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Evaluation of cereal straw treatments comparing anhydrous ammonia *vs* urea solution

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SUMMARY - Three studies were carried out to compare the effect of treatments with anhydrous ammonia and with urea on the nutritive value of straw. Experiment 1 was a study of the effect of moisture level either in anhydrous ammonia or in urea treatments, as well as the effect of the dose of urea in this treatment. Experiment 2 was a comparative study of treatments with anhydrous ammonia and with urea solution applied on barley straw stacks. Finally, in experiment 3, the effect of the suppression of plastic film in urea treatment was studied. The experiment 1 showed that the moisture content (9.2, 22.2 and 32.7%) did not affect the IVDMD when straw was treated with anhydrous ammonia. However, urea treatment presented the best results of IVDMD when it was done at 30% of moisture content. Either experiment 2 and 3 showed that both treatments improved *in vivo* organic matter digestibility of straw, being this improvement slightly greater in anhydrous ammonia than in urea treatment. In experiment 3, results showed that *in vivo* organic matter digestibility of straw treated with urea without plastic film was similar to that presented in urea treatment covered with plastic film.

Key words: Chemical treatment, anhydrous ammonia, urea, straw, moisture, dose, nutritive value.

RESUME - "Evaluation de traitements des pailles de céréales en comparant l'ammoniac anhydre et l'urée en solution". On a mené 3 études pour comparer l'effet du traitement avec de l'ammoniac anhydre et avec de l'urée, sur la valeur nutritive de la paille. L'expérience 1 était une étude de l'effet du niveau d'humidité soit avec le traitement à l'ammoniac anhydre ou à l'urée, ainsi que l'effet du niveau d'urée dans ce traitement. L'expérience 2 était une étude comparative de traitements à l'ammoniac anhydre et à l'urée en solution appliqués à des meules de paille d'orge. Finalement, lors de l'expérience 3 a été étudié l'effet de la suppression du film plastique lors du traitement à l'urée. L'expérience 1 a montré que la teneur en humidité (9,2, 22,2 et 32,7%) n'a pas affecté l'IVDMD lorsque la paille était traitée à l'ammoniac anhydre. Cependant, le traitement à l'urée a présenté les meilleurs résultats d'IVDMD lorsque la teneur en humidité était de 30%. Les expériences 2 et 3 ont montré que les deux traitements amélioraient la digestibilité in vivo de la matière organique de la paille, cette amélioration étant légèrement plus élevée dans le cas du traitement à l'ammoniac anhydre par rapport à celui à l'urée. Dans l'expérience 3, les résultats ont montré que la digestibilité in vivo de la matière organique de la paille traitée à l'urée sans film plastique était semblable à celle que présentait le traitement à l'urée avec couverture de film plastique.

Mots-clés *: Traitement chimique, ammoniac anhydre, urée, paille, humidité, dosage, valeur nutritive.*

Introduction

The treatment of lignocellulosic by-products with anhydrous ammonia in order to improve their nutritive value for ruminants has been largely evaluated (Lawlor and O'Shea, 1979; Wanapat *et al.*, 1985; Givens *et al.*, 1988), and Birkelo *et al.* (1986) observed an increase of 15% of metabolizable energy content due to the anhydrous ammonia treatment.

A similar increase could be obtained with urea in aqueous solution (Wanapat *et al.*, 1985; Dias da Silva and Sundstøl, 1986; Macdearmid *et al.*, 1988), although its effect is less consistent than those obtained with anhydrous ammonia.

The objective of this study was to study the efficiency of urea treatment compared with anhydrous ammonia treatment, as well as to determine the effect of the dosage and the moisture on the effectiveness of treatment.

Materials and methods

Experiment 1. Treatments of barley straw with anhydrous ammonia or with urea

Barley straw (*cv* Georgia) from an irrigated area of the Ebro Middle Valley was used. Thirteen samples of 2 kg of barley straw were treated in double plastic bags (66 x 100 cm). Three samples were treated with anhydrous ammonia at dose of 40 g kg^{-1} DM, and at 10, 20, or 30% of moisture. This treatment was applied injecting anhydrous ammonia directly into the bags containing straw previously moistured. The rest of the samples were treated with urea solution at 40, 65 or 80 g of urea per kg DM, and at 20, 30 or 40% of moisture. Urea solution was applied to the straw manually as homogenous as possible. The samples were kept at room temperature for 2 months.

Experiment 2. Comparative study of treatments with anhydrous ammonia and with aqueous urea solution applied on cereal straw stacks

Two stacks were formed with conventional bales of barley straw (*cv* Georgia) and with a final size of 1 t. One stack was treated with anhydrous ammonia at 35.6 g of anhydrous ammonia per kg DM, and at 22.4% of moisture. The other stack was treated with urea solution at 55 g of urea per kg DM, and at 35.5% of moisture.

These two treatments, with the untreated straw (control), were evaluated in *in vivo* trials, using lots of wethers in groups of eight animals distributed at random. Each

animal received a diet consisting essentially of cereal straw (75-85% of the diet) and 200 g concentrate [Concentrate composition: (% DM) = barley (63.7%), soya cake (25.0%), calcium carbonate (2.8%), bicalcium phosphate (5.07%), magnesium sulphate (1.23%), salt (0.83%), mineral-vitaminic complex (1.60%)]. When control straw was offered to the animal, 9 g of urea were added to the diet in order to even the non-protein N intake. Two meals a day were distributed (8 and 15 h) offering first the concentrate, so that all the quantity offered was totally ingested. Refusals were removed daily.

The experimental period consisted of three phases: (a) adaptation phase, longer than 20 days; (b) digestibility phase (10 days), where diet offered was limited to maintenance level (INRA, 1989), and ingestion and faeces were daily collected at 8 h am; (c) intake phase (20 days), where straw was offered ad libitum, allowing a refusal of 10-15%. The intake was measure during the last 10 days of these phase.

Experiment 3. Study of treatment with anhydrous ammonia and with urea covered or uncovered with plastic film, applied on big size bales (230kg) of straw

Three stacks were formed with bales of 230 kg of barley straw (*cv* Georgia) and with a final weight of 1 t. One stack was treated with anhydrous ammonia at 35 g of anhydrous ammonia per kg DM (Sundstøl *et al.*, 1978). The two rest of stacks were treated with urea solution at 40 g urea per kg DM and at 25% of moisture. One of them was sealed with a plastic film while the other was left uncovered. A fourth stack was used as control. These three treatments were tested in a *in vivo* study, as it has been explained above.

Chemical analysis

All samples were dried in a ventilated oven at 60°C, and grounded to pass 1 mm screen. The following contents were analyzed: ash, crude fibre (CF), total nitrogen (N) (AOAC, 1984), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL) (Goering and Van Soest, 1970), unhydrolysed urea (Watt and Chrisp, 1954), *in vitro* dry matter digestibility (IVDMD) (Tilley and Terry, 1963) and cellulases solubility (Aufrere, 1982).

Results

Experiment 1

Increasing moisture content in anhydrous ammonia treatment from 9.2 to 32.7% caused a decrease of NDF content between 4.3 and 13.5 units in comparison with

straw control (Table 1). Total nitrogen content of straw increased when moisture content increased from 9.2 to 22.2%, while further increases did not have effect on this content (Table 1).

Treatments with urea solution showed a positive relation between ureolysis or urea hydrolysis and moisture content of treatment, and a negative between ureolysis and dose of urea applied. The rate of ureolysis was almost complete at 40% of moisture, independently of the dose of urea applied, while was only about 67-77% when the moisture content was 20%. Treatments with the highest dose of urea (80 g per kg) presented a rate of ureolysis slightly lower than those done at 43 and 65 g urea per kg DM (Table 1).

Total nitrogen content followed the same pattern than ureolysis rate, increasing with the dose of urea (Jayasuriya and Pearce, 1983) and decreasing with the moisture level (Chermiti *et al.*, 1989). In contrast, anhydrous ammonia treatment showed an increase of N content with the moisture content of the treatment (Solaiman *et al.*, 1979; Mandell *et al.*, 1988), which could be related to the rate of fixation of N. This different pattern observed between both treatments was due to the different source of N, because nitrogen from unhydrolyzed urea was considered in the total nitrogen fraction.

Treatments with anhydrous ammonia at dose of 4% and with urea at doses of 4-6% caused a nitrogen fixation and IVDMD values similar between them when the moisture level was about 30%. In anhydrous ammonia treatment, the variation of moisture content (9.2, 22.2 and 32.7%) did not affect the IVDMD, which agrees with Waiss *et al.* (1972), Kiangi *et al.* (1981) and Solaiman *et al.* (1979), and only moisture contents between 2.5 and 10% were determinants (Borhami and Sundstøl, 1982). Supplying additional water would only be interesting in the hypothetic case of using high doses of ammonia, which would fix an amount of nitrogen likely inadequate for animal feeding (Dryden and Leng, 1986).

Experiment 2

Either anhydrous ammonia or urea treatments caused a decrease of NDF content (Table 2), being this reduction greater in anhydrous ammonia treatment.

The *in vivo* trial showed that both treatments caused an increase either in organic matter digestibility (OMD) of the diet or in the straw ($P<0.001$), with an increase in straw of 14.3 and 11.7 units in anhydrous ammonia and urea, respectively (Table 3).

Dry matter intake (DMI) and digestible organic matter intake (DOMI) of diet and straw were significantly increased ($P<0.001$) due to the treatments. The highest DOMI of straw corresponded to anhydrous ammonia treatment, with 24.1 g per kg $BW^{0.75}$, whereas urea treatment and control presented a DOMI of 17.4 g per kg $BW^{0.75}$ and 10.9 g per kg $BW^{0.75}$, respectively. Wanapat *et al.* (1985) and Cottyn and De Boever (1988) also found a slightly superiority of anhydrous ammonia *versus* urea treatment.

Table 1. Chemical composition (% DM basis), ureolysis rate, *in vitro* dry matter digestibility (IVDMD), and organic matter cellulases digestibility (DOM cellulases) of barley straw treated with anhydrous ammonia or with urea under different conditions

Treatment	Dose	Moisture	Nitrogen	Crude fibre	NDF	ADF	ADL	Ureolysis	IVDMD	DMD celulasas
1. Control	-	9.2	0.53	44.6	84.6	49.8	7.6	-	-	-
2. NH_3[1] treatment	4.0	9.2	1.34	44.5	80.3	49.6	8.9	-	50.8	-
3. NH_3 treatment	4.5	22.2	1.75	45.9	74.1	51.9	9.8	-	50.6	-
4. NH_3 treatment	4.1	32.7	1.72	46.2	71.1	52.6	13.6	-	52.9	-
5. Urea treatment	4.3	22.2	1.98	44.9	83.2	51.8	12.4	77	42.8	30.8
6. Urea treatment	4.3	31.1	1.55	45.0	80.3	-	-	93	51.5	34.6
7. Urea treatment	4.3	42.7	0.98	46.2	82.8	51.9	8.3	100	47.6	31.2
8. Urea treatment	6.5	21.2	2.59	44.1	81.77	49.6	8.1	74	43.2	31.1
9. Urea treatment	6.5	31.6	1.86	44.1	79.4	53.7	8.3	91	50.8	35.0
10. Urea treatment	6.5	43.1	1.39	46.5	80.3	53.3	8.4	97	51.4	32.5
11. Urea treatment	8.0	21.8	3.50	43.6	82.3	50.3	8.0	68	40.8	31.3
12. Urea treatment	8.0	32.5	2.61	44.7	78.7	51.3	8.7	83	53.3	36.6
13. Urea treatment	8.0	43.1	1.98	44.7	77.6	51.6	8.7	94	51.4	36.5

[1]NH_3: anhydrous ammonia treatment

Table 2. Chemical composition (% DM basis) of barley straw untreated (control) and treated with anhydrous ammonia (NH_3) or with urea solution, applied in stack

	Control	NH_3	Urea
N applied in stack (% DM basis)	-	2.93	2.37
Moisture content (%)	12.0	22.4	35.5
Chemical composition			
Ash	4.8	4.5	5.6
Crude fiber	45.0	47.2	45.8
NDF	86.1	74.2	78.7
ADF	52.2	52.9	52.1
ADL	8.6	9.8	9.2
Nitrogen	0.49	1.60	1.56

Table 3. Values of digestibility (%) and intake (g per kg $BW^{0.75}$) of barley straw untreated (control) and treated with anhydrous ammonia (NH_3) or with urea solution

	Control	NH_3	Urea	SE	Treatment effect
Digestibility (%)					
Organic matter of diet	54.1^c	64.7^a	61.9^b	1.59	***
Organic matter of straw[1]	41.0^c	55.3^a	52.7^b	1.86	***
Voluntary intake (g per $kg^{0.75}$)					
Dry matter of diet	35.3^c	52.7^a	42.5^b	3.94	***
Dry matter of straw	28.5^c	43.0^a	34.5^b	4.46	***
Organic matter digestibility of diet	17.7^c	32.5^a	24.3^b	2.16	***
Organic matter digestible of straw	10.9^c	24.1^a	17.4^b	2.35	***

[1]Obtained by difference
[a,b,c]Different letters in the same raw are significantly different (P<0.05)
Treatment effect: NS = P>0.05; * = P<0.05; ** = P<0.01; *** = P<0.001

Experiment 3

Chemical composition observed in treated straw showed a superiority of anhydrous ammonia treatment (Table 4), which agrees with the above experiment. NDF contents was reduced in 5 units when straw was treated with anhydrous ammonia, while no changes were reported with urea treatments in relation to control straw.

Table 4. Chemical composition (% DM basis) and *in vitro* dry matter digestibility (IVDMD) (%) of barley straw untreated (control), treated with anhydrous ammonia (NH_3) or treated with urea solution

	Control	NH_3	Urea	
			Uncovered	Covered
Ash	11.6	10.3	10.3	10.5
Nitrogen	0.53	1.71	1.38	1.47
NDF	77.2	72.4	77.1	77.3
IVDMD	41.1	53.3	49.0	46.8

Despite the no changes on NDF due to the urea treatment, OMD of the diet and of the straw was improved by either anhydrous ammonia or urea treatment ($P<0.001$) (Table 5), with values of 53.9, 51.7 and 51.1% in anhydrous ammonia, uncovered urea treatment, and covered urea treatment, respectively, *versus* 46.9% in control. Treatments also caused a significant increase of DMI, as well as of DOMI of the diet and straw ($P<0.001$) (Table 5). Uncovered urea treatment did not present differences with covered urea treatment, which agrees with the results found by Joy *et al.* (1992).

Conclusions

Anhydrous ammonia and urea treatments are two well known techniques to improve the nutritive value of the straw. Results from anhydrous ammonia treatment are more consistent and homogeneous.

It seems that the best results for urea treatment are registered when a dose of urea of 40 g per kg DM and a moisture content of 25-30% are applied. Results from the study of uncovered urea treatment show that the elimination of plastic film could be an attractive aspect to study, because it decreases the economic cost of the treatment.

Table 5. Digestibility (%) and voluntary intake (g per kg $BW^{0.75}$) of barley straw untreated (control) and treated with anhydrous ammonia (NH_3) or with urea solution

	Control	NH_3	Urea		Treatment effect	SE
			Uncovered	Covered		
Digestibility %						
Organic matter of diet	56.3^{b}	61.0^{a}	59.5^{a}	59.9^{a}	***	0.018
Organic matter of straw[1]	46.9^{b}	53.9^{a}	51.7^{a}	51.1^{a}	***	0.029
Voluntary intake (g per kg $BW^{0.75}$)						
Dry matter of diet	52.44^{c}	64.83^{a}	58.18^{b}	57.59^{b}	***	3.92
Dry matter of straw	41.19^{c}	52.69^{a}	45.67^{b}	44.88^{bc}	***	4.09
Organic matter digestible of diet	26.3^{c}	35.45^{a}	31.00^{b}	30.89^{b}	***	2.13
Organic matter digestible of straw	17.32^{c}	25.42^{a}	21.19^{b}	20.58^{b}	***	1.97

[1]Obtained by difference
[a,b,c]Different letters in the same raw are significantly different ($P<0.05$)
Treat effect: NS = $P>0.05$; * = $P<0.05$; ** = $P<0.01$; *** = $P<0.001$

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