Animal Feed Science and Technology, 38 (1992) 319–333
Elsevier Science Publishers B.V., Amsterdam

Chemical treatment of lignocellulosic residues with urea

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(Received 31 January 1991; accepted 24 February 1992)

ABSTRACT

Joy, M., Alibés, X. and Muñoz, F., 1992. Chemical treatment of lignocellulosic residues with urea. *Anim. Feed Sci. Technol.*, 38: 319–333.

A series of comparative studies were undertaken to determine the effects of treatment with anhydrous ammonia and urea mode under different conditions on digestibility and/or voluntary intake of barley straw, wheat straw and maize stover. The following experiments were carried out: Experiment 1: methods of ammoniation of barley straw — in which the treatment of barley straw with anhydrous ammonia (3.56% dry matter (DM) basis and 22.4% moisture content), and with urea applied in solution during baling (6.2% DM basis and 30.5% moisture) or in stack (5.5% DM basis and 35.5% moisture) were studied. Experiment 2: urea levels — wheat straw was treated with urea in increasing dosages (3, 4, 5 and 6% DM basis and 30% moisture). Experiment 3: modifications in form of application — a comparative study was undertaken of treatments of barley straw with urea in solution with and without plastic cover, together with treatment with urea in solid form (4% DM basis and 25% moisture). Experiment 4: voluntary intake by sheep of wheat straw treated with urea — the influence of moisture content (20, 30 and 40%), the form of urea application (solid or solution) and the addition of crude soya bean (3% DM basis), as a source of external ureases, were studied. The treatments were carried out on 300 kg DM stacks of wheat straw; urea was applied at 3% DM basis. Experiment 5: urea treatment of maize stover — maize stover was treated with urea in solution (4% DM basis and 30% moisture), with urea in solid form (4.3% DM basis and 23.3% moisture), and with urea in solid form (4.3% DM basis and 23.3% moisture) and addition of crude soya bean (4.2% DM basis).

All the treatments caused an increase in total nitrogen content and a decrease in neutral detergent fibre content as well as a significant effect ($P<0.01$) on the digestibility of the organic matter (DOM) in the straw. In Experiment 1 the digestibility increased 14.8, 12.8 and 11.7 percentual points in treatments with anhydrous ammonia, urea at baling and urea in stack, respectively. In Experiment 2 the four dosages of urea used were effective, and caused increases in DOM of 7.3, 5.3, 7.4 and 9.0 percentual points for dosages of 3%, 4%, 5% and 6%, respectively. Experiment 3 showed that modifications in the technique were possible, but that the highest digestibility was for plastic-covered urea. Experiment 4 showed that the addition of crude soya bean only had an influence when the treatment was applied at a low moisture level (20%) and that the application of urea in solid form gave an intake of DM lower than that observed for urea in solution. Finally, in Experiment 5 the application of crude soya bean on maize stover was particularly effective both on DOM and on voluntary intake.

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INTRODUCTION

Treatment with anhydrous ammonia (Sundstøl et al., 1978) has been widely studied (Lawlor and O'Shea, 1979; Wanapat et al., 1985; Sundstøl, 1988a,b; Givens et al., 1988) and is estimated to cause an increase in metabolisable energy content in straw of the order of 15% (Birkelo et al., 1986). In treatment with urea the improvements registered in digestibility and voluntary intake are comparable with those obtained with anhydrous ammonia treatment (Wanapat et al., 1985; Dias Da Silva and Sunstøl, 1986; Ochrimenko et al., 1987; MacDearmid et al., 1988 and Muñoz et al., 1991).

The bibliography consulted indicates that in treatment with anhydrous ammonia, temperature, moisture content, dosage and reaction time are all interrelated (Waagepetersen and Vestergaard-Thomnsen, 1977; Sundstøl et al., 1978; Solaiman et al., 1979; Alibés et al., 1983/1984; Cordesse et al., 1983 and Schneider and Flachowsky, 1990). In treatment with urea the same factors have also been observed to be interrelated (Cloete and Kritzinger, 1984; Williams et al., 1984 and Muñoz et al., 1991); the results are less consistent than those obtained with ammonia, however.

On the other hand, the technology of the application of treatments with urea in aqueous solution may be different in certain environmental situations and under certain working methods, and can be modified to adapt to these conditions (Preston and Leng, 1984; Ibrahim et al., 1986). Sundstøl and Coxworth (1984) cite experimental works in tropical countries in which a wide range of local materials, cheaper than polyethylene sheet, were tested to cover the hay.

The objective of this work was to determine the effectiveness of treatment with urea compared with treatment with anhydrous ammonia as well as to determine the influence of dosage and the form of application of the urea, the moisture content, the addition of an external source of ureases and the elimination of plastic cover on the effectiveness of the treatment.

MATERIALS AND METHODS

General methodology

Description of the treatments undertaken

Treatment with anhydrous ammonia. This was undertaken according to the method proposed by Sundstøl et al. (1978). A stack of approximately 1 t of straw was constructed on a 0.7 mm sheeting of transparent polyethylene. The top was covered with the same sheeting and then the two sheets were rolled to give a hermetic seal. Anhydrous ammonia was injected immediately and the stack was left sealed for a minimum of 2 months.

Treatment with urea in aqueous solution applied to stacks. Before treatment, the urea was dissolved in water in quantities relative to the dosage and moisture content desired for the treatment. The first layer of the stack was put in place and the urea solution was applied homogeneously. This process was repeated for all the layers. When the last layer was treated the stack was hermetically sealed in the same way as for treatment with ammonia.

Treatment with aqueous urea solution applied during baling. The urea solution was applied to the straw as it entered the spiral of the baler (Horn et al., 1983). To this end the solution was placed in a tank attached to the baling machine and activated by the pressure group of the tractor. A nozzle system above the entrance to the baler assured homogeneous distribution of the urea solution.

Treatment with urea and the addition of a source of ureases. This consisted in adding an external source of ureases to the treatment with urea (both in solution and solid form) before humidifying the layer in the stack. The source of ureases was crude soya bean (CSB) ground with a 1 mm diameter screen. All the treatments had a minimum duration of 2 months, after which the stack was uncovered and the straw cut up into 8 to 10-cm lengths.

'In vivo' trials

Animals. In the first experiment adult wethers of the 'Fleischaff×Rasa Aragonesa' were used, with weights of between 65 and 73 kg. In the fourth experiment dry 'Rasa Aragonesa' breed ewes were used. In the other experiments 'Rasa Aragonesa' breed wethers with weights of between 40 and 55 kg were used.

Diets. The diets offered consisted of the by-product to be evaluated supplemented with 184 kg dry matter (DM) of concentrate per animal per day. (Composition of concentrate (%DM basis): barley grain, 63.47; soya cake, 25.0; calcium carbonate, 2.80; bicalcium phosphate, 5.07; magnesium sulphate, 1.23; salt, 0.83; mineral–vitamin complex, 1.60.) When untreated straw or maize stover was offered, 9 g of urea was added to the feed per animal per day in order to balance the contribution of non-proteic nitrogen. The diet was distributed twice daily (08:00 and 15:00 h); the concentrate was always offered first to ensure its complete intake.

Experimental management. The animals were distributed randomly into lots so that each treatment was evaluated using four to eight animals. Each experimental period began with an adaptation period longer than 20 days, after which the 10 day digestibility phase started. In this phase the animals received a restricted quantity of the by-product corresponding to the maintenance level proposed by INRA (1989); intake and faeces were individually controlled. Next came the voluntary intake phase in which the by-product was offered 'ad libitum', allowing a refusal in the order of 10–15%, whilst the concentrate was offered in limited quantities (184 g day^{-1}). This phase lasted 20 days and only intake was controlled.

Collection and preparation of samples. During the digestibility phase samples of the basic diet offered, the refusal and faeces were collected daily. The samples, dried at 60°C, were accumulated for each treatment and phase were ground using a 1 mm diameter screen. The samples obtained were identified and stored for later analysis.

Chemical determinations

These were always duplicated; the following contents were determined: DM, ash and total nitrogen (N) (Association of Official Analytical Chemists, 1984), neutral detergent fibre (NDF), acid detergent fibre and acid detergent lignin (Goering and Van Soest, 1970), N-unhydrolysed urea (Watt and Chrisp, 1954), 'in vitro' dry matter digestibility (IVDMD) (Tilley and Terry, 1963). The degree of ureolysis corresponds to the percentage of urea transformed.

Calculations of the digestibility coefficients

Dry matter digestibility (DMD) and organic matter digestibility (OMD) of the by-product were calculated by difference. The DMD and OMD of the concentrate were 85% and 87%, respectively. These values were calculated from the composition of the concentrate, following INRA (1989) guidelines.

Statistical analysis

Individual data obtained were processed using variance analysis followed by Duncan's test (Steel and Torrie, 1980). The statistics package used was from 'Statistical Analysis Systems' (1987).

Experiments undertaken

Experiment 1: methods of ammoniation of barley straw

Three treatments were applied to conventional bales of barley straw (cultivar 'Georgia'): one with anhydrous ammonia (3.56% DM basis and 22.4% moisture), another with urea in solution applied at baling (6.2% DM basis and 30.5% moisture) and the last urea in solution applied in the stack (5.5. DM basis and 35.5% moisture) (Table 1).

The size of the stacks was approximately 1 t, and the three treatments together with untreated straw (control) were evaluated for four lots of five to eight animals.

TABLE 1

Characteristics of treatments with anhydrous ammonia and urea in solution, applied to the stacks or on baling, for barley straw (Experiment 1)

	Anhydrous ammonia	Urea solution	
		On baling	In stack
% DM at harvest	77.6	77.0	85.5
% DM after treatment	77.6	69.5	64.5
Dosage applied (g kg^{-1} DM)	35.6	61.9	55.0
Days of treatment	115	125	119

Experiment 2: urea levels

Five 1 t stacks of wheat (cultivar 'Anza') straw were made; four were treated with urea in solution of increasing dosages: 3, 4, 5 and 6% at a moisture content of 30%; the fifth stack was used as the control.

Experiment 3: modifications in the form of application

Conventional bales were used to make four 1 t stacks of barley straw (cultivar 'Kym'); three stacks were treated with a dosage of 4% urea and a theoretical final moisture content of 25%. The fourth stack was used as the control. One stack was treated only with urea in solution. Another stack was treated with urea in solution and then covered in plastic. The third stack was treated with urea in solid form and then covered in plastic.

Experiment 4: voluntary intake by sheep of wheat straw treated with urea

Twelve stacks of approximately 300 kg DM of wheat straw ('Anza') were made. They were treated with urea at a dosage of 3% and increased moisture-content levels of 20, 30 and 40%. For each moisture-content level, the treatment was carried out with both urea in solution or solid form and the addition or not of CSB as a source of ureases at 3%. A voluntary intake experiment in individual box was undertaken with 42 adult non-pregnant 'Rasa Aragonesa' breed ewes with an average live weight of 45 kg and distributed randomly. Six lots of seven ewes were formed. Because of the large number of treatments the experiment was done in two periods, in each of which six treatments were applied randomly.

Experiment 5: urea treatment of maize stover

Three treatments were applied to three 1 t stacks of maize stover (cultivar 'Pioneer-3183') which had been wetted by rain. The first treatment consisted of the application of urea in solution at a dosage of 4% and a final moisture content of about 30%. The two remaining treatments applied (moisture content: 23.3%) urea in solid form without the addition of water. One was applied with a dosage of urea of 3.9% and the other at a dosage of 4.2% with the addition of 4.2% CSB. The three treatments, together with the maize stover control, were evaluated in the corresponding 'in vivo' trials.

RESULTS

Experiment 1

The three treatments produced a positive effect on the chemical composition of the straw (Table 2). NDF content decreased 11.9, 7.4 and 5.3 percentual points for treatments with anhydrous ammonia, urea in stacks and urea at baling, respectively. The high N unhydrolysed urea content should be emphasised in the treatment with urea on baling as it made up about 50% of added urea.

The 'in vivo' trials (Table 3) showed that all the treatments caused an increase ($P<0.001$) of the OMD both in diet and in straw. This increase was greatest for the ammonia treatment, and was significantly greater ($P<0.05$) than for urea treatments. For voluntary intake there was also a significant effect ($P<0.001$) of the treatment on both intakes, DM ingested and digestible organic matter (DOM) ingested. The highest intake of DOM was for straw treated with ammonia (24.1 g DOM kg^{-1} $BW^{0.75}$) which was greater ($P<0.05$) than for straw treated with urea in stacks (17.4 g DOM kg^{-1} $BW^{0.75}$). The intake for straw treated with urea at baling was 14.8 g DOM kg^{-1} $BW^{0.75}$, which was greater ($P<0.05$) than the control and lower ($P<0.05$) than the other treatments.

Experiment 2

In Table 4 the chemical composition and the IVDMD of the straw are shown. The degree of ureolysis was greater than 80% for all the treatments

TABLE 2

Chemical composition of untreated barley straw and barley straw treated with anhydrous ammonia or urea in solution, applied on baling or to the stack (Experiment 1)

Chemical composition (% DM)	Control	Anhydrous ammonia	Urea solution	
			On baling	In stack
Ash	4.8	4.5	5.1	5.6
Neutral detergent fibre	86.1	74.2	80.8	78.7
Acid detergent fibre	52.2	52.9	50.9	52.1
Acid detergent lignin	8.6	9.8	9.5	9.2
Nitrogen content	0.49	1.60	2.64	1.56
N-unhydrolysed urea	–	–	1.43	0.41

TABLE 3

Digestibility and voluntary intake for treated and untreated barley straw (Experiment 1)

	Control	Anhydrous ammonia	Urea treatment		Significance	√MSE[1]
			On baling	In stack		
Number of animals	8	7	6	5	–	–
Digestibility (%)						
OM diet	54.1c	64.7a	62.5b	61.9b	***	1.59
OM straw	41.0c	55.3a	53.8b	52.8b	***	1.86
Voluntary intake ($g\ kg^{-1}\ BW^{0.75}$)						
DM diet	35.3c	52.7a	38.0bc	42.5b	***	3.94
DM straw	28.5a	43.0a	29.2bc	34.5b	***	4.46
DOM diet	17.7c	32.5a	21.8b	24.3b	***	2.16
DOM straw	10.9d	24.1a	14.8c	17.4b	***	2.35

***$P<0.001$.

$a \neq b \neq c \neq d = P<0.05$.

[1]√MSE, root square of mean square error.

TABLE 4

Chemical composition and 'in vitro' dry matter digestibility (IVDMD) for untreated wheat straw and wheat straw treated with urea in solution (Experiment 2)

Chemical composition (% DM)	Control	Urea treatment			
		3%	4%	5%	6%
Ash	8.9	7.2	8.7	8.1	7.9
Neutral detergent fibre	–	79.3	77.5	77.4	74.1
Nitrogen content	0.84	1.08	1.37	1.32	2.23
N-unhydrolysed urea	–	0.27	0.31	0.30	1.01
IVDMD	36.7	41.7	44.1	45.9	47.4

except treatment with urea dosage of 6%, which gave a degree of ureolysis of 63%. The IVDMD values tended to increase with the dosage.

The 'in vivo' trials (Table 5) showed that treatment with urea caused a significant ($P<0.001$) improvement both for OMD and DM straw intake; urea dosages made hardly any difference.

Experiment 3

The chemical composition of treated and untreated barley straw is shown in Table 6. The three treatments were effective, with a significant ($P<0.001$)

TABLE 5

Digestibility and voluntary intake coefficients for untreated wheat straw and wheat straw treated with urea (Experiment 3)

	Control	Urea treatment				Significance	√MSE[1]
		3%	4%	5%	6%		
Number of animals	8	6	6	5	6	–	–
Digestibility							
OM diet	52.8b	57.9a	56.7a	58.2a	59.1a	***	2.41
OM straw	44.1c	51.4ab	49.4b	51.5ab	53.1a	***	2.41
Voluntary intake ($g\ kg^{-1}\ BW^{0.75}$)							
DM diet	43.8b	54.4a	52.9a	56.6a	53.6a	**	5.42
DM straw	33.4b	44.5a	42.7a	48.9a	43.6a	***	5.56
DMO diet	21.2b	28.5a	27.1a	30.3a	28.5a	***	2.71
DMO straw	13.6a	20.9ab	19.2b	22.5a	21.6ab	***	2.41

$^{**}P<0.01$; $^{***}P<0.001$.
$a \neq b \neq c \neq d = P<0.05$.
[1] √MSE, root square of mean square error.

TABLE 6

Chemical composition (% DM) of untreated barley straw (control) and barley straw treated with urea in three types of treatment (Experiment 3)

	Control	Urea treatment			Significance	√MSE[1]
		Solution		Solid		
		Covered	Uncovered	Covered		
DM	98.5	85.5	89.8	81.5	**	1.68
Ash	9.5	9.6	9.6	9.5	NS	0.24
Neutral detergent fibre	76.9	73.4	75.5	75.3	NS	1.05
Acid detergent fibre	47.6	49.1	47.8	49.3	NS	2.20
Acid detergent lignin	6.3	5.1	5.6	6.1	NS	0.47
Nitrogen content	0.70	2.02	1.64	2.00	***	0.125
N-unhydrolysed urea	–	0.70	0.61	0.86	–	–

$^{**}P<0.01$; $^{***}P<0.001$; NS, $P>0.05$.
[1] √MSE, root square of average square error.

effect on N content. NDF content decreased ($P>0.05$) from 3.3 to 1.4 points compared with the control.

The 'in vivo' trials (Table 7) also showed the positive effect of these three treatments on straw OMD and on voluntary intake ($P<0.001$).

TABLE 7

Digestibility and voluntary intake for untreated barley straw and barley straw treated with urea in three types of treatment (Experiment 3)

	Control	Urea treatment			Significance	$\sqrt{MSE}$[1]
		Solution		Solid		
		Covered	Uncovered	Covered		
Number of animals	8	8	8	8	–	–
Digestibility						
OM diet	55.1c	63.4a	59.4b	62.5a	***	1.85
OM straw	48.2a	58.6a	53.9b	57.1a	***	2.13
Voluntary intake ($g\ kg^{-1}\ BW^{0.75}$)						
DM diet	55.8b	70.4a	58.5b	67.4a	***	5.43
DM straw	46.8b	61.5a	49.5b	56.9a	***	5.45
DMO diet	27.6d	40.0a	31.6c	36.9b	***	2.57
DMO straw	20.4d	32.5a	25.2c	29.3b	***	2.44

**$P<0.001$.

$a \neq b \neq c \neq d = P<0.05$.

[1]$\sqrt{MSE}$, root square of mean square error.

Experiment 4

The chemical composition and the IVDMD of wheat straw treated with urea under different conditions are shown in Table 8. At low moisture levels (20%) the addition of a source of ureases had a positive effect on the degree of ureolysis and IVDMD, the last giving values of 41.1 versus 33.7 and 38.2 versus 32.9 for treatments with urea in solution and in solid form, respectively.

In trials on voluntary intake in sheep (Table 8), treatment with urea in liquid form was appreciably superior ($P<0.01$) to treatment in solid form (49.8 versus 44.7 g DM $kg^{-1}\ BW^{0.75}$). A moisture content by ureases interaction ($P<0.001$) would explain the positive effect of the application of ureases when the moisture content is low.

Experiment 5

The most remarkable changes in chemical composition (Table 9) were the decrease in NDF content and the logical increase in N content for the three treatments. The degree of ureolysis was 100% for the treatment with urea in solution, while for treatments with urea in solid form it was 40.8% without the addition of CSB and 76.8% with the addition of CSB. The estimation of

TABLE 8

Chemical composition (% DM), 'in vitro' dry matter digestibility (IVDMD) and voluntary intake of wheat straw treated with urea under different conditions (Experiment 4)

Moisture content	Application of urea	Addition of ureasas	Ash	NDF	N	N-unhydro-lysed urea	IVDMD	Straw intake g DM kg^{-1} $BW^{0.75}$
20%	Solution	No	8.7	78.3	1.25	0.28	33.7	44.8
		Yes	9.0	72.4	1.40	0.19	41.1	58.6
	Solid	No	9.7	77.6	1.16	0.51	32.9	36.9
		Yes	9.2	75.0	1.49	0.17	38.2	50.7
30%	Solution	No	9.1	75.4	1.22	0.05	40.9	52.4
		Yes	9.2	76.6	1.03	0.04	44.4	44.4
	Solid	No	9.3	77.9	1.17	0.10	37.4	45.5
		Yes	9.8	75.7	1.32	0.15	34.4	40.1
40%	Solution	No	8.7	78.8	0.97	0.04	37.5	46.6
		Yes	9.7	75.5	1.02	0.01	42.3	50.4
	Solid	No	9.4	78.1	1.05	0.17	35.2	49.7
		Yes	9.5	76.3	1.20	0.17	40.8	45.7

TABLE 9

Chemical composition (% DM) and 'in vitro' dry matter digestibility (IVDMD) of untreated maize stover and maize stover treated with urea under different conditions (Experiment 5)

Chemical composition (% DM)	Control	Urea treatment		
		Solution	Solid	
			Without ureases	With ureases
DM after treatment	76.7	70.0	76.7	76.7
Ash	7.8	9.2	9.7	8.8
Neutral detergent fibre	76.5	72.8	71.0	71.6
Acid detergent fibre	43.7	43.1	–	41.4
Acid detergent lignin	7.0	6.0	–	5.7
Nitrogen content	0.68	1.45	2.02	1.78
N-unhydrolysed urea	–	0.00	1.06	0.49
IVDMD	49.9	55.5	50.0	54.8

TABLE 10

Digestibility and voluntary intake for untreated maize stover and maize stover treated with urea (Experiment 5)

	Control	Urea treatment			Significance	√MSE[1]
		Solution	Solid			
			Without ureases	With ureases		
Number of animals	4	6	6	4	–	–
Digestibility (%)						
OM diet	62.9a	61.6a	56.2b	61.1a	***	2.34
OM maize stover	50.5b	54.3a	49.5b	57.0a	***	2.29
Voluntary intake ($g\ kg^{-1}\ BW^{0.75}$)						
DM diet	40.9c	43.8c	53.4b	65.3a	***	3.71
DM maize stover	30.5c	33.4c	43.5b	55.3a	***	3.74
DOM diet	23.4c	24.8cd	26.9b	36.3a	***	2.00
DOM maize stover	14.2c	16.4c	19.4b	28.8a	***	1.95

***$P<0.001$.
$a \neq b \neq c = P<0.05$.
[1]√MSE, root square of mean square error.

the IVDMD showed that the treatment with urea in solid form without the addition of CSB did not improve this parameter; however the other treatments improved the parameters by about five points.

During the 'in vivo' trials (Table 10) no significant ($P>0.05$) improvement of the OMD of maize stover treated with urea in solid form without the addition of CSB was observed. On the contrary, the rest of the treatments significantly ($P<0.05$) improved both OMD and DOM ($g\ kg^{-1}\ BW^{0.75}$) intake of maize stover.

DISCUSSION

A comparison of the treatments with anhydrous ammonia and urea in solution (Experiment 1) reveals a slight superiority in the first, as has already been observed by Wanapat et al. (1985) and Cottyn and De Boever (1988). As to the two methods for applying urea, the results obtained from the application at baling were irregular; this concords with the observations of Cottyn and De Boever (1988). Apparently, the presence in excess of N-unhydrolysed residual urea may be the cause of the low intake (MacDearmid et al., 1988) for application at baling.

The effect of increased dosages of urea (Experiment 2) was not always evident. The treatments with highest dosages of urea (5 and 6%) gave values for OMD straw and intake which were slightly higher, although not always significantly so; this concords with the general behaviour of treatment with ammonia described by Sundstøl et al. (1978), Dryden and Leng (1988) and Schneider and Flachowsky (1990). In general terms a dosage of 3–4% urea can be considered sufficient when the treatment is carried out with a moisture content of about 30%.

Treatment with urea in solid form gave slightly inferior results to those obtained from treatment with urea in solution with plastic covering and superior to those for treatment without covering. The modifications to the proposed techniques in Experiment 3 are feasible although less effective than treatment with urea in solution and plastic covering.

The lower degree of ureolysis observed for treatment with urea in solid form together with the lower intake with respect to treatment with urea in solution could indicate that this type of treatment needs higher ambient temperature and moisture content, since these factors determine the dissolution of the urea and probably determine the posterior alkali effect.

The addition of CSB as a source of ureases noticeably improved the degree of ureolysis for treatments up to 20% moisture content. Williams et al. (1984) and Chermiti et al. (1989) did not observe any additional improvement when CSB was added in treatments undertaken at 30% and 25–50% moisture content, respectively. This would be the consequence, according to Dias Da Silva et al. (1988), of the interaction existing between moisture content and the addition of a source of ureases.

The four treatments applied to maize stover (Experiment 5) presented different circumstances. The application of urea in solid form gave low levels of ureolysis and a low response for digestibility; this could be because the treatment was applied with insufficient moisture-content levels so that the urea did not dissolve sufficiently. The application of urease gave a very positive response both for digestibility and for voluntary intake; this cannot be explained only by the modifications observed in the chemical parameters. Besle et al. (1990) also observed highly significant response in intakes related to the application of additional ureases.

CONCLUSIONS

In temperate climates, treatments of cereal straw with urea at dosages of about 4% and the addition of water to bring moisture levels up to between 25 and 30% produce an important improvement in digestibility and also in intake of the by-product. The quality of these treatments should be of the same order as for treatments with anhydrous ammonia. The addition of a source of ureases only seems necessary for moisture levels lower than 20% in the cases of barley and wheat straw; the case of maize stover seems much more interesting and would be worth studying in the future. The optimum dosages for different types of ureases are unknown.

The technique of applying urea in solid form could be interesting, although the results observed were inferior to those for treatments with urea in solution. It may also be possible, for economic reasons, to do without plastic covering, although this would have to be confirmed in future experiments.

ACKNOWLEDGEMENTS

The authors wish to thank the CICYT, CEE-STD and CONAI for funding this work and J. Perez Revuelto, T. Fustero and A. Legua for their help in carrying it out. Thanks are also due to E. Molina and A. Purroy for their helpful suggestions.

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