Animal Feed Science and Technology, 44 (1993) 59–72

0377-8401/93/$06.00

Ammonia and/or calcium hydroxide treatment of maize stover: intake, digestibility and digestion kinetics[1]

B.A. Oliveros*[,2], R.A. Britton, T.J. Klopfenstein

Department of Animal Science, University of Nebraska, Lincoln, NE 68583-0908, USA

(Received 30 October 1993; accepted 28 May 1993)

Abstract

Six ruminally fistulated steers were used in a 6×6 Latin square design to measure effects of treatments on maize stover. Maize stover was ground through a 0.95-cm screen and water was added to reduce the dry matter (DM) to 65% before chemical treatment. The chemical treatments were: 30 g NH_3, 56 g urea, 40 g $Ca(OH)_2$, 30 g NH_3 + 40 g Ca(OH)2 or 56 g urea + 40 g $Ca(OH)_2$ per kg maize stover DM. Untreated maize stover (65% DM) was used as the control. All chemical treatments were allowed to react for at least 14 days at 21 °C. Chemical treatment increased ($P<0.05$) the intake of organic matter (OMI) and digestible organic matter intake (DOMI), organic matter digestibility (OMD), fiber digestibility and rate of particulate passage. However, $Ca(OH)_2$ treatment of maize stover did not improve intake and digestibility. Treating maize stover with $Ca(OH)_2$, plus either NH_3 or urea increased ($P<0.05$) intake, digestibility and rate of particulate passage over $Ca(OH)_2$ treatment alone. Chemical treatment had no significant effect on the rate of fluid passage, flow rate or ruminal fluid volume. When steers were fed equal portions, chemically treated and untreated maize stover had slower, but similar rates of particulate passage and generally higher digestibilities compared with ad libitum intake. Chemical treatment increased ($P<0.05$) the extent of the cell wall digestion, but rates of fiber digestion were not affected. Among chemical treatments, NH_3 and urea consistently improved the feeding value of maize stover. The results of the study indicate that the addition of $Ca(OH)_2$ to either NH_3 or urea is no better than using NH_3 or urea alone.

Introduction

The productivity of ruminants consuming low quality crop residue diets is determined by voluntary feed intake and digestibility. Alkali treatment of crop residues has been shown to increase voluntary intake, and in vitro and in vivo dry matter (DM) digestibility. However, animal performance has not always

*Corresponding author.
[1]Published with the approval of the Director as Paper No. 10098, Journal Ser., Nebraska Agriculture Research Division.
[2]Present address: Institute of Animal Sciences, U.P. at Los Banos College, Laguna, Philippines 4031.

been greatly increased (Abidin and Kempton, 1981; Swingle et al., 1983). In addition, in vitro digestibility was higher than in vivo digestibility, especially for NaOH-treated crop residues (Acock et al., 1979; Berger et al., 1979). This was attributed to an increased rate of particulate passage and decreased rate of ruminal fiber digestion (Berger et al., 1980).

Calcium hydroxide and ammonia are weaker bases than NaOH and their effect on rate of passage and digestion may not be as large as NaOH. Aines (1985) reported that feeding NaOH-treated straw resulted in significantly faster fluid turnover rate than when $Ca(OH)_2$ or NH_4OH-treated straw was fed. Increased rate of particulate passage has been reported for ammoniated maize stover (Oji et al., 1979), maize cobs (Nelson et al., 1984) and wheat straw (Zorrilla-Rios et al., 1985).

The fractional rate of digestion of fiber fractions was not significantly affected by feeding either alkali treated wheat straw (Aines, 1985) or ammoniated crop residues (Dryden and Kempton, 1983; Zorrilla-Rios et al., 1985; Brown et al., 1987), but potential digestibility was increased. However, Ibrahim et al. (1989) reported that urea treatment of rice straw increased both the rate of degradation, and potential digestibility of organic matter and fiber fractions.

Ammonia treatment of crop residues is very effective as has been detailed by Sundstol and Coxworth (1984). Calcium hydroxide treatments, on the other hand, have been effective to varying degrees, perhaps related to the conditions of the experiment (Owen et al. 1984). Owen et al. (1984) also discussed improving the effectiveness of calcium hydroxide by combining it with other chemicals, such as ammonia. The effects of treating maize stover with urea or $Ca(OH)_2$ plus either urea or NH_3 on digestion kinetics have not been explored. Therefore, we designed this study to determine the effects of treating maize stover with ammonia and/or calcium hydroxide on intake, digestibility, rate of particulate and liquid passage, and the rate and extent of fiber digestion.

Materials and methods

Maize stover was ground through a 0.95-cm screen and water added to reduce the DM to 65% before chemical treatment. The chemical treatments were: 30 g NH_3, 56 g urea, 40 g $Ca(OH)_2$, 30 g NH_3 + 40 g $Ca(OH)_2$ or 56 g urea + 40 g $Ca(OH)_2$ per kg maize stover DM. Untreated maize stover (65% DM) was used as the control. For $Ca(OH)_2$ plus either NH_3 or urea, the chemicals were added to the maize stover at the time of treatment. The ammonia used in these treatments was anhydrous (gaseous); urea was added as prills and mixed. The treated materials were put in plastic-lined barrels and allowed to react for at least 14 days at 21 °C. Ammoniated maize stover was aerated at least 24 h before feeding.

Six steers fitted with permanent ruminal cannula were utilized in a 6×6 Latin square design with six treatments and six periods. Steers were fed equal portions of the different diets (Table 1), every 2 h using automatic feeders.

Each period of the Latin square consisted of an 8-day adaptation to ad libitum intake, a 6-day collection period, a 3-day adaptation to restricted intake (based on the lowest DM intake as a percentage of body-weight) followed by another 6-day collection period.

During the first day of each collection period, the steers were dosed with Cr-EDTA prepared using the procedure of Binnerts et al. (1968). Ruminal fluid samples were taken at 3, 6, 9, 12, 18 and 24 h post-dosing and kept frozen until analyzed. Prior to analysis, samples of ruminal fluid were thawed and then centrifuged at 15 000×*g* for 15 min. The Cr concentration of each sample was determined using atomic absorption spectrophotometry. The rate of fluid passage was calculated as the slope of the line defined by plotting the natural log of Cr concentration vs. time. Ruminal fluid volume was determined by dividing the dosage of Cr by the calculated Cr concentration at time zero.

Maize stover from each treatment was labeled with ytterbium (Yb) following the procedures of Ellis and Beaver (1985). On the second day of each collection period, steers were dosed with the Yb-labeled cell wall together with a portion of the diet. Feed and the Yb-labeled cell wall not consumed in 30 min were placed in the rumen via the ruminal cannula. Fecal grab samples were taken at 8, 16, 24, 32, 48, 72, 96 and 120 h post-dosing. All fecal samples were freeze-dried and ground through a 1-mm screen. Fecal samples were analyzed for Yb content by modifications of the technique by Karimi et al. (1986). Samples were extracted for Yb with 0.1 M diethylenetriaminepentaacetic acid, centrifuged, filtered and the supernatant analyzed for Yb by

Table 1
Composition of diets[1]

Ingredients	Treatments					
	Control	NH_3	Urea	$Ca(OH)_2$	$Ca(OH)_2$ $+NH_3$	$Ca(OH)_2$ +urea
Corn stover	90.00	91.22	91.22	92.74	93.96	93.96
Corn gluten meal	3.03	3.03	3.03	3.03	3.03	3.03
Blood meal	2.22	2.22	2.22	2.22	2.22	2.22
Limestone	2.74	2.74	2.74	–	–	–
Urea	1.22	–	–	1.22	–	–
Sodium monophosphate	0.43	0.43	0.43	0.43	0.43	0.43
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Trace mineral mix	0.05	0.05	0.05	0.05	0.05	0.05
Vitamin premix	0.01	0.01	0.01	0.01	0.01	0.01

[1]Percentage of dry matter basis.

atomic absorption spectrophotometry. The resulting Yb concentrations were fitted to a time-dependent one-compartment model (Ellis et al., 1983) using non-linear regression to determine the rate of particulate passage.

During the adaptation period to restricted intake, the rate of cell wall digestion was determined using the in situ dacron bag technique. Feed samples from each treatment were freeze-dried and ground through a 1-mm screen. Approximately 1 g of substrate was weighed into dacron bags (7.6 cm×12.4 cm) which were then sewn shut. Triplicate bags per substrate and two blank bags were prepared for each sampling time. Bags were tied to a chain and hydrated for 10 min prior to placing them in the rumen. Bags were removed from the rumen at 8, 16, 24, 32, 48 and 72 h and thoroughly rinsed with cool water. Samples in bags washed, but not placed in the rumen, served as the 0 h samples and were used as a basis for calculating the digestibility of each fiber fraction. The bag contents were analyzed sequentially for neutral detergent fiber (NDF) and acid detergent fiber (ADF) using the procedures of Goering and Van Soest (1970). Hemicellulose was calculated as the difference between NDF and ADF. The rate of digestion of NDF, ADF and hemicellulose was calculated as the slope of the line defined by regressing the natural log of the percentage potentially digestible fraction remaining against time. The 72 h digestion represents the potential extent of digestion. Both the 0 and 72 h digestibility values were excluded from the calculation of the slopes. The digestion lag time was calculated as the point in time along the regression line which corresponds to the natural log of 100.

Samples of feeds and orts were freeze-dried and ground through a 1-mm screen. Ground fecal samples were composited on DM basis by animal within period. Organic matter (OM) of all samples was determined by ashing in a muffle furnace at 600°C for at least 6 h. Feed samples were analyzed sequentially for NDF, ADF and permanganate lignin using the procedures of Goering and Van Soest (1970). Total nitrogen, NDF-nitrogen (NDF-N) and ADF-nitrogen (ADF-N) of feed samples were determined using the Kjeldahl method (Association of Official Agricultural Chemists (AOAC), 1980). Urea-treated maize stover was analyzed for urea-N (AOAC, 1980) and urea recovery was calculated. Orts and fecal samples were analyzed sequentially for NDF and ADF. Indigestible ADF (IADF) which represents the ADF remaining after 144 h of in vitro fermentation, was determined for feed, feces and orts. In vivo digestibility of organic matter, NDF, ADF and hemicellulose was calculated by the ratio technique using IADF as an internal marker.

Data of the chemical composition of maize stover were analyzed by analysis of variance for a randomized complete block (Steel and Torrie, 1980). The rest of the data were analyzed by analysis of variance for a 6×6 Latin square (Steel and Torrie, 1980). Period, animal and treatment were included in the model. Differences among treatments were determined using preplanned single-degree of freedom contrasts.

Results and discussion

Composition

Chemical treatment of maize stover decreased ($P<0.05$) NDF and hemicellulose without affecting ADF and cellulose (Table 2). Alkali treatment has consistently decreased total cell wall, measured as NDF, primarily by solubilizing hemicellulose (Klopfenstein, 1978). The combination of $Ca(OH)_2$ with either NH_3 or urea was more effective in solubilizing hemicellulose and in delignification than the different chemicals individually. However, the decrease in hemicellulose and lignin was greater ($P<0.05$) with the addition of NH_3 than urea. Kiangi et al. (1981) showed that NH_3 was more effective than urea in decreasing the cell wall content of maize stover. Ammoniation increased ($P<0.05$) total nitrogen content of maize stover. However, there was no significant increase in NDF-N and ADF-N owing to ammoniation, indicating that most of the added nitrogen may be present as free NH_3-N or urea-N in case of urea-treated maize stover. Nelson et al. (1984, 1985) and

Table 2
Chemical composition of untreated and chemically treated maize stover

Items	Treatments						Pooled standard error
	Control	NH_3	Urea	$Ca(OH)_2$	$Ca(OH)_2$ $+NH_3$	$Ca(OH)_2$ +urea	
Organic matter[a,e]	92.4	92.8	92.3	88.9	88.4	87.9	0.39
Urea recovery (%)	–	–	2.4	–	–	20.7	1.97
	Percentage of organic matter						
Fibre fractions							
Neutral detergent fibre[a,b,c,d,e]	90.0	78.4	82.9	83.3	74.4	79.2	1.34
Acid detergent fibre	51.9	52.8	51.3	52.2	51.1	51.0	0.61
Hemicellulose[a,b,c,d,e]	38.1	25.5	31.6	31.2	23.3	28.2	1.10
Cellulose[c]	39.6	41.1	39.2	40.6	40.6	39.5	0.56
Permanganate lignin[b,d,e]	9.3	9.0	9.2	9.3	7.9	8.8	0.29
Nitrogen fractions							
Total nitrogen[a,b,d]	1.1	2.8	2.6	1.1	2.2	2.9	0.10
Neutral detergent fibre nitrogen	0.4	0.5	0.4	0.5	0.5	0.5	0.02
Acid detergent fibre nitrogen	0.2	0.3	0.2	0.2	0.2	0.2	0.01

[a]Control vs. others; $P<0.05$.
[b]$Ca(OH)_2$ vs. $Ca(OH)_2+NH_3$ and $Ca(OH)_2$+urea; $P<0.01$.
[c]NH_3 vs. urea; $P<0.05$.
[d]$Ca(OH)_2+NH_3$ vs. $Ca(OH)_2$+urea; $P<0.05$.
[e]NH_3 and urea vs. $Ca(OH)_2+NH_3$ and $Ca(OH)_2$+urea; $P<0.05$.
[d]Significantly different; $P<0.01$.

Hargreaves et al. (1984) also reported an increase in total nitrogen, with slight increases in nitrogen bound to NDF and ADF of ammoniated maize residues. Total nitrogen content of maize stover treated with $Ca(OH)_2$+urea was higher ($P<0.05$) than $Ca(OH)_2+NH_3$-treated maize stover, but fiber bound nitrogen contents were similar. This could be due to unreacted urea present in $Ca(OH)_2$+urea-treated maize stover since 20.7% of the applied urea was apparently not hydrolyzed during storage.

Intake

Steers fed chemically treated maize stover had a higher ($P<0.05$) organic matter intake (OMI) than those fed untreated maize stover (Table 3). Consumption of OM was higher ($P<0.05$) when maize stover treated with $Ca(OH)_2$ in combination with either NH_3 or urea was fed compared with feeding $Ca(OH)_2$-treated maize stover. The same trends were observed for

Table 3
Intake and digestibility of untreated and chemically treated maize stover fed to steers

Items[a]	Treatments						Pooled standard error
	Control	NH_3	Urea	$Ca(OH)_2$	$Ca(OH)_2$ $+NH_3$	$Ca(OH)_2$ +urea	
Ad libitum period							
OMI[b,c,d] (kg day^{-1})	4.91	6.81	6.39	5.73	7.05	6.25	0.18
OMI[b,c,d] (% BW)	1.92	2.73	2.51	2.26	2.75	2.42	0.09
DOMI[b,c] (kg day^{-1})	2.54	4.04	3.86	2.94	3.99	3.84	0.13
OMD[b,c,d] (%)	51.7	59.4	60.6	51.5	56.2	61.2	1.09
NDFD[b,c,d] (%)	55.3	63.9	66.4	57.6	62.4	67.6	1.16
ADFD[b,c,d,e] (%)	56.0	61.4	66.2	56.9	57.5	66.2	1.32
HCELD[b,c] (%)	54.2	69.6	66.8	58.5	72.6	69.7	1.54
Restricted period							
OMI (kg day^{-1})	4.56	4.53	4.56	4.56	4.68	4.59	0.09
OMI (% BW)	1.79	1.81	1.80	1.80	1.82	1.77	0.02
DOMI[b,c,d] (kg day^{-1})	2.42	2.84	2.80	2.47	2.74	2.99	0.06
OMD[b,c,d] (%)	53.2	62.8	61.7	54.5	58.6	65.2	1.17
NDFD[b,c,e] (%)	57.2	71.4	65.3	59.2	65.6	69.0	1.23
ADFD[b,c,d] (%)	58.4	68.5	67.9	60.1	60.4	69.1	1.70
HCELD[b,c,e] (%)	55.5	77.1	60.8	57.6	73.6	69.9	1.96

[a]OMI, organic matter intake; BW, body weight; DOMI, digestible organic matter intake; OMD, organic matter digestibility; NDFD, neutral detergent fibre digestibility; ADFD, acid detergent fibre digestibility; HCELD, hemicellulose digestibility.
[b]Control vs. others; $P<0.05$.
[c]$Ca(OH)_2$ vs. $Ca(OH)_2+NH_3$ and $Ca(OH)_2$+urea; $P<0.05$.
[d]$Ca(OH)_2+NH_3$ vs. $Ca(OH)_2$+urea; $P<0.05$.
[e]NH_3 vs. urea; $P<0.05$.

digestibilities of OM, NDF, ADF and hemicellulose and digestible organic matter intake (DOMI). The addition of NH_3 to $Ca(OH)_2$ was more effective ($P<0.05$) in increasing OMI, but less effective ($P<0.05$) in increasing organic matter digestibility (OMD), NDF digestibility and ADF digestibility than urea. However, DOMI and hemicellulose digestibility of maize stover treated with $Ca(OH)_2+NH_3$ were not different ($P>0.10$) from $Ca(OH)_2$+urea-treated maize stover. The results obtained during the restricted intake phase followed the same trends observed in the ad libitum phase except for similar OMI among steers.

Consistent with previous studies (Grovum and Williams, 1977; Mudgal et al., 1982; Gates et al., 1987), reduced intake slowed the rate of particulate passage resulting in no significant difference between untreated and chemically treated maize stover. The effect of reduced intake on the rate of particulate passage was more pronounced for chemically treated than untreated maize stover. This is due to more severe feed restriction for steers fed chemically treated than untreated maize stover.

Intake of forage by ruminants is influenced by the rate and extent of ruminal digestion, and the rate of passage (Waldo et al., 1972). If there is no increase in the rate of digestion, as later shown in this trial, then the rate of passage could account for the increased intake of chemically treated maize stover. Van Soest et al. (1984) suggested that microbial digestion of treated cell walls have a tendency to undergo a greater degree of disintegration of particles with a subsequent increase in the rate of passage. Grovum (1987) indicated that treating roughages with NH_3, urea, NaOH or various delignifying agents promoted digestion and increased the rate of changing large particles to small particles which can exit the reticulo-rumen. Treating the roughage increases the amount of digesta that can be moved through the gastrointestinal tract within the limits of volume control to increase intake.

Improvement in OM and fiber digestibilities brought about by chemical treatments could be due to changes in cell wall composition and swelling, as well as saponification or ammonolysis of ester cross links between lignin and structural carbohydrates (Tarkow and Feist, 1969; Klopfenstein, 1978; Buettner et al, 1982; Saenger et al., 1982). Increased digestibility of organic matter and fiber fractions was also reported for urea-treated wheat straw (Cloete and Kritzinger, 1984) and ammoniated maize stover (Oji et al., 1979; Oji and Mowat, 1979; Morris and Mowat, 1980) and rice straw (Brown et al., 1987; Ibrahim et al., 1989). In this trial, however, $Ca(OH)_2$ treatment did not improve the digestibility of maize stover. Aines (1985) also reported a lack of improvement in digestibility of organic matter, NDF, ADF and hemicellulose of wheat straw treated with 4 or 8% $Ca(OH)_2$. On the other hand, Paterson et al. (1980) reported that treatment of maize cobs and wheat straw at 60% DM with 5% $Ca(OH)_2$ increased both DM and cell wall digestibilities in vivo, but the same treatment was not effective on maize stalks.

Table 4
Kinetics of liquid and particulate digesta in steers fed untreated and chemically treated maize stover

Items[1]	Treatments						Pooled standard error
	Control	NH_3	Urea	$Ca(OH)_2$	$Ca(OH)_2$ $+NH_3$	$Ca(OH)_2$ +urea	
Ad libitum period							
Rate of particulate passage[1,2] ($\% h^{-1}$)	4.52	6.24	5.05	4.62	6.36	5.67	0.46
Liquid digesta							
Rate of passage[3] ($\% h^{-1}$)	13.25	14.92	13.30	18.11	17.80	12.21	1.87
Flow rate $l h^{-1}$	7.71	8.28	7.64	12.39	10.89	8.08	1.39
Rumen volume (l)	59.56	57.57	56.14	67.88	59.39	63.80	3.54
Restricted period							
Rate of particulate passage[2] ($\% h^{-1}$)	4.36	5.08	4.49	3.77	5.03	4.27	0.29
Liquid digesta							
Rate of passage ($\% h^{-1}$)	8.94	8.64	11.19	9.87	10.67	8.29	0.89
Flow rate ($l h^{-1}$)	3.96	3.92	6.57	3.91	5.23	4.81	0.91
Rumen volume (l)	46.34	44.72	53.46	43.00	49.64	53.84	6.68

[1]Control vs. others; $P<0.05$.
[2]$Ca(OH)_2$ vs. $Ca(OH)_2+NH_3$ and $Ca(OH)_2$+urea; $P<0.05$.
[3]$Ca(OH)_2+NH_3$ vs. $Ca(OH)_2$+urea; $P<0.05$.

Table 5
In situ rate and exttent of digestion of untreated and chemically treated maize stover

Items	Treatments						Pooled standard error
	Control	NH_3	Urea	$Ca(OH)_2$	$Ca(OH)_2$ $+NH_3$	$Ca(OH)_2$ +urea	
Neutral detergent fiber							
Rate of digestion ($\% h^{-1}$)	5.64	5.12	4.82	5.36	4.64	5.20	0.50
72-h extent of digestion[1,2] (%)	66.88	78.52	76.95	74.36	73.10	77.94	1.44
Lag time[1] (h)	5.45	2.49	2.34	2.70	3.12	2.58	1.02
Acid detergent fiber							
Rate of digestion ($\% h^{-1}$)	5.39	4.82	4.82	5.22	4.58	5.00	0.46
72-h extent of digestion[1,2] (%)	67.73	77.72	76.60	73.24	70.22	77.78	1.58
Lag time[1] (h)	5.73	2.94	2.49	2.68	4.73	1.81	1.13
Hemicellulose							
Rate of digestion ($\% h^{-1}$)	5.19	5.39	4.66	5.54	4.88	5.92	0.50
72-h extent of digestion[1] (%)	67.37	80.24	78.63	75.86	79.71	79.03	1.85
Lag time[1] (h)	4.06	1.22	0.93	2.39	0.92	3.07	1.01

[1]Control vs. others; $P<0.05$.
[2]$Ca(CO)_2+NH_3$ vs. $Ca(OH)_2$+urea; $P<0.05$.

Digestibility values (Table 3) were generally higher during the restricted phase than during the ad libitum phase. Restricting intake slowed the rate of particulate passage (Table 4) and, consequently, feed is retained in the rumen for a longer period of time for further digestion. Warner (1981), based on an extensive review of literature, concluded that longer ruminal retention time of the digesta is associated with increased digestibility.

In situ rates of NDF, ADF and hemicellulose digestion of untreated and chemically treated maize stover were not significantly different (Table 5). However, chemically treated maize stover had a higher ($P<0.05$) 72-h extent of digestion and a shorter lag time compared with untreated maize stover.

Table 6
In situ disappearance of fibre fractions of untreated and chemically-treated maize stover at different incubation time

Treatments	Incubation time (h)				
	8	16	24	32	48
Neutral detergent fibre (%)					
Control	12.91[a]	27.95[a]	41.50[a,b]	50.52[a,b]	60.50[a,b]
NH_3	23.01	41.46	52.80	58.95	70.34
Urea	24.59	40.76	52.79	60.99	68.06
$Ca(OH)_2$	23.74	39.23	49.75	57.14	67.84
$Ca(OH)_2+NH_3$	18.86	33.88	45.90	52.91	64.54
$Ca(OH)_2$+Urea	23.75	40.94	53.64	60.94	70.26
Standard error	2.05	2.88	2.56	2.12	1.19
Acid detergent fibre (%)					
Control	12.30[a]	27.02[a,b]	39.44[a,b]	49.62[a,b]	60.86[a,b,e]
NH_3	18.80	36.91	49.14	55.35	67.29
Urea	21.65	38.16	51.15	59.99	67.70
$Ca(OH)_2$	20.58	36.80	47.21	55.68	64.88
$Ca(OH)_2+NH_3$	14.10	27.42	41.06	48.88	60.77
$Ca(OH)_2$+Urea	21.02	38.40	52.42	60.48	67.77
Standard error	2.25	3.13	2.82	2.32	1.47
Hemicellulose (%)					
Control	13.83[a]	29.40[a]	42.88[a]	51.14[a]	59.99[a,c,d]
NH_3	30.63	50.24	60.61	66.24	75.91
Urea	28.54	45.91	55.65	62.28	69.68
$Ca(OH)_2$	29.93	44.82	53.60	60.32	70.15
$Ca(OH)_2+NH_3$	31.57	46.85	56.10	63.11	72.76
$Ca(OH)_2$+Urea	28.54	46.48	54.34	63.01	73.40
Standard error	1.98	2.87	2.42	2.11	1.06

[a]Control vs. treated; $P<0.01$.
[b]$Ca(OH)_2+NH_3$ vs. $Ca(OH)_2$+urea; $P<0.01$.
[c]$Ca(OH)_2$ vs. ($Ca(OH)_2+NH_3$ vs. $Ca(OH)_2$+urea; $P<0.05$.
[d]NH_3 vs. urea, $P<0.01$.
[e]NH_3 and urea vs. $Ca(OH)_2+NH_3$ and $Ca(OH)_2$+urea; $P<0.01$.

Studies using ammoniated straw (Dryden and Kempton, 1983; Zorrilla-Rios et al., 1985; Brown et al., 1987) also showed the increased extent of digestion and the decreased lag time, but no significant effect on rates of fiber digestion. Latham et al. (1979) concluded that treatment with NaOH increased the number of adhesion sites available to the cellulolytic bacteria, but that alone did not permit them to digest many of the quantitatively important types of plant cell wall. This could explain the decreased lag time for chemically treated maize stover since the attachment of microorganisms to fiber particles is necessary to initiate digestion (Varga, 1987). In addition, forage substrates differ in rates of hydration or rates of chemical or physical alteration before enzymatic degradation (Mertens and Ely, 1982). It is possible that chemical treatment removed some chemical or physical inhibitors or increased the capability of the fibers to swell via hydration which is needed before enzymes can contact and react with fiber molecules.

The digestibilities of the different fiber fractions at 8, 16, 24, 32 and 48 h of incubation were higher ($P<0.05$) for chemically treated maize stover than the control (Table 6). This indicates that chemical treatment increased the digestible fiber pool. Although the digestion rates were similar, an increase in digestible fiber pool would consequently result in a greater amount of digested fiber fraction of chemically treated compared with untreated maize stover.

Rate of passage

Untreated maize stover had a slower ($P<0.05$) rate of particulate passage than chemically treated maize stover (Table 4). This is consistent with the increased rate of particulate passage reported for ammoniated maize stover (Oji et al., 1979), maize cobs (Nelson et al., 1984) and wheat straw (Zorrilla-Rios et al., 1985). Maize stover treated with $Ca(OH)_2$ had a slower ($P<0.05$) rate of particulate passage than maize stover treated with $Ca(OH)_2$ plus either NH_3 or urea. The rate of fluid passage, flow rate and ruminal fluid volume decreased with reduced intake with no significant differences observed between untreated and chemically treated maize stover, and among chemical treatments. $Ca(OH)_2$ probably does not increase the rate of passage or at least not as much as NaOH (Brandt and Paterson, 1981; Owen et al., 1982). Aines (1985) reported that the particulate turnover rate did not increase in $Ca(OH)_2$-treated wheat straw fed steers and appeared to decrease with the increasing level of $Ca(OH)_2$ treatment.

Chemical treatment had no significant effect on the rate of fluid passage, flow rate and ruminal fluid volume. This is in agreement with previous studies using ammoniated cobs (Nelson et al., 1984, 1985), wheat straw (Zorrilla-Rios et al., 1985; Naseeven and Kincaid, 1992) or $Ca(OH)_2$-treated wheat straw (Aines, 1985). Calcium hydroxide treatment, however, had a tendency to induce a faster rate of fluid passage and flow rate, and greater ruminal fluid volume than the other chemical treatments. Similarly, a significant difference in fluid rate of passage was observed between $Ca(OH)_2+NH_3$ and $Ca(OH)_2$+urea treatment.

Zorrilla-Rios et al. (1985) reported that fragility, estimated as the amount of DM that passed through a 1-mm sieve after 20 s of grinding and 10 min of sieving, was increased in ammoniated wheat straw indicating a greater susceptibility to mechanical fracture. A faster rate of reduction of ingested particles during chewing and rumination could be expected (Reid et al., 1979; Birkelo et al., 1986), resulting in a larger pool of small particles. This pool would have a positive effect on intake if cleared at a faster rate by digestion and passage, and by reducing the time that undigested particles remain in the rumen (Morrison, 1979). This could account for the relatively faster rate of passage and higher intake of maize stover treated with NH_3 and $Ca(OH)_2$+NH3 compared with other chemical treatments. On the other hand, the slow rate of passage could also be responsible for the low intake of $Ca(OH)_2$-treated maize stover.

The variable response of crop residues to $Ca(OH)_2$ treatment could be related to conditions prevailing during the reaction period. Since $Ca(OH)_2$ is a weaker base than NaOH, it takes longer to react with the cell wall. Aines (1985) reported that $Ca(OH)_2$-treated wheat straw could have undergone fermentation during the reaction period. Organic acids produced during fermentation may then have neutralized some of the $Ca(OH)_2$ before it was able to react with the cell wall. Thus, $Ca(OH)_2$ may act as a fermentation buffer rather than a delignifier.

Conclusion

Not surprisingly, among the chemical treatments NH_3 and urea consistently improved the feeding value of maize stover. However, the addition of $Ca(OH)_2$ alone or to either NH_3 or urea did not improve utilization of maize stover more than NH_3 or urea used alone.

References

Abidin, Z. and Kempton, T.J., 1981. Effects of barley straw with anhydrous ammonia and supplementation with heat-treated protein meals on feed intake and live weight performance of growing lambs. Anim. Feed Sci. Technol., 6: 145.

Acock, C.W., Ward, J.K., Rush, I.G. and Klopfenstein, T.J., 1979. Wheat straw and sodium hydroxide treatment in beef cow rations. J. Anim. Sci., 49: 354.

Aines, G.E., 1985. Effects of alkali source and level of treatment of crop residues on fiber composition and digestibility. Ph.D. Dissertation. University of Nebraska, Lincoln, NE.

Association of Official Agricultural Chemists (AOAC), 1980. Official Methods of Analysis (13th Edn.). Association of Official Agricultural Chemists, Washington, DC, pp. 126–129.

Berger, L.L., Paterson, J.A., Klopfenstein, T.J. and Britton, R.A., 1979. Effect of sodium hydroxide on efficiency of rumen digestion. J. Anim. Sci., 49: 1317.

Berger, L.L, Klopfenstein, T.J. and Britton, R.A., 1980. Rate of passage and rate of ruminal fiber digestion as affected by level of NaOH treatment. J. Anim. Sci., 50: 745.

Binnerts, W.T., van't Klooster, A.T. and Frens, A.M., 1968. Soluble chromium indicator measured by atomic absorption in digestion experiments. Vet. Rec., 82: 470.

Birkelo, C.P., Johnson, D.E. and Ward, G.M., 1986. Net energy value of ammoniated wheat straw. J. Anim. Sci., 63: 2044.

Brandt, R.T. and Paterson, J.A., 1981. Digestibility and rates of digestion of chemically-treated wheat straw. Am. Soc. Anim. Sci. Abstr. p. 580. Cited by Owen, E., Klopfenstein, T. and Urio., N., 1984. Treatment with other chemicals. In: F. Sundstol and E. Owen (Editors), Straw and Other Fibrous By-products as Feed. Elsevier, Amsterdam, p. 258.

Brown, W.F., Philipps, J.D. and Jones, D.B., 1987. Ammoniation or cane molasses supplementation of low quality forages. J. Anim. Sci., 64: 1205.

Buettner, M.R., Lechtenberg, V.L., Hendrix, K.S. and Hertel, J.M., 1982. Composition and digestion of ammoniated tall fescue (*Festuca arundinacea* Schreb.) hay. J. Anim. Sci., 54: 173.

Cloete, S.W.P. and Kritzinger, N.M., 1984. Urea ammoniation compared to urea supplementation as a method of improving the nutritive value of wheat straw for sheep. S. Afr. J. Anim. Sci., 14: 59.

Dryden, G. and Kempton, T.J., 1983. Digestion of organic matter and nitrogen in ammoniated barley straw. Anim. Feed Sci. Technol., 10: 65–75.

Ellis, W.C. and Beaver, D.E., 1985. Methods of binding rare earths to specific feed particles. In: P.M. Kennedy (Editor), Techniques in Particle Size Analysis of Feed and Digesta in Ruminants. Can. Soc. Anim. Sci. Occ. Publ. No. 1., pp. 154–165.

Ellis, W.C., Matis, J.H., Pond, K.R., Lascano, C.E. and Telford, J.P., 1983. Dietary influences on flow rate and digestive capacity. In: F.M. Gilchrist and R.I. Mackie (Editors) Herbivore Nutrition in the Subtropics and Tropics. Science Press, Craighall, South Africa, pp. 269–293.

Gates, R.N., Klopfenstein, T.J., Waller, S.S., Stroup, W.W., Britton, R.A. and Anderson, B.F., 1987. Influence of thermo-ammoniation on quality of warm-season grass hay for steers. J. Anim. Sci., 64: 1821.

Goering, J.K. and van Soest, P.J., 1970. Forage fiber analysis (Apparatus, Reagents, Procedures and Some Applications). Agricultural Handbook No. 379, Agriculture Research Series, United States Department of Agriculture, Washington, DC, 20 pp.

Grovum, W.F., 1987. A new look at what is controlling food intake. In: F.N. Owens (Editor) Symposium Proceedings: Feed Intake by Beef Cattle. Oklahoma State University, Stillwater, OK, pp. 1–40.

Grovum, W.L. and Williams, V.J., 1977. Rate of passage of digesta in sheep. 6. The effect of level of food intake on mathematical predictions of kinetics of digesta in the reticulorumen and intestines. Br. J. Nutr., 38: 425.

Hargreaves, A., Huber, J.T., Arroyoluna, J. and Kung Jr, L., 1984. Influence of adding ammonia to corn stalklage on feeding value for dairy cows and on fermentation changes. J. Anim. Sci., 59: 567.

Ibrahim, M.N.M., Tamminga, S. and Zemmelink, G., 1989. Effect of urea treatment on rumen degradation characteristics of rice straw. Anim. Feed Sci. Technol., 24: 83–95.

Karimi, A.R., Owens, F.N. and Horn, G.W., 1986. Simultaneous extraction of Yb, Dy, and Co from feces with EDTA, DCTA or DPTA. J. Anim. Sci., 63(Suppl. 1): 447.

Kiangi, E.M.I., Kategile, J.A. and Sundstol, F., 1981. Different sources of ammonia for improving the nutritive value of low quality roughages. Anim. Feed Sci. Technol., 6: 377.

Klopfenstein, T.J., 1978. Chemical treatment of crop residues. J. Anim. Sci., 46: 841.

Latham, M.J., Hobbs, D.G. and Harris, P.J., 1979. Adhesion of rumen bacteria to alkali-treated plant stems. Ann. Rech. Vet., 10: 244.

Mertens, D.R. and Ely, L.O., 1982. Relationship of rate and extent of digestion to forage utilization — a dynamic model evaluation. J. Anim. Sci., 54: 895.

Morris, P.J. and Mowat, D.N., 1980. Nutritive value of ground and (or) ammoniated corn stover. Can. J. Anim. Sci., 60: 327.

Morrison, I.M., 1979. The degradation and utilization of straw in the rumen. In: E. Grossbard (Editor), Straw Decay and Its Effects on Disposal and Utilization. John Wiley, New York, pp. 237–245.

Mudgal, V.D., Dixon, R.M., Kennedy, P.M. and Milligan, L.P., 1982. Effect of two intake levels on retention time of liquid, particle and microbial marker in the rumen of sheep. J. Anim. Sci., 54: 1051.

Naseeven, M.R. and Kincaid, R.L., 1992. Ammonia and sulfur dioxide treated wheat straw as a feedstuff for cattle. Anim. Feed Sci. Technol., 37: 111–128.

Nelson, M.L., Klopfenstein, T.J. and Britton, R.A., 1984. Protein supplementation of ammoniated roughages. I. Corn cobs supplemented with a blood meal-corn gluten meal mixture — lamb studies. J. Anim. Sci., 59: 1601.

Nelson, M.L., Klopfenstein, T.J. and Britton, R.A., 1985. Protein supplementation of ammoniated roughages. III. Corn cobs supplemented with a blood meal-corn gluten meal mixture — steer studies. J. Anim. Sci., 61: 1567.

Oji, U.I. and Mowat, D.N., 1979. Nutritive value of thermo-ammoniated and steam-treated maize stover. I. Intake, digestibility and nitrogen retention. Anim. Feed Sci. Technol., 4: 177.

Oji, U.I., Mowat, D.N. and Buchanan-Smith, J.G., 1979. Nutritive value of thermo-ammoniated and steam-treated maize stover. II. Rumen metabolites and rate of passage. Anim. Feed Sci. Technol., 4: 187.

Owen, E., Klopfenstein, T.J., Britton, R.A., Rump, K. and McDonald, M., 1982. Treatment of wheat straw with different alkalis. J. Anim. Sci., 53(Suppl. 1): 448 (Abstr.).

Owen, E., Klopfenstein, T.J. and Urio, N., 1984. Treatment with other chemicals. In: F. Sundstol and E. Owen (Editors), Straw and Other Fibrous By-products as Feed. Elsevier, Amsterdam, pp. 248–275.

Paterson, J., Stock, R. and Klopfenstein, T., 1980. Crop residues — Calcium hydroxide treatment. Nebraska Beef Cattle Report, EC 80-218, pp. 21–23.

Reid, L.S.W., John, A., Ulyatt, M.J., Waghorn, G.G. and Milligan, L.P., 1979. Chewing and the physical breakdown of feed in sheep. Ann. Rech. Vet., 10: 205.

Saenger, P.F., Lemenager, R.P. and Hendrix, K.S., 1982. Anhydrous ammonia treatment of corn stover and its effects on digestibility, intake and performance of beef cattle. J. Anim. Sci., 54: 419.

Steel, R.G.D. and Torrie, J.H., 1980. Principles and Procedures of Statistics. 2nd Edn. McGraw-Hill, New York, pp. 132–149.

Sundstol, F and Coxworth, E.W., 1984. Ammonia treatment. In: F. Sundstol and E. Owen (Editors) Straw and Other Fibrous By-products as Feed. Elsevier, Amsterdam, p. 196.

Swingle, R.S., Urias, A.R., Delfino, F.J. and Theurer, C.B., 1983. Ammoniated wheat straw and sources of supplemental protein in high roughage diets for growing steers. J. Anim. Sci., 57(Suppl. 1): 297.

Tarkow, H. and Feist, W.C., 1969. A mechanism for improving the digestibility of lignocellulosic materials with dilute alkali and liquid ammonia. Am. Chem. Soc. Adv. Chem. Ser., 95: 197.

Van Soest, P.J., Mascarenhas-Ferreira, A. and Hartley, R.D., 1984. Chemical properties of fiber

in relation to nutritive quality of ammonia treated forages. Anim. Feed Sci. Technol., 10: 155.
Varga, G.A., 1987. Factors which affect estimation of lag time in the rumen. In: F.N. Owens (Editor), Symposium Proceedings: Feed Intake by Beef Cattle. Oklahoma State University, Stillwater, OK, pp. 70–80.
Waldo, D.R., Smith, L.W. and Cox, E.L., 1972. Model of cellulose disappearance from the rumen. J. Dairy Sci., 55: 125.
Warner, A.C.I., 1981. Rate of passage of digesta through the gut of mammals and birds. Nutr. Abstr. Rev., 51: 789.
Zorrilla-Rios, J., Owens, F.N., Horn, G.W. and McNew, R.W., 1985. Effect of ammoniation of wheat straw on performance and digestion kinetics in cattle. J. Anim. Sci., 60: 814.