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The influence of urea treatment on the intake of wheat straw in sheep

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Summary — The aim of this experiment was to determine the factors responsible for the frequently negative effects on intake of straw treated with urea, a source of ammonia. Five forages were prepared from the same wheat straw: untreated straw (UNS) used a control; anhydrous ammonia treated straw (NH_3S); straw treated with urea alone (US); straw treated with urea and ground soyabean (USS); and straw treated with urea, soyabean and molasses (USMS). They were distributed *ad libitum* in conjunction with 170 g/day of soyabean oil cake to 5 sheep over 5 different periods. The experimental design was a 5 x 5 latin square. Ureolysis was low, moderate and high with US, USS and USMS respectively. Ammonia treatment had the greatest effect on the digestibility of plant cell walls (+12.5 points), followed by the treatment with urea and soyabean (+10.7 points). The treatment with urea alone was not very effective (+ 6.6 points). The treatments had a clearcut effect on the level of dry matter (DM) intake: +13%, –32%, –2% and +27% (of which 14% for the straw) for NH_3S, US, USS and USMS respectively. The intake of US and USS during the main meal after distribution was much lower than that of the other 3 straws. With US, there were a large number of secondary meals. The intake rate of US was very low, 1.78 g of DM/min, and that of USMS high, 3.09 g of DM/min, compared with 2.57 g on average for the other 3 straws. The other variables concerning intake and rumination are also presented. The reticulo-rumen contents were always lower with US than with the other straws. They were highest with NH_3S. In contrast, with NH_3S and US the turnover rates of the DM of the contents were the same (3.3%). The DM content, pH and volatile fatty acid contents of the reticulo-rumen contents were measured. With US and USS the ammonia content was high (596 and 455 mg/l respectively on daily average). The results suggest that urea treatment decreased straw intake because ureolysis was too low, owing to feed unpalatability and perhaps to high ammonia content in the rumen. It is unlikely that the animals'digestive capacities (rumen fill and content turnover rate) were in any way responsible. More work needs to be carried out on improving the methods of treatment to achieve maximum ureolysis with urea-treated straw so that its intake is higher than that of control samples.

straw / urea treatment / intake / digestion / sheep

Résumé — Influence, chez le mouton, du traitement à l'urée de la paille de blé sur son ingestibilité. *L'objectif de cet essai était de rechercher les facteurs qui peuvent expliquer les effets parfois négatifs du traitement des pailles à l'urée, source d'ammoniac, sur leur ingestibilité. Pour cela, à partir d'une même paille de blé 5 fourrages ont été préparés : la paille non traitée (UNS) servant de témoin; la paille traitée à l'ammoniac (NH_3S); la paille traitée à l'urée seule (US); la paille traitée à l'urée en présence de graines de soja broyées (USS); la paille traitée à l'urée, en présence de graines de soja et de mélasse (USMS). Ces 5 fourrages ont été distribués à volonté à 5 moutons*

pendant 5 périodes, selon un schéma expérimental en carré latin, avec 170 g/jour de tourteau de soja. L'uréolyse a été faible pour le traitement US, moyenne pour le traitement USS et élevée pour le traitement USMS. Sur la digestibilité des parois végétales le traitement le plus efficace a été celui à l'ammoniac (+12.5 points) suivi de celui avec urée-soja (+10.7 points). Le traitement à l'urée seule a été peu efficace (+6.6 points). L'influence des traitements a été nette sur les quantités de matière sèche ingérées : respectivement +13%, –32%, –2%, +27% (dont 14% pour la paille) pour NH3S, US, USS et USMS. Lors du grand repas suivant leur distribution, les pailles US et USS ont été nettement moins ingérées que les 3 autres pailles. Par ailleurs, il y a eu beaucoup de petits repas pour la paille US. La vitesse d'ingestion de la paille US a été très faible (1.78 g de MS/min) et celle de la paille USMS élevée (3.09 g de MS/min) contre 2.57 g en moyenne pour les 3 autres pailles. Les autres paramètres caractérisant l'ingestion et la rumination sont également donnés. Le contenu du réticulo-rumen a toujours été plus faible pour la paille US que les autres. Il a été le plus élevé pour la paille NH_3S. Par contre, avec les pailles NH_3S et US les taux de renouvellement de la matière sèche de ce contenu ont été identiques (3.3%/h). Enfin, les caractéristiques suivantes du contenu réticulo-ruminal ont été mesurées : teneur en matière sèche, pH, teneurs en acides gras volatils. Les teneurs en ammoniac de ce contenu ont atteint des valeurs élevées pour les pailles US et USS (596 et 455 mg/l respectivement en moyenne sur la journée). Compte tenu des observations effectuées, il semble bien que le traitement à l'urée diminue l'ingestibilité de la paille lorsque l'uréolyse est insuffisante et ce, par le biais d'une baisse de l'appétence et, peut-être, une forte teneur en ammoniac dans le rumen. Les capacités digestives (remplissage du rumen et taux de renouvellement du contenu) ne sont probablement pas du tout en cause. Pour obtenir une paille traitée à l'urée dont l'ingestibilité dépasse celle de la paille témoin il faut donc mettre en œuvre des modalités de traitement permettant une uréolyse maximale.

paille / traitement à l'urée / ingestibilité / digestibilité / mouton

INTRODUCTION

Wheat straw is an important by-product worldwide and there is much ongoing research into its use as an animal feed. Many studies have focused on improving its nutritive value, which is low (Andrieu and Demarquilly, 1987). There are 2 main avenues of research: supplementation, to improve digestibility and intake rate; and treatment of straw by different techniques, also to improve digestibility and intake but *via* direct modification of the structure of the plant cell walls, with supplementation when appropriate.

Since the early study of Sundstøl *et al* (1978), much work has been done on ammonia treatment. The treatment gives good results (Chenost and Dulphy, 1987) but ammonia is difficult to transport and so it cannot always be distributed in certain regions of a country, or even over the entire territory. Consequently, a substitute for ammonia has been sought. Jackson (1978) among others suggested the use of urea, which produces ammonia, and since then numerous workers including Kiangi *et al* (1981) and Saadullah *et al* (1981) have studied its effectiveness.

Intake, which is a determining factor in nutritive value, is markedly increased in straw by ammonia treatment (Chenost and Dulphy, 1987). With urea, however, results have been varying and even conflicting. Hadjipanayiotou (1982), Ørskov *et al* (1983), Dias da Silva and Sundstol (1986), Djajanegara and Doyle (1989a), Brand *et al* (1989) and Ochrimenko and Flachowsky (1991) reported positive effects, too great to be solely attributable to the nitrogen supply whereas Ibbotson (1983), Benhamed and Dulphy (1985) and Besle *et al* (1990a,b) found that straw intake was little or adversely affected by the treatment.

The aim of this study was to investigate the factors that may be responsible for the

negative effects of urea treatment. Residual urea has an unpleasant flavour (Williams *et al,* 1984) when it is incompletely hydrolysed and so we studied a technique for improving hydrolysis, both with the addition of molasses to mask the taste of the urea, and without. The same straw as that selected for the different urea treatments was used as control. Our study falls within the scope of work already done by Sahnoune *et al* (1989, 1990 and 1991) on ureolysis, and by Besle *et al* (1990a, 1990b) and Chenost and Besle (unpublished results) on the possibility of mechanizing the urea treatment of straw with moderate water addition.

MATERIAL AND METHODS

Animals, feeds and experimental design

Five castrated Texel sheep, aged 3 years old, were used. They were fitted with a ruminal cannula 75 mm in diameter. At the beginning of the experimental period, their average weight was 58 kg and at the end 60 kg. As the trial was carried out during a period of increasing day length, the animals were housed in a shed lit artificially from 6 h to 22 h, to prevent intake being affected by the varying amount of light (Michalet-Doreau and Gatel, 1983).

Five experimental forages were prepared with the same straw (table I): untreated straw (UNS), anhydrous ammonia treated straw (NH_3S), urea treated straw (US), urea + ground soyabean treated straw (USS), urea + soyabean + molasses straw (USMS). The treatments were the same as described by Chenost and Besle (1991). All treated straws had the same amount of added nitrogen in NH_3 or urea. Soyabean and urea were added in proportions so as to achieve a satisfactory treatment at low moisture level (25%), according to the results of Sahnoune (1990). The 3 urea-treated straws were prepared in a surface silo, in 20-cm thick layers, each layer being sprayed with the corresponding quantity of products mixed in water. The silos were then covered with a polythene sheet to produce an airlight seal. Anhydrous ammonia treatment was performed with the stack-method of Sundstøl *et al* (1978). The forages were cut in the middle of September, under a shed exposed to the south, and left during the autumn (13 weeks). The outside temperature was recorded daily. During the trial with the animals (20 weeks), the stacks were immediately resealed once the samples had been withdrawn.

The experimental design was a 5 x 5 Latin square. The animals were given 4 weeks to adapt to the untreated straw diet. Thereafter each experimental period lasted 28 days during which the animals were first allowed to rest for 10 days and were then housed in metabolic cages. The latter 18-day cycle consisted of adaptation to the cages (4 days), measurement of digestibility and feeding behaviour (6 days) and measurement of rumen fill (8 days).

Table I. Treatment carried out and products added.

Treatments [1]		*UNS*	*NH_3S*	*US*	*USS*	*USMS*
Urea or NH_3	g/kg[2] straw	–	34	60	60	60
Soya		–	–	–	12	12
Molasses		–	–	–	–	114
Water to reach final moisture (%)		–	–	25	25	25[3]

[1] UNS: untreated straw: NH_3S: anhydrous ammonia-treated straw; US: urea-treated straw; USS: urea + soya-treated straw; USMS: urea + soya + molasses-treated straw. [2] Quantities calculated for a "standard straw" with 90% DM. [3] Taking into account the water content of molasses.

The animals were fed *ad libitum* (about 15% refusal rate) throughout the trial, with a single distribution per day at 9.00. They were given permanent access to the forage, water and a salt block. They also received a 170 g soya bean oil cake and 20 g of mineral supplement enriched with sulphur each day before feed distribution. Water consumption was recorded at 9.00 and 13.00, before and after the main meal.

Measurements

Daily feed intake was determined by measuring the difference between the amount of straw fed (the soya meal was always entirely consumed) and that remaining the following day at 8.00. Feeding behaviour was recorded according to the technique of Baumont *et al* (1988) in sheep placed in metabolic cages for 5 consecutive days.

The digestibility of the different straws was determined after individual collection of faeces on 6 consecutive days at the beginning of the measurement period.

The *in sacco* digestion rate (Demarquilly and Chenost, 1969) of the straw samples offered was measured in 3 cows fed a diet of lucerne at kinetic points of 0, 4, 8, 14, 24, 48 and 72 h.

To roughly assess how animals selected feed in the trough, samples were taken at the beginning and the end of the main meal (as defined from the observation of feeding behaviour) and their cell wall contents compared.

The rumen and the reticulum of the 5 animals in the experiment were completely emptied manually and their contents measured. The feed intake from 9.00 on the day on which emptying was performed and the water consumption of each animal were recorded.

Three emptyings were carried out on different days during each period: at 9.00 before feed distribution; at 13.00, the estimated end of the main meal; and at 21.00, half-way between the end of the main meal and the distribution of feed the following day. To prevent the effects of one emptying biasing values recorded at the following emptying, there was a minimum interval of 72 h between 2 consecutive measurements in the same animal (Aitchison, 1985).

The ruminal contents were weighed and homogeneised. Three samples of about 250 g were dried for 48 h at 80 °C to determine dry matter (DM) content.

Chemical analyses

During the first week of each measurement period, the feed offered, the refusals and the faeces were recorded in all the sheep and weighed after drying at 80 °C for 48 h to obtain a representative sample for each animal. The samples from each period were then analysed.

The mineral content of the samples was determined after combustion at 550 °C for 6 h and the crude fibre content assessed by Weende's method. Total crude protein content was measured by Kjeldahl's method (N x 6.25). The cell wall contents (neutral detergent fibre (NDF), acid detergent fibre (ADF) and demineralised acid detergent lignin (ADL)) were determined by sequential analysis according to the method of Goering and Van Soest (1970).

Samples of the 5 straw types offered during the 5 experimental periods were dried for 48 h at 40 °C, and not at 80 °C, to limit volatile nitrogen compound losses. Total crude protein content and residual ammonia and urea were measured (Sahnoune *et al*, 1991).

Statistical analyses

The variables treatment, period and animal, were subjected to variance analysis according to the procedure of the generalised model of the Statistical Analysis System Institute.

RESULTS

Chemical composition of the straws

The results on ureolysis kinetics in the forages have been reported by Chenost and Besle (unpublished results). The moisture level in USMS was 5 points higher than in the other treatments. The mean outside temperature was given by period of 10 days from 10 September (date of treat-

ment) to 30 October: minimum: 10.6. 7.5, 4.8, 4.0 and 9.2; maximum: 21.0, 15.8, 12.5, 14.7 and 18.6.

Ureolysis reached 32, 77 and 95% for the US, USS and USMS samples. Owing to its low ureolysis level, US had a very high nitrogen content. Ammonia treatment increased the total crude protein content of the straw by only 39 g/kg DM. The amounts of fixed nitrogen from ammonia in the 4 treated straws were 56, 6, 36 and 63% of the final nitrogen contents of the samples for NH_3S, US, USS and USMS respectively, only a small quantity of which was found in the form of extractable ammonia (table II).

Drying the straw at 80 °C decreased the volatile bases of the samples and consequently led to an underestimation of the nitrogen content. The values obtained with samples dried at 40 °C correspond more closely to the animal's real intake.

Forage USMS had the lowest cell wall contents, but this was mainly due to the presence of molasses. The ammonia treatment was the only other that affected total cell wall contents, but then only slightly (–4%) while it had no effect at all on lignin and lignocellulose (ADF).

Digestibility of the straws

The treatments significantly affected the digestibility of the constituents studied except lignin (ADL). The effects of the variables period and animal were not significant. The ammonia treatment was the most effective, producing an increase of +10 points for organic matter and +12.5 for cell walls, followed by the treatment with urea and soya beans, which gave an increase of +8.7 points for organic matter and +10.7 for cell walls (table III). The treatment with urea alone was less effective, producing increases of +5.2 and +6.6 points for organic matter and cell walls respectively. The high digestibili-

Table II. Chemical composition of the different straws (mean for the 5 periods).

	Treatment [1]				
	UNS	*NH_3S*	*US*	*USS*	*USMS*
DM content (g/kg)	890	869	812	806	759
Level of (g/kg DM) :					
Ashes	100	106	89	100	100
Crude fibre	420	430	426	425	379
Neutral detergent fibre	817	782	818	803	685
Acid detergent fibre	513	519	527	527	447
Acid detergent lignin [2]	55	56	59	57	50
Crude protein (N x 6,25 at 80 °C)	30	62	152	88	78
Crude protein (40 °C):	30	69	172	115	89
Urea N (% total N)	0	0	77	38	11.6
NH_3 N (% total N)	0	7.5	3.0	5.5	8.7

[1] UNS: untreated straw: NH_3S: anhydrous ammonia-treated straw; US: urea-treated straw; USS: urea + soya-treated straw; USMS: urea + soya + molasses-treated straw. [2] Ash-free.

Table III. Digestibility of the straws studied (with their treatment solution).

Straw	*UNS*	*NH_3S*	*US*	*USS*	*USMS*	*Residual SD*	
Digestibility (%)							
Organic matter	47.8^{b}	57.6^{a}	53.0^{ab}	56.5^{a}	57.6^{a}	4.5	S*
Neutral detergent fibre	49.3^{c}	61.8^{a}	55.9^{ab}	60.0^{ab}	54.4^{bc}	4.6	S
Acid detergent fibre	49.2^{b}	60.1^{a}	56.5^{ab}	59.0^{a}	54.3^{ab}	5.1	S
Acid detergent lignin	3.0^{b}	15.6^{a}	14.3^{ab}	14.3^{ab}	15.8^{a}	8.1	S
Indigestible crude protein (g/kg DM)	31^{c}	46^{a}	34^{bc}	39^{b}	45^{a}	3.9	S

S* = significant difference in treatment; the figures followed by the same letter on the same line are not significantly different; SD = standard deviation.

ty of organic matter observed with the USMS samples (+10 points compared with control) was mainly due to the addition of molasses, since the digestibility of the cell walls was increased by only 5.1 points.

The indigestible crude protein content was small for the control samples. It increased by 15, 3, 8 and 14 g/kg DM in the NH_3S, US, USS and USMS diets respectively.

Figure 1 shows the kinetics of the *in sacco* disappearance of the 5 straws in the rumen and table IV the graph parameters. The amount of straw rapidly degraded with the UNS, NH_3S, US and USS diets was comparable, but was much greater with the USMS samples which contained molasses. However, there was little correlation between the order of in sacco digestibility after 24 h and that of in vivo digestibility. The breaking constants of the Ørskov graph differed from one straw type to another; they were low for USMS (slow digestion rate) and high for US and USS (faster digestion rate).

Intake

The different treatments had a clearcut effect on intake. The DM intake of US (–32%) and USMS (+27%) was significantly different from that of the control samples. That of NH_3S increased by 13%, but not significantly, while no variation was observed with USS (table V).

The increase in intake of the USMS samples was due in part to the presence of the molasses and soya beans (mean 10%

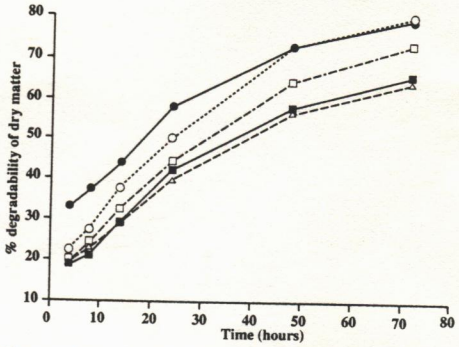

Fig 1. *In situ* kinetics of degradation of the straws. ●, USMS; ○, NH_3 S; □, USS; ■, UNS; Δ, US.

Table IV. *In sacco* digestibility of the different straws.

Straw	*UNS*	*NH_3S*	*US*	*USS*	*USMS*
Digestibility of DM in sacco (%)					
at 4 h	18.6	22.9	19.6	19.8	33.0
at 24 h	42.2	50.4	39.8	44.3	58.0
at 48 h	58.1	73.0	56.5	64.3	73.0
Characteristics of degradation curve					
a	9.1	12.4	10.9	9.6	24.6
a + b	70.1	87.4	63.8	74.4	87.8
c x 100	3.29	3.16	3.79	3.61	2.92

Table V. Intake and feeding behaviour characteristics.

Straw	*UNS*	*NH_3S*	*US*	*USS*	*USMS*	*Residual SD*	
Over a 24 h-period							
DM intake (g)	871^{b}	986ab	589c	850^{b}	1108^{a}	142	S
NDF intake (g)	712^{a}	771^{a}	482^{b}	683^{a}	759^{a}	108	S
Duration of eating (min)	355^{a}	369^{a}	331^{a}	344^{a}	365^{a}	46	NS
Eating rate (g/min)	2.50^{b}	2.71^{b}	1.78	2.49^{b}	3.09^{a}	0.20	S
Duration of rumination (min)	569^{a}	566^{a}	406^{c}	500^{b}	536^{ab}	38	S
Rumination efficiency (g/min)	1.53^{b}	1.76^{b}	1.47^{b}	1.70^{b}	2.09^{a}	0.23	S
During main meal							
DM intake (g)	514^{ab}	535^{a}	180^{c}	349^{b}	617^{a}	121	S
Duration of eating (min)	176^{a}	171^{a}	90^{c}	116^{bc}	153^{ab}	36	S
Eating rate (g/min)	2.97^{b}	3.10^{b}	1.95^{c}	2.95^{b}	4.00^{a}	0.28	S
During secondary meals							
Number	5.44^{b}	5.62^{b}	9.36^{a}	7.25^{b}	6.54^{b}	1.45	S
Total DM intake (g)	356^{a}	450^{a}	408^{a}	501^{a}	491^{a}	130	NS
Total duration (min)	179^{b}	198^{ab}	240^{a}	227^{ab}	212^{ab}	37	S
Eating rate (g/min)	2.01^{ab}	2.26^{a}	1.73^{b}	2.23^{a}	2.39^{a}	0.26	S
Rumination							
No of cycles/day	575^{ab}	604^{a}	388^{c}	525^{b}	554^{a}	44	S
Duration of a cycle (s)	60^{ab}	56^{b}	63^{a}	58^{b}	58^{b}	3.0	S
Latency time (min from distribution to rumination)	218^{a}	194^{a}	232^{a}	211^{a}	217^{a}	41	NS
Chewing							
Duration (min)	924^{a}	935^{a}	737^{b}	844^{a}	901^{a}	73	S
Chewing rate (gDM/min)	0.93^{b}	1.05^{b}	0.77^{c}	1.00^{b}	1.22^{a}	0.10	S
Chewing rate (gNDF/min)	0.77^{b}	0.82^{b}	0.65^{c}	0.81^{b}	0.84^{b}	0.08	S

NS: non-significant difference in treatments; ^{a,b,c} *cf* table III.

of the total DM). The amount of straw ingested rose only by 14%, equivalent to the increase with ammonia-treated straw.

There was little difference in the amount of cell walls ingested between the UNS, NH_3S, USS and USMS diets, but the intake of US was 32% lower than that of UNS.

The DM intake with the 5 forages increased significantly from 750 g during the first experimental period to 1 085 g during the fifth and last period. However, the differences observed between periods did not affect the results concerning the different treatments.

The DM amounts of UNS, NH_3 and USMS ingested during the main meal were large, and there was no significant difference between the intake of these straws, which made up 59, 54 and 56% respectively of the daily feed. The intake of US and USS was low during the main meals, *ie* 31 and 41% of that of control straw. In contrast, the animals fed US and USS, but also those receiving USMS, ingested again very soon after the main meal (+60, +74 and +65 g DM before 13.00). The DM intake during the rest of the day did not vary significantly between treatments. The number of secondary meals taken with the US samples, 9.4, was high in comparison with the other diets, which, taken together, had a mean of 6.2.

The animals drank mainly between 9.00 and 13.00 (table VI). During this period those given UNS, NH_3S, USS and USMS consumed on average 2 l, compared with only 1.3 l for those receiving US. During the rest of the day, irrespective of the forage, the sheep drank on average 0.8 l of water. The average daily water consumption in relation to straw intake for the UNS, NH_3S, USS and USMS diets taken together was 2.9 l per kg DM, with very little inter-forage variation, as against 3.9 l per kg DM for US samples.

Feeding behaviour

The average time spent feeding was 353 min, with little difference between the 5 forage types (table V). The intake rates differed, depending on the treatment, from 1.78 g DM/min in animals receiving US to 3.09 g/min in those given USMS. The intake rates of the other 3 straws were very similar, with an average of 2.75 g DM/min. During the main meal the intake rates were markedly different: about 2 g/min with US, 3 g/min with UNS, NH_3S and USS, and 4

Table VI. Intake of water (l) and dry matter (g) during the day.

Straw	*UNS*	*NH_3S*	*US*	*USS*	*USMS*	*Residual SD*	
Between 9–13 h							
Water	1.94^a	1.96^a	1.30^b	1.88^a	2.28^a	0.37	S
Dry matter	520^b	573^{ab}	240^c	423^b	682^a	107	S
Between 13–9 h							
Water	0.70^a	0.84^a	1.00^a	0.58^a	0.84^a	0.29	NS
Dry matter	350^a	413^a	349^a	427^a	425^a	128	NS

$^{a.b.c}$ *cf* table III.

g/min with USMS. The intake rate of US therefore remained low throughout the day.

The short duration of the main meals in animals fed US and USS is noteworthy – 103 min on average as against 167, for the 3 other types. In contrast, the total ingestion time during secondary meals was greatest with the US diet, albeit only significantly different from that observed with UNS.

A rough estimate of how the sheep selected feed at the trough can be made by comparing the NDF, ADF and demineralised ADL contents of feed that was offered and accepted and those of the straw that was refused (table VII). During the main meal, the animals were the least selective in eating US samples and the most when offered UNS and USMS. However, the intake of US at main meals was low. The same tendency was observed over the day as a whole. The USMS forage in this case should be considered apart: the sheep were probably attracted by the presence of the molasses in the straw since very little was found in the samples refused.

Rumination

The daily durations of rumination varied significantly from 406 min/day for US to 569 min/day for UNS (table V). Rumination efficiency (g DM/min) also differed, ranging between 1.47 g/min for US and 2.09 g/min for USMS. With UNS samples, the value was low and very close to that of US.

The duration of the rumination cycles varied significantly depending on treatment, from 56 s with NH_3 S to 63 s with US. The time between the distribution of the feed and the beginning of the first rumination period did not vary significantly between the forages, but was slightly lower with NH_3S (–24 min) and higher with US (+14 min).

Table VII. Levels of cell wall constituents in offered and refused forages (g/kg DM) (to estimate the effect of selection by sheep during the main meals or over the day).

Straw		*UNS*	*NH_3S*	*US*	*USS*	*USMS*	*Residual SD*	
During main meals								
NDF	Fed	808^{ab}	787^{b}	812^{a}	803^{ab}	675^{c}	15	S
	Refused	842^{a}	806^{b}	822^{b}	822^{b}	739^{c}	14	S
ADF	Fed	502^{b}	525^{a}	523^{a}	539^{a}	444^{c}	12	S
	Refused	530^{a}	540^{a}	525^{a}	545^{a}	487^{b}	15	S
ADL	Fed	59^{b}	55^{c}	61^{a}	64^{a}	50^{d}	1.7	S
	Refused	62^{ab}	60^{b}	61^{b}	65^{a}	56^{c}	2.0	S
During the day								
NDF	Fed	817^{a}	782^{b}	818^{a}	803^{ab}	685^{c}	16	S
	Refused	858^{a}	811^{b}	818^{b}	838^{a}	768^{c}	14	S
ADF	Fed	513^{a}	519^{a}	527^{a}	527^{a}	447^{b}	10	S
	Refused	547^{a}	544^{a}	518^{b}	565^{a}	508^{b}	16	S
ADL	Fed	55^{a}	56^{a}	59^{a}	57^{a}	50^{b}	3.3	S
	Refused	68^{a}	61^{b}	61^{b}	66^{a}	59^{b}	2.9	S

$^{a.b.c}$ *cf* table III.

Chewing activity

The time animals spent chewing (table V) was comparable with UNS, NH_3S, USS and USMS (on average 901 min/day) but significantly shorter with US (737 min/day). The chewing rate (g DM/min) was low with US and high with USMS, but once again, the latter result was due to the presence of molasses in the straw. Expressed in g of cell walls chewed per min, the rates for the 4 treated straws (mean 0.81 g NDF/min) were comparable, while the rate for US was lower (0.65 g NDF/min).

State of fill of the reticulo-rumen

For all times and all criteria (table VIII), the variables treatment, period and individual were significant. Whatever the conditions, rumen fill with US was low. These levels were highest after the main meal with UNS and USMS but in the evening with US and USS. With the US type, the greatest fill, in terms of fresh matter, was only 69% of that observed with UNS.

The greatest fresh matter and dry matter fills were obtained with the NH_3-treated straw, but they were not significantly different

Table VIII. Effect of type of straw on rumen fill.

Straw	*UNS*	*NH_3S*	*US*	*USS*	*USMS*	*Residual SD*	
Wet weight of digesta (g) at:							
9 h	9079^{ab}	9834^{a}	6371^{d}	8023^{bc}	7653^{cd}	951	S
13 h	11776^{a}	11798^{a}	7225^{b}	10992^{a}	11576^{a}	1268	S
21 h	11112^{ab}	11819^{a}	8130^{c}	11162^{ab}	9693^{b}	1060	S
Dry weight of digesta (g) at:							
9 h	1130^{a}	1077^{ab}	781^{c}	996^{ab}	904^{bc}	145	S
13 h	1567^{a}	1595^{a}	925^{b}	1444^{a}	1503^{a}	162	S
21 h	1532^{a}	1615^{a}	1054^{b}	1539^{a}	1353^{a}	205	S
NDF (g) at :							
9 h	835^{a}	724^{ab}	558^{c}	701^{abc}	634^{bc}	108	S
13 h	1158^{a}	1113^{a}	631^{b}	1006^{a}	1026^{a}	122	S
21 h	1144^{a}	1106^{a}	745^{b}	1085^{a}	962^{a}	146	S
ADF (g) at:							
9 h	513^{a}	471^{ab}	343^{c}	448^{ab}	392^{bc}	72	S
13 h	705^{a}	709^{a}	383^{b}	643^{a}	653^{a}	78	S
21 h	715^{a}	725^{a}	470^{b}	694^{a}	600^{a}	88	S
ADL (g) at:							
9 h	102^{a}	102^{a}	72^{c}	95^{ab}	78^{bc}	14	S
13 h	128^{a}	125^{a}	77^{b}	128^{a}	120^{a}	18	S
21 h	135^{a}	146^{a}	98^{b}	134^{a}	110^{b}	15	S

^{a,b,c} *cf* table III.

from those with UNS and USS. Rumen fill was slightly less with USMS than with UNS.

It was difficult to measure precisely the rate of disappearance of rumen digesta, particularly after the main meal (table IX). The average emptying rate of DM (absorption and flow to the omasum) was fairly constant throughout the day. It was slowest with US and fastest with USMS.

As regards total cell wall contents, however, the disappearance rate of digesta was low between 9.00 and 13.00 h with all 5 diets (average 17.5 g NDF/h) and there was no significant difference between straw types. Throughout the rest of the day, the emptying rate was fairly constant, again will all 5 diets (average 33.6 g/h for NDF and 21.4 g/h for ADF), the lowest values being observed with US.

In contrast, when lignin content is considered, the emptying rate increased during the day: no loss between 9.00 and 13.00, 1.56 g/h between 13.00 and 21.00, and 3.36 g/h between 21.00 and 9.00. However, as there was a high residual standard deviation, the differences between the diets were not significant.

The turnover rates of DM content in the rumen per h were 3.02, 3.31, 3.31, 3.12, and 4.22% for UNS, NH_3 S, US, USS and USMS diets respectively. For cell wall contents the respective rates were 2.93. 3.37, 3.20, 3.13 and 3.74%.

Characteristics of reticulo-rumen contents

These caracteristics are given in tables X and XI. The different treatments had barely any effect on DM content. However, there were slight differences in the pH (average values of 6.30, 6.13, 6.42, 6.20 and 6.18 for the 5 straw types respectively) and in total VFA content (76.6, 96.5, 84.4.

Table IX. Rate of disappearance of rumen digesta (g/h).

Straw	*UNS*	*NH_3S*	*US*	*USS*	*USMS*	*Residual SD*	
Dry matter							
9–13 h	53.3^{a}	37.3^{a}	46.0^{a}	18.9^{a}	65.7^{a}	31.3	NS
13–21 h	51.3^{ab}	51.0^{ab}	18.0^{c}	40.0^{bc}	73.6^{a}	18.7	S
21–9 h	39.7^{ab}	52.1^{a}	32.4^{b}	55.2^{a}	43.6^{ab}	12.6	S
NDF							
9–13 h	25.7^{a}	8.1^{a}	22.0^{a}	3.0^{a}	28.5^{a}	27.0	NS
13–21 h	39.9^{a}	42.6^{a}	13.6^{b}	31.7^{ab}	45.5^{a}	15.9	S
21–9 h	30.9^{ab}	37.6^{ab}	23.6^{b}	40.1^{a}	31.7^{ab}	9.5	NS
ADF							
9–13 h	18.4^{a}	10.1^{a}	15.8^{a}	3.2^{a}	17.1^{a}	16.6	NS
13–21 h	22.8^{a}	25.7^{a}	7.2^{b}	21.0^{a}	31.2^{a}	9.9	S
21–9 h	20.9^{ab}	24.9^{a}	15.8^{b}	25.8^{a}	20.1^{ab}	6.1	S
ADL							
9–13 h	0.6^{a}	1.4^{a}	1.3^{a}	-2.9^{a}	-1.8^{a}	3.7	NS
13–21 h	1.7^{ab}	0.4^{b}	-0.6^{b}	2.2^{ab}	4.1^{a}	2.0	S
21–9 h	3.1^{a}	4.1^{a}	2.8^{a}	3.8^{a}	3.0^{a}	1.0	NS

$^{a,b,c.}$ *cf* table III.

Table X. Characteristics of reticulo-ruminal contents.

Straw	*UNS*	*NH_3S*	*US*	*USS*	*USMS*	*Residual SD*	
Dry matter (%)							
9 h	12.4^{a}	10.8^{b}	12.1^{a}	12.2^{a}	11.9^{ab}	0.76	S
13 h	13.2^{a}	13.4^{a}	12.6^{a}	13.3^{a}	13.0^{a}	0.90	NS
21 h	13.6^{a}	13.6^{a}	12.8^{a}	13.8^{a}	14.0^{a}	0.86	NS
pH							
9 h	6.42^{ab}	6.30^{b}	6.39^{ab}	6.33^{b}	6.52^{a}	0.12	S
13 h	6.43^{ab}	6.17^{c}	6.51^{a}	6.35^{b}	6.17^{c}	0.11	S
21 h	6.05^{b}	5.91^{bc}	6.36^{a}	5.91^{bc}	5.86^{c}	0.12	S
N-NH3 (mg/l)							
9 h	152^{b}	160^{b}	313^{a}	302^{a}	177^{b}	70	S
13 h	204^{d}	335^{cd}	794^{a}	594^{b}	373^{c}	114	S
21 h	181^{c}	311^{bc}	681^{a}	469^{b}	200^{c}	150	S
Total VFA (mmol/l)							
9 h	73.2^{bc}	82.5^{a}	70.5^{c}	80.1^{ab}	77.7^{abc}	6.23	S
13 h	74.3^{c}	103.8^{a}	89.4^{b}	100.5^{ab}	109.7^{a}	9.01	S
21 h	88.3^{c}	103.2^{ab}	93.2^{bc}	100.6^{ab}	107.1^{a}	7.42	S
Acetic acid (%)							
9 h	71.3^{ab}	70.7^{ab}	72.4^{a}	70.8^{ab}	69.9^{b}	1.60	S
13 h	70.6^{ab}	72.1^{a}	68.5^{b}	73.2^{a}	68.6^{b}	1.92	S
21 h	72.2^{ab}	72.7^{ab}	71.3^{bc}	73.5^{a}	69.7^{c}	1.33	S
Propionic acid (%)							
9 h	18.7^{a}	18.6^{a}	17.4^{a}	18.8^{a}	18.1^{a}	1.11	NS
13 h	19.0^{a}	18.1^{ab}	18.4^{ab}	17.4^{b}	18.2^{ab}	1.04	S
21 h	18.7^{a}	17.8^{a}	18.4^{a}	17.6^{a}	18.6^{a}	1.11	NS
Butyric acid (%)							
9 h	7.5^{b}	8.3^{ab}	7.1^{b}	7.5^{b}	9.0^{a}	0.78	S
13 h	7.9^{b}	8.0^{b}	9.3^{ab}	7.1^{b}	11.5^{a}	1.68	S
21 h	7.0^{b}	7.7^{b}	7.6^{b}	6.9^{b}	10.3^{a}	1.07	S

^{a,b,c} *cf* table III.

93.7 and 98.2 mmol/l), and large differences in the ammonia nitrogen content (179, 269, 596, 455 and 250 mg/l respectively).

The pattern of rumen fermentation was similar in all but the USMS diet, for which there was a smaller proportion of acetic acid and a higher level of butyric acid.

The particles of forage in the rumen contents were divided into 3 groups: large, retained by an 8-mm mesh; intermediate, retained by 1.2 and 4-mm meshes; small, retained by 0.05, 0.10, 0.25 and 0.50-mm meshes. At all emptying times, the smallest number of large particles and the great-

Table XI. Characteristics of particles in reticulo-ruminal contents (g DM/kg DM).

Straw	*UNS*	*NH_3S*	*Treatment US*	*USS*	*USMS*	*Residual SD*	
At 9 h:							
8 mm	17.9^{b}	37.9^{a}	30.1^{a}	31.2^{a}	29.3^{a}	6.4	S
1–4 mm	186^{ab}	170^{ab}	200^{a}	201^{a}	155^{b}	25	S
0.050–0.50 mm	553^{a}	479^{b}	502^{b}	486^{b}	506^{b}	31	S
Soluble	244^{b}	313^{a}	267^{ab}	282^{ab}	310^{a}	44	S
At 13 h:							
8 mm	48.0^{c}	97.9^{a}	49.0^{c}	68.0^{bc}	85.0^{ab}	18.8	S
1–4 mm	290^{a}	260^{abc}	234^{c}	254^{bc}	271^{ab}	22	S
0.050–0.50 mm	469^{a}	395^{cd}	455^{ab}	419^{bc}	371^{d}	33	S
Soluble	192^{b}	247^{a}	262^{a}	259^{a}	273^{a}	26	S
At 21 h:							
8 mm	45.8^{c}	91.9^{a}	59.5^{c}	64.7^{bc}	85.6^{ab}	17.2	S
1–4 mm	278^{a}	253^{a}	245^{a}	271^{a}	273^{a}	36	NS
0.050–0.50 mm	454^{a}	383^{bc}	418^{ab}	400^{bc}	364^{c}	33	S
Soluble	223^{a}	273^{a}	277^{a}	265^{a}	277^{a}	37	NS

est number of small particles were found with the UNS diet. The NH_3 S samples had the greatest amount of large particles, and a high number was also found with the USMS diet over the day as a whole. In the treated straws, therefore, it appears that the number of large particles increased in proportion to the effectiveness of the treatment. There was little difference in the amount of intermediate particles between the 5 feeds. The lowest daily total of small particles was observed with USMS; their number increased very slightly when the treatment was less effective, with an average of 419, 414, 435 and 458 g/kg DM for NH_3 S, USMS, USS and US respectively.

DISCUSSION AND CONCLUSION

For complete success the treatments should be carried out in summer. Under these conditions urea treatment can be performed even in a temperate climate (Sahnoune, 1990). However, our treatments in September were interesting because they gave a good range of ureolysis allowing the effect of residual urea on intake to be studied.

It has been shown (Sahnoune *et al,* 1989; Sahnoune, 1990) that at low moisture levels, when soyabean is combined with urea, the treatment is successful. Ureolysis takes twice as long when the temperature decreases from 30 to 20 °C (Sahnoune, 1991), and likewise thereafter for each drop in temperature of 10 °C, down to 0 °C, according to the data of Sumner (1951) on the initial rate of ureolysis kinetics. This explains why, under our low moisture and temperature conditions, ureolysis was better in USS than in US. In USMS, because of the higher moisture level (Sahnoune) and perhaps because microbial urease also had an effect (Hassoun, 1990), ureolysis was almost complete.

Similarly, the poor result of the ammonia treatment was also due to the low temperature and moisture of the original straw. In fact, the crude protein content of the NH_3S was less than the mean value of 51 g/kg DM observed in the review of Chenost and Dulphy (1987), despite an increase in digestibility of 10 points.

The intake of the untreated straw in this trial was quite high, 41 g DM/kg w0.75, as against 30–32 g observed in earlier experiments (Andrieu and Demarquilly, 1987). This probably attenuated slightly the effects of the ammonia treatment: +5.5 g DM/kg w0.75, as against 14.2 g in a previously reported series of 38 comparisons (Chenost and Dulphy, 1987). However, even when this is taken into consideration, the ammonia treatment was still not entirely successful, since the increase in crude protein content was less than the mean value of 51 g/kg DM observed in the latter trials, despite an increase in digestibility of +10 points, which is the level found in a successful treatment. In contrast, and in agreement with results reported elsewhere (Ibbotson, 1983; Benhamed and Dulphy, 1985; Besle *et al,* 1990a, b), the intake of the straw treated with urea alone was low. However, when ureolysis was improved, intake increased, and that of cell walls reached practically the same level as with NH_3 S and USMS samples.

One of the most striking differences between the 5 straws was their residual urea content. Urea, unlike ammonia, which even at high concentrations does not reduce appetite in sheep (Behamed and Dulphy, 1986), probably had a negative effect on intake. In contrast, there was little difference in digestibility between the 4 treated straws.

The low intake of the straw treated with urea alone cannot be explained by its digestibility, particularly since the turnover rate of the rumen content and the digestion rate of the straw, variables closely linked to digestibility, were not widely different from those of the control samples. However, with urea-treated straw, the sheep did not make full use of their rumen capacity, whereas with the control and ammonia-treated straws the rumen was reasonably well-filled. This tendency towards under-filling was less clear-cut with the USS and USMS diets and is at variance with results obtained by Djajanegara and Doyle (1989b), who found no difference in rumen filling between urea-treated straw and control samples, even though the intake of the treated straw was slightly higher (Djajanegara and Doyle, 1989a).

Animal appetite may be lessened by products resulting from the fermentation of straw, or, more precisely, from the transformation of urea in the rumen. It is unlikely that volatile fatty acids (VFA) played an important role in this trial, since their levels were normal and the total DM intake was small compared with the amounts sheep are capable of ingesting. In contrast, the ammonia levels in the rumen were quite high with the US and USS diets. The excess ammonia content may have led the sheep to reduce intake so as to avoid adverse effects on their health. In addition, the intake of these straws during the main meal was relatively low, perhaps because the excessive ammonia in the rumen caused a loss of appetite and a subsequent reduction in feeding time during the main meal. This is not certain, however, since although their rumen ammonia content remained very high, the animals receiving the US and USS diets took more small meals than those fed the other straws and their reticulo-rumen continued to increase throughout the course of the day. With US, rumen content remained at a constant level until the evening and with USS it rose slightly.

The greater water intake observed with the US diet may have been caused by an

imbalance in the rumen, or even perhaps in the blood, that animals sought to compensate for by drinking more. In this case they would probably have urinated more, but this latter value was not measured. Djajanegara and Doyle (1989a) observed no increase in water intake per kg of straw DM.

Another particularity of the US forage was its slow intake. The USS forage was unexceptional in this respect while the rate of intake of straws enriched with molasses increased, especially during the main meal. These findings suggest that the palatability of the forages plays a not unimportant role, be it negative or positive. Curiously, the slow intake rate of straw treated with urea alone cannot be explained by the animals being more selective at the trough, perhaps because the unpleasant taste of urea interfered with the usual effect of cell wall content on forage selection.

From the times recorded, it does not seems that rumination has a limiting effect on intake of the US and USS feeds. Clearly rumination times of these 2 straws were shorter because of a reduced intake. This is also a clear demonstration of the fact that intake of these diets was determined by factors other than the physical limitations. The values recorded were, in fact, similar to those reported by Doyle and Chanpongsang (1990) with 7 rice straws.

The effect of mastication on the proportion of large (> 8 mm) and small (< 1 mm) particles present in the rumen is fairly clearcut. The overall trend showed that in proportion to the effectiveness of the treatment, the more large particles and fewer small ones there were. In this respect, the straw treated with urea was little different from the others. This was unexpected: it had a low intake rate and hence should have been chewed more thoroughly. It is therefore probable that the real amount of time the straw was chewed by the animal, compared with the total time it remained in the mouth was lower with US than with the other diets. This would lend support to the hypothesis that the straw has a low palatability.

In the present trial, there was only a slight increase in the intake rate of the ammonia-treated straw, but this seems to have been due solely to the effectiveness of the treatment since no notable problems were encountered with the animals. In contrast, the intake of urea-treated straw was not limited by the animals' digestive capacities but by excessive residual urea in the forage, which considerably reduced palatability, and also produced excessive ammonia in the rumen. These problems were considerably lessened but not completely resolved by the addition of soya beans, which improved ureolysis (Sahnoune *et al,* 1991). The addition of molasses not only improved ureolysis (Williams *et al,* 1984) but also probably masked the unpleasant flavour of the residual urea. There are 2 explanations for the divergent results in the literature. First, sheep may be more susceptible than cattle. Here again however, there is a discrepancy, since although several authors have reported positive effects in cattle fed urea-treated straw, Ibbotson (1983) and Mira *et al* (1983) found the treatment to be unsuccessful. Second, varying experimental conditions, even for treatment with urea alone, produce very different levels of ureolysis. If there is better urea breakdown, intake reaches a level close to normal as with the USS diet, and when the urea is completely hydrolysed, intake is fully normal. When this occurs, the intake of the treated straw is greater than that of control, as observed by Cloete *et al* (1983), Brand *et al* (1989), Cloete and Kritzinger (1984), Saadullah *et al* (1981), and Djajanegara and Doyle (1989a).

The treatment of straw with urea must be successfully carried out to achieve a

satisfactory level of intake. In fact, unlike soda or anhydrous ammonia treatments, if urea treatment fails negative effects may ensue, mainly as a result of a lowering of the organoleptic qualities of the forage caused by insufficient hydrolysis. The outcome is a decrease in nutritive value caused by a reduction in intake.

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