may be an advantage to give large amounts of protein in early life. Gütte & Rachau (1956) concluded that an intake of 9–11 g N/d gave maximum N retention in pigs 7 d of age. This is equivalent to an intake intermediate between scales B and C.

At each level, frequency of feeding and environmental temperature were found to have little effect on N retention. The apparently greater values for N retention obtained from feeding twice daily compared with hourly, particularly when scale C was used (Figs. 2, 3), may have been due to errors associated with accurate assessment of spillage of milk when the pigs were fed twice daily.

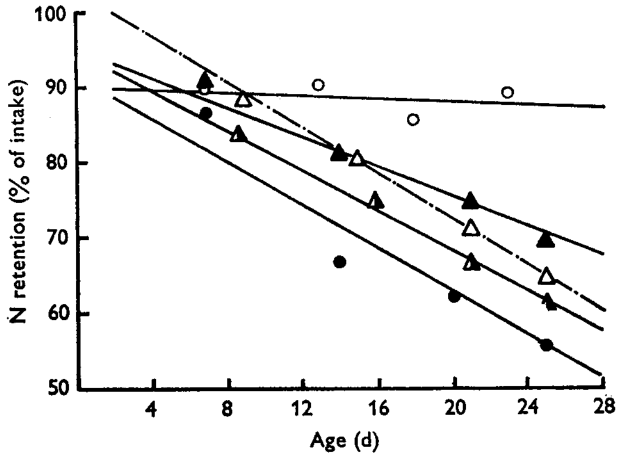

Fig. 2. Decline in nitrogen retention by pigs as a percentage of intake, and its relationship with level of feeding.

Scale of feeding	Regression equation	No. balance periods at each age
○ A	$y = 90.2 - 0.11 \pm 0.120x$ ($r = -0.21$, NS)	11–12
▲ B	$y = 95.1 - 0.98 \pm 0.077x$ ($r = -0.71$***)	47–49
▲ C (hourly)	$y = 95.3 - 1.37 \pm 0.094x$ ($r = -0.79$***)	4–6
△ C (twice daily)	$y = 103.2 - 1.54 \pm 0.177x$ ($r = -0.91$***)	2–3
● D	$y = 91.8 - 1.45 \pm 0.065x$ ($r = -0.79$***)	5–8

NS, $P > 0.05$; ***$P < 0.001$.

The apparent digestibility of N was found to be independent of age, level of feeding or treatment and was invariably 99–99.5%. It has been previously well established that milk protein is efficiently digested by the baby pig (Hays, Speer, Hartman & Catron, 1959; Combs, Osegueda, Wallace & Ammerman, 1963; Kellogg, Hays, Catron & Speer, 1964).

Digestion studies

The number of pigs slaughtered from each treatment is given in Table 3, together with the number of degrees of freedom of the standard errors of the treatment means presented in subsequent tables. The two time-intervals after feeding at which pigs on the twice-daily feeding regime were slaughtered (except on scale C) was a complicating factor in the statistical analysis of the results, since the number of animals available from each of the twice-daily feeding treatments was only half that available from the hourly treatments. Statistical analysis was, therefore, based on cell means, where one cell contained all litter-mates subjected to the same treatment, i.e. either one or two animals (cf. Snedecor, 1956). The standard errors of the treatment means were calculated from the harmonic mean of the number of cells per treatment.

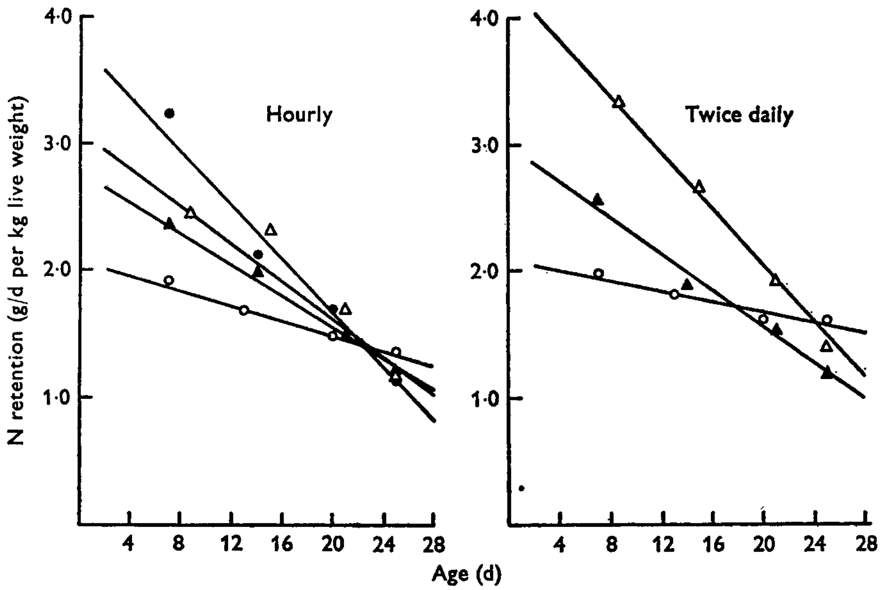

Fig. 3. Decline in nitrogen retention of pigs (g/d per kg live weight) with age, and its relationship with level of feeding.

Scale	Hourly feeding: Regression equation	Hourly feeding: No. balance periods at each age	Twice-daily feeding: Regression equation	Twice-daily feeding: No. balance periods at each age
○ A	$y=2·07-0·029\pm0·0023x$ ($r=-0·91$)	8	$y=2·08-0·021\pm0·0026x$ ($r=-0·91$)	3–4
▲ B	$y=2·78-0·061\pm0·0022x$ ($r=-0·93$)	35–39	$y=3·00-0·072\pm0·0054x$ ($r=-0·91$)	9–12
△ C	$y=3·08-0·074\pm0·0127x$ ($r=-0·80$)	4–6	$y=4·26-0·110\pm0·0240x$ ($r=-0·95$)	2–3
● D	$y=3·79-0·106\pm0·0088x$ ($r=-0·93$)	5–8	—	—

All correlation coefficients were highly significant ($P<0·001$).

Table 3. *No. pigs per treatment and degrees of freedom for the standard errors of the treatment means in the digestion studies*

Treatment no. ...		1	2	3	4	
Frequency of feeding ...		Hourly		Twice daily		
Initial environmental temperature (°C) ...		30	20	30	30	df for calculation of standard error
Slaughter time (h after last meal) ...		1	1	1	2	
Expt no.	Feeding scale					
1	A	14	13	8	7	20
2	B	10	12	6	5	14
3	C	8	6	6	—	6
4	D	5	—	—	—	3

Stomach contents

The amount of digesta in the stomach was much greater in pigs fed twice daily than in pigs fed at hourly intervals. Only a small portion of the clotted digesta emptied from the stomach of the pigs fed twice daily between the 1st and 2nd h after the meal, whereas the soluble or 'whey' fraction rapidly drained from the stomach during this period (Tables 4, 5).

The regulatory role of the stomach in the passage of digesta was also evident in the pigs fed hourly, the total amount of digesta increasing with the level of feeding, although the weight of dry matter in the stomach was similar at the two highest

Table 4. *Effect of frequency and level of feeding and environmental temperature on the amount and composition of the clotted digesta in the stomach of 28 d old pigs*

Treatment no. ...		1	2	3	4				
Frequency of feeding ...		Hourly		Twice daily					
Initial environmental temperature (°C) ...		30	20	30	30				
		Time of slaughter (h after feeding)				SEM and treatment differences significant at the 5 % level			
		1	1	1	2	Within expts*		Between expts† (43 df)	
	Feeding scale								
Dry matter (g)	A	3·08	4·19	27·34	24·89	2·35	3,4 > 1,2		
	B	13·95	14·50	24·74	21·74	1·94	3,4 > 1,2	3·20	C > A,B(3)
	C	20·99	16·37	38·19	—	5·36	3 > 1,2		B,C,D > A(1)
	D	19·35	—	—	—	—	—		
Total N (mg)	A	128	192	1460	1185	127	3,4 > 1,2		
	B	744	813	1330	1210	121	3,4 > 1,2	182	B,C,D > A(1)
	C	1240	830	2075	—	304	3 > 1,2		C > A,B(3)
	D	1070	—	—	—	—	—		
Fat (g)	A	2·04	2·34	14·02	11·54	1·24	3,4 > 1,2		
	B	7·00	7·02	11·06	10·60	0·83	3,4 > 1,2	1·71	B,C,D > A(1)
	C	9·45	7·04	18·33	—	4·82	NS		C > A,B(3)
	D	9·17	—	—	—	—	—		
Ratio, fat: protein	A	2·49	1·92	1·51	1·53	0·24	1 > 3,4		
	B	1·47	1·35	1·30	1·37	0·12	NS	0·25	A > B,C,D(1)
	C	1·19	1·33	1·38	—	0·09	NS		
	D	1·34	—	—	—	—	—		

Within-experiments SEM calculated from cell means (see p. 509); between-experiments SEM calculated from combined residual errors for each experiment.

* Degrees of freedom for the standard error of the within-experiments treatment means are given in Table 3.

† Number in parentheses = treatment number.

levels of feeding. This result in conjunction with the increased amount of digesta found in the small intestine in the pigs fed to scale D (see Table 7) indicates that such a level of feeding may lead to some breakdown of this regulatory function of the stomach, and indeed there was a high incidence of scouring among pigs fed to this level. These results are in agreement with those of Dollar (1958) and Walker (1959), who both attached importance to the clotting of milk in the stomach of the baby pig.

Table 5. *Effect of frequency and level of feeding and environmental temperature on the amount and composition of the soluble digesta (whey fraction) in the stomach of 28 d old pigs*

						SEM and treatment differences significant at the 5 % level			
Treatment no. ...		1	2	3	4				
Frequency of feeding ...		Hourly		Twice daily					
Initial environmental temperature (°C) ...		30	20	30	30				
Time of slaughter (h after feeding)		1	1	1	2	Within expts*		Between expts† (43 df)	
	Feeding scale								
Volume of liquid (ml)	A	8·7	9·4	121	37	12·4	3>1,2,4	13·0	A>B,C(3)
	B	6·6	6·4	36	10·5	10·3	NS		
	C	13·6	18·0	20	—	5·2	NS		
	D	22·0	—	—	—	—	—		
Dry matter (g)	A	0·78	0·92	12·80	5·36	1·15	3,4>1,2; 3>4	1·40	C,D>A,B(1) A>B,C(3)
	B	1·61	1·49	5·36	2·61	0·92	3>1,2		
	C	5·34	2·67	5·53	—	1·96	NS		
	D	5·06	—	—	—	—	—		
Total N (mg)	A	52·2	56·4	403	264	54·1	3,4>1,2	48	C,D>A,B(1) A>B(3)(4)
	B	99·5	92·6	264	137	29·8	3>1,2,4		
	C	253	146	361	—	62·1	NS		
	D	305	—	—	—	—	—		
NPN as % of total soluble N	A	43	43	26	23	4·7	1,2>3,4	5·3	A,B>C,D(1) B>A(4)
	B	46	44	29	39	5·8	NS		
	C	30	39	26	—	8·7	NS		
	D	28	—	—	—	—	—		
pH	A	2·9	2·9	5·1	4·1	0·2	3,4>1,2; 3>4	0·2	B,C,D>A(1) A>B(3)
	B	3·8	3·8	4·4	4·6	0·2	3,4>1,2		
	C	3·4	3·7	5·2	—	0·4	3>1,2		
	D	3·5	—	—	—	—	—		

Within-experiments SEM calculated from cell means (see p. 509); between-experiments SEM calculated from combined residual errors for each experiment.

* Degrees of freedom for the standard error of the within-experiments treatment means are given in Table 3.

† Number in parentheses = treatment number.

Table 6. *Mean pH values of the clot and whey fractions of the stomach digesta from pigs fed twice daily*

No. of pigs per treatment	Feeding scale	1 h after feeding: Clot	1 h after feeding: Whey	2 h after feeding: Clot	2 h after feeding: Whey	SEM
4	A	5·3	4·8	4·3	3·8	0·1
4	B	4·6	3·8	5·1	4·3	0·2
4	C*	5·6	5·0	—	—	0·1

* These pigs were slaughtered 1 h after feeding.

The composition of digesta in the stomach did not differ from that of the diet, except at the lowest level of hourly feeding when a relatively higher proportion of fat to protein was present. The similarity in composition of diet and stomach digesta was also reported by Holub (1963) and Padalikova (1964).

The amount of non-protein N (NPN) relative to the total N content of the soluble fraction was lower at the higher levels of feeding (scales C, D) than at the lower

Table 7. *Effect of frequency and level of feeding and environmental temperature on the amount and composition of digesta in the small intestine of 28 d old pigs*

	Feeding scale					SEM and treatment differences significant at the 5 % level			
Treatment no. ...		1	2	3	4				
Frequency of feeding ...		Hourly		Twice daily					
Initial environmental temperature (°C) ...		30	20	30	30				
Time of slaughter (h after feeding)		1	1	1	2	Within expts*		Between expts† (43 df)	
Insoluble dry matter (g)	A	2·34	2·30	4·28	2·30	0·75	NS	0·62	D > A,C(1); A > B,C(3)
	B	2·96	2·01	1·87	3·19	0·44	NS		
	C	1·98	1·55	1·90	—	0·33	NS		
	D	4·58	—	—	—	—	—		
Total insoluble N (mg)	A	117	132	188	68	38	3 > 4	0·33	D > A,B,C(1); A > B(3)
	B	152	101	83	132	22	1 > 3		
	C	117	80	106	—	31	NS		
	D	232	—	—	—	—	—		
Soluble dry matter (g)	A	3·88	4·74	8·02	3·50	1·12	3 > 1,4	0·94	C,D > A,B(1); A,C > B(3); B > A(4)
	B	5·52	4·96	5·08	6·58	0·64	4 > 2		
	C	8·63	8·42	9·14	—	0·44	NS		
	D	8·47	—	—	—	—	—		
Total soluble N (mg)	A	447	505	603	383	62	3 > 4	54	C,D > A; D > B(1); B > A(4)
	B	515	511	494	603	42	NS		
	C	604	593	613	—	44	NS		
	D	739	—	—	—	—	—		
NPN as % of total soluble N	A	76	73	76	79	3	NS	3·3	B > A(3)
	B	80	82	88	84	3	NS		
	C	83	88	80	—	4	NS		
	D	81	—	—	—	—	—		

Within-experiments SEM calculated from cell means (see p. 509); between-experiments SEM calculated from combined residual errors for each experiment.

* Degrees of freedom for the standard error of the within-experiments treatment means are given in Table 3.

† Number in parentheses = treatment number.

levels (scales A, B) when the diet was given at hourly intervals (Table 5). The amount of NPN relative to the total soluble N at each level of feeding was invariably lower in the pigs fed twice daily. Thus, increasing the amount of digesta in the stomach resulted in less protein digestion (as measured by NPN) in the 1st h after feeding. The higher pH values in the digesta from the stomachs of pigs fed twice daily reflected the buffering capacity of the larger feeds, creating conditions under which proteolysis would proceed very slowly. The pH value of the soluble fraction was always lower than that of the clotted digesta in the stomachs of pigs fed twice daily, as shown in Table 6.

Intestinal and caecal contents

The effect of level and frequency of feeding on the amount and composition of the digesta in the small intestine and caecum is shown in Tables 7 and 8.

There was no significant difference in the amount of insoluble digesta present in the small intestine of pigs fed at hourly intervals to scales A, B and C. However, a significantly increased amount of insoluble digesta was present in the small intestine

Table 8. *Effect of frequency and level of feeding and environmental temperature on the amount and composition of digesta in the caecum of 28 d old pigs*

	Feeding scale	1	2	3	4	SEM and treatment differences significant at the 5 % level: Within expts*		Between expts† (43 df)	
Treatment no. ...		1	2	3	4				
Frequency of feeding ...		Hourly		Twice daily					
Initial environmental temperature (°C) ...		30	20	30	30				
Time of slaughter (h after feeding)		1	1	1	2				
Total dry matter (g)	A	5·14	6·54	3·87	3·51	0·67	2 > 3,4	0·9	D > C(1)
	B	4·45	6·07	4·38	4·12	0·90	NS		
	C	4·00	2·26	5·77	—	1·20	NS		
	D	6·84	—	—	—	—	—		
Total N (mg)	A	225	279	204	162	26	2 > 3,4	41	NS
	B	150	240	216	180	49	NS		
	C	231	106	249	—	59	NS		
	D	280	—	—	—	—	—		
pH	A	6·4	6·5	6·5	6·5	0·1	NS	0·2	NS
	B	6·6	6·6	6·7	6·7	0·1	NS		
	C	6·5	6·6	7·0	—	0·2	NS		
	D	6·8	—	—	—	—	—		

Within-experiments SEM calculated from cell means (see p. 509); between-experiments SEM calculated from combined residual errors for each experiment.

* Degrees of freedom for the standard error of the within-experiments treatment means are given in Table 3.

† Number in parentheses = treatment number.

of pigs fed to scale D, indicating that at this level of intake the clotted digesta were less efficiently retained in the stomach than at the lower levels of feeding. The amount of soluble N in the small intestine increased with level of feeding, the differences were significant between the higher and the lower levels ($P < 0·05$). Thus, the increased amount of digesta in the small intestine at the high levels of feeding may be associated with a small decline in the efficiency of absorption in agreement with the deterioration in the feed conversion efficiency found in the growth experiments. Frequency of feeding had little effect on the amount and composition of the digesta in either the small intestine or the caecum.

Although the amount of NPN relative to the total soluble N in the stomach was lower at the higher levels of hourly feeding and when the feed was given twice daily

(Table 5), in the small intestine the soluble N was mainly in the NPN fraction, and furthermore, the proportion of NPN was unaffected by level or frequency of feeding. Therefore, it seems likely that when only a limited amount of protein digestion occurs in the stomach, digestion of milk protein will be efficiently completed within the small intestine.

Table 9. *Effect of frequency and level of feeding and environmental temperature on the weights of some organs as a percentage of live weight in 28 d old pigs*

Treatment no. ...		1	2	3	4				
Frequency of feeding ...		Hourly		Twice daily					
Initial environmental temperature (°C) ...		30	20	30	30				
		Time of slaughter (h after feeding)				SEM and treatment differences significant at the 5% level			
	Feeding scale	1	1	1	2	Within expts*		Between expts† (43 df)	
Stomach	A	0·55	0·54	0·76	0·67	0·02	3,4 > 1,2; 3 > 4	0·02	NS
	B	0·55	0·53	0·60	0·67	0·02	4 > 2		
	C	0·57	0·54	0·66	—	0·03	NS		
	D	0·54	—	—	—	—	—		
Small intestine	A	3·73	3·81	5·35	4·41	0·26	3 > 1,2,4	0·28	C,D > A,B(1); A > B,C(3)
	B	3·09	3·21	3·74	4·25	0·13	3,4 > 1,2		
	C	4·13	3·99	4·36	—	0·11	NS		
	D	4·21	—	—	—	—	—		
Liver	A	3·17	3·33	3·40	3·55	0·09	4 > 1	0·09	D > A,B,C(1); B,C > A(3)
	B	3·38	3·55	3·91	3·92	0·10	3,4 > 1		
	C	3·60	3·37	3·89	—	0·11	3 > 1,2		
	D	3·83	—	—	—	—	—		
Pancreas‡	A	—	—	—	—	—	—	0·01	NS
	B	0·15	0·14	0·15	0·15	0·01	NS		
	C	0·14	0·15	0·15	—	0·01	NS		
	D	0·15	—	—	—	—	—		
Caecum	A	0·02	0·20	0·21	0·20	0·01	NS	0·02	NS
	B	0·15	0·17	0·16	0·18	0·01	NS		
	C	0·19	0·16	0·18	—	0·01	NS		
	D	0·16	—	—	—	—	—		

Within-experiments SEM calculated from cell means (see p. 509); between-experiments SEM calculated from combined residual errors for each experiment.

* Degrees of freedom for the standard error of the within-experiments treatment means are given in Table 3.

† Number in parentheses = treatment number.

‡ Not collected.

Weights of body organs

The weights of the liver, empty stomach, small intestine, caecum and pancreas as a percentage of the live weight immediately before slaughter are presented in Table 9. The relative weight of the stomach was unaffected by the level of feeding, whereas the relative weight of the small intestine was increased at the two highest levels of hourly feeding. This increase was associated with the greater amount of digesta present

(Table 7), indicating that adaptation had occurred. In general, less frequent feeding had a marked effect in increasing the weight of the stomach and small intestine relative to live weight.

The weight of liver was affected by the level of feeding, and the relative weight was greatest at the highest levels of feeding. There was also evidence that less frequent feeding may have resulted in heavier livers. The relative weights of the pancreas and caecum were unaffected either by level or frequency of feeding.

Digestion of cow's milk compared with that of reconstituted cow's milk

The amount and composition of the digesta in the stomach and small intestine were similar when either milk was fed.

General discussion and conclusions

In these studies diets of cow's milk were used, but these can only be justified for experimental purposes. The future of artificial rearing of pigs will depend on the development of a cheap but nutritionally adequate milk replacer, possibly based on skim milk and a cheap source of fat.

Pigs have been weaned at 2 d of age and successfully reared away from the sow. The nutrient intake of the pigs given the whole-milk diets was considerably greater than that of pigs sucking their dams. The artificially reared pigs, which, during the experimental period from 2 to 28 d of age, received the lowest level of feeding (scale A), grew at a rate similar to that of sucking pigs, but those receiving the higher levels of feeding grew considerably faster. As these experiments terminated when the pigs were only 28 d old, it must be left to future experiments to demonstrate whether the advantages gained by artificial rearing can be maintained in the subsequent growth period. Another problem which will have to be solved before artificial rearing can be applied in practice is how to achieve a smooth change-over from a liquid to a solid diet without inflicting a setback in the development of the pig.

Under the controlled environment of these experiments, the mortality rate of the pigs was low. There was some evidence that deaths, which occurred in the first few days, mainly amongst pigs given the higher levels of feeding, may have been influenced by the quantity of diet ingested. Evidence from other experiments (unpublished) indicated that a gradual increase in intake during the first few days of life may eliminate these difficulties.

In the present experiments, it was established that the dietary N was most efficiently utilized by the pigs during the first few days of life, and it may be possible to improve the performance further by increasing their intake of protein at this age. The important factors in the efficient digestion of the milk protein would seem to be the ability of the diet to clot, the retention of digesta in the stomach (particularly when the diet was given twice daily) and, as will be reported later, a high proteolytic enzyme activity in the small intestine resulting in the rapid hydrolysis of the dietary N.

Under the conditions of these experiments it was found unnecessary to maintain the temperature in the environment at 30° during the first few days of the pig's life, as equally good performance was obtained with an environmental temperature of 20°

throughout. This finding draws attention to the limited amount of information on the environmental requirements of very young pigs, and it may well be that under different conditions and with different diets the lower environmental temperature would not give such satisfactory results as in these experiments.

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