

Factors affecting the voluntary intake of food by cows

3.* The effect of urea on the voluntary intake of oat straw

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There is now considerable evidence suggesting that the voluntary intake of roughages by cows is related directly to their digestibility (Crampton, 1957; Blaxter, Wainman & Wilson, 1961). In an earlier experiment (Campling, Freer & Balch, 1961) the mean voluntary intake of a medium-quality hay by cows was 21.8 lb daily whereas the cows ate only 10.0 lb of oat straw. It was shown that this difference was directly related to the relative rates of disappearance from the reticulo-rumen of digesta derived from the two foods. The slower rate of disappearance of digesta derived from straw was due both to a slower rate of digestion and to a longer mean time of retention of undigested residues in the alimentary tract.

The oat straw used in our earlier experiments contained only 0.47% nitrogen. Additional N in the form of either protein or urea is known to increase the digestibility of poor-quality roughages (Harris & Mitchell, 1941; Hoflund, Quin & Clark, 1948). The administration of urea might, therefore, be expected to increase the voluntary intake of poor roughages by ruminants and such effects have, in fact, been reported (Clark & Quin, 1951; Morris, 1958; Coombe, 1959).

In four further experiments with cows we have examined the effect of urea administration on the voluntary intake of oat straw. The urea was infused directly into the reticulo-rumen and measurements of digestibility, mean time of retention of food residues in the gut and the rate of disappearance of digesta from the reticulo-rumen were made with both *ad lib.* and restricted intakes of straw. The effect of giving soluble carbohydrate, as sucrose, with the urea was also investigated.

A preliminary report of the results of some of these experiments has been published (Campling & Freer, 1961).

EXPERIMENTAL

Four experiments were made, with two to four cows in each experiment.

The following were the experimental treatments:

Expt 1. Three cows were used to study the effect of administration of urea on the voluntary intake of oat straw. The three treatments were: (1) control—oat straw *ad lib.*, no urea; (2) oat straw *ad lib.* + 150 g urea + 500 g sucrose daily; (3) oat straw *ad lib.* + 150 g urea daily. The treatments were applied according to a Latin square design with periods of 3 weeks' duration. The rate of breakdown of cotton thread in the rumen was estimated with each treatment.

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Expt 2. Four cows were used to compare the effects of administering urea at three levels on the voluntary intake of straw. The treatments, which were applied according to a Latin square design with 3-week periods, were: (1) control—oat straw *ad lib.*, no urea; (2) oat straw *ad lib.* + 25 g urea daily; (3) oat straw *ad lib.* + 75 g urea daily; (4) oat straw *ad lib.* + 150 g urea daily. The rate of breakdown of cotton thread in the rumen was again estimated with each treatment.

Expt 3. Two cows were used to investigate the effect of administering a mixture of urea and sucrose on the digestibility, N retention, rate of digestion and mean time of retention of straw residues in the alimentary tract of the cow. The treatments for both cows were: (1) control—10 lb oat straw daily, no urea or sucrose; (2) 10 lb oat straw + 150 g urea + 500 g sucrose daily. Each period consisted of an 18-day preliminary period followed by a 12-day collection period.

Expt 4. Three cows were used to confirm and extend the observations made in Expt 3. The treatments were: (1) control—oat straw *ad lib.*, no urea; (2) oat straw, restricted to the level consumed voluntarily on treatment 1, + 150 g urea daily; (3) oat straw *ad lib.* + 150 g urea daily. These treatments were according to a 3 × 3 Latin square design with periods of 30 days subdivided as in Expt 3 and a further 2 days during which the contents of the reticulo-rumen were measured.

Cows and housing. A total of seven adult, non-lactating, non-pregnant Friesian and Shorthorn cows was used in the four experiments. Each cow had a permanent rumen fistula which was closed by means of the cannula and bung described by Balch & Johnson (1948). The cows were kept in standings which prevented food being stolen by neighbours. Water and salt licks containing trace minerals were accessible at all times.

Foods. Two batches of oat straw were used; straw A was used in Expts 1 and 3 and straw B in Expts 2 and 4. The chemical composition of both batches was similar and is given in Table 1. Each cow received daily 40 g of a proprietary mineral mixture (Churn 105, British Glues and Chemicals Ltd), together with a weekly supplement of a vitamin A and D concentrate (Drivite, Boots Pure Drug Company Ltd).

Table 1. *Chemical composition of the oat straw*

Expt no.	Dry matter (%)	Crude protein	Ether extract	Crude fibre	Nitrogen-free extract	Ash
		As percentage of straw dry matter				
1 and 3	87.0	2.9	2.2	40.6	48.9	5.4
2 and 4	81.0	3.3	1.4	41.2	44.1	10.0

Determination of voluntary intake of straw. The daily allowance of oat straw was offered in one meal for 5 h and the uneaten straw was then removed and weighed. The amount offered was adjusted daily so that the uneaten food was about 10% of the amount offered.

Administration of urea and sucrose. To avoid affecting the taste of the straw, the daily allowances of urea and sucrose were dissolved in 20 lb of tap water and given as a continuous infusion through the rumen fistula.

Digestibility. The digestibility of the straw and retention of N were determined in the usual way, with the harness and equipment described by Balch, Bartlett & Johnson (1951), during 12-day collection periods.

Digestibility in the reticulo-rumen. The extent of digestion of food in the reticulo-rumen was estimated by application of the lignin-ratio technique to bulked samples of digesta taken from close beside the reticulo-omasal orifice. Details of this method and of the analyses used were given by Campling *et al.* (1961).

Rate of breakdown of cotton thread in the reticulo-rumen. A modification of the cotton-thread technique was used to obtain an index of the rate of breakdown of cellulose in the reticulo-rumen (Campling *et al.* 1961). Pairs of coils of cotton were removed from the rumen at intervals of 24 h when the cows received straw alone. When urea was administered, pairs of coils were removed after 12, 24, 28 and 32 h.

Mean time of retention of undigested residues. On the 2nd day of each collection period about 3% of the daily intake of straw was stained with magenta (Campling *et al.* 1961). At the same time a small quantity of milled straw stained with victoria blue was introduced into the abomasum through the rumen fistula. The mean times of retention of stained particles in the whole gut and in the hind gut were calculated by the method of Castle (1956).

Amount of digesta in the reticulo-rumen. The contents of the reticulo-rumen were measured directly by manually emptying, weighing, sampling and returning the digesta before and after feeding on 2 days at the end of each treatment period.

Empty body-weight. In Expt 4 the empty body-weights of the animals were calculated by subtracting from the live weight the estimated weight of the contents of the alimentary tract. It was assumed that the contents of the reticulo-rumen made up 73% of the total content of the gut (Mäkelä, 1956).

Heart rate. In Expt 4 the heart rate of each cow was counted on several days during each collection period; counts were made on the standing, resting animal at least 2 h after a meal.

RESULTS

Voluntary intake of straw. The mean daily voluntary intakes of oat straw during the last 8 days of each period in Expts 1 and 2, and throughout the 12-day collection periods in Expt 4 are summarized in Table 2. In Expt 1 the cows offered straw *ad lib.* consumed 11.9 lb and, on being given 150 g urea daily, increased their intake by 39% to 16.5 lb. With the same quantity of urea and 500 g sucrose the intake was again 16.5 lb. Further observations in Expts 2 and 4 confirmed that an increase of about 40% in the voluntary intake of oat straw resulted from the daily administration of 150 g urea. However, it was also found, in Expt 2, that 75 g urea led to a similar increase in intake, but an increase of only 26% occurred with 25 g urea. Thus, for a maximum effect on the voluntary intake of straw the optimum quantity of urea daily was between 25 and 75 g. The voluntary intake of oat straw by the cows reached a maximum by the 5th day after the infusion of urea began as shown in Fig. 1 for the preliminary periods in Expt 4.

Digestibility. The addition of urea to a ration of oat straw caused a marked increase

in the digestibility of oat straw (Table 3); in Expt 3 the digestibility of the dry matter increased from 44.0 to 53.4%, and in Expt 4 a similar increase, from 39.3 to 48.4%, occurred. These increases were due mainly to an increased digestibility of the crude-fibre and nitrogen-free extract of the oat straw. The addition of sucrose did not modify the effect of the urea on the digestibility of the straw.

Digestion in the reticulo-rumen. Estimates of the digestibility of the oat straw in the reticulo-rumen as measured by the lignin-ratio technique are given in Table 4.

Table 2. *Mean voluntary intake of straw, rate of digestion of cotton threads and time of retention of straw particles in the alimentary tract of the cow*

Expt no.	Treatment	Mean daily intake of straw (lb)	Rate of digestion of cotton threads. Time for 25% loss in weight (h)	Mean time of retention of straw (h)	
				Whole gut	Hind gut
1 (three cows)	1, control, straw <i>ad lib.</i>	11.9	223	*	*
	2, straw <i>ad lib.</i> + 150 g urea + 500 g sucrose†	16.5	33	*	*
	3, straw <i>ad lib.</i> + 150 g urea†	16.5	28	*	*
	SE of difference between two means	± 0.47	± 24.4		
2 (four cows)	1, control, straw <i>ad lib.</i>	12.4	166	*	*
	2, straw <i>ad lib.</i> + 25 g urea†	15.6	28	*	*
	3, straw <i>ad lib.</i> + 75 g urea†	17.4	23	*	*
	4, straw <i>ad lib.</i> + 150 g urea†	17.8	24	*	*
	SE of difference between two means	± 0.60	± 22.3		
3 (two cows)	1, control, 10 lb straw†	10.0	208	109	20
	2, 10 lb straw + 150 g urea + 500 g sucrose†	10.0	27	82	19
4 (three cows)	1, control, straw <i>ad lib.</i>	12.2	155	99	18
	2, straw equal in amount to that eaten on treatment 1 † + 150 g urea†	12.6	22	83	21
	3, straw <i>ad lib.</i> + 150 g urea†	17.4	22	72	16
	SE of difference between two means	± 0.70	± 28.7	± 3.2	± 3.1

* Not determined. † Daily. ‡ Precisely equal intakes were not in fact obtained.

Table 3. *Mean apparent digestibility of the oat straw*

Expt no.	Treatment	Digestibility (%)						
		Dry matter	Organic matter	Crude protein	Ether extract	Crude fibre	Nitrogen-free extract	Ash
3 (two cows)	1, control, 10 lb straw*	44.0	40.9	-3.0	53.7	50.1	41.8	38.6
	2, 10 lb straw + 150 g urea + 500 g sucrose*	53.4	52.7	-20.8	31.2	61.3	50.9	35.1
4 (three cows)	1, control, straw <i>ad lib.</i>	39.3	40.8	9.1	49.9	47.5	33.1	34.8
	2, straw equal in amount to that eaten on treatment 1 + 150 g urea*	48.4	49.3	-5.5	44.0	58.9	42.5	40.7
	3, straw <i>ad lib.</i> + 150 g urea*	47.3	48.8	1.0	33.3	58.4	41.8	32.1
	SE of difference between two means	± 1.35	± 1.81	—	—	± 2.97	± 1.43	—

* Daily.

Administration of urea or urea and sucrose greatly increased the apparent digestibility of the organic matter and crude fibre of the straw in the reticulo-rumen.

Digestion in the remainder of the alimentary tract. Urea administration appeared to exert little consistent effect on the digestibility of organic matter in the remainder of the gut (Table 4).

Retention of N. The administration of urea and sucrose in Expt 3 caused a change in the mean daily retention of N from -20 to $+13$ g (Table 5). Similarly in Expt 4 the addition of urea caused a change in the retention of N from -13 to about $+5$ g/day.

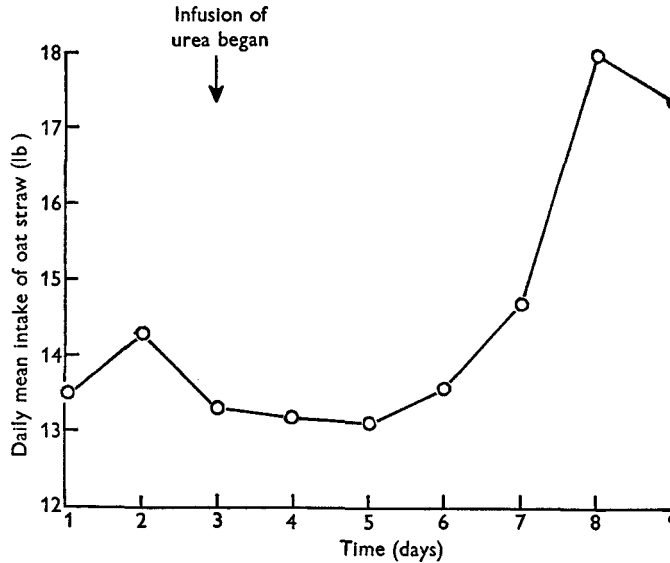


Fig. 1. Expt 4. Effect of infusion of urea into the rumen on the mean daily voluntary intake of oat straw by two cows during the preliminary feeding periods.

Table 4. *Apparent digestibility (%) of oat straw in the reticulo-rumen and in the remainder of the alimentary tract*

Expt no.	Treatment	Digestibility in reticulo-rumen			Digestibility in remainder of alimentary tract		
		Organic matter	Crude fibre	Nitrogen-free extract	Organic matter	Crude fibre	Nitrogen-free extract
3 (two cows)	1, control, 10 lb straw*	26.6	30.3	26.1	14.3	19.8	15.6
	2, 10 lb straw + 150 g urea + 500 g sucrose*	32.1	46.1	28.1	20.6	15.1	22.8
4 (three cows)	1, control, straw <i>ad lib.</i>	21.0	28.0	17.4	19.8	19.4	15.6
	2, straw equal in amount to that eaten on treatment 1 + 150 g urea*	33.4	43.4	23.5	15.9	15.5	18.9
	3, straw <i>ad lib.</i> + 150 g urea*	32.4	42.6	22.8	16.4	15.9	19.0
SE of difference between two means		± 3.03	± 1.26	± 3.91	—	—	—

* Daily.

Although the effect did not approach statistical significance the addition of urea appeared to reduce, by about one-half, the rate of loss of empty body-weight in Expt 4 (Table 5), a finding in agreement with that of Williams, Pearce, Delaney & Tribe (1959).

Table 5. *Mean daily retention of nitrogen and daily change in empty body-weight of the cows*

Expt no.	Treatment	Nitrogen retention (g)	Daily change in empty body-weight (lb)
3 (two cows)	1, control, 10 lb straw*	-19.6	†
	2, 10 lb straw + 150 g urea + 500 g sucrose*	13.2	†
4 (three cows)	1, control, straw <i>ad lib.</i>	-12.9	-2.2
	2, straw equal in amount to that eaten on treatment 1 + 150 g urea*	5.8	-1.0
	3, straw <i>ad lib.</i> + 150 g urea*	4.4	-0.6
SE of difference between two means		± 4.45	± 1.34

* Daily. † Not determined.

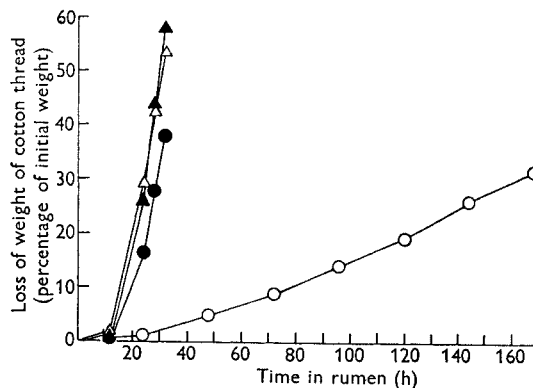


Fig. 2. Expt 2. Mean rate of disappearance of cotton threads suspended in the ventral sac of the rumen of four cows receiving oat straw *ad lib.* with: ○—○, no urea; ●—●, 25 g urea/day; △—△, 75 g urea/day; ▲—▲, 150 g urea/day.

Rate of digestion. The mean time required for the weight of a coil of cotton thread suspended in the ventral sac of the rumen to be reduced by 25% fell from 155–223 h with straw alone to 22–33 h when urea or urea and sucrose were given (Table 2). An example of this effect, taken from Expt 2, is given in Fig. 2. There was a close parallel between the rate of disappearance of cotton thread in the rumen and the voluntary intake of oat straw after the beginning or ending of the urea infusion, as shown in Fig. 3 which illustrates the results for one cow in Expt 2.

Mean time of retention of undigested residues. The mean times of retention of undigested straw residues in the alimentary tract are given in Table 2. The results showed that administration of urea to cows given straw in controlled amounts decreased the mean retention time of straw residues in the whole gut from 109 to 82 h in Expt 3 and

from 99 to 83 h in Expt 4. When straw was given *ad lib.* in Expt 4, the retention time was reduced further to 72 h. Urea administration had no effect on the mean time of retention of particles of milled straw in the hind gut.

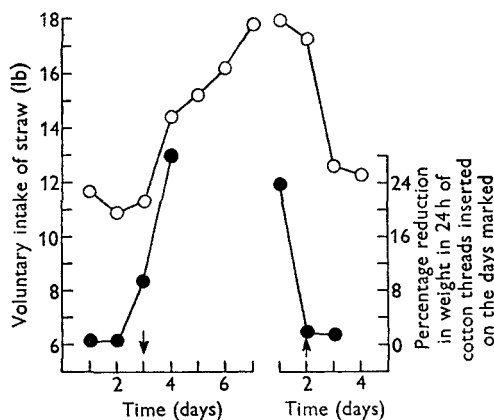


Fig. 3. Expt 2. Relationship between the rate of loss of weight of cotton threads suspended in the ventral sac of the rumen and the voluntary intake of oat straw by one cow after the beginning and ending of urea infusion. ○—○, intake of oat straw; ●—●, percentage reduction in weight of cotton thread in 24 h; ↓, beginning of infusion; ↑, ending of infusion.

Amount of digesta in the reticulo-rumen. The mean amounts of digesta present in the reticulo-rumen in Expt 4 are given in Table 6. When straw was offered to the cows *ad lib.* the mean amount of digesta in the reticulo-rumen before feeding was 159 lb (18.5 lb dry matter) and during urea administration 170 lb (18.5 lb dry matter). There was thus a difference of only 7% in the weight of total contents and no difference in the weight of dry matter. After feeding, the difference in the total amount of digesta increased by about 7% when urea was given, while the difference in the amount of dry matter increased by 11%. These differences after feeding would have been larger if the rate of disappearance of straw from the reticulo-rumen during a meal had not increased when urea was given.

Table 6. *Amount of digesta in the reticulo-rumen of cows before and after feeding (lb)*

Expt no.	Treatment	Time of emptying	Amount of digesta in reticulo-rumen	
			Total	Dry matter
4 (three cows)	1, control, straw <i>ad lib.</i>	Before feeding	158.9	18.5
	2, straw equal in amount to that eaten on treatment 1 + 150 g urea*		135.3	12.7
	3, straw <i>ad lib.</i> + 150 g urea*		170.3	18.5
	SE of difference between two means		± 15.12	± 0.02
	1, control, straw <i>ad lib.</i>	After feeding	219.5	27.5
	2, straw equal in amount to that eaten on treatment 1 + 150 g urea*		197.3	24.0
3, straw <i>ad lib.</i> + 150 g urea*	235.0		30.5	
SE of difference between two means		± 18.59	± 0.97	

* Daily.

Heart rate. In Expt 4 urea administration with a controlled level of straw intake had no effect on the mean heart rate of the cows. When, however, straw was offered *ad lib.* during urea administration the mean daily intake of digestible organic matter increased from 3.6 to 6.2 lb/cow, which was accompanied by an increase in the mean heart rate from 42 to 52 beats/min. This increase is in general agreement with the results of Sykes, Wrenn, Moore & Thomas (1948).

DISCUSSION

The results of these experiments confirm that the administration of urea can increase the voluntary intake by cattle of a roughage of poor nutritive value. An increase in voluntary intake of about 40% occurred with a daily infusion of 75 g urea into the rumen of cows consuming straw containing about 3% crude protein. The addition of soluble carbohydrate was not necessary to achieve this response. However, it is still possible that the administration of larger amounts of urea or soluble carbohydrate might have a beneficial effect on the N retention of cows with foods such as straw.

In a previous communication in this series (Campling *et al.* 1961) we reported results which suggested that the voluntary intake by a cow of hay or oat straw offered once daily was regulated in relation to the respective rates of disappearance from the reticulo-rumen of digesta derived from the hay or straw. The slower rate of disappearance of digesta from straw was due to (a) the lower digestibility in the reticulo-rumen, and (b) the longer mean time of retention of undigested residues in the alimentary tract. The situation observed approximated closely to that expected if the point at which the cows stopped eating were so regulated in relation to these rates of disappearance of digesta that almost equal amounts of undigested residues remained in the reticulo-rumen immediately before the next meal.

In the experiments now described, the addition of urea to the rumen of cows on diets of oat straw markedly improved the digestibility of the straw in the reticulo-rumen and reduced the mean time for which straw residues were retained in the alimentary tract, even when the retention time was measured at equal levels of straw intake. The combined effect of these changes in digestibility and retention time was an increase in the rate of disappearance of dry matter from the reticulo-rumen which was quantitatively related to the increase in voluntary intake. Despite a 40% increase in the voluntary intake of straw when cows received urea, the amount of digesta dry matter found in the reticulo-rumen 24 h after feeding was no greater than when the cows were not receiving the urea. These results provide additional support, therefore, for the concept of the regulation of the intake of roughages outlined previously by Campling *et al.* (1961).

It is widely supposed (e.g. by Mäkelä, 1956) that one of the reasons for differences in the voluntary intake of individual foods by animals is that the 'palatability' of the foods differs. The *Shorter Oxford Dictionary* defines 'palatable' as: 'Agreeable to the palate; pleasant to the taste; savoury', a definition to which objections may be raised in applications to animals because of its subjective human connotation. Whatever the

semantics of the expression, it may be argued that, as the urea was infused through a rumen fistula and would not be expected to affect the taste of the straw, these results also support our earlier suggestion and that of Blaxter *et al.* (1961) that the 'palatability' of a roughage is of relatively minor importance in determining its voluntary intake by ruminants when offered without choice.

The greater digestibility of straw dry matter in the presence of urea was largely due to the increased digestion of crude fibre in the reticulo-rumen. Urea has been shown to increase the digestion of cellulose in *in vitro* experiments (Belasco, 1954), and also in experiments with sheep receiving roughages low in N (Harris & Mitchell, 1941). In the ruminant the breakdown of cellulose is dependent on cellulolytic bacteria, and Bryant (1960) has shown that several important species of these bacteria obtain some or all of their N from ammonia. In our experiments no information was collected about changes in the rumen microflora, although the marked change in the digestibility of straw, and in the breakdown of cotton thread, must have been due to greatly increased bacterial activity. In considering the possible nature of this increased activity it may be of significance that the rate of breakdown of cotton thread was very markedly increased even in the first 24 h after the introduction of urea.

When straw was given in limited amounts, the administration of urea reduced the time for which undigested residues were retained in the gut, which could be due to one or more of three factors: (1) an increase in the rate of breakdown of straw in the reticulo-rumen to a particle size suitable for onward passage; (2) an increase in the rate of disappearance, by digestion, of digesta in the abomasum and intestines, leading to a more rapid emptying of the reticulo-rumen; (3) an effect of the improved N intake status of the animal on metabolic rate, leading to an increase in the motility of the gastro-intestinal tract.

The results presented here suggest the importance of the first of the factors listed above. Any increase in the rate of production of small particles was clearly due to increased digestion, since the time spent ruminating per lb straw eaten was reduced during the administration of urea (Freer, Campling & Balch, unpublished). The results suggest also that the second factor, digestion in the abomasum and intestines, was not markedly changed by administration of urea. Though there was no direct evidence concerning the third factor, urea administration did not affect the heart rate of cows receiving limited amounts of oat straw. It has been observed also (Freer *et al.* unpublished) that the administration of urea did not increase the frequency of reticular contraction. The additional possibility that under the conditions of this experiment urea may have stimulated the motility of the hind gut and hence the rate of emptying of the reticulo-rumen is not supported by our results, since there was no consistent difference in the mean time of retention of milled straw particles in the hind gut with or without urea.

SUMMARY

1. The effect of urea on the voluntary intake of oat straw by adult non-lactating cows was examined in a series of four experiments, each with two to four cows. The urea was given in solution, alone or with sucrose, as a continuous intraruminal infusion.

2. The infusion of 75 g or 150 g urea/day caused a mean increase of about 40% in the voluntary intake of oat straw. The inclusion of 500 g sucrose in the infusion caused no further increase in intake. A daily infusion of 25 g urea caused an increase of only 26% in voluntary intake.

3. The infusion of 150 g urea/day increased the mean digestibility of the organic matter of the straw from 41 to 50%, owing entirely to increases in the digestibility of crude fibre and nitrogen-free extract of 11 and 9 percentage units respectively. The rate of disappearance of cotton threads suspended in the rumen of cows receiving urea was six to seven times faster than in cows not receiving urea.

4. When measured at controlled levels of straw intake, the mean retention time of food residues in the alimentary tract was decreased from 104 to 83 h during urea administration.

5. Twenty-four hours after feeding began approximately equal amounts of digesta dry matter were found in the reticulo-rumens of cows offered straw *ad lib.* with or without the infusion of urea.

6. These results are discussed in relation to the hypothesis that the voluntary intake of this roughage is related to its rate of disappearance from the reticulo-rumen.

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