Urea ammoniation compared to urea supplementation as a method of improving the nutritive value of wheat straw for sheep

S.W.P. Cloete, N.M. Kritzinger
Winter Rainfall Region, Elsenburg

The ammoniation of wheat straw by urea in a stack method was investigated and compared to urea supplemented and untreated straw in an intake and *in vivo* digestibility trial.

Ammoniation and supplementation significantly ($P \leqslant 0,01$) improved the mean daily consumption of wheat straw by 46,7 and 35,6% respectively. The improvement of 8,1% in the voluntary intake of ammoniated wheat straw compared to urea supplemented wheat straw was not significant. Apparent digestibility of DM, OM, CWC, ADF and hemicellulose was significantly ($P \leqslant 0,01$) improved by 17,5; 15,1; 24,1; 14,3 and 39,2% respectively, when ammoniated straw was compared to untreated straw. Corresponding improvements of 10,0; 8,4; 17,8; 8,7 and 29,2% were obtained when ammoniated straw was compared to urea supplemented straw. All these differences were significant at least at $P \leqslant 0,05$. Similarly, urea supplementation tended to increase the digestibility of the above-mentioned fractions marginally. Both ammoniation and urea supplementation of wheat straw significantly ($P \leqslant 0,01$) improved the apparent digestibility of CP as well as the N-balance. The apparent digestibility of CP of ammoniated wheat straw was significantly ($P \leqslant 0,01$) reduced by 22,1% compared to urea supplemented wheat straw. The N-balance of ammoniated wheat straw, on the other hand, was marginally higher than that of urea supplemented wheat straw, mainly owing to a higher level of urinary N-excretion observed on the latter treatment.
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Die ureum-ammonifisering van koringstrooi volgens die miedmetode is ondersoek en vervolgens in 'n inname- en *in vivo*-verteringstudie met ureum-aangevulde en onbehandelde koringstrooi vergelyk.

Ureum-ammonifisering en ureum-aanvulling van koringstrooi het vrywillige inname hoogsbetekenisvol ($P \leqslant 0,01$) met onderskeidelik 46,7 en 35,6% verbeter. Die verbetering van 8,1% in die vrywillige inname van geammonifiseerde strooi bo dié van ureum-aangevulde strooi was nie betekenisvol nie. Skynbare verteerbaarheid van droë materiaal, organiese materiaal, selwande, suurbestande vesel en hemisellulose is hoogsbetekenisvol ($P \leqslant 0,01$) verhoog met 17,5; 15,1; 24,1; 14,3 en 39,2% onderskeidelik bo die ooreenstemmende verteerbaarhede van onbehandelde strooi. Ooreenstemmende en betekenisvolle ($P \leqslant 0,05$) verhogings van 10,0; 8,4; 17,8; 8,7 en 29,2% bo die onderskeie verteerbaarhede van die ureum-aangevulde koringstrooi is verkry. Ooreenkomstiglik het ureum-aanvulling geneig om die skynbare verteerbaarheid van bogenoemde fraksies tot 'n geringe mate te verbeter. Ureum-ammonifisering sowel as ureum-aanvulling het die skynbare verteerbaarheid van ruproteïen sowel as die stikstofbalans van koringstrooi hoogsbetekenisvol ($P \leqslant 0,01$) verhoog. Die skynbare verteerbaarheid van ruproteïen van geammonifiseerde strooi was hoogsbetekenisvol ($P \leqslant 0,01$) laer as dié van ureum-aangevulde koringstrooi. Stikstofbalans van geammonifiseerde strooi daarenteen, was tot 'n geringe mate hoër as dié van ureum-aangevulde strooi, hoofsaaklik as gevolg van 'n hoër stikstofuitskeiding in die urine van skape op die laasgenoemde behandeling.
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S.W.P. Cloete and N.M. Kritzinger
Winter Rainfall Region, Private Bag, Elsenburg, 7607
Republic of South Africa

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Introduction

Chemical upgrading of low quality roughages by either sodium hydroxide (Jackson, 1977) or ammonia (Sundstøl, Coxworth & Mowat, 1978) has been frequently investigated over the past few years. An indirect method of ammoniation, where ammonia is supplied by urea, also received attention (Dolberg, Saadullah, Haque & Ahmed, 1981; Hadjipanayiotou, 1982). This treatment is dependent on the enzymatic release of ammonia from urea in an aqueous medium.

Previous work at this institute proved ammoniation by urea to be effective in increasing the *in vitro* organic matter digestibility of wheat straw (Kritzinger & Franck, 1981). Further investigations indicated wheat straw treated in this way to be more palatable and of a higher digestibility than untreated wheat straw when fed to sheep (Cloete, De Villiers & Kritzinger, 1983). Results from this experiment, however, also suggested relatively poor utilization of the nitrogen added to the straw during the ammoniation process. In previous experiments, ground wheat straw was thoroughly mixed in a continuous mixer with a urea solution to provide an even distribution of urea. As this practice is labour intensive and time consuming, it may not be acceptable as a practical method of treating large quantities of roughage.

Seen against this background a practical method of urea ammoniation of wheat straw was investigated. Palatability, digestibility and nitrogen utilization of ammoniated wheat straw were simultaneously compared to untreated and urea supplemented wheat straw.

Materials and Methods

One hundred and ninety two bales of wheat straw were stacked in four layers of 48 bales each in a silage pit. Feed grade urea was spread evenly onto each layer of bales to provide approximately 50 kg urea per ton straw. Subsequently each layer was sprayed with approximately 400 ℓ water per ton straw, after which the stack was covered airtightly with a plastic sheet.

After a treatment period of eight weeks, the stack was uncovered, the bales untied and spread on a cement floor to dry to approximately 90% dry matter. The dried ammoniated straw and untreated straw from the same batch were hammermilled through a 12 mm screen. The following three diets were subjected to an intake and *in vivo* digestibility trial over a period of 35 days:

- Untreated wheat straw;
- Untreated wheat straw thoroughly mixed with a urea solution to provide approximately the same nitrogen level determined analytically in the ammoniated straw;

– Ammoniated wheat straw.

These diets were each fed to five adult S.A. Mutton Merino wethers in a completely randomized design. During the collection period of seven days the sheep were fed at a level of 15% below *ad lib* voluntary intake. Representative samples of the experimental diets and the faeces and urine of individual sheep were taken and analysed according to the methods of the A.O.A.C. (1970) for dry matter (DM), organic matter (OM) and crude protein (CP). The fibre fractions were analysed according to methods described by Van Soest (1963) and Van Soest & Wine (1967), while urea and ammonium (NH^+_4) contents of the respective diets were determined according to methods described by Technicon Auto Analyser (1977) and Technicon Auto Analyser II (1977) respectively. Apparent digestibility coefficients were calculated for DM, OM, CP, cell-wall constituents (CWC), acid detergent fibre (ADF) and hemicellulose. The nitrogen intake (N-intake), nitrogen excretion (N-excretion), and nitrogen balance (N-balance) were calculated for all the animals on the respective diets. Malfunction of the collection funnels caused leakage of urine in two sheep, one each on the urea supplemented and the ammoniated diets respectively. The data obtained from these sheep were thus excluded from the N-balance calculations. Results were analysed according to standard procedures for a completely randomized design. Differences in voluntary intake and apparent digestibility were tested for significance by the Student-Newman-Keuls method, while Scheffé's test was used for the N-balance results (Van Ark, 1981).

Results and Discussion

Chemical composition

The chemical composition of the diets is presented in Table 1. From Table 1 it is evident that differences between the OM, CWC and ADF contents of the three experimental diets were relatively small. Supplementation and ammoniation increased the CP content of the wheat straw from 3,1 to 8,9 and 9,7% respectively. Hemicellulose content tended to decrease slightly owing to ammoniation. Comparable reductions in the hemicellulose content of ammoniated low quality roughages were reported by Horton (1981); Abadin & Kempton (1981) and Ibrahim & Pearce (1983). Abadin & Kempton (1981) reported a reduction of 20% in the hemicellulose content of barley straw ammoniated with anhydrous ammonia. In the present study, however, the reduction of hemicellulose appears to be related to a slight increase of ADF, together with a marginal decrease of CWC. Oji & Mowat (1979); Solaiman, Horn & Owens (1979); Cloete *et al.* (1983) and Herrera-Saldana, Church & Kellems (1983) published comparable results concerning the ADF content of ammoniated straw.

Table 1 Chemical composition of the experimental diets (DM-basis)

	Treatment		
Fractions (%)	Untreated	Urea supplemented	Ammoniated
OM	97,50	97,59	97,44
CP	3,10	8,91	9,67
CWC	82,86	81,03	82,13
ADF	48,60	48,32	50,45
Hemicellulose	34,26	32,72	31,68
Urea	0,07	1,80	0,80
Ammonium (NH^+_4)	0,07	0,08	0,51

Solaiman *et al.* (1979) related the increase of ADF in ammoniated roughages to a dilution effect caused by the solubilization of hemicellulose from ammoniated roughages. The urea supplemented straw contained 1,8% urea, while 0,8% unchanged urea was analytically determined in the ammoniated wheat straw. The latter diet also had a free ammonium content of 0,5%, while only negligible amounts of free ammonium were found in the other two diets.

Voluntary intake

The voluntary intake per unit metabolic mass ($W^{0,75}$) for the respective diets are presented in Table 2. Urea supplementation significantly ($P \leqslant 0,01$) improved voluntary intake of the wheat straw by 35,7%. This result is in agreement with results obtained by Umunna (1982) on the supplementation of poor quality veld hay. Voluntary intake of the ammoniated straw was 46,7% higher than that of untreated straw, the difference being significant ($P \leqslant 0,01$). This finding agrees fairly well with results obtained by Dolberg *et al.* (1981) and Hadjipanayiotou (1982). Improvements of respectively 32,6 and 47,0% in the mean daily consumption of rice and barley straw ammoniated by urea were reported by these authors. Comparable results on anhydrous ammoniation were published by Oji, Mowat & Winch (1977); Horton (1978) and Herrera-Saldana, Church & Kellems (1982). These authors reported respective increases of 45 to 51%, 41% and 11,6% in the voluntary DM or OM intake of ammoniated maize stover, ammoniated cereal straws and ammoniated wheat straw. When the ammoniated wheat straw was compared to the urea supplemented straw, a difference of 8,1% in favour of the ammoniated straw was obtained. This difference did not reach statistical significance, and is somewhat smaller than the difference of 27,3% obtained in earlier work (Cloete *et al.*, 1983). It should however be kept in mind that the previous results were obtained on a different batch of straw, and that ammoniation in that case was carried out by a treatment of 75 kg urea per ton ground wheat straw. Results from the present investigation correspond fairly well with results obtained by Jayasuriya & Perera (1982), who actually reported a slightly lower consumption of rice straw ammoniated by 4% of urea, compared to urea supplemented rice straw.

Table 2 Voluntary intake per metabolic mass ($W^{0,75}$) and apparent digestibility coefficients

	Treatment			
	Untreated	Urea supplemented	Ammoniated	SE Mean
Voluntary intake gDM/$W^{0,75}$/day	$27,4^{1}$	$37,2^{2}$	$40,2^{2}$	0,784
Apparent digestibility (%)				
DM	$44,2^{a\ 1}$	$47,2^{a\ 1,2}$	$51,9^{b\ 2}$	0,785
OM	$47,1^{a\ 1}$	$50,0^{a\ 1,2}$	$54,2^{b\ 2}$	0,768
CP	$-3,3^{1}$	$64,1^{3}$	$49,9^{2}$	0,938
CWC	$50,2^{1}$	$52,9^{1}$	$62,3^{2}$	0,899
ADF	$48,2^{a\ 1}$	$50,7^{a\ 1,2}$	$55,1^{b\ 2}$	0,783
Hemicellulose	$53,0^{1}$	$57,1^{1}$	$73,8^{2}$	1,326

^{a,b,c} – denotes significant differences ($P \leqslant 0,05$) in the same row

^{1,2,3} – denotes significant differences ($P \leqslant 0,01$) in the same row

Apparent digestibility

The apparent *in vivo* digestibility coefficients of DM, OM, CP, CWC, ADF and hemicellulose for the experimental diets are presented in Table 2. The apparent digestibility of DM and OM was non-significantly improved by respectively 6,9 and 6,2% owing to the urea supplementation of wheat straw. This result agrees fairly well with results obtained by Umunna (1982), who also reported non-significant improvements in the apparent DM digestibility of urea supplemented veld hay. Respective improvements of 17,5 and 15,1% were obtained in the apparent DM and OM digestibility coefficients of the ammoniated diet, when compared to untreated straw. These improvements were statistically significant ($P \leqslant 0,01$), and are in general agreement with reports from the literature. Comparable results were obtained by Dolberg *et al.* (1981); Saadullah, Haque & Dolberg (1982) and Hadjipanayiotou (1982). The latter author reported an increase of 26% in the apparent DM digestibility of barley straw ammoniated by urea. Results obtained by Oji *et al.* (1977); Horton (1978); Oji & Mowat (1979); Garrett, Walker, Kohler & Hart (1979); Horton & Steacy (1979) and Horton, Nicholson & Christensen (1982) may also be compared to the present results. In general these authors reported improvements in the apparent digestibility of DM and/or OM over a wide range of ammoniated low quality roughages. Ammoniation also significantly ($P \leqslant 0,05$) improved apparent DM and OM digestibility by 10,0 and 8,4% respectively, when compared to the urea supplemented straw. These results agree fairly well with previous results on the OM digestibility of ammoniated wheat straw (Cloete *et al.*, 1983). Morris & Mowat (1980); Saadullah *et al.* (1982) and Jayasuriya & Perera (1982) similarly reported increases of 9,0; 10,9 and 13,1% in the apparent digestibility of diets based on ammoniated maize stover and rice straw respectively, when compared to urea supplemented diets.

The CP digestibility of the ammoniated and urea supplemented diets was significantly ($P \leqslant 0,01$) higher than that of wheat straw alone. Umunna (1982) reported corresponding improvements in the nitrogen digestibility of veld hay supplemented with urea. These improvements were, however, comparatively small and statistically non-significant. Results regarding the effect of ammoniation on the apparent digestibility of CP, compared to unsupplemented wheat straw, agree fairly well with results obtained by Hadjipanayiotou (1982) and Herrera-Saldana *et al.* (1982). The apparent digestibility of CP in the urea supplemented and the ammoniated straws could directly be compared, as these diets were presented on an approximate isonitrogenous basis. A significant reduction of 22,1% was obtained in the apparent digestibility of CP of the ammoniated straw, compared to that of the urea supplemented straw. This finding supports previous results of Cloete *et al.* (1983), who reported a comparable reduction of 25,3% in the apparent digestibility of CP in ammoniated wheat straw based diets compared to urea supplemented diets. Corresponding reductions of the apparent digestibility of CP in ammoniated low quality roughages were reported by Oji *et al.* (1977); Garrett *et al.* (1979); Morris & Mowat (1980); Horton *et al.* (1982); Saenger, Lemenager, Hendrix & Gessert (1982) and Stallcup, Harrison, Kreider & Bayley (1982). Herrera-Saldana *et al.* (1983) also reported a decrease in the apparent digestibility of CP on an ammoniated diet containing approximately 12% CP. Results obtained by Oji *et al.* (1977); Horton *et al.* (1982); Saenger *et al.* (1982) and Herrera-Saldana *et al.* (1983) were statistically significant, while Morris & Mowat (1980) reported a reduction of 14,2% in the CP digestibility of ammoniated maize stover.

An attempt was made to estimate the digestibility of CP added to the straw by ammoniation and/or urea supplementation, by assuming that the contribution of wheat straw as such to the digestible CP content of urea ammoniated and urea supplemented wheat straw remained constant at 0%. By determining the digestible CP content of these diets, estimated digestibility coefficients of 73,4 and 98,3% were calculated for the CP added to these diets by ammoniation (unchanged urea included) and supplementation respectively. If it was further assumed that the unchanged urea in the ammoniated straw also had an apparent digestibility of 98,3%, the apparent digestibility of CP added to the straw by ammoniation (unchanged urea excluded) could be calculated at 59,1%. These results seem to indicate that some of the ammonia added to the straw by ammoniation was not readily utilized by the rumen microbes. Supplemental urea, on the other hand, was easily degraded by the microbes, resulting in the above-mentioned difference in CP digestibility in favour of the urea supplemented wheat straw. Even though these calculations are based on assumptions, and therefore debatable from a scientific viewpoint, it may contribute to a better understanding of CP digestion and utilization of ammoniated low quality roughages.

Ammoniation significantly ($P \leqslant 0,01$) improved the apparent digestibility of CWC, ADF and hemicellulose by 24,1; 14,3 and 39,2% respectively, in comparison with untreated wheat straw. Corresponding improvements of 17,8; 8,7 and 29,2% were obtained when ammoniated wheat straw was compared to urea supplemented wheat straw, the differences being significant at $P \leqslant 0,01$; $P \leqslant 0,05$ and $P \leqslant 0,01$ respectively. The latter results agree fairly well with previous findings of Cloete *et al.* (1983). Corresponding improvements were reported in the apparent digestibility of CWC (Oji & Mowat, 1979; Morris & Mowat, 1980; Saenger *et al.*, 1982), ADF (Oji *et al.*, 1977; Garrett *et al.* 1979; Oji & Mowat, 1979; Morris & Mowat, 1980; Herrera-Saldana *et al.* 1982; Horton *et al.* 1982; Herrera-Saldana *et al.* 1983) and hemicellulose (Saenger *et al.*, 1982). Results obtained from the literature and the present investigation thus indicate that the apparent digestibility of CWC, ADF and hemicellulose tend to be significantly improved by various methods of ammoniation over a wide range of low quality roughages studied. Urea supplementation, on the other hand, tended to improve the apparent digestibility of the various fibre fractions marginally compared to untreated wheat straw. None of these differences were, however, statistically significant.

Nitrogen balance

N-balance figures for the respective diets are represented in Table 3. Ammoniation and urea supplementation significantly ($P \leqslant 0,01$) improved N-intake of wheat straw compared to the control diet. The difference between the former two diets was also statistically significant ($P \leqslant 0,05$) in favour of the urea ammoniated diet. Fecal N-excretion was significantly ($P \leqslant 0,01$) increased by ammoniation when compared to the other two diets. Furthermore, significantly ($P \leqslant 0,05$) more fecal N was excreted on the urea supplemented diet than on the untreated wheat straw. Slightly more nitrogen was excreted in the urine of sheep on the urea supplemented diet compared to the ammoniated diet. This difference was not statistically significant. N-balance was significantly ($P \leqslant 0,01$) improved by urea supplementation and ammoniation. No significant difference in N-balance was obtained between the latter two

treatments. The N-balance of ammoniated straw tended to be marginally higher than that of urea supplemented wheat straw. These results are in general agreement with results obtained by Morris & Mowat (1980); Dolberg *et al.* (1981) and Ummuna (1982). Results obtained by Morris & Mowat (1980) also indicated a higher level of fecal N on ammoniated maize stover diets, while urinary N tended to be higher in urea supplemented diets. Dolberg *et al.* (1981) reported the mean N-balance of untreated rice straw and rice straw ammoniated by 5% of urea to be −2,5 and −0,02 to 0,40 g N/day respectively.

Table 3 Nitrogen balance

	Treatment			SE
	Untreated	Urea supplemented	Ammoniated	mean
N-intake (g/day)	2,3[1 a]	9,4[2 b]	11,1[2 c]	0,144
N-excretion:				
faeces (g/day)	2,4[1 a]	3,4[1 b]	5,3[2 c]	0,099
urine (g/day)	1,8[1]	6,1[2]	5,5[2]	0,128
N-balance (g/day)	−1,9[1]	−0,1[2]	0,3[2]	0,081

[a,b,c] – denotes significant differences ($P \leqslant 0,05$) in the same row
[1,2,3] – denotes significant differences ($P \leqslant 0,01$) in the same row

Conclusions

Mean daily consumption of wheat straw was markedly improved by urea supplementation and urea ammoniation. Voluntary DM intake of ammoniated wheat straw was non-significantly improved by 8,1% over that of urea supplemented wheat straw.

Ammoniation improved the apparent digestibility coefficients of DM, OM and the various fibre fractions significantly over that of urea supplemented and untreated wheat straw. Urea supplementation tended to increase the apparent digestibility of the above-mentioned fractions marginally in comparison with untreated straw.

Both ammoniation and urea supplementation markedly improved the apparent digestibility of CP. The ammoniated and urea supplemented diets were presented on an approximate isonitrogenous basis, and were thus directly comparable. The apparent digestibility of CP in the ammoniated straw was significantly reduced by 22,1% compared to that of urea supplemented wheat straw. It was calculated that approximately 59% of the CP added to the straw by ammoniation was apparently digestible.

N-balance followed the same trend as far as differences between untreated and treated (urea supplemented and ammoniated) wheat straw were concerned. N-balance of ammoniated straw was marginally higher than that of urea supplemented wheat straw, mainly owing to a higher level of urinary N excreted on the latter diet.

Results seem to indicate that wheat straw can effectively be ammoniated by urea in a stack. This method appears to be practical for the ammoniation of wheat straw under farming conditions.

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