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Nutritional value and use of ligno-cellulosic feed treated with urea in the ruminant diet

V. Cañeque*, S. Velasco* and J.L. Sancha**
*Area de Producción Animal, Centro de Investigación y Tecnología (CIT), Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA), Puerta de Hierro s/n, 28040 Madrid, Spain
**Servicio de Investigación Agraria (SIA), Comunidad de Madrid, Finca "El Encín", P.O. Box 127, Alcalá de Henares, 28800 Madrid, Spain

SUMMARY - Urea is an interesting alternative to anhydrous ammonia in the treatment of ligno-cellulosic foodstuffs due to its lower cost and easier handling. The urea treatment is based on adequate ureolysis and on the effect of ammonia on the composition of straw. Its outcome is influenced by a series of factors considered in the present study which include: dose of urea applied, initial quality and moisture content of the material treated, duration of the treatment and temperature conditions under which the treatment is applied.

Key words: Straw, urea treatment, nutritional value, composition.

RESUME - *"Valeur nutritionnelle et utilisation d'aliments lignocellulosiques traités à l'urée pour le régime des ruminants". L'urée devient une alternative valable par rapport au traitement avec de l'azote pour les produits à composition lignocellulosique. L'intérêt de son utilisation ressort de son prix inférieur et de sa plus grande facilité de manipulation. La base des traitements à l'urée repose d'un côté sur la production d'une correcte uréolyse, et de l'autre sur l'effet de l'azote ainsi produit sur la composition chimique finale des aliments traités. Dans ce travail on analyse plusieurs facteurs qui peuvent influencer les résultats du traitement : la dose d'urée, la teneur initiale en humidité du produit à traiter, la durée et la température du traitement, et la qualité initiale du produit traité.*

Mots-clés : *Paille, traitement à l'urée, valeur nutritionnelle, composition chimique.*

Introduction

Every year, Spain produces 3 million Mt of wheat straw, 15 million Mt of barley straw and approximately 300,000 Mt of oat straw (MAPA, 1994), a large portion of which could be used for ruminant feed. The utilization of this straw is limited, owing to the low digestibility of its organic matter (OM) and its reduced intake. On the other hand, its high level of structural carbohydrates, like cellulose and lignin, (70-80% of the dry matter, DM, according to Dias-da-Silva, 1988a), makes it a potentially important source of energy, although its protein content will always remain low.

Improving the quality of straw is possible, either by the addition of easily fermentable nitrogenous material, minerals and carbohydrates which increase its intake and make it more beneficial to ruminants, or through diverse treatments which make it more readily digestible and even contribute all or part of the nitrogenous components which it lacks.

One of the best known methods for improving the digestibility and intake of straw or ligno-cellulosic foodstuffs is through chemical treatment with alkalis (Chenost and Dulphy, 1987; Sundstøl, 1988). Treatment with ammonia has been widely practised as it improves the nutritional value of the straw; however, the use of ammonia is in decline as its handling presents certain difficulties.

A possible alternative to the use of ammonia is the utilization of its precursor, urea. This substance presents a series of advantages, such as its easy acquisition and simple and danger-free use, as well as its lower cost. Furthermore, urea is non-toxic to animals when used at a dose of 5% of DM of the ration, or lower (Jarrige, 1978).

The principle of the urea treatment consists in the release of ammonia from urea due to the effect of the enzyme urease. Ureolysis occurs slowly and progressively while the ureasic activity of the medium is stable (Garambois, 1986). The ammonia thus released under favourable environmental conditions gives rise to the modification of the ligno-cellulosic bonds, which in turn increases its nutritional value.

In addition, treatment with urea enriches the nitrogen content of the feed, multiplying it by two or three times its initial value at the average urea dose of 5-6% of the DM (Chenost *et al.*, 1987). The improvement seen is in general superior to that obtained through the treatment with anhydrous ammonia, in part because of the effect of the residual, non-decomposed urea (Besle *et al.*, 1990a), and in part due to the fact that volatile nitrogen losses are generally inferior to those which occur with ammonia treatments. The percentage of nitrogen retention varies greatly according to different authors, ranging from figures inferior to 30% (Abdouli and Khorchani, 1987), to between 39-50% (Hadjipanayiotou, 1982) or above 50% (Abdouli *et al.*, 1988).

The nitrogen retained in the treated foodstuffs is found under different forms, such as:

(i) Water-soluble ammoniacal nitrogen, which represents 43-53% of the nitrogen retained (Michalet-Doreau and Guedes, 1989).

(ii) Water-soluble non-ammoniacal nitrogen, accounting for about 23% of the nitrogen retained (Nelson *et al.*, 1984).

(iii) Water-insoluble non-ammoniacal nitrogen, which constitutes a quantity similar to that of the water-soluble nitrogen. One part is soluble in neutral detergents, while the other is not, being tightly bound to the cell walls.

Factors which influence the treatment of ligno-cellulosic feed with urea

The efficiency of the treatment of ligno-cellulosic feed with urea is influenced by diverse factors such as the dose applied, the initial moisture content, the duration of the treatment, the initial quality of the material to be treated and the temperature conditions under which the treatment is carried out. The effects of these factors are set forth below.

Effect of moisture

Moisture greatly influences the efficacy of the treatment (Dias-da-Silva, 1988a; Chermiti *et al.*, 1989; Muñoz *et al.*, 1991). This is even more the case when urea is used than when ammonia is applied directly (Joy, 1991), as the presence of water is necessary in order for ureolysis to take place (Dias-da-Silva, 1988b). Furthermore, increased moisture favours contact between ammonium and the cell wall (Mandell *et al.*, 1988).

Our values of residual urea for feed treated with 6% urea at different initial levels of moisture for 45 days are set out in Table 1. It is clear that these values were strongly influenced by the moisture level, being high when moisture was only 20%, markedly decreasing at a 30% moisture level, and practically displaying total ureolysis when moisture was 40%. Sahnoune (1990) found that ureolysis was complete at a moisture level of 30% at the third week of treatment, although the dose of urea used was only 40 g kg^{-1}; when the dose was doubled 12 weeks of treatment were needed, while this period was reduced to three weeks when the initial moisture was increased to 40%. Other authors, such as Dias-da-Silva *et al.* (1988) and Hassoun *et al.* (1990), also note that ureolysis improves when the moisture level rises, producing a better final result in the feed thus treated.

The drop in neutral detergent fibre (NDF) of straws treated with urea, in comparison with that of control straws, was essentially due to the partial solubilization of the hemicellulose, as seen in Table 1. The degree of solubilization varied in accordance with the initial moisture of the straw, reaching 25% at a 40% moisture content, and decreasing to 16% at a 30% moisture level, in the case of barley straw. Cell walls respond best to treatments with urea at a high moisture level as this causes them to swell (Gómez-Cabrera, 1979), expediting the effect of the ammonia produced and its retention.

The acid detergent fibre (ADF) content of the straw generally increases with the urea treatment and is normally favoured by a high moisture level (Hassoun *et al.*, 1990).

The crude protein (CP) value of the feed treated displayed an inverse evolution with regard to the moisture content (Table 1); the highest levels were found at the lowest moisture level, due to the greater proportion of urea which did not react and thus appeared as residual urea. On the contrary, when moisture increases, residual urea decreases (more intense ureolysis), and greater losses of volatile ammoniacal nitrogen may occur (Cloete and Kritzinger, 1984; Abdouli and Khorchani, 1987), for which reason the CP usually decreases.

Table 1. Mean values of the parameters affected by the treatment of ligno-cellulosic feed with urea under diverse moisture and temperature conditions

Treatment conditions		Effect on						
		Chemical composition (% DM)			Nitrogenous fraction		Rexen digestibility (%)	Theoretical degradability of DM $K_p = 3\%\ h^{-1}$
Moisture	Temperature	NDF	Hemicellulose	CP	Residual N-urea x 6.25 (% DM)	Retained nitrogen (%)		
Barley straw								
20%	20°C	69.34	22.72	21.26	15.75	0.00	38.26	47.64
20%	35°C	69.06	28.81	22.87	16.81	0.00	41.94	51.47
30%	20°C	70.08	27.21	14.68	5.18	18.05	40.58	51.00
30%	35°C	68.35	25.31	18.87	7.43	27.91	51.11	56.01
40%	20°C	70.32	26.47	11.71	1.18	23.43	44.91	50.40
40%	35°C	66.57	22.74	14.71	0.69	39.69	54.91	57.03
Untreated		71.31	30.19	5.88	–	–	31.56	44.16
Wheat straw								
20%	20°C	73.15	30.16	20.11	12.50	13.74	37.10	
20%	35°C	73.95	30.25	21.35	13.00	17.59	39.35	
30%	20°C	73.63	28.72	11.64	1.87	24.67	36.89	
30%	35°C	73.07	26.95	15.58	5.68	25.19	46.99	
40%	20°C	75.15	28.17	10.06	0.00	26.25	39.93	
40%	35°C	71.51	24.25	12.89	0.00	40.57	47.79	
Untreated		74.33	30.69	4.47	–	–	32.01	
Vetch-oats hay								
20%	20°C	44.44	18.97	32.46	16.50	12.73	59.81	
20%	35°C	46.12	20.80	33.90	13.43	35.35	61.80	
30%	20°C	46.54	18.77	27.73	9.69	23.27	60.34	
30%	35°C	49.85	20.27	30.16	7.62	45.90	64.18	
40%	20°C	45.66	15.44	23.34	1.37	43.04	61.91	
40%	35°C	49.53	18.84	27.29	1.25	63.62	67.05	
Untreated		45.15	18.16	14.16	–	–	59.47	

In short, the efficacy of nitrogen fixation measured as retained nitrogen (RN) increases along with the moisture, reaching values of close to 40% in wheat and barley straws.

$$RN\ (\%) = \frac{\text{Total N - Initial N - Residual urea N}}{\text{Added N}}$$

Other authors have found values similar to those noted in Table 1. Thus, Hadjipanayiotou (1982) found a 44% nitrogen retention after 40 days of treatment and Ben Salen *et al.* (1994) note values close to 40%.

Soluble nitrogen decreases with increased moisture as a result of the drop in the residual urea. This reduction is in part compensated for by the increase in ammoniacal nitrogen, for which reason a high level (over 50%) of soluble nitrogen, beneficial to the ruminal microflora (Ben Salen *et al.*, 1994) is generally maintained.

The urea treatment elevated the straw's *in vitro* digestibility [Rexen (1977) method] by 10 points at 30% moisture, and 15 points at 40% (Table 1). Digestibility increased for two reasons: on the one hand because of the solubilization of a fraction of the NDF (Laurent *et al.*, 1982), and on the other, due to an indirect effect of the treatment through which the crystalline structure of the cellulose is altered (Han *et al.*, 1983), favouring the action of micro-organisms. Other authors have also reported this effect of moisture on digestibility (Williams *et al.*, 1984a; Dias-da-Silva, 1988b).

The degradability of the barley straw also improved (Table 1) as a result of the urea treatment; the best results were observed at high moisture levels. When moisture rose from 20% to 30% the theoretic degradability jumped from 51.5% to 56%, in comparison with the 44.1% of untreated straw. Kundu (1988) also found that the degradability of wheat straw (40.4% when untreated) rose to 46.9% and 53.1% after 48 hours of treatment with 3.2 g of urea per 100 g of DM for 25 and 34 ml of water per 100 g of straw DM, respectively.

Effect of the temperature

After reviewing the data, Du Preez (1983) and Muñoz *et al.* (1991) have concluded that 30°C is the optimum temperature for the urea treatment, in so far as its effect on ligno-cellulosic residues.

Higher temperatures accelerate the process of the urea treatment. Thus, an 8-week long treatment at 24°C would be similar to a scarcely 1-week long treatment at 35°C (Cloete and Kritzinger, 1984).

The greater effect of the urea treatment at high temperatures may also be related to increased ureasic activity, as the optimum temperature for this enzyme's activity in the soil is 30°C (Du Preez, 1983), while it decreases as the temperature drops (Ørskov *et al.*, 1983).

On the other hand, ureasic activity can drop as a result of both low and of high temperatures. Thus, Cloete and Kritzinger (1984) observed lower ureasic activity in the urea treatments at temperatures of 4°C and 35°C.

Table 1 sets forth the results regarding the effect of temperature on straw treated with urea. As the temperature rose the proportion of NDF dropped, being low at a moisture level of 20%, and high at one of 40%, thereby demonstrating an interaction between moisture and temperature. The greatest solubilization of hemicellulose for barley straw (about 25%) was achieved with a combination of 40% moisture and 35°C. The ADF was not affected by temperature, although the results of other authors are contradictory (Reid *et al.*, 1988). Nitrogen bound to the fibre was slightly affected by the moisture level, rising along with it; this effect was potentiated when the temperature also rose.

Authors including Muñoz *et al.* (1991) have also reported the beneficial effect of high temperatures, especially in conjunction with high moisture levels. The latter note that an increase of the temperature from 15°C to 35°C reduces the NDF content of the straw by three points. In turn Cloete and Kritzinger (1984) report moisture x temperature interaction as a result of a greater quantity of urea hydrolysed at high temperature and moisture levels.

Ureolysis was not favoured by increased temperature in the case of barley and wheat straws, as the values of the residual urea increased along with the temperature (Table 1), especially at an intermediate moisture level of 30%. We observed moisture x temperature interaction. Muñoz *et al.* (1991) and Dulphy *et al.* (1992) also note that this interaction exists for ureolysis, although the improvement is generally greater as the temperature rises.

Temperature also affected the crude protein content of the straw (Table 1), which increased as the temperature rose. The highest CP values were seen at 20% moisture, coinciding with data reported by Cloete *et al.* (1983b) and Muñoz *et al.* (1991). These authors note that the conversion index of urea to ammonia is inferior at 35°C than at lower temperatures, possibly due to lower ureasic activity at high temperatures when sufficient moisture is lacking.

More nitrogen was retained as the temperature and moisture levels increased. The maximum nitrogen retention in straw (nearly 40%) occurred at 35°C and a 40% moisture level. Similar values have been found by Hadjipanayiotou (1982) and Ben Salen *et al.* (1994).

Alibés *et al.* (1984) point out the importance of a high atmospheric temperature in order to achieve optimum results in urea treatments, and in particular to insure good nitrogen retention, provided that the moisture level is also sufficient.

In vitro digestibility, determined by the Rexen method (Rexen, 1977), rose between 10 and 15 points at 20°C in the case of barley straw (Table 1), and 20 points when the temperature was 35°C, and this increase was greatest at high moisture levels. Other authors have also noted this interaction between moisture and temperature. Cloete and Kritzinger (1984), for example, report that the moisture level has no effect on *in vitro* digestibility at low temperatures, while it does when temperature increases.

The clearest effect of temperature was seen on the degradability parameters. In the case of the DM, when the temperature rose from 20°C to 35°C, the value of the soluble fraction (a) climbed from 20.56% to 23.53%; the potentially degradable fraction (b) increased from 60.33% to 62.32%; the velocity of degradation climbed from 2.81% h^{-1} to 3.05% h^{-1} and the theoretic degradability (Table 1) rose from 49.68% to 54.83%. In every case, significant differences with regard to control straw values were observed at 35°C.

The maximum improvement in the degradability parameters was seen when the treatment was carried out at 40% moisture and 35°C, while the results at 30% moisture and 35°C were very close. The reduction of the indigestible fraction by 6 points and the increase of the theoretic degradability by 12 points, as compared with the same parameters of untreated barley straw, should be noted (Table 1).

The effect of temperature on the degradability parameters of the fibres (ADF and NDF) was also marked, and the best results occurred at 30% and 40% moisture and 35°C. The theoretic degradability values were particularly high; in the case of NDF these jumped from 32.71% in untreated barley straw to 45.17% and 46%, respectively, in straw treated at 30% and 40% moisture and 35°C.

In general, the values determined in our study for the parameters that define degradability are superior to those of other authors, although the latter vary greatly. Thus, in a compilation of studies on straws from different sources, Susmel *et al.* (1994) note values for "a" from 1.1% to 21.46%, although the average for cereal straws of Spanish origin was 14.6%. For fraction "b", these authors report values ranging from 44.5% to 86.1%, with a mean value of 55% for Spanish straws. The value of "c" ranged between 1.6% h^{-1} and 5.6% h^{-1}, with an average value of 3.6% h^{-1} for Spanish straws.

Ørskov *et al.* (1990) studied several varieties of winter and summer barley straws, noting differences in their degradability. According to these authors, degradability is greatest in years or seasons with low rainfall, because when abundant water exists, losses in the soluble fraction of the straw occur due to a faster passage of this fraction to the grain. This would help to explain the high degradability values for the soluble fraction found in our study, as our straws were harvested during a year of severe drought.

Magheni *et al.* (1993) also found that the degradability parameters of rice straw treated with urea were higher than those of untreated rice straw. These authors report that the sum of the fractions "a" and "b" for the DM rose from 65.4% to 72.0% as a result of the treatment, and that "c" jumped from 1.9% to 4.3% h^{-1}. The theoretic degradability for a passage rate of k_p = 2% h^{-1} also increased from 39.6% to 53.6%.

In studies carried out by Ben Salen *et al.* (1994) on sorghum stovers, the DM value of the "a" + "b" fraction rose from 61.4% in untreated stovers to 68.4% after urea treatment. The rate of disappearance of DM from the sorghum stover was always above that of the untreated stover at whatever incubation time; other authors, including Fahmy and Ørskov (1984), Dryden and Leng (1988) and Silva and Ørskov (1988), have also noted the same phenomenon in various cereal straws.

Among others, Ben Salen *et al.* (1994) note that the degradation of the DM after 48 hours in the rumen is similar to the digestibility of crude fibre, making this value a useful estimate of crude fibre digestibility.

Effect of the initial quality of the material treated

The effect of the urea treatment on the digestibility of the organic material (OM) depends on the initial characteristics of the material treated. The best results, both with ammonia-based (Kernan *et al.*, 1979) as well as other alkali-based (Lufadeju *et al.*, 1985; Ørskov, 1987) treatments are generally obtained from poor quality feeds.

Various authors have quantified the relationship that exists between the increased digestibility produced by the treatment and the digestibility of the initial material, and have found that a high and negative correlation exists between them. Thus, Gómez-Cabrera *et al.* (1985) noted a correlation of r = -0.8, pointing out that the poorer the initial quality of the treated product the greater the effect on the nutritional value of the fibrous foodstuffs as a result of the alkali treatment. A somewhat lower correlation was found by Chenost and Dulphy (1987) from a compilation of bibliographic data; these authors note that the increase in digestibility of the OM *in vivo* dropped from 14.5 to 6.3 points when the OM digestibility of the untreated forage rose from 30% to 60%.

We observed (Table 1), a somewhat better solubilization of the hemicellulose in barley straw, in spite of this straw's higher initial quality due to its lower NDF content. Real differences were seen for the vetch-oats hay, which contained only 45.15% of NDF, and whose composition after urea treatment was not affected, as scarcely any hemicellulose solubilization occurred. This coincides with the general idea that treatments of fibrous material with alkalis affect low-quality forages, whereas the effect tends to be annulled as the initial quality of the material improves (de Boever *et al.*, 1987; Cottyn and de Boever, 1988; Mann *et al.*, 1988; Reid *et al.*, 1988).

As previously noted, ureolysis is normally favoured by increased moisture, decreasing somewhat when temperatures rise. This was not the case, however, with vetch-oats hay, in which ureolysis clearly improved as the temperature rose, particularly when the moisture level was low (20%). The quantity of nitrogen retained improved slightly in the case of wheat straw as compared to barley straw, but the improvement was especially marked in the case of vetch-oats hay, which displayed values of 43% at 20°C and 63% at 35°C, at a 40% moisture level, far higher than those of the aforementioned cereal straws.

It must also be noted that more nitrogen was bound to the NDF of vetch-oats hay than to that of cereal straws, passing from 1.5% in untreated material to 3.28% in vetch-oats treated at low moisture and temperature levels, and increasing to values near 6% at 35°C and high moisture levels (30% and 40%).

The effect of the urea treatment on Rexen digestibility was most important in the case of barley straw (Table 1), which increased more than 20 points at high moisture and temperature levels. The next most important result was found in wheat straw, whose digestibility increased or decreased coinciding with the rise or fall of moisture and temperature values. Lastly, vetch-oats hay saw only limited changes; an important improvement (8 points) was observed only at high moisture levels and temperatures. This was due to the lack of hemicellulose solubilization, and the improvements which occurred can only be attributed to an alteration of the cellulose structure. This limited improvement in the digestibility of vetch-oats hay has been noted by different authors (Chenost and Dulphy, 1987) who indicate that the improvement in the nutritional value of fibrous foodstuffs is related to the initial digestibility of the product to be treated: the higher the initial quality, the less the improvement due to treatment.

Effect of the duration of the treatment

The duration of the urea treatment is a key factor in regard to its efficacy (Borhami and Sundstøl, 1982; Sundstøl and Coxworth, 1984). An important interaction between temperature and treatment duration exists, as a longer treatment period is needed at moderate temperatures (Cloete *et al.*, 1983b). Joy (1991) also notes that the length of the treatment period is related to the temperature, dose of urea applied and the moisture level.

In our study (Table 2), using barley straw treated with 5% urea, we found that prolonging the urea treatment made the NDF content decrease, although an interaction with the initial moisture of the treated feed existed. The best results were obtained at a combination of a 30% moisture content and 60 days of treatment, after which the NDF dropped to 64.4% from an initial value of 67.91%. Mascarenhas-Ferreira *et al.* (1989) also point out that the reduction of the NDF depends on the reaction time and that the nutritional value of the material treated is significantly improved when the treatment period increases from 45 to 60 days.

Table 2. Mean values of the parameters affected by the urea-treatment of barley straw under diverse conditions (Dihaj *et al.*, 1995)

Treatment conditions	Effect on						
	Chemical composition (% DM)			Nitrogenous fraction		Rexen digestibility (%)	Theoretical degradabilit y of DM K_p = 3% h^{-1}
	NDF	Hemicel-lulose	CP	Residual N-urea x 6.25 (% DM)	Retained nitrogen (%)		
Moisture							
20%	66.28	31.66	21.59	22.25	22.92	46.04	55.27
30%	65.20	29.45	18.40	6.56	48.67	53.34	60.24
Added urease							
With	65.37	30.37	19.25	12.68	38.58	50.25	58.14
Without	66.11	30.75	20.25	16.12	33.00	49.13	57.35
Treatment duration							
40 d	66.33	31.15	19.39	15.31	29.33	48.18	57.03
60 d	65.15	29.96	20.52	13.43	42.25	51.21	58.46
Untreated	67.91	32.82	7.45	–	–	38.61	51.59

The nitrogen bound to the NDF was not affected by the length of the treatment but that bound to the ADF, on the other hand, dropped from 4.5% to 4% of the total nitrogen value when the treatment lasted 40 and 60 days, respectively.

The duration of the treatment affected the nitrogenous fraction, although its effect was less marked than that of moisture. Moisture x treatment-duration interaction was observed. Thus, residual urea dropped to 4.56% of the DM at 30% moisture after 60 days of treatment, remaining at 22.38%, however, when moisture was 20% (Table 2).

Dias-da-Silva and Sundstøl (1986) also report that increased reaction time favours urea hydrolysis, although Hadjipanayiotou (1982) indicates that the degree of ureolysis is only important during the first 30 days of the treatment, as from that time on hydrolysis is weak.

The longer the treatment, the higher the CP value (Table 2). The treatment duration also affected the quantity of nitrogen retained by the straw which was greatest (59%) in straw with a 30% moisture content after a 60-day treatment period, as these conditions increased the quantity of ammonia retained by the straw.

Addition of an exogenous source of urease

Ureolysis is a hydrolytic reaction that produces the alkaline medium essential for modifications to take place in the cell walls of the treated material. A certain quantity of the enzyme urease must be present for the urea treatment to be effective, as it permits the reaction to take place at a particular temperature and level of moisture (Dias-da-Silva, 1988a).

Urease is found naturally in plants, including cereal straw (Cloete and Kritzinger, 1984); nevertheless, several studies have been carried out in which an external source of urease has been added in order to improve the rate of ureolysis, particularly when the moisture content of the material treated and the temperature are both low (Chenost, 1994).

Residual urea is affected by the addition of urease in the form of soya bean meal (30 g l^{-1} of urea solution). In our study (Table 2), the quantity of residual urea dropped from 16.12% to 12.68% of the DM after adding urease, indicating enhanced ureolysis. The interaction of moisture and additional urease was significant: the addition of soya bean meal caused residual urea to drop by 2% in DM at a 30% moisture level, and by 4.94% at a 20% moisture level.

Crude protein (Table 2) also dropped when soya bean meal was added, thus improving the treated straw's nitrogen retention by increasing the ammoniacal nitrogen content, as Sahnoune (1990) and Chenost (1994) have also noted. On the other hand, the addition of soya bean did not improve *in vitro* digestibility, although it did affect degradability, raising the values of the "a" and "b" fractions, as well as the theoretical degradability. The non-degradable fractions of both the NDF and the ADF were lowered by the addition of soya bean meal.

Several authors (Wanapat *et al.*, 1985; Muñoz *et al.*, 1991) have reported that the addition of urease does not improve the digestibility of straw, although others, including Jayasuriya and Pearce (1983), note that the addition of urease in the form of soya bean seeds significantly improves digestibility and reduces the minimum duration of the treatment in 2-4 days. The different results with regard to digestibility after adding urease to the straw may be due to the different initial digestibility of the materials treated: an improvement of 14.5 and 6.3 points was seen in straws with initial OM digestibility values of 30% and 60%, respectively.

Nevertheless, the addition of an exogenous source of urease seems to have given rise to contradictory conclusions. Thus, Sundstøl and Coxworth (1984) note that the addition of urease to the urea treatment depends on the ureasic activity of the material to be treated. Other authors, including Sahnoune (1990) and Muñoz *et al.* (1991), report that the addition of soya bean increases the speed of the ureolytic reaction when temperatures and moisture level are low. Chenost and Besle (1992) point out that urease should not be added except at moisture levels of less than 25-30%. Williams *et al.* (1984b) and Hassoun *et al.* (1990) believe that the microbial flora present in straw is enough to assure ureolysis, making the addition of an exogenous source of urease unnecessary.

Urea dosage

Medearmid *et al.* (1988) studied the effects of adding increasing doses of urea to the cereal straw treatment, and observed an improvement in DM, OM and NDF digestibility, noting that an addition of 2% was not sufficient nitrogen for the microbial population of the rumen. Chenost (1994) points out that the straw treatment requires between 3-6 kg of ammonia per 100 kg DM of straw. These amounts, if ureolisys is complete, correspond to addition of between 5.3 and 8.8 kg of urea per 100 kg of DM straw, but this author notes that the addition of 5-6 kg of urea per 100 kg of DM straw is, in practice, the recommended dose.

Kraiem *et al.* (1991) and Muñoz *et al.* (1991) recommend a dose of 4% to improve the crude protein content, OM digestibility and voluntary intake. Muñoz *et al.* (1994) also recommend 40 g urea per kg of DM of straw as the optimum dose at a 25-30% moisture level. A high dose of 8% may have negative consequences on the NDF and hemicellulose, Abdouli and Khorchani (1987) and Chermiti *et al.* (1989) state that the best results are achieved with a dose of urea of 6%.

In our studies (Souza, 1996), an increase in the quantity of urea added to the straw caused the NDF content to drop. This coincides with the findings of Abdouli and Khorchani (1987), Hassoun *et al.* (1990) and Muñoz *et al.* (1991), which report that NDF drops as the quantity of urea used in the treatment increases. Furthermore, we have observed an interaction between moisture and urea content, as in addition to improving with higher doses of urea, solubilization improves with high moisture levels.

Digestibility is also favoured by the addition of more urea, especially at high moisture levels (Souza, 1996). Hassoun *et al.* (1990) also reports better digestibility when the urea added increased from 17.5 to 53 g per kg of DM, confirming the results of Jayasuriya and Perera (1982) and Williams *et al.* (1984b). Furthermore, Abdouli and Khorchani (1987) note that the addition of 0, 20, 40, 80 g of urea per kg of DM of straw causes *in vitro* digestibility to rise from 47.6% in control straw to 59.5%, 68.1% and 67.4%, respectively.

Souza (1996) reports that residual urea increases as more urea is added to the treatment, confirming what Jayasuriya and Pearce (1983) and Muñoz *et al.* (1991) have also observed. The decrease of ureolysis when urea content is high has also been reported by Ghate and Bilanski (1979) and Hassoun *et al.* (1990), who observed this phenomenon at urea levels which varied between 17.5 and 53 g per kg of DM, and from 35.6 to 106 g per kg of DM, respectively. The latter authors note that the moisture x urea interaction was responsible for the poor ureolysis results.

Hassoun *et al.* (1990) report that the crude protein content of the treated straw increases when urea is added. Abdouli and Khorchani (1987) also note that additions of 0, 20, 40, 80 g of urea (g per kg of DM) result in total nitrogen levels of 0.88, 1.52, 2.06 and 3.88%, respectively.

Nutritional value of straw treated with urea

Table 3 sets forth data from our studies on *in vivo* digestibility, using diets based on urea-treated barley straw. The treatment was carried out using two urea levels (4% and 6%), combined with two initial moisture levels (25% and 35%). The levels of both parameters were considered the most appropriate, taking into consideration the data previously mentioned.

Table 3. *In vivo* digestibility of the ration† and straw treated†† under conditions of varying initial moisture and urea levels (Souza, 1996)

Treatments	*In vivo* digestibility								Intake per kg $LW^{0.75}$
	DM ration	DM straw	OM ration	OM straw	NDF ration	NDF straw	CP ration	CP straw	
(1) 4% urea 25% M	56.46^{ab}	48.95	58.63^{ab}	52.33^{ab}	55.52^{a}	53.95^{a}	75.28^{a}	74.24^{a}	48.09
(2) 6% urea 25% M	58.07^{ab}	50.86	60.92^{ab}	55.16^{ab}	56.90^{a}	54.82^{a}	79.70^{c}	80.65^{c}	43.86
(3) 4% urea 35% M	56.85^{ab}	49.38	58.92^{ab}	52.56^{ab}	56.51^{a}	54.46^{a}	69.02^{d}	64.80^{d}	48.08
(4) 6% urea 35% M	60.60^{ca}	53.69	62.97^{ca}	57.43^{ca}	62.00^{a}	60.28^{a}	76.34^{a}	76.00^{a}	40.91
(5) Control	52.53^{db}	43.86	54.43^{db}	46.72^{db}	47.97^{b}	43.97^{b}	50.97^{b}	15.43^{b}	43.79

†Ration: straw *ad libitum* + 210 g of barley + 90 g of soya bean meal + vitamin supplement
††Determined using the method of differences (Crampton and Lloyd, 1959)
[a,b,c,d]Values showing different letters differ significantly ($P \leq 0.05$)

The digestibility of the DM, OM and NDF displayed a tendency to increase as the urea and moisture levels increased. The digestibility of untreated barley straw differed significantly from that of the OM and the fibre of the treated straws. The greatest differences were found for the 6% urea treatment at a 35% moisture level, under which conditions there was a 8.5 point difference in the OM of the ration and a 10.7 point difference in that of the straw alone. The differences in the digestibility of the NDF were of 14.8 points in the ration and 16.3 points in the straw alone.

Muñoz *et al.* (1994) report that the digestibility of the OM of the barley straw ration was 7.8 points higher than that of the treated straw with urea (55 g per kg of DM) at a moisture level of 35.5%. These data are quite similar to the results of our study. Ben Salen *et al.* (1994) report that using sorghum stover treated with 5.3% urea and 25% water the digestibility of the OM of the ration with this stover improved 7.3 points, and 16.5 points that of the stover alone. These values are somewhat higher than those seen in our study, but they refer to a different feed. These same authors found that the ADF of the ration improved by 11.4 points and that of the straw alone, 13 points. The improvement seen in the NDF was similar to that found in our study, while that of ADF was inferior to our results.

Using wheat straw treated with 40 g of urea per kg and 30 litres of water per 100 kg, Kraiem *et al.* (1991) found improvements of only 4.3 points for the ration and 5.5 points for the straw. These results coincide with those reported by Cloete *et al.* (1983a) for urea-treated wheat straw and Dulphy *et al.* (1992) who also used urea.

The crude protein digestibility of the ration (Table 3) dropped significantly at both levels of urea studied (4% and 6%) as the moisture level rose, due to the lower content in residual urea. On the other hand, an increase in the quantity of urea added improved the digestibility of the protein at both moisture levels (25% and 35%).

The digestibility of the control straw was significantly inferior ($P \leq 0.05$) to that of the treated straw. The second treatment, which resulted in a protein digestibility of 80%, both for the ration and for the straw, proved the best.

The digestibility of the protein in the ration (Table 3) increased by 24.3 points in treatment 1 (4% urea and 25% moisture) and 28.7 points in treatment 2 (6% urea and 25% moisture). These results are similar to those of Ben Salen *et al.* (1994), who note an increase of 24 points in diets based on urea-treated sorghum stover. These authors also note an important improvement in the retention of nitrogen after treating the straw with urea. Kraiem *et al.* (1991) reported increased digestibility of the protein in wheat straw treated with urea, as well as better nitrogen retention, both compared with the control straw and with the ammonia-treated straw. Similar results are reported by Males and Gaskins (1982), Herrera-Saldaña *et al.* (1983), Dulphy *et al.* (1984) and Muñoz *et al.* (1987), all of whom note that the nitrogen retained in the treatment of straw with urea was assimilated well by the animals.

Intake (Table 3) improved in treatments with 4% urea, regardless of the level of moisture, but remained the same as that of untreated straw when 6% of urea was added.

Although several authors have found that intake improves using ammonia-treated straw (Chenost and Dulphy, 1987), the results of the urea treatments are contradictory. Hadjipanayiotou (1982), Ørskov *et al.* (1983), Dias-da-Silva and Sundstøl (1986), Brand *et al.* (1989), Djajanegara and Doyle (1989) and Ochrimenko and Flachowsky (1991) have reported positive effects, but too important to be attributable to nitrogen supplementation alone. On the other hand, authors including Ibbotson (1983), Benahmed and Dulphy (1985) and Besle *et al.* (1990a,b) have reported that straw intake is scarcely affected, or is negatively so, by the urea treatment. The presence of incompletely hydrolysed residual urea, which gives the straw a disagreeable taste, has negative repercussions on the results of the urea treatment (Williams *et al.*, 1984a).

We have also studied the intake, by nursing ewes, of treated straw in rations in which the quantity of concentrate varied, Cañeque *et al.* (1994). The results are set out in Table 4.

Table 4. Intake of nursing sheep and digestibility of the rations based on urea-treated straw and varying quantities of concentrate (Cañeque *et al.*, 1994)

	Contribution of concentrate ($g\ d^{-1}$)			Significance
	200	400	600	
Liveweight (kg)	58.75	68.60	61.40	–
Straw intake (g of DM per kg $LW^{0.75}$)	59.55	51.79	48.95	*
DM intake (g of DM per kg $LW^{0.75}$)	67.89	66.64	73.16	NS
OM digestibility (%)	53.25	57.93	57.95	*
DOM† consumed (g per kg $LW^{0.75}$)	33.04	34.80	38.26	NS
CP digestibility (%)	72.38	75.75	75.95	NS
Digestible protein consumed (g per kg $LW^{0.75}$)	10.45	10.59	11.49	NS
Lamb growth ($g\ d^{-1}$)	193.00	187.00	201.00	NS
Ewe weight loss ($g\ d^{-1}$)	158.70	158.50	117.00	**

†DOM: digestible organic matter
*$P \leq 0.05$; **$P \leq 0.01$; NS: non significant

Table 4 displays how the intake level of treated straw, which remained stable throughout the 7-week study period, was significantly greater ($P \leq 0.05$) in those sheep that received a smaller quantity of concentrate. Sheep of the other two treatment groups, who received 400 g and 600 g of concentrate per day and whose intake was similar, consumed less straw. The total DM intake was greater in the group that received more concentrate.

The organic matter digestibility was lower ($P \leq 0.05$) for the ration with the lowest concentrate content, while it was the same for the other two rations. This indicates that beyond a certain level of concentrate (400 g in our case), the digestibility of the ration does not improve, as it can cause a drop in the number of cellulolytic bacteria (INRA, 1988), with negative consequences on the digestibility of the fibre.

The growth of the lambs (Table 4) was similar in all the treatment groups, although those whose mothers received more concentrate gained somewhat more weight. All the ewes lost weight throughout the test period, although those that received more concentrate lost less weight ($P \leq 0.01$).

When treated straw is given *ad libitum* to ewes rearing lambs, an additional 200 g of concentrate is sufficient to ensure that the lambs gain adequate weight. Nevertheless, when ewes must maintain a certain body condition for an upcoming mating period, about 600 g of concentrate per head and day are necessary.

Conclusions

The best values of hemicellulose solubilization, *in vitro* digestibility and degradability were obtained at initial moisture values of the straw of between 30-40% and a temperature of 35°C.

The combination of 40% moisture and 35°C also gave the best results for the nitrogenous fraction, as even though the total and soluble nitrogen values were somewhat lower than those of the 30% moisture lot, the retained nitrogen values were higher, indicating a greater treatment efficacy in spite of the loss of ammonia in gas form.

The *in vivo* digestibility studies indicate that a great improvement for both OM as well as crude protein values occurs under conditions of 6% urea and 35% moisture.

The optimum treatment duration is 60 days, and no external source of urease is needed.

Intake is favoured by low levels (4%) of urea, and high levels of moisture (35%) as well as by the addition of a small quantity (200 g d^{-1}) of concentrate to the ration.

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