Digestion in the pig between 7 and 35 d of age
2. The digestion of dry matter and the pH of digesta in pigs given milk and soya-bean proteins

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1. In two separate experiments, forty-four pigs weaned at 4–5 d of age were given diets containing milk or soya-bean proteins until slaughtered at 14, 28 or 35 d of age.

2. The retention times of digesta in the stomach and the entire gastro-intestinal tract did not differ between pigs given pelleted diets containing milk or soya-bean protein.

3. Digesta retention times in the stomach were shorter (61 *v.* 146 min) in pigs given a milk-protein diet in a liquid form than in pigs given the same diet in a pelleted form. The retention times in the whole gastro-intestinal tract were 42·8 *v.* 29·6 h on the respective diets.

4. The total retention time of digesta in the gastro-intestinal tract increased with age of pigs between 14–35 d of age when given pelleted diets but not when given a liquid diet.

5. The daily amount of digesta flowing through the anterior small intestine was unaffected by the source of protein. Greater endogenous secretions into the anterior small intestine were observed when pigs were fed *ad lib.* than when fed at 2 g nitrogen (45 g dry matter (DM))/kg live weight$^{0.75}$ per d.

6. The apparent digestion of DM to the ileum of pigs given milk, isolated soya-bean protein (ISP) (Promine D) or soya-bean meal (SBM) protein at 28 d of age was 0·826, 0·825 and 0·644 respectively.

7. The apparent digestion of DM to the ileum of pigs given ISP (Supro 610) significantly increased with age of pigs from 0·851 at 14 d of age to 0·883 at 35 d of age. No increase was observed for pigs given milk protein.

8. Differences in the digestibility of DM between protein sources were greater to the ileum than over the entire gastro-intestinal tract. The greatest increase in DM digestion from the ileum to the faeces occurred in pigs given SBM (0·644–0·874).

9. Neither the protein source nor age of pigs influenced gastric pH values, the mean value being 4·05. pH increased along the small intestine and was not affected by the protein source or age of pig.

The digestive system of the newborn pig is naturally adapted to sow's milk. The rearing of pigs after weaning is often associated with poor growth and gastro-intestinal disorders which are primarily due to unsuitable food ingredients and poor management (Manners, 1970). However, successful rearing of pigs weaned at 4–5 d of age given dry diets based on cow's milk has been demonstrated (Van der Heyde, 1969; Wilson & Leibholz, 1979).

The substitution of cow's-milk protein with soya-bean protein has been shown to depress the growth of young pigs (Wilson & Leibholz, 1981), but this difference is reduced by increasing age of pigs (Hays *et al.* 1959). Hence, it was of interest to study the digestion of these protein sources in young pigs.

Methods available to study the digestive processes in single-stomach animals have been extensively reviewed by Low (1977). Cannulas have been surgically introduced into the intestines of pigs to allow continuous sampling of digesta from conscious animals. Most reports have described digesta flow measurements over a 24 h collection period (e.g. Zebrowska & Buraczewska, 1972; Braude *et al.* 1976; Ivan & Farrell, 1976).

Serial slaughter has also been used for studying digestion and absorption in pigs as it is relatively simple and allows simultaneous measurements to be made in the whole

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gastro-intestinal tract (Kidder *et al.* 1968). However, only one measurement per pig is possible and therefore large numbers of animals are required. A criticism of this method is the possibility of epithelium shedding into the lumen of the intestinal tract at the time of death (Badawy, 1964).

The present experiments were designed to investigate the effect of soya-bean protein as substituted for cow's milk on the amount and retention time of digesta, sites of dry matter (DM) absorption and digesta pH. The experimental technique used was the slaughter method after feeding indigestible markers.

EXPERIMENTAL

Animals and diets

Expt 3. Thirty-six pigs (mean weight 2·05 kg, mean age 7 d) were allocated to six diets as a 3 × 2 factorial with three replicates of two pigs per replicate. Three protein sources were compared in isonitrogenous diets: milk, isolated soya-bean protein (ISP) (Promine D; Central Soya Co., Chicago, Ill.) and soya-bean meal (SBM), each with and without methionine supplementation, and lysine supplementation of the ISP and SBM diets. The composition of the diets is given in Wilson & Leibholz (1981). After 17 d, one pig per pen was removed and the remaining eighteen pigs were given the experimental diets sprayed with indigestible markers for a further 5 d. The pigs were then slaughtered as described below.

Expt 4. Twenty-four pigs (mean weight 2·43 kg, mean age 7 d) were allocated to three diets; an all-milk-protein diet fed either pelleted or liquid or a pelleted diet in which the protein source was ISP (Supro 610; Ralston Purina, St Louis, Mo.). There were eight replicates of one pig per replicate. The composition of the diets is given in Wilson & Leibholz (1980).

Twelve pigs were fed the diets *ad lib.* from 4–5 d of age until 9 d of age and then at 2 g nitrogen/kg live weight$^{0·75}$ per d for 5 d until slaughter at 14 d of age. The other twelve pigs were given the diets *ad lib.* until 30 d of age and then at 2 g N/kg live weight$^{0·75}$ per d for 5 d until slaughter at 35 d of age. An N-free diet was fed to a further two pigs from 30–35 d of age at 45 g DM/kg live weight$^{0·75}$ per d which was similar to the DM intakes of pigs given the protein diets. The pigs were given equal amounts of food every 2 h over the 5 d preceding slaughter. Indigestible markers were administered to the pigs immediately preceding each 2 h feed.

The composition of the N-free diet used in Expt 4 is given in Table 1.

Indigestible markers

The markers used were the ^{51}Cr complex of ethylenediaminetetra-acetic acid (EDTA) (^{51}Cr EDTA) (Downes & McDonald, 1964) and ^{103}Ru-labelled Tris-(1,10-phenanthroline)-ruthenium (II) chloride (^{103}Ru-P) (Tan *et al.* 1971).

In Expt 3 the markers were sprayed evenly onto the pelleted diets in solution with water at a rate of 50 ml/kg food to provide an isotope concentration in the diet of approximately 5 μCi ^{103}Ru-P/kg and 25 μCi ^{51}Cr EDTA/kg. This was calculated to ensure an intake of marker of approximately 2 μCi ^{103}Ru-P and 10 μCi ^{51}Cr EDTA/d respectively. The labelled food was offered *ad lib.* for 5 d.

In Expt 4, to provide a more regular intake of marker for equilibrium throughout the gastro-intestinal tract, a 2 ml solution containing the markers was orally administered via a syringe every 2 h for 5 d. The daily intake of markers was calculated to be approximately 20 μCi ^{51}Cr EDTA and 4 μCi ^{103}Ru-P. For pigs given the liquid diets the marker solution was added directly to the liquid milk.

Faeces and urine were collected daily over the 5 d marker administration period, the samples counted for markers and the remainder stored at −20° for chemical analysis.

Table 1. *Expt 4. Composition (g/kg) of the nitrogen-free diet*

Ingredients	
Lactose	315
Wheat starch	585
Soya-bean oil	40
Dicalcium phosphate	35
Calcium stearate	20
Premix*	5

* Premix (/kg diet): 1·5mg retinol, 0·025mg cholecalciferol, 20 mg α-tocopheryl, 2 mg menadione, 200 mg ascorbic acid, 20 μg cyanocobalamin, 1·5 mg thiamine, 6 mg riboflavin, 20 mg niacin, 10 mg pantothenic acid, 3 mg pyridoxine, 1 g choline chloride, 0·3 mg folic acid, 0·1 mg biotin. Minerals: 200 mg magnesium, 100 mg iron, 10 mg copper, 40 mg manganese, 70 mg zinc, 2·5 mg cobalt, 0·1 mg iodine, 0·1 mg selenium, 2600 mg potassium, 700 mg sodium. Other additives: 100 mg ethoxyquin, 50 mg oxytetracycline, 50 mg neomycin sulphate.

Slaughter procedure and digesta sampling

The pigs were given an intramuscular injection of Stresnil (Ethnor Pty Ltd, Sydney) for mild sedation followed by an intravenous administration of Surital (sodium thiamylal; Parke Davis & Co., Sydney) to maintain anaesthesia for several minutes. The intestinal tract was removed under these conditions to prevent, as much as possible, the shedding of epithelium into the intestinal lumen.

The body cavity was opened and the stomach ligated with thread below the pyloric sphincter and at the distal end of the oesophagus. The stomach was removed and the total contents weighed. The caecum and large intestine were ligated with thread, removed and the total contents weighed. The small intestine were stripped of its mesentary and the total length measured. The small intestine was sectioned into the first 1·5 m (duodenum), the next 2·0 m (jejunum) and the remainder (ileum). For the pigs slaughtered at 2 weeks of age, the small intestine were sectioned into two equal lengths (duodenum and jejunum, and ileum), so as to obtain sufficient sample for analysis. The total contents in each section of the small intestine were weighed. Immediately upon obtaining the digesta from each section, the pH was determined with a glass electrode, a known weight taken for isotope counting and the remainder homogenized and stored at $-20°$ for subsequent chemical analysis.

Isotope counting

The digesta samples were counted together in an Auto Gamma Spectrophotometer (Model 5320, Packard Instrument Co. Inc., Ill.).

The flow rate of digesta through the sections of the gastro-intestinal tract were calculated from equation no. 1:

$$\text{flow rate} = \frac{\text{rate of administration marker}}{\text{concentration of marker in sample}} \qquad (1)$$

The retention time of marker in each section of the gastro-intestinal tract was calculated from equation no. 2:

$$\text{retention time (min)} = \frac{\text{weight of digesta (g)}}{\text{flow-rate of digesta (g/d)}} \times 1440. \qquad (2)$$

$$1440 = 60\,\text{min} \times 24\,\text{h}.$$

^{51}Cr concentrations were corrected for ^{51}Cr counts recovered in the urine; these values ranged from 7–11% of the daily dose of ^{51}Cr.

Analytical techniques

DM was determined on ground food samples and digesta samples in a forced-air oven at 95° for 24 h.

Statistical methods

The experiments were of a randomized block design. The results were subjected to analysis of variance with treatment means being statistically compared using least significant difference comparisons (Steel & Torrie, 1960). The values obtained from the pigs given the N-free diet were not included in the statistical analysis.

RESULTS

Equilibrium of the markers was established throughout the gastro-intestinal tract as indicated by the constant marker concentration in the faeces over the last 2–3 d of administration. The mean recovery of ^{51}Cr corrected for loss in the urine was 92·4% (range 88–96%) and for ^{103}Ru, 97·8% (range 92–101%).

Due to the small amounts of digesta sample collected from the sections of the intestinal tract, particularly in the small intestine, it was not possible to centrifuge the samples of digesta to obtain sufficient subsamples of fluid for accurate radoisotope counting and chemical analysis. The flow-rates of true digesta thus could not be calculated from the reconstitution of the fluid and digesta portions as outlined by Faichney (1975). However, as the entire contents of the intestinal sections were sampled, there should be no sampling errors, and if the solutes and particulate matter are not behaving independently, or the distribution of the markers between the water and solids is the same, then the calculated mean retention times of the two markers should be similar (Faichney, 1975). The values for mean retention time of ^{51}Cr EDTA: ^{103}Ru-P calculated from the pigs given the diets in Expt 3 are shown in Table 2.

The values for mean retention time of ^{51}Cr EDTA: ^{103}Ru-P was close to unity, except in the stomach contents, which indicated that the markers were travelling together through the intestinal tract. A value of less than one in the stomach would indicate that ^{51}Cr EDTA was leaving the stomach with the fluid digesta faster than the ^{103}Ru-P associated with the milk clot. It has been shown that ^{103}Ru-P was not strongly adhered to the curd formed in the abomasum of the milk-fed lamb and, therefore, cannot be used as a solids marker in the abomasum. It was also demonstrated (Faichney, 1975) that ^{103}Ru-P was associated with cellular debris in the first two sections of the small intestine and with the microbial population in the large intestine of the milk-fed lamb. In the present experiment the results indicated that ^{103}Ru-P was absorbed onto the milk clot in the stomach and that the calculated mean retention times of marker in the small intestine, caecum and large intestine were similar for both ^{51}Cr EDTA and ^{103}Ru-P which suggests that the results were equally valid from either marker. It is for these reasons that the results presented for the flow-rates of digesta and DM and the retention times of digesta were calculated from the concentrations of ^{103}Ru-P in the total digesta only.

There are no markers available which could be considered more suitable than ^{103}Ru-P or ^{51}Cr EDTA for studies with milk-fed animals, although deviations from the criteria of an ideal marker have been observed with ^{103}Ru-P (Faichney, 1975). It has also been suggested that ^{51}Cr EDTA is partially bound to casein in the abomasum of the milk-fed calf (Smith & Hill, 1967).

Table 2. *Mean retention time of solute:mean retention time of particulate digesta* (^{51}Cr *EDTA*: ^{103}Ru*-labelled Tris-*(1,10-*phenanthroline*)*-ruthenium* (*II*) *chloride*) *within the gastro-intestinal tract of* 28-*d-old pigs*

Intestinal section	Protein source: Milk	Isolated soya-bean protein*	Soya-bean meal	SEM
Stomach	0·70	0·85	0·81	0·070
Duodenum	0·94	1·03	0·97	0·049
Jejunum	1·02	0·92	1·10	0·048
Ileum	0·93	1·05	0·98	0·043
Caecum	1·09	1·05	1·03	0·035
Large intestine	1·04	1·08	1·04	0·033

* Promine D; Central Soya Co., Chicago, Ill.

There were no significant differences in any of the measurements studied related to the dietary amino acid supplementation in Expt 3. Therefore, the results were calculated by combining the amino acid treatments for each protein source and are presented as the means of six pigs per treatment.

Digesta flow and retention time of marker

The total flow of digesta through the stomach was greater when pigs were given pelleted diets containing soya-bean protein as compared to pigs given milk as the source of dietary protein (Tables 3 and 4). These differences were significant for the pigs in Expt 4 at both 14 and 35 d of age. However, when milk-protein diet was given in a liquid form to pigs, the mean total flow of digesta through the stomach was greater than for pigs given the same diet in a pelleted form and similar to the flow of digesta from pigs given the ISP diet.

In Expt 4, the flow of digesta through the stomach is in accord with the mean retention time of marker in the stomach; greater flow-rates being associated with lower mean retention times of digesta (Tables 5 and 6). Pigs given the liquid-milk diet had significantly shorter retention times of digesta in the stomach than pigs given the same diet pelleted. The total

Table 3. *Expt* 3. *Flow of digesta* (*g/d*) *through the gastro-intestinal tract*

Intestinal section	Protein source: Milk	Isolated soya-bean protein†	Soya-bean meal	SEM
Stomach	1119·1	1549·1	1484·1	204·36
Duodenum	2679·3	2548·0	3864·1	585·15
Jejunum	1642·2	1411·4	2710·8	536·39
Ileum	767·5	290·8	883·5	106·97**
Caecum	278·8	127·0	372·4	29·38***
Large intestine	175·3	68·8	205·4	18·06***

** $P < 0·01$, *** $P < 0·001$.
† Promine D; Central Soya Co., Chicago, Ill.

Table 4. *Expt 4. Total flow of digesta (g/d) through the gastro-intestinal tract*

			Intestinal section				
Protein source	Form	Age (d)	Stomach	Duodenum and jejunum	Ileum	Caecum	Large intestine
Milk	Pelleted	14	279·3	335·2	131·2	46·6	38·8
		35	728·3	664·4	223·2	80·1	41·6
		Mean	503·8	499·8	177·2	63·3	40·2
Milk	Liquid	14	550·9	158·3	54·1	20·7	19·5
		35	1274·9	666·3	206·5	26·2	32·3
		Mean	912·9	412·3	130·3	23·4	25·9
Isolated soya-bean protein†	Pelleted	14	501·5	227·4	118·0	59·6	59·0
		35	1289·3	616·6	188·1	51·1	69·0
		Mean	895·4	422·0	153·0	55·3	64·0
Mean		14	443·9	240·3	101·1	42·3	39·1
		35	1097·5	649·1	205·9	52·5	47·6
Statistical significance and SEM due to:							
Protein			54·07***	82·77	21·07	9·91*	4·89***
Age			44·14***	67·58***	17·21***	8·09	4·00
Protein × age			76·46	117·05	29·80	14·01	6·91

* $P < 0·05$, *** $P < 0·001$.

† Supro 610; Ralston Purina, St. Louis, Mo.

Table 5. *Expt* 3. *Retention time of marker* ([103]*Ru-labelled Tris-*(1,10-*phenanthroline*)-*ruthenium* (*II*) *chloride*) (*min*) *in the gastro-intestinal tract*

Intestinal section	Protein source			
	Milk	Isolated soya-bean protein†	Soya-bean meal	SEM
Stomach	123·8	73·1	125·0	23·86
Duodenum	1·9	2·9	1·4	0·52
Jejunum	9·4	10·4	4·2	2·29
Ileum	112·6	263·0	109·1	41·31*
Caecum	87·3	172·4	116·7	21·43*
Large intestine	1021·6	1305·6	1031·4	199·12
Total	1362·0	1830·0	1386·0	189·0

* $P < 0·05$.
† Promine D; Central Soya Co., Chicago, Ill.

flow of digesta was significantly greater for pigs at 35 d of age than at 14 d of age, but there was no effect of age on the mean retention time of marker in the stomach.

In Expt 3, there was considerable endogenous secretion of digestive juices into the duodenum as digesta flow had increased by 1·5–2·5 times the amount flowing through the stomach. This increase was not observed with the pigs in Expt 4. However, pigs were fed *ad lib.* in Expt 3 and at 2 g N/kg live weight$^{0·75}$ per d in Expt 4. The mean retention time of marker in the duodenum and jejunum was not influenced by protein source, method of feeding or the age of pigs.

Significantly less digesta associated with a greater retention time of marker was found in the ileum of pigs given ISP (Promine D) than for pigs given either milk or SBM as the protein source (Expt 3). There were no differences due to protein source or method of feeding for the flow of digesta or mean retention time of marker in the ileum of pigs in Expt 4. However, the amount of digesta flowing through the ileum for 35-d-old pigs was greater than for 14-d-old pigs.

In Expt 4, there was less total digesta flowing through the caecum and large intestine for pigs given the liquid milk diets at both age-groups compared to pigs given the pelleted milk and ISP (Supro 610) diets. There were no differences in the caecum for digesta flow between the two pelleted diets but in the large intestine there was significantly more digesta flowing for pigs given the ISP diet than for pigs given the pelleted milk-protein diet.

The nature of the protein source fed in Expt 3 did not significantly affect the total retention time of marker in the gastro-intestinal tract, although for pigs given the ISP diet the total retention time was approximately 8 h greater than for pigs given milk or SBM as the protein source. In Expt 4, the total retention time of digesta was significantly greater for pigs given the liquid diet at both 14 and 35 d of age than for pigs given the pelleted diets. The total retention time of marker in the gastro-intestinal tract did not increase with age of pigs when given the liquid diet, but increased 34 and 85% with age for pigs given the pelleted milk and ISP diets respectively.

DM *flow*

There were no significant differences in the flow of DM through the stomach, duodenum and jejunum of pigs given the three protein sources in Expt 3 even though the DM intakes of pigs given the ISP diet were significantly below the intakes of pigs on the other two

Table 6. *Expt 4. Mean retention time of marker* ^{103}*Ru-labelled Tris-*(1,10-*phenanthroline*)*-ruthenium* ($\overline{II}$) *chloride* (*min*) *in the gastro-intestinal tract*

Protein source	Form	Age (d)	Intestinal section: Stomach	Duodenum and jejunum	Ileum	Caecum	Large intestine	Total
Milk	Pelleted	14	147·6	38·5	123·9	296·0	910·9	1518·0
		35	143·1	22·8	121·7	340·0	1382·8	2034·0
		Mean	145·4	30·6	122·8	318·0	1146·9	1776·0
Milk	Liquid	14	62·2	42·6	152·0	398·5	1817·7	2472·0
		35	59·4	16·6	93·9	828·0	1642·4	2658·0
		Mean	60·8	29·6	122·9	613·2	1730·1	2565·0
Isolated soya-bean protein†	Pelleted	14	96·5	56·9	116·9	234·7	592·7	1098·0
		35	67·8	29·4	157·2	829·3	919·6	2034·0
		Mean	82·2	43·2	137·0	532·0	756·1	1566·0
Mean		14	102·1	46·0	130·9	309·7	1104·1	1696·0
		35	90·1	22·9	124·3	665·8	1314·9	2242·0
Statistical significance and SEM due to:								
Protein			18·80*	8·31	25·14	19·95*	117·9***	139·2***
Age			15·35	6·79	20·52	16·29***	96·20	113·4**
Protein × age			26·59	11·75	35·55	28·21***	166·73	196·8
Nitrogen-free diet			68·7	22·0	90·6	601·0	799·7	1602·0

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

† Supro 610; Ralston Purina, St Louis, Mo.

Table 7. *Expt 3. Flow of dry matter* (DM) *(g/d) through the gastro-intestinal tract*

	Protein source			
	Milk	Isolated soya-bean protein†	Soya-bean meal	SEM
DM intake	324·1	226·9	263·4	20·36**
Intestinal section				
Stomach	261·7	253·2	232·5	18·98
Duodenum	238·7	210·1	224·9	12·81
Jejunum	138·7	98·1	140·5	17·17
Ileum	56·5	39·9	93·6	6·72***
Caecum	28·9	25·8	55·2	4·17***
Large intestine	26·2	20·6	45·3	4·01**
Faeces	7·4	17·1	32·8	2·28***

** $P < 0·01$, *** $P < 0·001$.
† Promine D; Central Soya Co., Chicago, Ill.

treatments (Table 7). The amount of DM flowing through the ileum and large intestine of pigs given the SBM diet was significantly greater than for pigs given the milk and ISP diets. Also, greater amounts of DM appeared in the faeces of pigs given the ISP and SBM diets than for pigs given the milk-protein diet.

In Expt 4 (Table 8), there were no differences in the DM intakes of pigs between the three dietary treatments as the pigs were all given 2 g N/kg live weight$^{0·75}$ per d (45 g DM/kg live weight$^{0·75}$ per d). The flow of DM through the stomach and small intestine of 14-d-old pigs was similar for each dietary treatment. However, by 35 d of age there was significantly less DM flowing through the stomach of pigs given the liquid milk diet than for pigs given pelleted milk and ISP diets. Greater amounts of DM flowed through the stomach of pigs given the pelleted milk diets than for pigs given the pelleted ISP diet. However, when expressed relative to DM intake, this difference was not significant.

The apparent digestion of DM to the ileum of pigs given the SBM diet was less than that of pigs given the ISP and milk-protein diets: 0·64, 0·82 and 0·83 for the SBM, ISP and milk-protein diets respectively (Table 9). Over the entire gastro-intestinal tract the values were 0·87, 0·92 and 0·98 for pigs given the SBM, ISP and milk-protein diets respectively.

In Expt 4, the apparent digestibility of DM to the ileum of 14-d-old pigs given the liquid milk diet was significantly greater than for pigs given the pelleted diets (Table 10), while at 35 d of age there were no differences between the dietary treatments. The apparent digestibility of DM to the ileum increased with the age of the pigs given the ISP (Supro 610) diet, but decreased with increasing age of pigs given the liquid milk diet.

Values for DM digestion were similar for pigs given the N-free diet and for pigs given the protein diets (Table 10).

pH

Mean stomach pH values were 4·05 (Expt 3) and 4·04 (Expt 4) (Table 11). The pH of the intestinal contents gradually increased from a mean of 5·91 in the duodenum to 6·74 recorded in the ileum and an abrupt drop to 6·02 in the caecum followed by a slight increase to 6·32 in the large intestine (Expt 3). The mean intestinal pH values obtained in Expt 4 also showed a similar trend (Table 12).

Table 8. *Expt 4. Flow of dry matter* (DM) *(g/d) through the gastro-intestinal tract*

				Intestinal section					
Protein source	Form	Age (d)	DM intake	Stomach	Duodenum and jejunum	Ileum	Caecum	Large intestine	Faeces
Milk	Pelleted	14	84·9	75·6	27·8	10·3	5·7	8·7	3·1
		35	205·9	217·7	75·7	22·1	7·4	10·2	5·7
		Mean	145·4	146·6	51·8	16·2	6·5	9·4	4·4
Milk	Liquid	14	80·2	67·0	16·1	6·7	3·3	5·8	1·0
		35	182·9	177·4	61·0	20·9	4·5	10·5	3·2
		Mean	131·5	122·2	38·6	13·8	3·9	8·1	2·1
Isolated soya-bean protein†	Pelleted	14	89·9	76·6	21·1	12·7	7·0	13·1	5·6
		35	181·0	198·7	59·4	21·2	7·1	16·8	8·9
		Mean	135·4	137·6	40·2	17·0	7·0	14·9	7·2
Mean		14	85·0	73·1	21·7	9·9	5·3	9·2	3·2
		35	189·9	197·9	65·4	21·4	6·3	12·5	5·9
Statistical significance and SEM due to:									
Protein			6·22	5·29*	8·23	1·40	0·51***	1·08***	0·70***
Age			5·08**	4·32***	6·72***	1·14***	0·42	0·80*	0·58
Protein × age			8·80	7·48	11·64	1·98*	0·72	1·53*	0·99

* $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.
† Supro 610; Ralston Purina, St Louis, Mo.

Table 9. *Expt 3. Uptake of dry matter (DM) to the ileum and the total intestinal tract and the apparent digestion (AD) of DM of 28-d-old pigs*

Protein source	Intake (g/d)	Ileum: Amount absorbed (g/d)	Ileum: AD	Total: Amount absorbed (g/d)	Total: AD
Milk	324·1	267·6	0·826	316·6	0·977
Isolated soya-bean protein†	226·9	187·1	0·825	209·8	0·925
Soya-bean meal	263·8	169·8	0·644	230·6	0·874
SEM	20·36**	20·51*	0·029**	18·03**	0·007***

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.
† Promine D; Central Soya Co., Chicago, Ill.

DISCUSSION

With suckled pigs, Kidder & Manners (1968) reported the passage time of digesta through the whole digestive tract to be 24–30 h and the total marker excretion time of 2–4 d. In the present experiment, the total retention time of digesta in the gastro-intestinal tract of pigs given the liquid milk diet every 2 h was 41 and 44 h for pigs 14 and 35 d of age respectively, while the pelleted milk diet fed every 2 h had a mean retention time in the gastro-intestinal tract of 25 and 34 h for pigs 14 and 35 d of age respectively. This difference between the mean retention time of digesta from pigs given a liquid or pelleted diet is due to the long retention of digesta in the large intestine; 62–74% of the total retention time, with pigs given the liquid diet.

The mean retention time of digesta in the gastro-intestinal tract of pigs given the soya-bean protein diets in Expts 3 and 4 was similar to that of pigs given the pelleted milk diets, i.e. 23–34 h. In contrast, Maner *et al.* (1962) and Kidder & Manners (1978) obtained an over-all passage time of digesta of less than 24 h with SBM and commercial diets.

Although there were significant differences in the apparent digestion of the diets fed in Expt 3 there were no significant differences in the mean retention time of marker in the gastro-intestinal tract. Similar findings have been reported (Searley *et al.* 1962). Entringer *et al.* (1975) noted a tendency, however, for the mean digestion to vary directly with passage time of digesta.

The retention of digesta in the stomach of suckling pigs has been reported as 1·5–2·0 h (Kidder & Manners, 1968), while in the present experiment the retention time of digesta in the stomach was approximately 1·0 h for pigs given the liquid milk diet. For pigs given the pelleted milk diet the retention of digesta in the stomach was 2·0–2·5 h. Kidder *et al.* (1961) obtained stomach retention times of 2·5–3·0 h for artificially-reared pigs fed twice daily.

It has been shown that pigs given cow's-milk-protein diets form a firm casein clot in the stomach (Braude *et al.* 1970) contrary to the relatively soft casein precipitate obtained normally with sow's milk (Cranwell *et al.* 1976; Decuypere *et al.* 1978). Cow's milk was found to clot in the stomach within 15–30 min after a meal, with the whey fraction leaving the stomach rapidly, while most of the clotted digesta had left the stomach 2 h after the meal (Braude *et al.* 1970). In the present experiment the average retention time of liquid milk in the stomach was 60 min, which would suggest that a milk clot had formed.

Zebrowska (1973) found that the rate of stomach emptying in the growing pig was greater

Table 10. *Expt 4. Uptake of dry matter* (DM) *to the ileum and the total intestinal tract, and the apparent digestion of* DM *in* 14- *and* 35-*d-old pigs*

Protein source	Form	Age (d)	DM intake	DM absorbed: Ileum	DM absorbed: Total	Apparent digestion: Ileum	Apparent digestion: Total
Milk	Pelleted	14	84·9	74·6	84·8	0·878	0·963
		35	205·8	183·7	200·1	0·892	0·972
		Mean	145·3	129·2	142·4	0·886	0·967
Milk	Liquid	14	80·2	73·5	79·2	0·917	0·987
		35	182·9	162·1	179·8	0·886	0·983
		Mean	131·5	117·8	129·5	0·901	0·985
Isolated soya-bean protein†	Pelleted	14	89·9	76·5	84·4	0·853	0·938
		35	181·0	159·8	172·2	0·884	0·951
		Mean	135·4	118·2	128·3	0·867	0·945
Mean		14	85·0	74·9	82·8	0·882	0·963
		35	189·9	168·5	184·0	0·887	0·969
Statistical significance and SEM due to:							
Protein			6·22	5·43	6·00	0·010*	0·004***
Age			5·08***	4·43***	4·89***	0·008*	0·003
Protein × age			8·80	7·68	8·48	0·014*	0·006
N-free diet			182·7	148·1	175·7	0·812	0·963

* $P < 0·05$, *** $P < 0·001$.
† Supro 610; Ralston Purina, St Louis, Mo.

Table 11. *Expt 3. pH in the gastro-intestinal tract*

Intestinal section	Protein source			SEM
	Milk	Isolated soya-bean protein†	Soya-bean meal	
Stomach	4·08	3·97	4·10	0·351
Duodenum	6·03	5·80	5·90	0·126
Jejunum	5·73	5·98	6·10	0·091*
Ileum	6·68	6·82	6·72	0·074
Caecum	6·06	6·16	5·83	0·129
Large intestine	5·88	6·53	6·55	0·075***

* $P < 0{\cdot}05$, *** $P < 0{\cdot}001$.
† Promine D; Central Soya Co., Chicago, Ill.

when natural feedstuffs were fed than when purified diets were fed. In the present experiments, pigs given the ISP diet had shorter mean retention times of digesta in the stomach than pigs given the pelleted milk diet, although there were no differences in the stomach retention time for pigs given the SBM diet and pelleted milk diet.

Dietary supplementation of amino acids of the protein sources in Expt 3 did not influence the rate of stomach emptying which has also been observed by Rolls *et al.* (1972) in rats.

Little difference was observed in the time food remained in the small intestine between sow-reared and artificially-reared pigs (Kidder *et al.* 1961), the passage time being approximately 2·5–3·0 h. Similar values were obtained by Braude *et al.* (1970) of 2·0–3·0 h for the transit time of polyethylene glycol from ingestion to the terminal ileum. The mean retention time of digesta in the small intestine of pigs in Expt 4 ranged from 1·6–2·6 h.

The mean retention of digesta in the caecum increased with age of pigs from 14–35 d of age. Similar observations have been made with rats in which the transit time of intestinal contents in the caecum increased five-fold from weaning to adult age (Varga, 1976). This may be explained by the age-induced changes in the microflora in the digestive tract as Iwai *et al.* (1973) found lower transit rates of intestinal contents in germ-free mice than in conventional mice, and a significant correlation between caecal size in early life and transit rate of intestinal contents from the ileum to colon.

Retention time of digesta in the large intestine of pigs given the pelleted diet ranged from 18–29 h, although for pigs given the liquid diet this was much greater. Horszczaruk (1962) found the transit time from the caecum to marker appearance in the faeces to be 12–18 h in growing pigs, while Hecker & Grovum (1975) calculated the passage time of digesta in the large intestine of 30 kg pigs to be approximately 30 h.

A 2–3-fold dilution of the food plus water intake by endogenous secretions in the anterior small intestine has been reported in older pigs by a number of workers (Horszczaruk, 1971; Zebrowska, 1973; Braude *et al.* 1976). Although water intakes were not measured in the present experiments, the total amount of digesta flow in the duodenum of pigs from Expt 3 was 2·5–3·8 kg/24 h. DM food intakes were 227–324 g/d and so this would indicate also considerable endogenous secretion into this area. This large volume of digesta in the anterior small intestine was not so apparent in the pigs of Expt 4. This may be explained by the method of feeding as the pigs in Expt 3 were fed *ad lib.*, while in Expt 4 they were fed at 45 g DM/kg live weight$^{0{\cdot}75}$ per d (2 g N/kg live weight$^{0{\cdot}75}$ per d) in twelve two-hourly feeds.

There was only a small decrease in DM flow along the large intestine of pigs in the present

Table 12. *Expt 4. pH in the gastro-intestinal tract of* 14 *and* 35-*d-old pigs*

Protein source	Form	Age (d)	Intestinal section: Stomach	Duodenum and jejunum	Ileum	Caecum	Large intestine
Milk	Pelleted	14	4·25	6·13	6·48	6·65	6·53
		35	4·73	6·04	6·45	6·65	6·88
		Mean	4·49	6·09	6·47	6·65	6·71
Milk	Liquid	14	3·90	5·88	6·25	6·13	6·05
		35	4·45	6·21	6·98	7·05	7·35
		Mean	4·17	6·05	6·62	6·59	6·70
Isolated soya-bean protein†	Pelleted	14	3·20	6·00	6·43	5·98	6·18
		35	3·68	6·14	6·93	6·53	6·68
		Mean	3·44	6·07	6·68	6·26	6·43
Mean		14	3·78	6·00	6·39	6·25	6·25
		35	4·28	6·13	6·79	6·74	6·97
Statistical significance and SEM due to:							
Protein			0·320	0·170	0·116	0·087*	0·132
Age			0·261	0·138	0·094**	0·071**	0·108***
Protein × age			0·452	0·240	0·164	0·123	0·187*
Nitrogen-free diet			3·60	6·58	6·45	6·55	7·10

* $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.
† Supro 610; Ralston Purina, St Louis, Mo.

experiments, but a large decrease in the total digesta flow. Similar results were obtained by Horszczaruk (1971) which confirms that the large intestine is a major site for water absorption, although Hecker & Grovum (1975) indicated that the large intestine of growing pigs may have a low potential for water absorption.

Studies with growing pigs utilizing re-entrant cannulas in the duodenum (Zebrowska & Buraczewska, 1972; Zebrowska, 1973; Zebrowska *et al.* 1975) obtained values between 0·86 and 1·08 for 24 h DM output at the duodenum: input values for a variety of diets. The latter authors found more DM after giving pigs diets containing natural feedstuffs than with purified diets. In the present experiments the type of protein source fed did not influence the amount of DM flowing through the duodenum.

The apparent digestibility of DM to the ileum for pigs given the N-free diet was 0·812 for the 35-d-old pigs, which is similar to values obtained from N-free diets with older pigs (Zebrowska & Buraczewska, 1972; Holmes *et al.* 1974).

The significant increase in the apparent digestibility of DM with age of pigs given the ISP diet in Expt 4 would confirm the results of Hays *et al.* (1959). The apparent digestibility of the milk-protein diets tended to decrease with increasing age of the pigs.

The gastric pH values obtained in the present experiments were similar to values reported by other workers (Kidder & Manners, 1978). No differences in gastric pH values were observed between pigs given the milk- or soya-bean-protein diets. However, the very large buffering capacity of high protein level weaning diets (Manners, 1970) would influence gastric pH values, as is evident from the results of a number of studies (Kidder & Manners, 1978).

The gastric mucosa of the very young pig is able to secrete acid (Cranwell & Titchen, 1976; Decuypere *et al.* 1978) and although intake of solid food was found to increase acid secretion in the stomach of young pigs, acid secretion did not change during the first 4 weeks of life (Decuypere *et al.* 1978). There was no change in gastric pH with age of pigs from 14–35 d of age which supports the findings of Decuypere *et al.* (1978), who found no pH alterations with suckling or early-weaned pigs during the first 4 weeks of life.

pH values along the intestine did not differ with the source of dietary protein and were similar to values obtained by other workers using young pigs (Smith & Jones, 1963; Hamilton & Roe, 1977). As also shown by these latter workers, the pH values showed a gradual increase from the duodenum to the ileum.

There was an increase in the pH at the ileum and large intestine with increasing age of pigs from 14–35 d of age. This increase is difficult to explain as increased bacterial activity in this region with age would tend to reduce pH values. The contents, however, must have been sufficiently buffered by intestinal secretions to result in an over-all increase in pH. In addition, the longer retention times of digesta in the large intestines of the older pigs may have influenced pH.

From these results it must be concluded that the differences in the performance of pigs fed milk and soya-bean proteins cannot be explained by the sites of digestion of DM, the pH of the gastro-intestinal tract, or the retention times of digesta in the gastro-intestinal tract.

The experiments show that endogenous secretions and sites of absorption of DM in the pig between 14 and 35 d of age were similar to those observed with older pigs (Zebrowska, 1973; Holmes *et al.* 1974; Braude *et al.* 1976) and that the apparent digestion of soya-bean protein improved with increasing age of the pigs.

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