Effect of dietary nitrogen source on carbohydrate metabolism in the rumen of the young steer

By A. B. McALLAN and R. H. SMITH

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

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1. Steers, fitted with simple rumen and duodenal cannulas, were given diets of approximately equal parts of flaked maize and hay (A) (containing 16 g nitrogen/kg dry matter (DM)) or diets of flaked maize and straw supplemented with decorticated groundnut meal (B), fish meal (C), or heated (D) or unheated (E) soya-bean meal (containing 24 g N/kg DM). Chromic oxide was given as a marker with the feeds, and flows of different combined sugars at the duodenum estimated from the values for sugars: marker at this site. Contributions of bacterial constituents to these flows were estimated from amounts of RNA present.

2. Rumen bacteria from steers receiving diet A contained approximately 110 g α-dextran-glucose/kg DM and contributed about 60 g α-dextran-glucose/d at the duodenum; bacteria from steers receiving diets B, C, D or E contained 25–40 g α-dextran-glucose/kg DM and contributed about 20–30 g α-dextran-glucose/d at the duodenum. There were no significant differences between different N supplements. About half the α-dextran-glucose, varying amounts of the mannose and galactose, and nearly all the rhamnose and ribose in duodenal digesta were contributed by the bacteria. Almost all the arabinose, xylose and cellulose-glucose was of dietary origin.

3. For steers receiving diet A, mean coefficients of digestibility between mouth and duodenum, corrected where necessary for bacterial contribution, were 0·96, 0·73, 0·58, 0·22 and 0·53 for starch-glucose, galactose, arabinose, xylose and cellulose-glucose respectively. Corresponding mean values when diets B, C, D and E were given, which did not differ significantly amongst themselves, were 0·98, 0·79, 0·81, 0·59 and 0·58. Most values for galactose, arabinose and xylose were significantly higher than the diet A values.

There is considerable published information on apparent digestibilities of starch and fibre between the mouth and duodenum of the ruminant (e.g. MacRae & Armstrong, 1969; Thivend & Journet, 1970; Beever, Thomson, Pfeffer & Armstrong, 1971). In some studies (Jarrige & Minson, 1964; Bailey & MacRae, 1970; Gaillard & van't Klooster, 1973) cellulose and hemicellulose fractions, generally separated by taking advantage of solubility differences, have been studied individually and have usually been found to have similar digestibilities. There is some indication that the different monosaccharide constituents of the dietary hemicelluloses may be degraded to different extents (Bailey, 1967) but there is little information on such differences. There is also very little information on the ways in which digestibilities of individual constituents of the various dietary polysaccharides respond to variations in diet composition.

Interpretation of results for some constituents may be rendered difficult by uncertainty about the extent of the contribution of microbial matter to duodenal digesta. Most reported digestibilities for starch, for example, are expressed as net values and it is generally considered that the bacterial contribution is negligible. Studies with animals given all-roughage diets support this view. Thus, for example, Heald (1951) and Porter & Singleton (1971) found the amounts of microbial starch entering the small intestines of ruminants given such diets to be less than 6 g/d, and similar values

Table 1. *Daily amounts* (kg) of the components of cereal–roughage-based diets given to steers weighing 136–158 kg, together with total nitrogen and metabolizable energy* (ME) *contents*

Component	Diet A	B	C	D	E
Barley straw	—	1·50	1·50	1·50	1·50
Hay	1·50	—	—	—	—
Flaked maize	1·56	1·30	1·30	1·30	1·30
Decorticated groundnut meal	—	0·64	—	—	—
White fish meal	—	—	0·56	—	—
Heated soya-bean meal†	—	—	—	0·61	—
Unheated soya-bean meal†	—	—	—	—	0·61
Total N (g/kg DM)	16	24	24	24	24
ME (MJ/kg DM)	11·3	10·4	10·3	10·5	10·5

* These amounts were increased or decreased by about 120 g/kg for each 20 kg difference in live weight.

† The preparation of the heated soya-bean meal included a commercial toasting whereas the unheated soya-bean meal was isolated with the minimum amount of heating.

were estimated by Thompson & Hobson (1971) from in vitro findings. However, for animals receiving large amounts of concentrates, Thompson & Hobson (1971) concluded that microbial starch could be expected to contribute as much as 25 g/d. More recently, McAllan & Smith (1974) estimated the contribution of microbial carbohydrates to total carbohydrates entering the duodenum of protozoa-free calves and calculated that for calves (approximately 160 kg body-weight) receiving diets containing 0·5–0·9 g concentrates/g intake, up to about 100 g bacterial α-dextran-glucose/d entered the duodenum.

The present study was undertaken to study the contribution of bacterial carbohydrates to duodenal carbohydrates and at the same time to determine the true digestibilities of the different combined dietary monosaccharides between mouth and duodenum. Comparisons were made between diets supplemented with different nitrogen sources and a diet providing a lower N intake.

MATERIALS AND METHODS

Animals and diets

Three Friesian steers, aged 34–52 weeks and weighing 127–195 kg, were used in the experiments. They had been fitted with rumen cannulas and simple duodenal cannulas at 13–18 weeks as described by Smith & McAllan (1970). The steers all received initially either a basal diet of flaked maize and hay containing 16 g N/kg dry matter (DM) (diet A, Table 1) or one of the four diets (diets B–E) given in Table 1, consisting of flaked maize, straw and a supplementary protein source (decorticated groundnut meal, fish meal, unheated or heated soya-bean meal, respectively), and containing 24 g N/kg (DM). Diets were each given for a period of 24 d and in the following sequences: steer no. 1, A, E, C, D, B, A; steer no. 2, A, C, E, D, B, A; steer no. 3, A, C, D, B, E (this steer lost its duodenal cannula before diet A could be

repeated). The concentrate part of the diet was given in two equal portions at 09.00 and 17.00 hours and the roughage part was provided at 17.00 hours only. Shredded paper impregnated with chromic oxide was introduced into the rumen at each feed, at a rate of 0·85 g Cr_2O_3/kg DM intake, throughout the experimental period.

Digesta collection

Samples of rumen and duodenal digesta were collected as described by Smith & McAllan (1970), on days 22 and 24 of each experimental period from each steer. Mixed bacteria were separated by the procedure of Smith & McAllan (1974) from rumen digesta taken 4 h after the morning feed. Duodenal digesta samples were taken immediately before the morning feed and at 2 h intervals up to 8 h, or in some experiments 24 h after that feed.

Analytical methods

Rhamnose, ribose, mannose, arabinose, galactose, xylose and α-dextran-glucose were determined by ion-exchange chromatography of their borate complexes as described by Smith & McAllan (1971) in acid-hydrolysates (0·5 M-sulphuric acid) of mixed rumen bacteria, duodenal digesta and dietary components prepared as described by McAllan & Smith (1974). Cellulose-glucose was estimated after more stringent acid-hydrolysis of the residue from the first hydrolysis, according to the procedure of McAllan & Smith (1974). RNA was determined by the procedure of McAllan & Smith (1969).

Chromium was estimated by the method described by Williams & Smith (1974).

RESULTS

Carbohydrate composition of dietary components and mixed rumen bacteria

Values given in Tables 2 and 3 are the amounts of sugars released by acid-hydrolysis from samples of dietary components and mixed rumen bacteria respectively. For bacterial samples from steers receiving diet A the mean amount of α-dextran-glucose was 113 g/kg DM. For the protein-supplemented diets B, C, D and E the amount varied from 25 to 40 g/kg DM. Differences between the different protein sources were not significant but all values were significantly lower ($P < 0·01$) than that for diet A. Amounts (g/kg DM) of the other sugars in the bacterial samples indicated no significant differences related to diet. Arabinose and xylose were generally present in amounts less than 3 g/kg DM and may have represented slight contamination with food material. Cellulose-glucose estimations were also carried out on a few samples for each diet but, as was found in earlier studies (McAllan & Smith, 1974) the amounts present were less than 0·5 g/kg DM and were probably also due to food contamination.

Contribution of bacterial carbohydrates to total carbohydrate entering the duodenum

Estimates were made of the concentration of bacterial carbohydrates in duodenal digesta of the steers by measuring (*a*) the ratio, RNA:carbohydrate for samples of mixed bacteria, and assuming this to be representative of the bacteria passing to the

Table 2. *Carbohydrate composition (g/kg dry matter) of components of cereal–roughage-based diets given to steers*

(Amounts of sugars released by acid-hydrolysis with 0·5 M-sulphuric acid (ribose, mannose, arabinose, galactose, xylose and α-dextran-glucose) or 13 M-sulphuric acid (cellulose-glucose). Results are mean values with their standard errors)

Component*	No. of samples	Ribose		Mannose		Arabinose		Galactose		Xylose		α-Dextran-glucose		Cellulose-glucose		Total carbohydrate	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Barley Straw	8	nd		1·4	0·1	33·8	2·6	11·2	1·3	141	6·8	20·8	1·9	317	11·3	525	47·6
Hay	4	nd		1·3	0·1	36·3	2·9	20·2	2·1	103	2·5	40·6	3·0	262	9·3	464	37·2
Flaked maize	10	nd		tr		23·8	1·7	26·1	1·9	24·9	1·0	720	31·3	14·8	1·5	810	42·1
Fish meal	2	0·8	0·1	0·6	0·1	0·3	0·0	1·3	0·2	0·2	0·0	2·3	0·3	1·7	0·1	7·2	0·2
Decorticated groundnut meal	3	1·3	0·2	1·2	0·3	36·1	2·3	16·9	1·1	15·9	1·5	91·6	3·8	48·5	2·7	212	6·3
Soya bean meal	2	nd		4·5	0·2	31·4	0·6	63·9	1·2	9·4	1·2	47·6	0·9	8·5	0·3	165	1·3

nd, Not determined; tr, trace. * For details, see Table 1.

Table 3. *Carbohydrate composition and RNA content (g/kg dry bacterial cells) of mixed rumen bacteria from steers receiving cereal–roughage-based diets with various protein supplements*

Amounts of sugars released by acid-hydrolysis in 0·5 M-sulphuric acid for 4 h at 105°, from samples of mixed bacteria separated from rumen digesta of steers collected 4 h after feeding. Results are given as between-animal mean values with their standard errors; for supplemented diets, mean values are derived from three individual animal means each from two experiments; for supplemented diets, the mean value for one steer is derived from the mean of two experiments and mean values for two steers are derived from the means of four experiments)

Diet‡	Supplement	Nitrogen intake (g/kg dry matter)	Rhamnose		Ribose		Mannose		Arabinose		Galactose		Xylose		α-Dextran-glucose		RNA	
			Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
A	None	16	9·4	1·8	11·1	2·3	4·9	0·9	2·3	0·4	9·1	0·9	2·2	0·6	113***	8·8	28·1	4·0
B	Decorticated groundnut meal	24	8·8	2·4	13·6	0·5	1·8	0·2	1·8	0·1	6·9	0·3	2·7	0·6	33·1	3·8	38·1	1·6
C	Fish meal	24	4·8	0·8	17·7	2·1	2·7	1·2	2·5	0·3	5·9	0·2	2·2	0·6	25·7	6·1	44·1	3·4
D	Heated soya-bean meal	24	6·2	1·1	15·6	2·0	2·4	0·3	2·6	0·6	7·4	0·6	2·5	0·6	39·2	9·1	34·0	3·9
E	Unheated soya-bean meal	24	9·4	3·0	12·1	2·0	2·8	0·5	2·1	0·2	7·9	1·2	1·8	0·2	29·8	6·7	33·8	3·7

Value significantly different from those for protein-supplemented diets: *** $P < 0·01$.
‡ For details of diets, see Table 1.

Table 4. *Estimated contribution of bacterial carbohydrates to total carbohydrates (g/g) entering the duodenum of steers receiving cereal–roughage-based diets with various protein supplements*

(Results were calculated from values for carbohydrate: RNA in samples of mixed bacteria separated from digesta taken 4 h after feeding, and in whole duodenal digesta taken 2 h later, and are given as between-animal mean values with their standard errors, mean values are derived from three individual animal means each from two experiments)

Diet*	Supplement	Rhamnose		Ribose	Mannose		Arabinose		Galactose		Xylose		α-Dextran-glucose	
		Mean	SE		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
A	None	0·97	0·17	nd	0·84	0·17	0·04	0·01	0·30	0·05	0·08	0·01	0·58	0·06
B	Decorticated groundnut meal	0·90	0·27	1·03‡	0·40	0·06	0·04	0·02	0·25	0·06	0·01	0·01	0·50	0·09
C	Fish meal	0·94‡		0·93‡	0·44	0·06	0·06	0·02	0·25	0·02	0·01	0·01	0·49	0·07
D	Heated soya-bean meal	1·00	0·09	1·21‡	0·51	0·26	0·11	0·03	0·51	0·07	0·02	0·01	0·50	0·09
E	Unheated soya-bean meal	1·18	0·21	1·16‡	0·84	0·02	0·08	0·02	0·48	0·11	0·02	0·01	0·58	0·08

nd. Not determined. * For details, see Table 1. ‡ Value from one steer only.

Table 5. *Comparison of total 24 h duodenal flows of carbohydrates (g/24 h) estimated over different sampling periods, and daily intakes of metabolizable energy (ME) for one steer receiving cereal–roughage-based diets with various protein supplements*

(Results were calculated from values for carbohydrate: chromic oxide in spot samples of duodenal digesta taken at 2-h intervals, after feeding, for 24 h, and known daily intakes of Cr_2O_3, and are given as mean values with their standard errors for 8 h (five samples) and 24 h (twelve samples))

Diet* ...	A				B				C			
Period of sampling (h) ...	8		24		8		24		8		24	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Arabinose	17·9	2·0	18·3	1·0	22·4	2·0	19·7	1·3	28·9	4·8	30·2	0·6
Galactose	11·3	1·5	11·8	0·7	13·2	0·7	12·1	0·8	17·3	2·9	17·2	1·1
Xylose	219·7	7·0	223·1	6·6	117·2	9·1	106·9	4·8	176·7	30·5	178·3	11·3
α-Dextran-glucose	74·2	5·5	77·7	4·4	38·3	1·4	39·5	2·3	54·8	10·4	59·3	5·6
Cellulose-glucose	223·7	13·9	221·5	5·8	163·7	9·4	172·6	9·4	225·3	29·9	234·2	16·1
ME intake (MJ/d)	42·5				41·0				41·2			

Diet* ...	D				E			
Period of sampling (h) ...	8		24		8		24	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Arabinose	23·8	3·0	25·1	1·8	25·6	3·9	27·8	2·1
Galactose	19·7	1·9	21·1	1·6	15·3	1·8	16·5	1·0
Xylose	119·9	20·0	127·6	11·4	145·0	21·0	146·8	10·6
α-Dextran-glucose	68·0	6·2	68·1	3·9	46·3	11·6	47·8	4·9
Cellulose-glucose	243·8	21·1	228·6	32·1	211·9	7·3	249·9	7·8
ME intake (MJ/d)	43·0				38·9			

* For details, see Table 1.

duodenum; (*b*) the concentration of RNA in digesta at the duodenum, and assuming this to be derived only from the rumen bacteria (McAllan & Smith, 1974). It appeared from results given in Table 4 that all the rhamnose and ribose and much of the mannose came from the bacteria together with up to half the galactose and at least half the α-dextran-glucose, while almost all the xylose, arabinose and cellulose-glucose was of dietary origin. There were no significant differences in estimated proportions provided by bacteria between the different diets for any of the carbohydrates studied.

Carbohydrate flow at the duodenum

Estimates of the total amounts of different carbohydrate components entering the duodenum in 24 h were obtained from the value for carbohydrate component: Cr_2O_3 for a number of duodenal samples, and the known 24 h intake for Cr_2O_3. For the experiments in which samples were taken at 2 h intervals over a whole 24 h period it can be assumed that the mean value obtained for carbohydrate component: Cr_2O_3 would be reasonably representative of that for the total flow. The results given in Table 5 for one steer indicate that values based on a mean value for the ratio for samples taken over 8 h periods were nearly identical to those based on 24 h collection periods. Similar results were obtained in six further experiments with the other two steers for all diets used. Many experiments were carried out, therefore, with only 8 h collections and results reported in Table 6 were obtained in this way. In Table 6 estimates have been made (from estimates of proportions of bacterial carbohydrate components obtained as described previously) of the amount of the flow of various carbohydrates at the duodenum which were of bacterial origin and, by difference, of dietary origin. From the latter, corrected values for rumen digestibilities of the different components were calculated.

Appreciable amounts of α-dextran-glucose of bacterial origin entered the duodenum of steers receiving the unsupplemented diet (diet A). Amounts were significantly less for the diets containing protein supplements (diets B–E) but there were no significant differences between protein sources. The amounts of other bacterial carbohydrates entering the duodenum were small and no significant differences, related to diet, were found.

Calculated amounts of residual dietary α-dextran-glucose, galactose, arabinose and xylose entering the duodenum in 24 h (Table 6), were usually significantly greater for diet A than for diets B–E (Table 6) although intakes of galactose, arabinose and xylose were generally less for diet A. For these latter sugars differences must therefore have reflected lower rumen digestibilities when diet A was given. Values for apparent and true (i.e. those corrected for microbial contribution, where necessary) digestibilities are also given in Table 6. Cellulose-glucose differed from the hemicellulose components, xylose and arabinose, as there were no appreciable differences in its digestibility in the rumen between the protein-supplemented diets and diet A.

Table 6. *Daily intakes (g/d), duodenal flows (g/d) and rumen digestibilities (g/g intake) of dietary carbohydrates, together with the relative contributions and absolute amounts of microbial carbohydrates at the duodenum for steers receiving cereal–roughage-based diets with various protein supplements*

(Mean values with their standard errors for three steers, unless otherwise stated)

Diet	A		B		C		D		E	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
α-Dextran-glucose										
Intake	1022	66	1082	26	900	35	989	53	949	63
Duodenal flow:										
Food residue	45	5·8	21***	3·1	24***	4·8	28*	9·0	24***	3·7
Microbial	62	9·0	21**	3·7	23**	6·2	28*	7·1	33*	4·2
Digestibility in rumen:										
Apparent	0·90	0·02	0·96*	0·02	0·95	0·01	0·94	0·01	0·94	0·02
True‡	0·96	0·01	0·98	0·01	0·97	0·01	0·98	0·00	0·97	0·00
Galactose										
Intake	52	6·1	58	2·3	51	1·7	83	5·0	75	7·0
Duodenal flow:										
Food residue	14·2	2·2	9·0*	1·7	10·2	1·4	6·9***	2·0	7·9**	1·7
Microbial	6·1	0·8	3·0	0·4	3·4	0·3	7·2	1·3	7·3	1·2
Digestibility in rumen:										
Apparent	0·61	0·05	0·80*	0·03	0·74	0·03	0·83**	0·02	0·80*	0·02
True‡	0·73	0·04	0·84	0·03	0·81	0·02	0·92**	0·01	0·89**	0·02
Arabinose										
Intake	77	7·8	111	3·4	75	2·9	100	6·2	94	7·9
Duodenal flow:										
Food residue	32	3·7	19**	2·0	17**	1·4	18**	2·4	18**	1·8
Microbial	All values negligible (< 2 % of total)									
Digestibility in rumen:										
True‡	0·58	0·05	0·83***	0·02	0·77*	0·02	0·82**	0·02	0·81*	0·02
Xylose										
Intake	164	18	269	9	221	11	245	16	234	19
Duodenal flow:										
Food residue	126	13	105**	12	96*	7	99*	4	100	12
Microbial	All values negligible (< 2 % of total)									

Table 6 (*cont.*)

	A		B		C		D		E	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Digestibility in rumen:										
True‡	0·22	0·08	0·61**	0·05	0·56**	0·03	0·60**	0·02	0·57*	0·05
Cellulose-glucose										
Intake	343	38	553	17	446	22	487	33	465	38
Duodenal flow:										
Food residue	161	14	208**	9·2	187	11	219	33	206	22
Microbial	All values negligible (< 2 % of total)									
Digestibility in rumen:										
True‡	0·53	0·03	0·62	0·02	0·58	0·04	0·55	0·07	0·56	0·04
Mannose										
Intake	3·0	0·3	3·9	0·1	2·9	0·1	5·7	0·3	5·0	0·5
Duodenal flow:										
Food residue	3·5	0·3	3·2	0·2	2·7	0·2	2·1	0·1	3·9	0·3
Microbial	2·3	0·3	1·2	0·4	1·3	0·4	1·6	0·1	2·5	0·7
Digestibility in rumen:										
Apparent	−0·16	0·05	0·18	0·03	0·07	0·03	0·63	0·04	0·22	0·04
True‡	0·59	0·04	0·57	0·05	0·53	0·04	0·91	0·09	0·72	0·11
Ribose										
Intake	< 0·5									
Duodenal flow:										
Microbial	4·6§		3·8§		3·7§		4·9§		4·5§	
Rhamnose										
Intake	< 0·2									
Duodenal flow:										
Microbial	6·8	1·1	3·2*	0·6	3·8§		3·3*	0·1	5·2	0·3

Values significantly different from that for diet A: $*P<0·05$, $**$ $P < 0·02$, $***$ $P < 0·01$. †For details, see Table 1.
‡ Corrected for microbial contributions. § Value from one steer only.

DISCUSSION

It was found previously (McAllan & Smith, 1974) that relatively large amounts of α-dextran accumulated in mixed rumen bacteria when young steers received a low N intake. It seems probable that such accumulation occurs when excess energy is available to the bacteria and their growth is limited by the intake of degradable N (Walker & Nader, 1970). If it is assumed that the mean degradability of the protein in flaked maize and hay is about 70% (Smith & McAllan, unpublished results) and the N requirement for maximum microbial growth is 1·66 g/MJ metabolizable energy (Miller, 1973), then it can be calculated that microbial growth in the rumens of steers receiving diet A would be markedly N-limited. The fact that all the protein-supplemented diets led to rumen bacteria with lower α-dextran contents than did diet A indicated that all probably provided adequate supplements of degradable N for microbial growth. Such a decrease in the α-dextran-glucose content of rumen bacteria was not found in another similar experiment in which formaldehyde-treated casein formed the protein supplement (Williams, McAllan & Smith, 1973). The finding that a fish-meal supplement produced effects similar to those obtained with supplements of decorticated groundnut meal or soya-bean meals is consistent with our findings (McAllan & Smith, unpublished results) based on RNA and α,ε-diaminopimelic acid flows at the duodenum, indicating that this sample of fish meal was extensively (about 70%) degraded in the rumen of the steer. This was in apparent disagreement with reports that fish-meal is very resistant to degradation in the rumen of sheep (Miller, 1974), possibly because of animal differences or because different types of fish meal were used.

The method used to estimate microbial contributions to carbohydrates in duodenal digesta, based on measurements of RNA as a reference material in bacteria and digesta samples, was described previously and its validity discussed (McAllan & Smith, 1974). The presence of protozoa in the rumens of steers used in the present experiments may have affected the amounts of RNA and carbohydrate components at the duodenum to some extent but the effects were probably small as protozoal counts were generally low (37000–140000 counts/ml rumen fluid). Calculated contributions of microbial α-dextran-glucose and galactose at the duodenum for diet A were, in fact, closely similar to those found previously for protozoa-free calves receiving similar diets (McAllan & Smith, 1974). Thus, although the present estimates of bacterial carbohydrates entering the duodenum cannot be expected to be highly accurate, because bacterial preparations obtained from rumen fluid are unlikely to represent exactly the bacteria passing to the duodenum, it appears that they should be approximately correct.

Present findings supported earlier findings (Thompson & Hobson, 1971; McAllan & Smith, 1974) indicating that bacterial components may sometimes make a considerable contribution to the α-linked glucose polymers and galactose-containing polymers entering the duodenum of the ruminant. The present results agree with other reports for diets containing considerable amounts of most types of cereals (Armstrong, 1974) that apparent digestibilities of starch between

mouth and duodenum are high even for fairly low N intakes (Ørskov, Fraser & McDonald, 1971) but they also indicate that true digestibilities are even higher.

Differences in digestibilities of cellulose and hemicellulose constituents between mouth and duodenum for steers given diet A and the protein-supplemented diets were probably influenced in part by the inclusion of hay in diet A and straw in the protein-supplemented diets. However, supplementing low-N diets with a N source has been found to lead to increased fibre (Campling, Freer & Balch, 1962) and cellulose digestion (Ammerman, Verde, Moore, Burns & Chicco, 1972; Winter & Pigden, 1971) between mouth and duodenum, and many of the differences in digestibilities found in the present studies were probably due to differences in N intake.

Published values for digestibilities, up to the duodenum, of dietary cellulose and hemicellulose containing fractions (e.g. Balwani, Johnson & Dehority, 1969; MacRae & Armstrong, 1969; Gaillard & van't Klooster, 1973) have generally been found to be broadly similar to the values found in the present studies (assuming the sum of galactose, arabinose and xylose digestibilities to represent hemicellulose digestibility). There are, however, few published values for relative digestibilities of the individual monosaccharide components of these carbohydrates up to the duodenum, although Bailey (1967) reported that the arabinose and galactose in dietary hemicelluloses were degraded in the rumen more rapidly than the xylose. The present findings (Table 6) indicated that for steers given diet A the digestibilities of individual monosaccharide components differed considerably and decreased in the order: galactose, arabinose, cellulose-glucose, xylose. Digestibilities in animals transferred from diet A to the protein supplemented diets (which did not differ significantly amongst themselves) increased but to greatly differing extents so that, for example, digestibilities of xylose more than doubled while that of cellulose-glucose increased only slightly.

Fermentation of starch provided the greatest amount of energy for the rumen bacteria on all diets. It is known that under these circumstances digestion of celluloses and hemicelluloses may be reduced (MacRae & Armstrong, 1969; Thivend & Journet, 1970) but they were nevertheless fermented to considerable extents. In absolute terms, amounts (g/d) of galactose, arabinose, xylose and cellulose-glucose fermented by the rumen bacteria were 38, 45, 38 and 182 respectively for diet A and as an average 58, 77, 142 and 283 for the protein-supplemented diets. Thus not only the total energy but the relative amounts of monosaccharides providing that energy differed for the two types of diet. Different monosaccharides may be used with differing efficiencies in providing energy for the synthesis of bacterial protein or other organic matter (Henderickx, Demeyer & Van Nevel, 1972), so such variations may lead to differences in the extent of bacterial growth in the rumen supported by a particular energy expenditure.

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