Utilization of low-quality roughages; effects of supplementing with casein treated or untreated with formaldehyde on digesta flows, intake and growth rate of cattle eating wheat straw

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1. Expt 1. Forty 200 kg heifers were given wheat straw *ad lib.* plus one of five pelleted supplements, each of which supplied 40 g/nitrogen as urea/d. Treatment A did not supply other sources of N, and other treatments supplied daily 40 g digestible N as casein and formaldehyde-treated casein (HCHO-casein) in the following proportions (w/w): 100:0 (B), 70:30 (C), 30:70 (D), 0:100 (E). After 5 weeks (period 1) all supplements were withdrawn from half (four) of the animals in each treatment group (NS) over a period of 8 weeks (period 2). At the end of period 2, N balances were measured in four animals on each of treatments E and NS.

In period 1 the mean intake of straw by animals on treatments D and E was higher than the mean intake by animals on treatments A, B and C (3·32 *v.* 2·83 kg/d respectively; $P < 0·01$) and live-weight changes also differed significantly (+72 and −126 g/d respectively; $P < 0·01$). Intakes of straw in period 2 were 3·74 and 3·20 kg/d for animals with and without supplements respectively ($P < 0·01$) and live-weight changes were +110 and −157 g/d on the respective treatments ($P < 0·01$). For animals receiving supplements in period 2, intakes of straw did not differ significantly between supplements; live-weight changes were −14 g/d on treatment A and +141 g/d on treatments B, C, D and E ($P < 0·01$).

N balances on treatments E and NS were +11·4 and −3·3 g/d respectively ($P < 0·01$), although digestibility of organic matter (OM) was similar on the two treatments.

2. Expt 2. Four 185 kg steers with rumen and abomasal cannulas were given wheat straw *ad lib.* plus one each of treatments A, B and E in a randomized block sequence. Dry matter (DM) intakes were 3·44, 3·89 and 4·05 kg/d on treatments A, B and E respectively ($P < 0·05$). N intakes were 29 and 37 g/d higher on treatments B and E respectively than on treatment A, but abomasal flows of N were only 4 and 14 g/d higher on the respective treatments. The latter value indicates that approximately 0·62 of HCHO-casein was degraded in the rumen. Efficiencies of bacterial protein synthesis were 31, 24 and 26 g bacterial N/kg OM apparently digested in the rumen ($P > 0·05$) on treatments A, B and E respectively.

3. It was concluded that efficiency of bacterial protein synthesis in the rumen was not limited by the supply of peptides and amino acids, and that protein supplements do not consistently stimulate intake of low-quality roughages when requirements for rumen degradable N have been met. Higher flows of N to the intestines when HCHO-casein, and to a lesser extent casein, were given were associated with a shift from negative to positive live-weight changes. These live-weight changes were not significantly correlated with DM intakes from which it appears that effects of casein supplements on live weight may have been attributable to effects of absorbed amino acids on efficiency of tissue protein synthesis either directly or through gluconeogenesis.

Food intake by ruminants is regulated by physical and metabolic factors. Although physical factors appear to predominate with forages of low digestibility and metabolic factors with forages of high digestibility (Conrad *et al.* 1964), it has been suggested that there may be a mechanism of interacting physical and metabolic factors throughout the whole range of diets utilized by ruminants (Egan, 1970). This suggestion was based on observations that post-rumen infusions of casein increased intake of oaten hay by increasing gut fill, which implied some metabolic control of gut capacity. However, intake of oaten hay was increased much more when casein was sprayed onto the diet than when it was infused into the duodenum which may be attributable to the provision of ammonia or peptides or both in the rumen. Intake responses to post-rumen infusions of casein were reported to be +11% for six low-quality forages (Egan, 1977). It is possible that much of this response was attributable to nitrogen recycling to the rumen, which could have been supplied with a dietary supplement of urea.

Table 1. *Expts 1 and 2. Components (g/kg air dry) and chemical composition (g/kg dry matter (DM)) of five pelleted supplements given with wheat straw to cattle together with daily amounts given in the respective experiments*

	Supplements				
	Control	Casein + HCHO-casein (w/w)			
		100:0	70:30	30:70	0:100
Treatment...	A	B	C	D	E
Components					
Molasses	365	365	356	346	338
Wheat chaff	177	177	173	168	164
Maize flour	335	—	—	—	—
Casein	—	335	230	95	—
HCHO-casein	—	—	121	274	383
Urea	113	113	110	107	105
NaCl	10	10	10	10	10
DM	985	985	983	985	994
Chemical composition					
Nitrogen	57·1	110·6	113·4	112·6	117·5
Ash	188	171	—	—	165
Lignin	17	19	—	—	20
Acid-detergent fibre	98	104	—	—	110
Amounts fed daily (g air-dry)					
Expt 1	746	746	762	787	804
Expt 2	597	597	—	—	643

In an earlier experiment it was found that intake of oaten chaff was increased 23% by giving N supplements in the form of urea, casein or formaldehyde-treated casein (HCHO-casein) (Redman *et al.* 1980). In the present experiment, responses to soluble protein (casein) and rumen undegraded protein (HCHO-casein) were determined with cattle given wheat straw plus sufficient urea to supply likely requirements for microbial growth in the rumen. A preliminary account of this work has already been published (Sriskandarajah *et al.* 1980).

EXPERIMENTAL

Expt 1

Animals and management. Forty Hereford heifers aged approximately 18 months, and weighing an average of 209 kg were used. Animals were housed in individual stalls with sawdust bedding and water available *ad lib.* They were allocated to five supplements on a live-weight basis, using restricted randomization. Live weights were recorded weekly and live-weight changes estimated by regressions of live weight *v.* time.

Diets and feeding procedure. The basal diet was chaffed wheat straw (variety 'Gatcha') containing (g/kg dry matter (DM) 5·0 N, 809 neutral-detergent fibre (Goering & Van Soest, 1970), 68 ash and 78 lignin. The composition of the five pelleted supplements is given in Table 1. HCHO-casein was prepared by spraying at the rate of 100g formalin solution supplying 15 g HCHO/kg casein DM.

Degradability of HCHO-casein in vitro was measured by incubating duplicate 0·5 g samples in 40 ml rumen fluid, which was filtered through cloth to remove coarse particles. Tubes, fitted with bunsen valves, were incubated at 37°, under anaerobic conditions, for 24 h. Blank tubes were incubated with rumen fluid only; residue weights in these tubes were

subtracted from residue weights in sample tubes. Degradability of HCHO-casein in vivo was measured by placing unground 6 g samples in nylon bags (180 × 70 mm, 25 pores/mm², 1500 μm² pore area) which were suspended at a depth of 120 mm in the rumen of three sheep eating lucerne chaff *ad lib.* and removed at intervals up to 120 h. Measurements were made on two occasions to give six observations for each of six time intervals. Degradability in vitro and in vivo was measured in terms of DM disappearance. The daily intakes of supplements on treatments B, C, D and E were designed to provide 250 g digestible casein/d on the basis of tests described by Redman *et al.* (1980). Supplement A contained maize flour to make it isoenergetic with the other diets. The amounts offered provided equal daily intakes of molasses, wheat chaff and urea from the five supplements (Table 1).

All animals were offered the basal diet of chaffed wheat straw *ad lib.* and one of the five supplements (treatments A, B, C, D and E), weighed quantities of which were placed on top of the straw each morning. Feed refusals were recorded weekly. After 5 weeks (period 1) the pellet supplements were withdrawn from four animals in each treatment group (treatment NS) for a period of 8 weeks (period 2).

Sampling procedures. During weeks 1, 2, 3, 5 and 8 of period 2, blood samples were collected from the jugular vein of all animals, plasma was separated and stored at −10°. At the end of the experiment, samples of rumen fluid collected from all animals through a stomach tube were filtered, acidified to pH 2 and stored at −10°.

N balance measurements. At the end of period 2, four animals each from treatments E and NS were kept in metabolism crates. Foley catheters were inserted into the bladder to permit separate collections of faeces and urine during 7 d collection periods. Urine was collected in trays containing sufficient 6 M-hydrochloric acid to keep the pH < 2; portions (20 ml/l collected) of daily collections were stored at −10°. Faeces were collected daily and dried at 60° before weighing.

Chemical analyses. Feed and faecal samples were analysed for DM by drying to constant weight at 80° and organic matter (OM) by ashing at 550° overnight. Feed, faeces, urine and HCHO-casein were analysed for N by a micro-Kjeldahl technique. Volatile fatty acids (VFA) in rumen samples were determined by gas–liquid chromatography. Ammonia in rumen samples and urea in plasma samples were determined by the method of Chaney & Marbach (1962).

Expt 2

Animals and management. Four 18-month-old Friesian steers (average live weight 185 kg), fitted with simple cannulas in the rumen and abomasum, were tethered in individual pens with water available *ad lib.* and continuous lighting. Animals were allocated to each of treatments A, B and E (Table 1) according to a randomized block design.

Diets and feeding procedure. The basal wheat straw diet used in Expt 1 was fed *ad lib.* together with one of three supplements (treatments A, B and E) in amounts given in Table 1. The pellet supplements were fed in two equal meals placed on top of the straw at 08.00 and 20.00 hours daily. After 10 d, feed intake was held constant for 7 d, on the last 3 d of which samples of digesta were collected.

Digesta markers and collection procedure. The dual markers used were acid-detergent lignin (Goering & Van Soest, 1970) and the chromium complex of ethylenediaminetetraacetic acid (Cr-EDTA). Cr-EDTA was prepared according to Binnerts *et al.* (1968) and sprayed onto 50 kg batches of wheat straw in a paddle mixer, to give a concentration of 280 mg Cr/kg DM. During 3 d periods abomasal digesta samples were collected at 08.30, 12.30 and 16.30 hours daily and bulked. Digesta samples were stored at −10°.

Sample preparation and chemical analyses. Abomasal samples were centrifuged at 2400 ***g*** for 20 min to obtain liquid-rich fractions; total abomasal samples and the liquid-rich

fractions were analysed for DM, OM and N as in Expt 1, Cr by atomic absorption spectroscopy, acid-detergent lignin by the method of Goering & Van Soest (1970). Total abomasal digesta was analysed for 2,6-diaminopimelic acid (DAPA) by ion-exchange chromatography, following 24 h hydrolysis in 6 M-HCl at 136°. Flows of abomasal digesta were calculated from the concentrations of lignin and Cr using equations nos. 1–3 from Faichney (1975). Proportions of abomasal N present as bacterial N were calculated as mg DAPA/g N in digesta × g N/mg DAPA in bacterial samples. Bacterial samples, isolated from rumen fluid samples collected from steers eating similar wheat straw, contained 42 mg DAPA/g N.

Ling & Buttery (1978) in a comparison of bacterial markers found that the concentration of DAPA in bacterial species showed variation and suggested that estimates of DAPA concentration in appropriate microbial isolates should be undertaken in each study. The mean DAPA concentration (mg DAPA/g bacterial N) in their study was 45·8 and was similar to reported values of 41·0 (Hogan & Weston, 1970), 47·7 (Bird, 1972) and 43·3 (Ulyatt *et al.* 1975) determined in animals given a wide range of diets. Forty-two mg DAPA/g N obtained in the present study in animals fed wheat straw does not differ widely from the above values or the mean of 44·9 obtained in six isolates from steers fed untreated and alkali-treated wheat straw (N. Sriskandarajah, A. C. Dunlop and R. C. Kellaway, unpublished results). It appears that the DAPA concentration in bacteria does not vary widely within a type of diet and, hence, a mean value could be satisfactorily used to estimate microbial protein synthesis, particularly in studies comparing similar diets.

VFA and ammonia in rumen samples were analysed as in Expt 1.

RESULTS

Expt 1

Animals were allowed to adapt to the basal diet and supplements for 10 d before recordings were started. They remained in good health throughout the experiment, with the exception of one animal not eating on treatment NS in period 2, which was removed from the experiment.

In vitro tests on the degradability of HCHO-casein showed that the proportion of DM degraded after 24 h was (mean ± SEM) 0·02 ± 0·035. In vivo tests with HCHO-casein showed that the proportions of DM degraded after 24, 48, 60, 72, 96 and 120 h were (mean ± SEM) −0·01 ± 0·002, 0·06 ± 0·016, 0·12 ± 0·002, 0·37 ± 0·041, 0·65 ± 0·044 and 0·84 ± 0·025 respectively (each value was the mean of six measurements).

Live-weight changes and intakes of wheat straw are given in Fig. 1. During period 1, the mean intake of straw by animals on treatments D and E was significantly higher than the mean intake by animals on treatments A, B and C (3·32 *v.* 2·83 kg/d respectively; $P < 0·01$) and live-weight changes also differed significantly (+72 and −126 g/d respectively; $P < 0·01$). In period 2 intakes of straw by animals which received supplements did not differ between the supplements; live-weight changes were −14 g/d on treatment A and +141 g/d on treatments B, C, D and E ($P < 0·01$).

Intakes of straw by animals with and without supplements in period 2 were 3·74 and 3·20 kg/d respectively ($P < 0·01$) and live-weight changes were +110 and −136 g/d on the respective treatments ($P < 0·01$).

Total VFA concentrations (Table 2) in rumen fluid were lower with supplements containing most HCHO-casein (treatments D and E) and with no supplement (treatment NS) although these differences were not significant ($P > 0·05$). VFA proportions did not differ significantly between treatments although there was a trend towards higher proportions of branched-chain VFA on supplements containing soluble casein (treatments B, C and D).

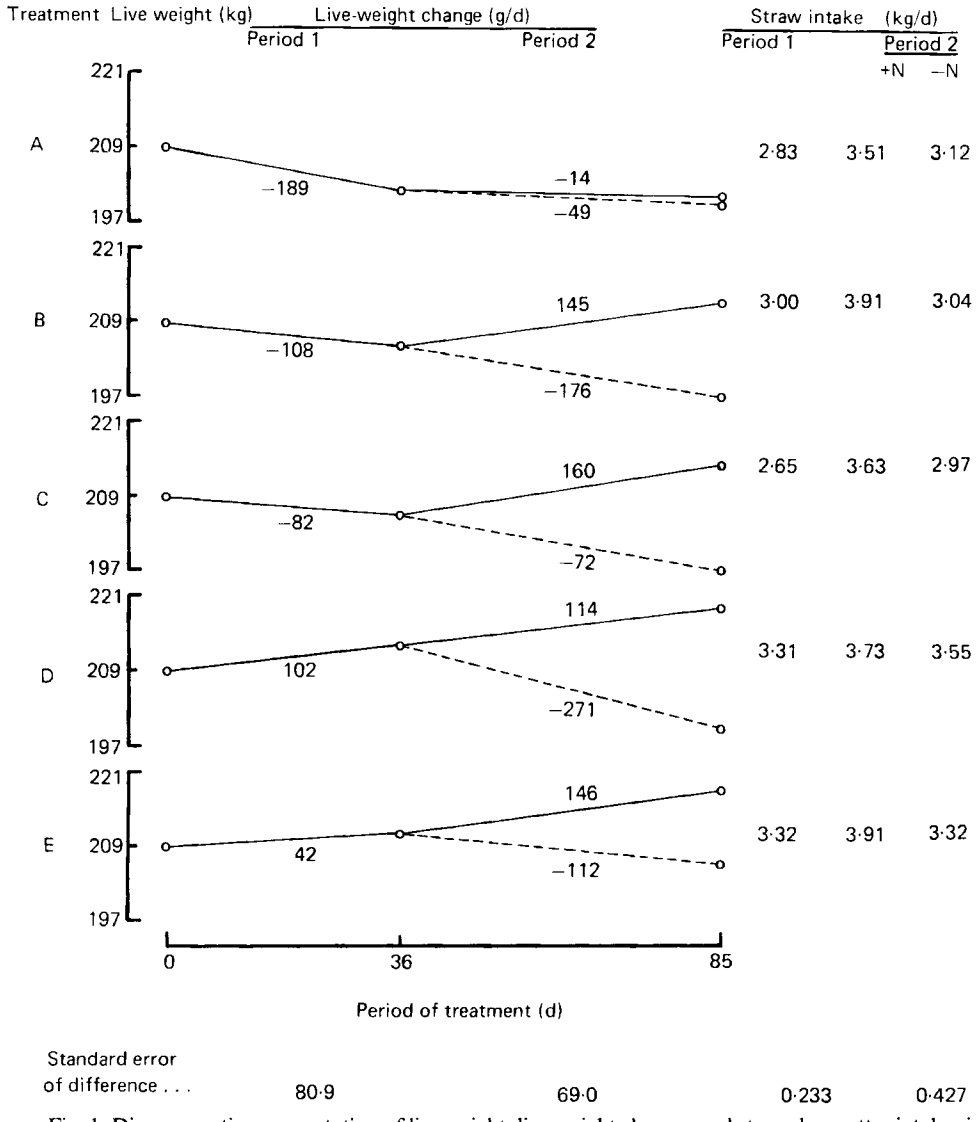

Fig. 1. Diagrammatic representation of live weight, live-weight changes and straw dry matter intakes in heifers given wheat straw with different nitrogen supplements (○——○) (for details, see Table 1) and after withdrawal of these supplements (○---○). Values are means for eight animals per treatment in period 1 and four animals per sub-treatment in period 2.

Rumen ammonia concentrations differed significantly ($P < 0{\cdot}001$) being highest on treatment B, which contained most soluble protein, lower with supplements containing less-soluble protein and least with no supplement in period 2.

In animals which received N supplements during period 2, plasma urea concentrations did not differ between treatments or times (Table 3). In animals from which N supplements were withdrawn at the start of period 2, plasma urea concentrations were much lower than in the other animals 1 week after the supplement was withdrawn and continued to decline slowly during the 8 week period, with the exception of week 4 when values were high in all animals for reasons which were not apparent.

Table 2. *Expt 1. Concentrations of volatile fatty acids (VFA) and ammonia in rumen fluid of heifers eating wheat straw with no supplement (NS) and with supplements**

	Supplements							
	Control	Casein + HCHO-casein (w/w)					Standard error of difference	
		100:0	70:30	30:70	0:100			
Treatment...	A	B	C	D	E	NS	A–E	A–E *v.* NS
Total VFA (mM/l)	46·7	47·9	46·7	36·4	33·8	38·7	7·64	5·92
VFA proportions								
Acetic	0·694	0·699	0·688	0·677	0·712	0·693	0·0241	0·0187
Propionic	0·202	0·197	0·218	0·208	0·198	0·203	0·0179	0·0139
iso-Butyric	0·008	0·010	0·011	0·018	0·008	0·008	0·0023	0·0018
n-Butyric	0·086	0·076	0·087	0·078	0·073	0·084	0·0109	0·0084
iso-Valeric	0·007	0·012	0·011	0·014	0·009	0·008	0·0024	0·0019
n-Valeric	0·003	0·007	0·008	0·007	0·002	0·004	0·0028	0·0021
Ammonia (mM/l)	9·4	13·4	11·1	7·5	7·7	1·2	1·83	1·43

* For details, see Table 1.

Table 3. *Expt 1. Plasma urea levels (mg N/l) of forty heifers eating wheat straw* ad lib. *with or without one of five supplements* in period 2*

						SE of difference	
	Week of treatment					Within treatments	Within treatment
Treatment	1	2	3	4	8	A–E	NS
A	173	155	169	201	149	22·2	7·4
B	212	152	176	225	165		
C	185	175	170	226	160		
D	193	222	236	245	227		
E	201	194	174	211	163		
NS	62	45	43	57	35		

* For details, see Table 1.

Balance measurements (Table 4) were made after animals had been on treatments E and NS for 13 and 8 weeks respectively. Although N concentrations in the diets differed substantially (23 and 5 g/kg DM on treatments E and NS respectively), and N balances differed substantially, OM digestibilities did not differ significantly.

Expt 2

OM intakes on treatments B and E were 13 and 17% higher (Table 5) respectively than on treatment A and abomasal flows of OM were 10 and 13% higher on the respective treatments, although these differences were not significant ($P > 0·05$). N intakes were 29 and 37 g/d higher on treatments B and E respectively than on treatment A ($P < 0·01$), but abomasal flows of N were only 4 and 14 g/d higher on the respective treatments. The latter value indicates that approximately 0·62 ((37–14)/37) of HCHO-casein was degraded in the rumen. Proportions of bacterial N in total N flowing at the abomasum were substantially lower on treatments B and E than on treatment A. Efficiencies of bacterial N synthesis did not differ significantly between treatments ($P > 0·05$).

Table 4. *Expt 1. Intakes of dry matter (DM) and organic matter (OM), OM digestibility and nitrogen balances in heifers eating wheat straw with no supplement (NS) and with a supplement* containing formaldehyde-treated casein (E)*

(Mean values for four heifers/treatment)

	Treatment		
	E	NS	SEM
DM intake (kg/d)	3·45	2·65	0·241
OM intake (kg/d)	3·18	2·48	0·219
OM apparent digestibility	0·49	0·47	0·021
N intake (g/d)	79·5	14·3	9·40
Faeces N (g/d)	20·4	12·5	1·63
Urine N (g/d)	47·8	5·1	6·75
N apparent digestibility	0·74	0·09	0·040
N balance (g/d)	11·4	−3·3	1·41

* For details, see Table 1.

Table 5. *Expt. 2. Intakes and digestion of organic matter (OM) and nitrogen and efficiencies of bacterial N synthesis in steers eating wheat straw plus supplements**

	Supplements			
	Control	Casein + HCHO-casein (w/w)		
Treatment...	A	100:0 B	0:100 E	SEM
Dry matter intake (g/d)	3440	3886	4053	209·2
OM intake (g/d)	3141	3560	3723	193·6
OM flow at abomasum (g/d)	1878	2063	2213	165·5
N intake (g/d)	51	80	88	0·7
N flow at abomasum (g/d)	40	44	54	3·4
Proportion of bacterial N in abomasal N	0·99	0·82	0·76	0·052
Bacterial N flow at abomasum	39	37	41	3·3
Bacterial N (g/kg) OM apparently digested in rumen	31	24	26	2·5
Rumen ammonia (mM/l)	10	18	14	0·3
Total rumen VFA (mM/l)	55·8	63·5	64·2	9·59

* For details, see Table 1. VFA, volatile fatty acids.

DISCUSSION

N supplements and bacterial protein synthesis

The estimate of mean efficiency of bacterial protein synthesis (g bacterial N/kg OM apparently digested in the rumen) was 27 in the present experiment, which was higher than 19 found in an experiment with oaten chaff (Redman *et al.* 1980) and similar to the general value of 30 suggested by Smith *et al.* (1978). High proportions of bacterial N in abomasal N (0·76–0·99) indicate that protozoa made only small contributions to microbial N, probably through sequestration within the rumen (Weller & Pilgrim, 1974). Relatively low concentrations of VFA in the rumen in this study indicate that energy availability in the rumen was low but this did not result in low efficiencies of microbial protein synthesis.

Non-protein-N. An objective in formulating diets for the experiments reported was to make availability of ammonia in the rumen non-limiting for bacterial protein synthesis. Satter & Roffler (1977) found in vitro that the optimum concentration of ammonia was 3·5 mmol/l, after allowing for a small margin of excess. In vivo, the optimum concentration was found to be 20 mmol/l on a diet of alkali-treated wheat straw (Leibholz & Kellaway, 1980) and 54 mmol/l on a diet of sorghum grain and hay (Bartley & Deyoe, 1977). Ammonia concentrations in the rumen reflect the balance between production and utilization, and as such vary with several factors including the extent of synchrony between energy and ammonia release. Frequent samplings through rumen cannulas in Expt 2 are likely to have given a more accurate measure of rumen ammonia concentrations than single sampling through the oesophagus in Expt 1. Observations in Expt 2 (Table 5) indicate that efficiency of bacterial protein synthesis was not increased when rumen ammonia levels were in excess of 10 mmol/l. This occurred on a diet with an estimated energy content of 6·8 MJ metabolizable energy (ME)/kg and urea content of 21 g/kg. The optimum rumen ammonia concentration is higher on diets of higher energy content, such as those cited, and on these the optimum level of urea in the diet is much higher when rumen-degradable N in the diet is low, e.g. the optimum level of urea with alkali-treated wheat straw was found to be 35 g/kg (Leibholz & Kellaway, 1980).

Peptides and amino acids. Incorporation of amino acid and peptide-N into rumen micro-organisms was demonstrated by Maeng *et al.* (1976), Nolan & Leng (1972) and Nolan & Stachiw (1979). These reports suggest that availability of amino acids and peptides might limit efficiency of bacterial protein synthesis. Hume (1970) replaced 50% of urea-N in a purified diet with casein or zein and found increases in efficiencies of microbial protein synthesis. In the present experiment with wheat straw and in experiments with alkali-washed wheat straw (Leibholz & Kellaway, 1979) and oaten chaff (Redman *et al.* 1980) provision of amino acids and peptides as casein did not improve efficiencies of microbial protein synthesis. Pellet supplements containing casein were fed once daily in Expt 1 and twice daily in Expt 2. These procedures would not have provided a continuous supply of peptides and amino acids from casein due to rapid degradation of casein in the rumen. A more continuous supply of peptides and amino acids in the rumen would have been provided by pellet supplements containing HCHO-casein, due to extensive degradation of HCHO-casein in the rumen.

Incubation of HCHO-casein in nylon bags in the rumen indicated 0·06 and 0·65 degradation after 48 and 96 h respectively. Abomasal flows of N (Table 5) in Expt 2 indicate that approximately 0·62 of HCHO-casein was degraded during passage through the rumen. A relationship between retention times of lignin and HCHO-casein in the rumen was established with sheep (Sriskandarajah *et al.* 1981). Retention times of low-quality forages in the rumen are longer in cattle than in sheep (Poppi *et al.* 1980). The mean retention time of lignin in the rumen of cattle given wheat straw was found to be 115 h (Thiago, 1979) and by extrapolation, using the relationship established with sheep (Sriskandarajah *et al.* 1981), the corresponding mean retention time of HCHO-casein would be 50 h. Although our observations on HCHO-casein in nylon bags suggest that extensive degradation would not have occurred at 50 h, abomasal flows of N suggest that extensive degradation did occur. The level of HCHO treatment (15 g/kg casein) was based on the findings of Ferguson *et al.* (1967). It is significant that in later work at the same laboratory, HCHO was applied at 20 g/kg soya-bean protein (Faichney & White, 1977). We conclude that optimum levels of HCHO and conditions of treatment have yet to be defined for different proteins and different retention times of protein in the rumen.

Ben-Ghedalia *et al.* (1978) replaced 10% of urea-N in a purified diet with casein, maize gluten or fish meal and obtained increases in efficiency of microbial protein synthesis only

with maize gluten. They attributed the lack of response to casein to its rapid degradation in the rumen. In the present experiment, extensive degradation of HCHO-casein in the rumen would have provided a slow release of amino acids and peptides. We conclude that availability of amino acids and peptides is unlikely to limit efficiency of microbial protein synthesis on diets including forages with less than 40 g crude protein (N × 6·25)/kg DM such as wheat straw in the present experiment and oaten chaff (Redman *et al.* 1980).

Intake of straw

In Expts 1 and 2, straw intakes by animals receiving HCHO-casein (treatments D and E) were 13 and 4% higher respectively than by animals receiving an isonitrogenous supplement of casein (treatment B), although only the former was significant. When sheep were given wheat straw supplemented with urea, duodenal infusion of casein increased intake of straw ($P < 0·05$) by 10% (Egan, 1965). When sheep were given various roughages without a urea supplement, post-rumen infusions of casein increased intake by a mean of 11% ($P < 0·05$) when the protein energy value, defined as g protein digested in the intestines per MJ digestible energy, was less than 5 (Egan, 1977); it is likely that much of this response in intake could have been obtained with a urea supplement. In three experiments with lambs given solka floc and oat hulls, intakes of the basal diet by lambs receiving HCHO-casein were 26, 12 and 13% higher respectively than intakes by lambs receiving iso-nitrogenous supplements of casein, of which only the first was significant ($P < 0·05$) (Kempton & Leng, 1979). In cattle given oaten chaff, N supplements of urea, casein and HCHO-casein increased intake to the same extent (Redman *et al.* 1980). It appears that protein supplements do not consistently stimulate intake of low-quality roughages when requirements for rumen-degradable N have been met.

Live-weight changes

Live-weight responses in Expt 1 indicate that the basal diet of wheat straw, supplemented with urea, provided less than maintenance requirements of the cattle. Addition of soluble casein reduced live-weight losses and HCHO-casein resulted in significant gains in period 1, but this differential response to casein supplements had disappeared in period 2. This indicated that previous exposure to the low-quality diet (period 1) made the animals less sensitive to protein deficiencies in the diet (period 2). A similar adaptation phenomenon has been reported by Williams *et al.* (1959) in sheep given oat straw with a urea supplement.

Live-weight changes and intakes of straw DM in Expt 1 did not show any significant correlation in our study. Correlation coefficients for curvilinear and linear regressions between calculated ME intake from straw and live-weight changes were 0·47 and 0·16 respectively, and were not significant. Thus, it is not possible to attribute growth responses in our study to higher feed intakes, as was concluded by Kempton & Leng (1979), but rather to an increased supply of amino acids post-ruminally. These amino acids may have brought about more efficient synthesis of tissue protein and, hence, increased growth, or contributed to the energy requirements of the animal through gluconeogenesis and, hence, reduced breakdown of tissue protein.

N recycling

During the second period of Expt 1, animals that continued to receive protein supplements ate more straw than they did previously. This effect of adaptation to previous diet on voluntary intake was more evident in animals that were deprived of the supplement; although the mean intake was lower in this group, intakes did not decrease with time during the 7 weeks of protein restriction. Rumen ammonia and plasma urea concentrations were low and the animals were in negative N balance. However, rumen VFA concentrations did

not differ from those receiving N supplements and OM digestibility was similar between treatments E and NS, indicating normal rumen activity accompanying the steady straw intake in group NS. This would only be possible through extensive recycling of N to the rumen.

Microbial requirement for N in steers eating wheat straw alone (NS) on the balance trial in Expt 1 (Table 4) was approximately 20 g/d, if it is assumed that 0·65 OM digestion occurred in the rumen, and microbial N was 27 g/kg OM apparently digested in the rumen (Table 5). Faecal and urinary N outputs of 13 and 5 g/d correspond closely with likely endogenous outputs of 13 and 6 g/d (Agricultural Research Council, 1965). N intake from straw was only 14·3 g/d and if it is assumed that rumen degradability of this N was 0·5, approximately 13 g N/d would have entered the rumen as urea or endogenous protein secretion. Endogenous protein secretion anterior to the duodenum can be as high as 7 g N/d in sheep (MacRae & Reeds, 1980) and much of this may be accounted for as sloughed epithelial cells from the rumen wall (Wallace *et al.* 1979). Animals on treatment NS in period 2 lost 157 g/d which corresponds, approximately, with the loss of 3·3 g N/d in the balance trial (Table 4). Visual appraisal of these animals indicated substantial atrophy of skeletal muscles. It would appear that normal function of the digestive tract on a very low dietary intake of N was maintained by transfer of N from skeletal muscle to the digestive tract and secretion of endogenous protein N into the rumen.

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