Studies on digestion and absorption in the intestines of growing pigs

2. Measurements of the flow of dry matter, ash and water

BY A. G. LOW, I. G. PARTRIDGE AND I. E. SAMBROOK

National Institute for Research in Dairying, Shinfield, Reading, Berks. RG2 9AT

(*Received* 6 *September* 1976 – *Accepted* 5 *July* 1977)

1. Digesta were collected from twenty-three pigs, initially of 30 kg live weight, and fitted with single Ash re-entrant cannulas in either the duodenum, jejunum or ileum. A further twenty-four pigs were used in a conventional digestibility trial.

2. The diets contained: barley, fine wheat offal, white fish meal, minerals and vitamins (diet BWF); starch, sucrose, maize oil, cellulose, minerals, vitamins and either groundnut (diet SSG) or casein (diet SSC).

3. The flow-rates of dry matter (DM), ash and water were measured hourly in the duodenum and jejunum, and every 6 h in the ileum during 24 h collection periods. Faeces were collected during 5 d periods.

4. Marked increases in the flow rates of each of the digesta components after feeding each diet were observed in the duodenum and jejunum, but not in the ileum. The total flow in 24 h periods was much lower in the ileum than at the other sites.

5. Values for the ratio, DM output: intake for DM outputs from the duodenal, jejunal or ileal cannulas, and in faeces, in 24 h periods were respectively 0·94, 0·81, 0·28 and 0·22 for diet BWF; 0·96, 0·76, 0·20 and 0·15 for diet SSG; 0·96, 0·73, 0·08 and 0·04 for diet SSC. The corresponding values for ash were: 1·47, 1·65, 0·74 and 0·53 for diet BWF; 1·28, 1·34, 0·59 and 0·51 for diet SSG; 1·63, 1·35, 0·50 and 0·26 for diet SSC. The corresponding values for water were: 3·49, 3·41, 0·88 and 0·18 for diet BWF, 2·75, 2·80, 0·80 and 0·08 for diet SSG and 2·61, 1·87, 0·23 and 0·01 for diet SSC.

The desirability of improving the utilization of feedingstuffs by farm livestock has stimulated research on the digestive processes in these animals. Until recently, digestion in the pig has been relatively little studied. The methods available for such investigations in simple-stomached species have been reviewed in detail by Laplace (1972) and the results of trials with pigs were discussed by Low (1976).

The re-entrant cannula method has been used at this Institute to study the general characteristics of digestion of a variety of diets in the intestines of growing pigs. The methods used, and the flow and pH characteristics of the digesta were reported by Braude, Fulford & Low (1976). The present account describes the movement of the dry matter (DM), ash and water components of the digesta collected in the same study. The detailed composition of the DM and ash fractions will be described in future publications.

EXPERIMENTAL METHODS

Animals. Castrated male pigs from the Large White herd of the National Institute for Research in Dairying were used for these studies. Twenty-three pigs were fitted with single re-entrant cannulas (Ash, 1962) which were sited as follows: (*a*) duodenum, approximately 0·15 m from the pylorus and distal to the bile and pancreatic ducts (twelve pigs); (*b*) jejunum, 2·0–2·5 m from the pylorus (i.e. 13–17 % of the distance along the small intestine) (five pigs), or (*c*) the ileum (0·3 m from the ileo-caecal junction, i.e. over 98 % of the distance along the small intestine) (six pigs). The initial live weight of these pigs was approximately 30 kg.

A further twenty-four pigs of initial live weight 17–19 kg and without cannulas were used for a conventional digestibility trial.

Table 1. *Composition of experimental diets (g/kg diet)*

Ingredients	Diets BWF and BWF_f*	Ingredients	Diet SSG	Diet SSC
Barley meal	713·5	Maize starch	277·0	612·7
Fine wheat offal	200·0	Sucrose	276·9	100·0
White fish meal	70·0	Maize oil	30·0	30·0
NaCl	2·7	Solka Floc‡	20·0	30·0
$CaHPO_4.2H_2O$	5·6	Groundnut meal	350·0	—
$CaCO_3$	6·2	Casein	—	184·0
Vitamin mix no. 1†	2·0	Trace mineral mix§	10·0	10·0
$CuSO_4.5H_2O$	1·0	$CaHPO_4.2H_2O$	17·9	20·6
		$CaCO_3$	4·6	4·6
		Vitamin mix no. 2‖	2·0	2·0
		Choline HCl	1·1	1·1
		NaCl	5·0	5·0
		L-lysine HCl	2·5	—
		DL-methionine HCl	3·0	—

* Diet BWF after milling through a 1 mm mesh; this diet was given to pigs with ileal re-entrant cannulas, and to some pigs in the digestibility trial.

† Supplied (/kg diet): 0·75 mg retinol, 7·50 μg cholecalciferol, 3·25 mg riboflavin, 30·00 μg cyanocobalamin, 15·75 mg nicotinic acid, 13·00 mg pantothenic acid, 3·25 mg pyridoxine, 200·00 mg choline chloride 2·00 mg DL-α-tocopheryl acetate.

‡ Brown and Co., Berlin, New Hampshire, U.S.A.

§ Supplied (/kg diet): 4·47 g K_2CO_3, 1·73 g $MgCO_3.H_2O$, 0·33 g $FeSO_4.7H_2O$, 60 mg $MnSO_4.H_2O$, 0·10 g $ZnCO_3$, 8·00 mg NaF, 17·50 mg $CuSO_4.5H_2O$, 6·00 mg $CoCl_2$.

‖ Supplied (/kg diet): as vitamin mix no. 1 (omitting choline chloride) and in addition 2·00 mg thiamin, 50·00 μg biotin, 0·50 mg pteroylmonoglutamic acid, 20·00 mg *p*-aminobenzoic acid, 194·00 mg *myo*-inositol, 30·00 mg ascorbic acid, 2·00 mg menaphthone.

Housing. Details of the housing and metabolism cage design were as described by Braude *et al.* (1976).

Diets. Diets BWF, SSG and SSC (for details, see Table 1) contained respectively (g/kg): DM 868·2, 925·2 and 911·8; ash 53·1, 52·0 and 34·0. Because of previous experience of frequent blockages of ileal re-entrant cannulas after feeding the normally-milled diet BWF, this diet was finely-milled through a 1 mm mesh (diet BWF_f); this diet was offered to pigs with ileal re-entrant cannulas and subsequently to six of the pigs without cannulas used in the digestibility trial. The dry diet was mixed with water (1:2·5, w/v) and offered twice daily at 09.00 and 15.00 hours. The animals were weighed weekly and fed on a scale based on their live weight (Barber, Braude, Mitchell & Pittman, 1972). On this scale pigs of 20 kg live weight received 1·05 kg air-dry diet/d; the amount increased linearly to 2·40 kg at 60 kg live weight.

Cannula design, surgery and digesta and faeces collection procedures. These were as described by Braude *et al.* (1976).

DM *and ash determination.* Duplicate 8–10 g samples of digesta were taken from rapidly-stirred digesta with a 10 ml graduated pipette, the tip of which had been removed to provide an aperture of 5–6 mm diameter. The samples were put into glass liquid-scintillation counting vials and heated at 102° for 18 h in a fan-ventilated oven.

After drying, the samples were weighed and then the same vials were heated at 460° for 18 h for ash determination.

After mixing the faeces output from each 5 d collection period, 4–6 g samples were taken for drying and ashing using the same procedures as for digesta.

Presentation and statistical analysis of results. The amounts of DM, ash and water are expressed as the ratio, weight collected in a specified time:weight in diet and water consumed

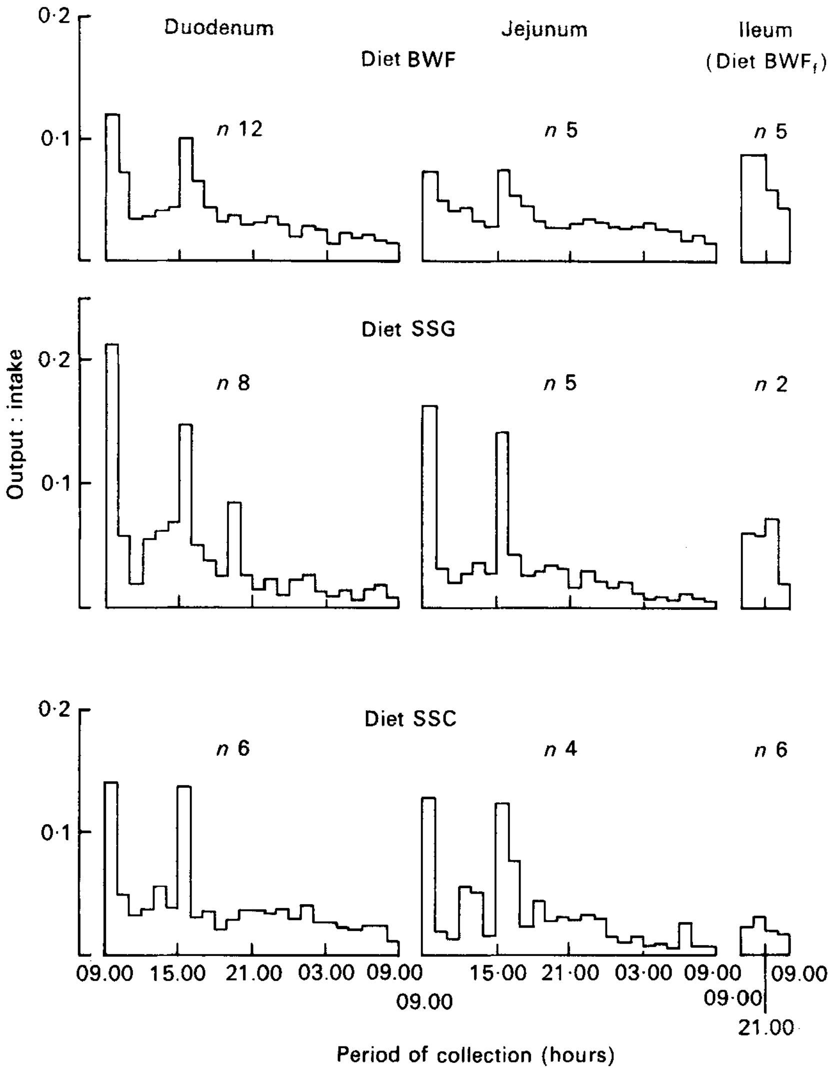

Fig. 1. Mean hourly (6-hourly in ileum) flow of dry matter (output:intake) in pigs each fitted with a re-entrant cannula at one of three sites (for details, see p. 515) and given successively diets BWF (or BWF$_f$), SSG and SSC (for details, see Table 1). Pigs were fed at 09.00 and 15.00 hours; *n* is the no. of pigs completing collections.

in 24 h (output: intake) to indicate the direction and extent of net movements through the gut wall in each region.

To aid interpretation of the results, Table 5 shows the weights of DM, ash and water intakes and outputs/d for a 40 kg pig receiving 1·70 kg air-dry diet and 4·25 l water/d. The average weight of the cannulated pigs and those used in the digestibility trial was 40 kg.

Flow pattern during 24 h periods. The mean values for flow of DM, ash and water during 24 h collection periods were calculated from the average values for all 24 h collections completed by each pig on a diet. For pigs with duodenal and jejunal cannulas the mean values are for each hour of the 24 h periods and for those with ileal cannulas are for the four successive 6 h periods of the 24 h periods.

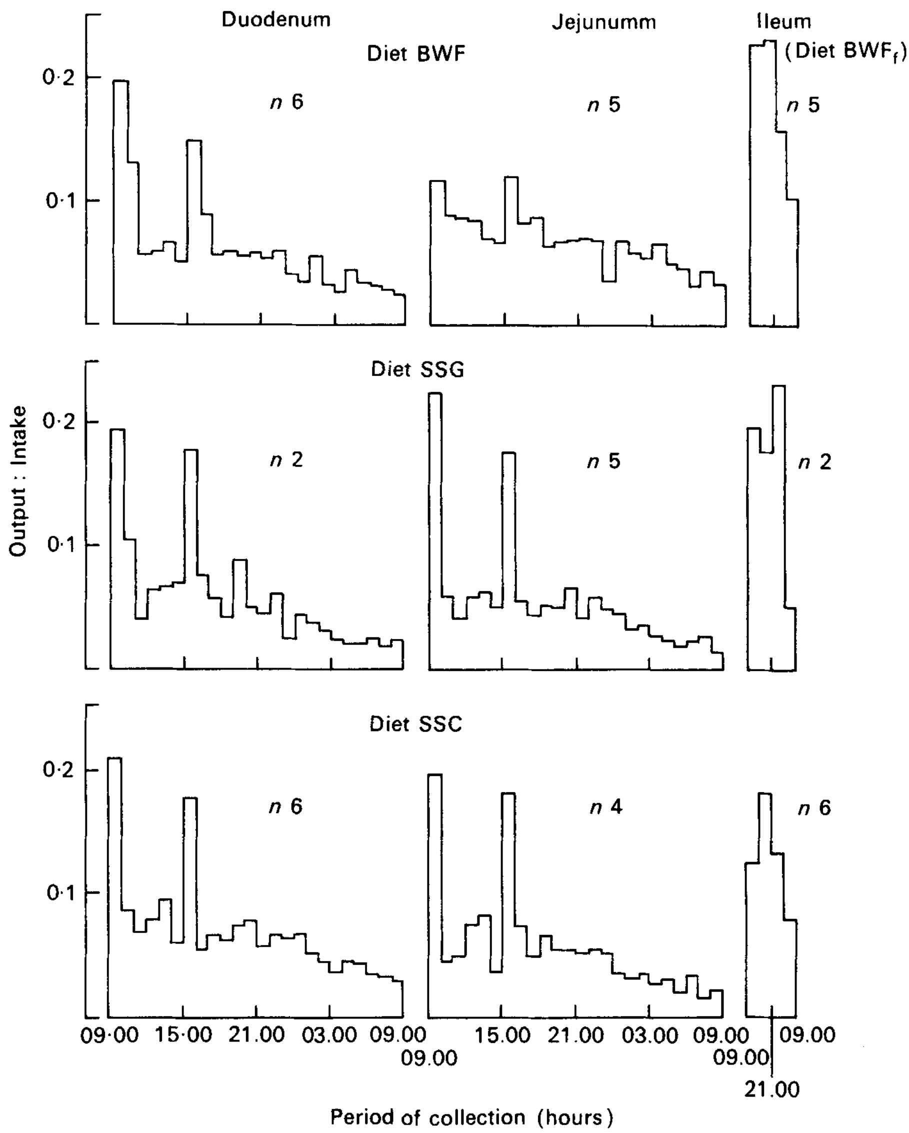

Fig. 2. Mean hourly (6-hourly in ileum) flow of ash (output:intake) in pigs each fitted with a re-entrant cannula at one of three sites (for details, see p. 515) and given successively diets BWF (or BWF$_f$), SSG and SSC (for details, see Table 1). Pigs were fed at 09.00 and 15.00 hours; *n* is the no. of pigs completing collections.

Total flow in 24 *h periods.* The average output:intake values for the whole of each 24 h collection period for each pig on a diet were subjected to analysis of variance. The average values for the four faeces collections from each of the pigs without cannulas were similarly treated. The standard error of the difference between the means is not the same for each pair of cannula sites or for each pair of diets because different numbers of animals completed collections for the various site/diet combinations.

The least and greatest values are given in Tables 2, 3 and 4. The statistical methods used in these studies were described in more detail in a previous paper (Braude *et al.* 1976)

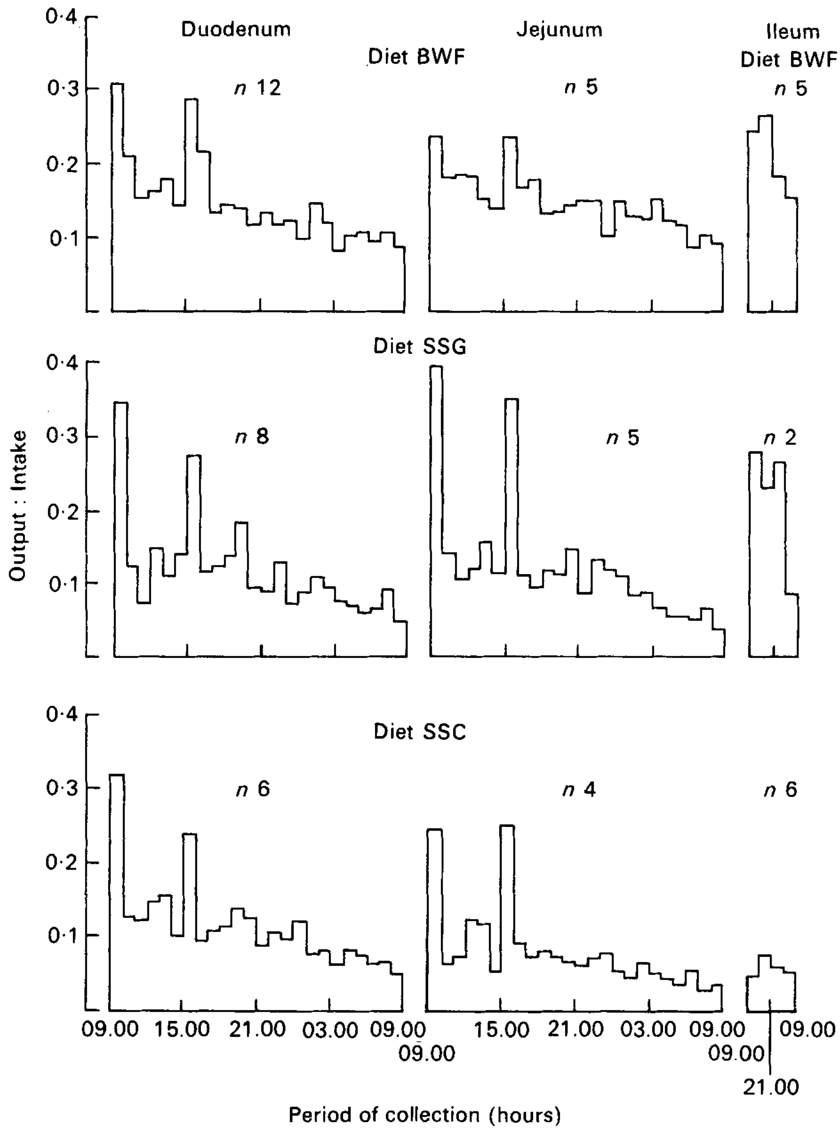

Fig. 3. Mean hourly (6-hourly in ileum) flow of water (output:intake) in pigs each fitted with a re-entrant cannula at one of three sites (for details, see p. 515) and given successively diets BWF (or BWF$_f$), SSG and SSC (for details, see Table 1). Pigs were fed at 09.00 and 15.00 hours; *n* is the no. of pigs completing collections.

RESULTS

During the course of this study a total of thirty-five pigs were fitted with re-entrant cannulas. However, because of a variety of difficulties in maintaining pigs with re-entrant cannulas, satisfactory results were obtained from only twenty-three of these pigs. A detailed account of the reasons for the unbalanced numbers of pigs used for the various site and diet combinations was given by Braude *et al.* (1976).

The mean hourly flow patterns of DM, ash and water during 24 h collection periods (output:intake) are shown in Figs 1, 2 and 3 respectively. For each of these measurements

Table 2. *Mean 24 h output:intake for dry matter in pigs given different diets (a) for digesta collected from pigs with intestinal re-entrant cannulas at one of three sites, (b) for faeces collected from pigs without cannulas*

(*a*) Cannulated pigs (No. of pigs completing collections in parentheses)

Site of re-entrant cannula*	Diet BWF†	Diet SSG	Diet SSC
Duodenum	0·94 (12)	0·96 (8)	0·96 (6)
Jejunum	0·81 (5)	0·76 (5)	0·73 (4)
Ileum	0·28 (5)	0·20 (2)	0·08 (6)

SE of difference between site means: least value 0·060, greatest value 0·094
SE of difference between diet means: least value 0·023, greatest value 0·066

(*b*) Pigs without cannulas (six pigs/diet)

	Diet BWF	Diet BWF_f	Diet SSG	Diet SSC
Faeces	0·22	0·21	0·15	0·04

SE of difference between diet means: 0·004
SE of difference between means for faeces and ileum: least value 0·012, greatest value 0·018

* For details of sites, see p. 515.
† Diet BWF was finely milled (diet BWF_f) when fed to pigs with ileal cannulas; for details of diets, see p. 516 and Table 1.

Table 3. *Mean 24 h output:intake for ash in pigs given different diets (a) for digesta collected from pigs with intestinal re-entrant cannulas at one of three sites, (b) for faeces collected from pigs without cannulas*

(*a*) Cannulated pigs (No. of pigs completing collections in parentheses)

Site of re-entrant cannula*	Diet BWF†	Diet SSG	Diet SSC
Duodenum	1·47 (6)	1·28 (2)	1·63 (6)
Jejunum	1·65 (5)	1·34 (5)	1·35 (4)
Ileum	0·74 (5)	0·59 (2)	0·50 (6)

SE of difference between site means: least value 0·099, greatest value 0·172
SE of difference between diet means: least value 0·055, greatest value 0·118

(*b*) Pigs without cannulas (six pigs/diet)

	Diet BWF	Diet BWF_f	Diet SSG	Diet SSC
Faeces	0·53	0·54	0·51	0·26

SE of difference between diet means: 0·027.
SE of difference between means for faeces and ileum: least value 0·052, greatest value 0·073

* For details of sites, see p. 515.
† Diet BWF was finely-milled (diet BWF_f) when fed to pigs with ileal cannulas; for details of diets, see p. 516 and Table 1.

the highest flow-rates were observed immediately after feeding at the duodenal and jejunal cannula sites; these peaks were usually higher after the pigs received the purified diets SSG and SSC than the cereal-based diet BWF. It was usually observed that the flow of digesta in the ileum was lowest 12–18 h after the afternoon feed. The individual hourly values were very variable indeed: the coefficients of variation (%) of the 'within-hourly' flow of DM (within

Table 4. *Mean 24 h output:intake for water in pigs given different diets (a) for digesta collected from pigs with intestinal re-entrant cannulas at one of three sites, (b) for faeces collected from pigs without cannulas*

(*a*) Cannulated pigs (No. of pigs completing collections in parentheses)

Site of re-entrant cannula*	Diet BWF†	Diet SSG	Diet SSC
Duodenum	3·49 (12)	2·75 (8)	2·61 (6)
Jejunum	3·41 (5)	2·80 (5)	1·87 (4)
Ileum	0·88 (5)	0·80 (2)	0·23 (6)

SE of difference between site means: least value 0·269, greatest value 0·422
SE of difference between diet means: least value 0·094, greatest value 0·231

(*b*) Pigs without cannulus (six pigs/diet)

	Diet BWF	Diet BWF_f	Diet SSG	Diet SSC
Faeces	0·18	0·14	0·08	0·01

SE of difference between diet means: 0·009
SE of difference between means for faeces and ileum: least value 0·048, greatest value 0·068

* For details of sites, see p. 515.
† Diet BWF was finely-milled (diet BWF_f) when fed to pigs with ileal cannulas, for details of diets, see p. 516 and Table 1.

any 6 h period in the ileum) were on average, duodenum 70, jejunum 61, and ileum 36; the corresponding values for ash were 47, 47 and 30, and for water 50, 45 and 31 respectively.

The mean 24 h output:intake values for DM are shown in Table 2. The corresponding weights of DM for a 40 kg pig are shown in Table 5. For each diet there was slightly less DM flow in the duodenum than ingested in 24 h. Significant ($P < 0·05$) reductions in the amounts of DM flow were observed in each of the successive sections of the intestines studied for all diets. Within either the duodenum or the jejunum there were no differences between the three diets in the amounts of DM flow. On the other hand there was significantly ($P < 0·05$) less DM from diet SSC than from diets BWF and SSG in the ileum. In the case of faeces, there was no significant difference between diets BWF and BWF_f, but there was significantly ($P < 0·001$) less DM for diets SSG than for diets BWF and BWF_f, and significantly ($P < 0·001$) less for diet SSC than for the other three diets.

The mean 24 h output:intake values for ash are shown in Table 3. The corresponding weights of ash for a 40 kg pig are shown in Table 5. Samples were analysed for their ash content from all pigs except the first six with duodenal cannulas. For each diet there was substantially more ash in the duodenum than ingested. The mean values for ash in the jejunum were higher (not significant) than in the duodenum for diets BWF and SSG, but the value for diet SSC was significantly ($P < 0·05$) lower in the jejunum than in the duodenum. For all diets there was significantly ($P < 0·01$) less ash in the ileum than in the duodenum and jejunum. There was a further reduction in the amount of ash between the ileum and faeces which was significant for diets BWF_f and SSC ($P < 0·01$). In the comparisons within sites it was found that there was a significantly ($P < 0·05$) higher value for diet SSC than for other diets in the duodenum, but in the jejunum the value was significantly ($P < 0·01$) higher for diet BWF than for the other diets. In the ileum the value was significantly ($P < 0·05$) higher for diet BWF than for diet SSC; no other differences at this site were significant. The value in the faeces was significantly lower for diet SSC than for the other diets. Since the output:intake values mask the fact that absolute intakes for the diets differed considerably, it is important to consider the ash flow in weight terms. In Table 5

Table 5. *Daily intakes (g) of dry matter* (DM) *and ash and volumes of water (ml) in the diet and in digesta and faeces collected during 24 h, calculated for a pig of 40 kg live weight given* 1·7 kg *air-dry diet and* 4·25 *l water/d*

	Diet BWF or BWF_f*	Diet SSG	Diet SSC
DM			
Intake	1476	1573	1550
Duodenum	1387	1510	1488
Jejunum	1196	1195	1132
Ileum	413*	315	124
Faeces	325 310*	236	62
Ash			
Intake	92	90	60
Duodenum	135	115	98
Jejunum	152	121	81
Ileum	68*	53	30
Faeces	49 50*	46	16
Water			
Intake	4474	4377	4400
Duodenum	15614	12037	11484
Jejunum	15256	12256	8228
Ileum	3937*	3502	1012
Faeces	805 626*	350	44

* Diet BWF was normally-milled when fed to pigs with duodenal and jejunal cannulas but was finely-milled (diet BWF_f) when fed to pigs with ileal cannulas. Both versions of this diet were compared in the digestibility trial. For details of diets, see p. 516 and Table 1.

Table 6. *Mean concentrations of dry matter (mg/g digesta) in* 24 *h periods in pigs given different diets*

(Mean values and standard deviations; no. of animals in parentheses)

	Diet BWF BWF_f*		Diet SSG		Diet SSC	
	Mean	SD	Mean	SD	Mean	SD
Intake	248·1		264·3		260·5	
Duodenum	81·8	5·24 (12)	111·3	4·78 (8)	114·7	7·28 (6)
Jejunum	72·5	3·45 (5)	88·9	8·78 (5)	121·1	11·29 (4)
Ileum	99·2	7·79* (5)	82·6	7·42 (2)	104·3	2·64 (6)
Faeces	285·7 334·3	16·86 (6) 29·05* (6)	397·0	45·34 (6)	572·3	36·19 (6)

* For details, see Table 5.

for diets BWF, SSG and SSC respectively it can be seen that net amounts of 43, 25, and 38 g ash were added to the digesta by the time it reached the duodenal cannula, while 84, 68 and 51 g were absorbed between the jejunum and ileum, and 18, 7 and 14 g were absorbed in the large intestine.

The mean 24 h output:intake values for water are shown in Table 4. The corresponding volumes of water for a 40 kg pig are shown in Table 5. The amount of water in the duodenum was much greater than intake as a result of endogenous secretions anterior to the cannula site. The amounts of water in the jejunum were similar to those in the duodenum for diets BWF and SSG, but were significantly ($P < 0.05$) less for diet SSC. There was

Table 7. *Mean concentrations of ash (mg/g digesta), in 24 h periods in pigs given different diets*

(Mean values and standard deviations, no. of animals in parentheses)

	Diet BWF BWF$_f$*		Diet SSG		Diet SSC	
	Mean	SD	Mean	SD	Mean	SD
Intake	15·4		15·1		10·0	
Duodenum	7·8	0·42 (6)	8·6	0·23 (2)	6·8	0·48 (6)
Jejunum	9·2	0·55 (5)	9·0	0·49 (5)	8·8	1·06 (4)
Ileum	16·3	1·65* (5)	15·0	2·33 (2)	25·3	4·02 (6)
Faeces	43·7	3·09 (6)	81·1	6·10 (6)	143·0	17·23 (6)
	54·0	4·78* (6)				

* For details, see Table 5.

significantly less ($P < 0·001$) water in the ileum than at the jejunum for all diets, and a further significant ($P < 0·001$) reduction occurred between the ileum and faeces. Within the duodenum there was significantly ($P < 0·001$) more water flow for diet BWF than for the other diets. In the jejunum the water flow was greatest for diet BWF and least for diet SSC; the differences between the diets were significant ($P < 0·01$) in each case. At the ileal site there was significantly ($P < 0·01$) less water for diet SSC than for the other diets. In the faeces the amounts of water flow decreased in the order BWF > BWF$_f$ > SSG > SSC. The differences between each diet pair were all significant ($P < 0·05$).

The mean concentrations of DM in the digesta are shown in Table 6. The concentrations remained relatively similar at all of the small intestinal sites for each diet, but were much higher and more variable in the faeces. The mean concentrations of ash (Table 7) increased slightly between the duodenum and jejunum, followed by a larger increase in the distal small intestine and a major further increase in the large intestine.

DISCUSSION

1. DM. The pattern of flow of DM was similar to the flow of digesta (Braude *et al.* 1976), and, as with digesta, the individual hourly or 6-hourly values were highly variable. However, the peaks in flow after feeding in the duodenum and jejunum were larger relative to the average flow over 24 h than those for whole digesta, indicating a more marked response to feeding. There was also a greater reduction in flow with increasing time after feeding than for digesta. These differences can be explained by the fact that while the DM fraction of digesta consists mainly of dietary material, digesta as a whole contains large quantities of endogenous material (of very low DM content), the secretion of which is relatively continuous. Similar, but less detailed, patterns of flow at various intestinal sites were observed by Kvasnitskii (1951), Zebrowska & Buraczewska (1972), Zebrowska (1973) and Zebrowska, Buraczewska, Buraczewski & Horszczaruk (1975). There was a greater flow of DM in the duodenum immediately after feeding when the pigs received the purified diets SSG and SSC than diet BWF which contained natural feedingstuffs. This contrasts with the observation by Zebrowska (1973) that there were higher flow-rates in the duodenum immediately after pigs received natural feedingstuffs than when purified diets containing casein or gluten were given. It may be noted that the purified diets used in the present study contained less cellulose than those in the work of Zebrowska (1973) and also that maize starch and sucrose were the only other carbohydrate components while the purified diets used by Zebrowska (1973) contained up to 420 g potato flakes/kg. Differences such as these in diet composition may have been responsible for the differences observed in the pattern of gastric emptying.

It is notable that for each diet there was slightly less DM passing the duodenum than ingested in 24 h collection periods, in spite of the contributions of the salivary, gastric, biliary, pancreatic and digestive tract mucosal secretions to the DM at this site. This suggests that at least 10 % of the dietary DM was absorbed anterior to this site in 24 h, a result confirming work by Kvasnitskii (1951). In similar studies on pigs with re-entrant cannulas in the duodenum Horszczaruk (1971 *c*), Zebrowska & Buraczewska (1972), Zebrowska (1973) and Zebrowska *et al.* (1975) obtained values for 24 h output:intake between 0·86 and 1·08 for a range of diet types. In general these authors found more DM after giving pigs natural feedingstuffs than after purified diets. By the time the jejunum was reached diets SSG and SSC were more rapidly digested and absorbed than diet BWF. At this point, 13–17 % along the length of the small intestine, there was 14, 21 and 24 % less DM than at the duodenum for diets BWF, SSG and SSC respectively; the corresponding amounts of digesta were 3, 1 and 28 % lower (Braude *et al.* 1976), indicating that the amount of digesta is markedly influenced by factors other than the DM it contains per se. In this connexion the differences in the DM concentration of the digesta at this site may be noted.

The fact that 91, 94 and 96 % of the total apparent absorption of DM had occurred anterior to the ileal cannula site for diets BWF, SSG and SSC indicates the minor role of the large intestine in this process. The values obtained in the ileum were similar to those observed by Zebrowska (1973) for comparable diets. Both the intestinal and the faecal values confirm the general observation in pigs that purified diets are more completely digested than those containing natural ingredients.

2. *Ash*. The 24 h patterns of ash flow in the duodenum and jejunum for each diet were more similar to those for digesta (Braude *et al.* 1976) and for water than for DM, indicating that its flow, like that of water, is less dependent on stomach emptying than the flow of DM, and is influenced by the relatively constant flow of ash into the duodenum in the biliary and pancreatic secretions.

The values for 24 h output:intake in the duodenum ranging from 1·3 to 1·6 compare well with values of 1·0–1·8 for a range of practical diets used by Evseeva (1953) and values of 1·3 and 1·5 obtained by Horszczaruk (1971 *c*). Although these values indicate that extensive secretion occurred anterior to the duodenal cannula site, the possibility remains that absorption may also have occurred. Further net secretion occurred between the duodenum and the jejunum for diets BWF and SSG, while net absorption occurred for diet SSC. Results of Partridge (1978) indicate that certain elements were consistently secreted to a greater extent than absorbed in this region, and others were consistently absorbed to a greater extent than secreted irrespective of diet type.

The only information in the literature with which the ileal values may be compared is by Horszczaruk (1971 *a*, *b*) who obtained values for output:intake of approximately 0·9 for pigs with cannulas in the caecum and mid-ileum, and 0·67 in faeces. These values may be higher than those obtained in the present study because ash intakes were higher; it is possible that the absolute weights of ash absorbed may have been similar to those in the present study (Table 5) which were 43–44 g/d for a 40 kg pig (comparing intake and faeces output).

Although more ash absorption occurred in the small intestine than in the large intestine, the latter region was of much greater importance in ash absorption than in DM absorption.

The much wider range of ash (Table 7) than of DM (Table 6) concentrations in the intestine is notable. Partridge (1978) has shown that while the concentrations of most minerals varied markedly, as shown here for ash in general, the concentration of sodium was maintained within narrow limits.

3. *Water*. The 24 h pattern of water flow for each diet and at each site was very similar to that of digesta (Braude *et al.* 1976) of which it was the predominant constituent.

The values for 24 h output:intake for water indicated that major water addition to the intestinal contents occurred anterior to the duodenal cannula site, originating from the secretions of the salivary glands, oesophagus, stomach, liver, pancreas and intestinal mucosa. The marked differences between the diets in the amount of water flow in the duodenum and in the amount of water retained in the digesta at the more distal intestinal sites can only partially be accounted for. It is notable that there was an inverse relationship between the ranking of the diets in order of increasing DM digestibility, measured at the ileum and faeces (BWF < BWF_f < SSG < SSC) and the amount of water in the digesta and faeces. This suggests that the more digestible a diet is, the less water is required for its digestion and absorption (cf. Table 6 showing DM concentrations in digesta and faeces increasing in the order BWF < BWF_f < SSG < SSC, except for diet SSG in the ileum). It might be expected that the water content of digesta would be maintained at a level providing uniform osmolarity but in fact the purified diets had a higher content of solutes which would be osmotically active (sucrose and free salts) than diet BWF; the minerals secreted into the digesta also complicate this situation. The fibre nature and content of the diets are a further factor known to influence the water content of digesta (Cooper & Tyler, 1959*a*,*b*,*c*; Farrell & Johnson, 1970). The acid-detergent fibre contents of diets BWF, SSG and SSC were 72, 98 and 30 g/kg respectively; the higher level for diet BWF than for diet SSC may account for the differences in the amounts of water in the digesta from these diets. It should be noted that diet BWF contained a mixture of hemicelluloses and cellulose, while diets SSG and SSC contained added purified cellulose only. A high proportion of the fibre fraction of groundnut is lignin in nature ((US) National Research Council, 1969); this is known not to bind water to an appreciable extent (McConnell, Eastwood & Mitchell, 1974), and may be a factor influencing the lower water content of digesta with diet SSG than with diet BWF.

It was found that the water content of faeces was approximately 13 % less with diet BWF_f than with diet BWF. Similarly, McConnell *et al.* (1974) found that find grinding of bran reduced its water-binding capacity by nearly 40 %. These observations indicate that diet particle size may have an important influence on the amount of water contained in the digestive tract.

The authors gratefully acknowledge the advice given by Dr R. Braude during the course of this work, the help of Dr H. L. Buttle who performed the surgical procedures involved in cannulation, and the assistance given by Mrs Rosemary Fulford in statistical analyses.

REFERENCES

Ash, R. W. (1962). *Anim. Prod.* **4**, 309.
Barber, R. S., Braude, R., Mitchell, K. G. & Pittman, R. J. (1972). *Anim. Prod.* **14**, 199.
Braude, R., Fulford, R. J. & Low, A. G. (1976). *Br. J. Nutr.* **36**, 497.
Cooper, P. H. & Tyler, C. (1959*a*). *J. agric. Sci., Camb.* **52**, 332.
Cooper, P. H. & Tyler, C. (1959*b*). *J. agric. Sci., Camb.* **52**, 340.
Cooper, P. H. & Tyler, C. (1959*c*). *J. agric. Sci., Camb.* **52**, 348.
Evseeva, Z. I. (1953). In *The Nutritional Physiology of Farm Animals* [A. D. Sineshchekov, editor]. Original in Russian. Translation, 1963. Boston Spa: National Lending Library.
Farrell, D. J. & Johnson, K. A. (1970). *Anim. Prod.* **14**, 209.
Horszczaruk, F. (1971*a*). *Biul. Inst. Genet. Hodow. Zwierz. pol. Akad. Nauk.* no. 21, p. 101.
Horszczaruk, F. (1971*b*). *Biul. Inst. Genet. Hodow. Zwierz. pol. Akad. Nauk.* no. 21, p. 117.
Horszczaruk, F. (1971*c*). *Biul. Inst. Genet. Hodow. Zwierz. pol. Akad. Nauk.* no. 21, p. 137.
Kvasnitskii, A. V. (1951). *Voprosy Fiziologii Pischevarenija u Svinei.* Moscow: Sel'Khozgiz (Translated by D. E. Kidder).
Laplace, J.-P. (1972). *Annls Zootech.* **21**, 83.
Low, A. G. (1976). *Proc. Nutr. Soc.* **35**, 57.
McConnell, A. A., Eastwood, M. A. & Mitchell, W. D. (1974). *J. Sci. Fd Agric.* **25**, 1457.

National Research Council (1969). *Publs natn. Res. Coun., Wash.* no. 1684.
Partridge, I. G. (1978). *Br. J. Nutr.* **39**, 527.
Zebrowska, T. (1973). *Roczn. Nauk. roln.* **95B**, 115.
Zebrowska, T. & Buraczewska, L. (1972). *Roczn. Nauk. roln.* **94B**, 81.
Zebrowska, T., Buraczewska, L., Buraczewski, S. & Horszczaruk, F. (1975). *Roczn. Nauk. roln.* **96B**, 79.

Printed in Great Britain