Table 2. Straw intake digestibility and gains of lambs

Level of supplement fed,	Supplemental crude protein/lamb/day, lb (g)					
	.128(58)[a]			.256(116)[b]		
lb/day: g/day:	.44 (200)	.88 (400)	1.32 (600)	.66 (300)	.88 (400)	1.32 (600)
Mean lamb wt during trial, lb	66	67	67	68	64	69
Straw DM intake[c]						
lb/day	1.44	1.29	1.04	1.54	1.44	1.21
% of body wt	2.20	1.92	1.55	2.26	2.27	1.74
Lamb daily gains[d], lb	.038	.139	.250	.136	.182	.254
Straw DM digestibility[e], %	43.2	40.0	27.5	50.3	46.0	35.4

[a]Low-protein supplements.
[b]High-protein supplements.
[c]Significant protein level (P<.05) and supplement level (P<.001) effects.
[d]Significant supplement level (P<.001) effect.
[e]Significant protein level (P<.001) and supplement level (P<.001) effects.

Low-protein supplements: Straw DM intake = 1.65 lb - .45 (lb supplement fed)
High-protein supplements: Straw DM intake = 1.88 lb - .50 (lb supplement fed)

Straw dry matter digestibility (DMD) was decreased (P<.001) with increasing level of supplement (Table 1 and Figure 1), and feeding additional protein increased (P<.001) straw DMD. The rate of reduction of straw DMD with increasing supplement was similar (P>.19) for the low- and high-protein supplements (Figure 1) as follows:

Low-protein supplements: Straw DMD = 52.29 - 17.8 (lb supplement fed)
High-protein supplements: Straw DMD = 65.71 - 22.9 (lb supplement fed)

Gains of lambs were not increased (P>.25) by amount of supplemental crude protein indicating that the low-protein supplements met the protein needs for the low rates of gain that were achieved. Gains were increased (P<.001) with increasing levels of supplement, which would be attributable to increased energy intake.

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Ammoniation of Wheat Straw and Prairie Hay

G. W. Horn, C. L. Streeter, G. Manor,[1] D. G. Batchelder and G. L. McLaughlin

Story in Brief

Wheat straw and prairie hay were treated with ammoniated water (aqua-ammonia) during baling of large round bales. The effects which 1) crimping and 2)

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adding a surfactant to the aqua-ammonia had on crude protein content and *in vitro* dry matter digestibility (IVDMD) were studied. Crude protein content of non-treated straw was 2.82 percent. Mean crude protein content of ammoniated straw after storage ranged from 5.84 to 7.28 percent, and was increased ($P<.004$) by addition of surfactant. The effect of surfactant on crude protein content of straw was greater for the crimped straw, which was increased by 1.44 percentage units. The effect of crimping was not significant ($P>.10$). Adding surfactant or crimping the straw did not increase ($P>.10$) IVDMD of ammoniated straw, which was increased only about 10 percent. The small improvement in IVDMD may be due to the low level of ammonia (1.7 percent of straw DM) that was applied. Prairie hay readily absorbed the aqua-ammonia, and the crude protein content was increased from about 4.7 to 13.9 percent by ammoniation. The ammoniated hay contained about 29 percent water after baling and molded during storage in the open. IVDMD was increased only 3.1 percentage units by ammoniation. Loss of the more digestible nutrients during heating of the hay which accompanies mold growth would result in a smaller improvement in IVDMD. The water content of ammoniated prairie hay probably should not exceed 24 percent.

A device for 1) mixing water and anhydrous ammonia on the tractor and 2) applying the aqua-ammonia during baling was developed and is described.

Introduction

For each acre of wheat that yields 20 to 25 bushels of grain, an estimated ton of wheat straw is available as a potential feedstuff (Anderson, 1978). Both the digestibility and crude protein content of wheat straw are generally low. Chemical treatment of crop residues with various alkalis, such as sodium hydroxide and potassium hydroxide, has increased digestibility and often has increased intake and animal performance (Klopfenstein and Woods, 1970; Klopfenstein *et al.*, 1972; Ololade *et al.*, 1970; Singh and Jackson, 1971). Ammoniation of wheat straw has the potential of 1) reducing the chemical cost of treatment and 2) increasing the crude protein content of the straw as well as increasing the digestibility of the treated straw.

In our first attempt (Horn *et al.*, 1979) to ammoniate wheat straw during baling of large round bales, water and ammonia were applied separately. Water was sprayed onto the straw as it traveled over the pickup frame of the baler. The USS Cold-Flo Converter (Model K-3S) was used to convert anhydrous ammonia to liquid ammonia. Liquid ammonia was applied evenly across the bale width directly *behind* the large rubber compression roller and in *front* of the starter roller at the entrance of the bale chamber of a John Deere Model 510 baler. Ammonia loss during application was about 74 percent.

During the 1980 wheat harvest we treated wheat straw with a solution of ammonia in water (aqua-ammonia) in hopes of reducing ammonia loss during the baling operation. Because of the slick nature of wheat straw, penetration of the straw by the aqua-ammonia is believed to be a problem. Effects which 1) crimping the straw during baling and 2) adding a surfactant to the aqua-ammonia had on penetration of the straw by the aqua-ammonia were studied. Prairie hay was also treated with aqua-ammonia during baling in late July.

Experimental Procedure

Wheat straw

Aqua-ammonia was produced in the field by adding anhydrous ammonia to water through a perforated pipe submerged to the bottom of a 200-gallon water tank. The aqua-ammonia was added directly to two tanks of about 78 gallons each mounted over the front tractor wheels. A small air compressor, driven by the front-end tractor PTO, was used to pressurize the aqua-ammonia tanks. An in-line flow controller was used to control application rate of the aqua-ammonia at 3.6 gallons per minute during a baling time of 3 minutes per bale. The aqua-ammonia was sprayed onto the straw through 8 Tee Jet SS 8010 nozzles spaced 7 inches apart across the baler. Positioning of the nozzles on the baler was the same as the previous year. The aqua-ammonia solutions were sampled in the field and tested for ammonia concentration by drop-wise titration with an HCl-indicator solution. The aqua-ammonia solutions contained about 8 percent ammonia.

Crimping was accomplished by changing the original chain sprocket (33 teeth) of the platform lower belt drive roller of the baler to a sprocket of 36 teeth to obtain a slower speed of the lower belt drive roller by .92 (33/36).

Six-hundred (600) ml of a surfactant, Super Kem Flak Liquid[2], was added directly to the aqua-ammonia tanks on the tractor prior to baling straw to make a concentration (v/v) of .2 percent surfactant in the aqua-ammonia.

Core samples of the bales were taken immediately after baling (July 1, 1980) and after storage on August 29, 1980 (59 days after baling) for dry matter, crude protein and *in vitro* dry matter digestibility (IVDMD) determinations. The bales were stored on the ground with no shelter after baling. Crude protein content of the samples was determined prior to drying to avoid ammonia losses.

Prairie hay

A device for 1) mixing water and anhydrous ammonia and 2) applying the aqua-ammonia to the hay during baling was developed. The device is shown in Figure 1 and consisted of the following:

A. Anhydrous ammonia tank suitable for mounting on a tractor.
B. Ammonia flow meter on high pressure side of pressure regulator(D).
C. Electronic readout of ammonia flow meter.

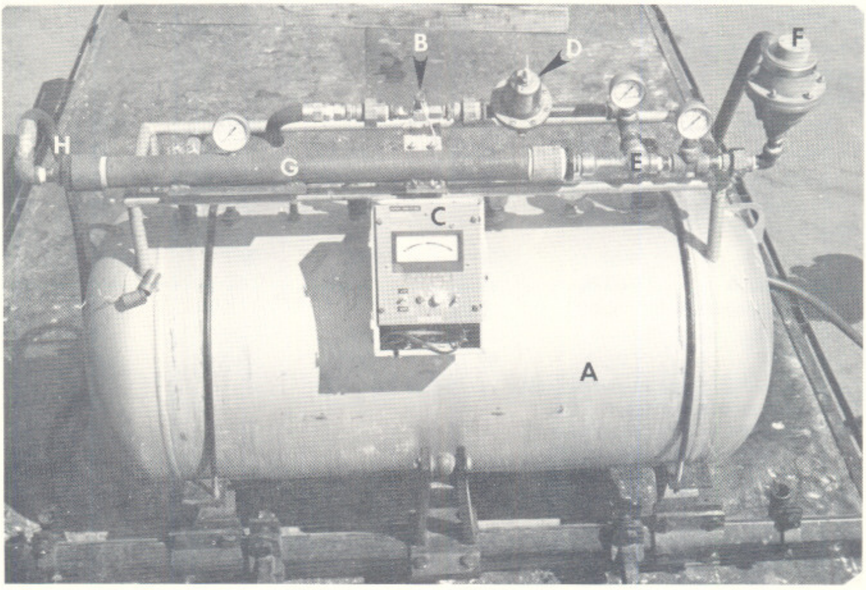

Figure 1. A device for mixing water and anhydrous ammonia for applying aqua-ammonia to prairie hay

[2]Kemin Industries, Inc., Des Moines, Iowa.

D. Pressure regulator. Replacement of the pressure regulator with an ammonia flow rate controller will be evaluated as an improvement to the aqua-ammonia mixer/applicator.

E. Eductor or other suitable device for mixing anhydrous ammonia and water to form aqua-ammonia.

F. Water Flow Rate Controller. Water was delivered by hose from water tanks mounted on tractor. Pressure was maintained on water tanks by PTO-powered air compressor.

G. Cooling device for aqua-ammonia.

H. Hose to deliver aqua-ammonia to nozzle system mounted on baler.

Results and Discussion

Wheat straw

The crude protein content of the straw was increased from 3.06 percent (non-treated straw) to 6.24 to 7.46 percent immediately after baling (Table 1). Addition of the surfactant to the aqua-ammonia increased the crude protein content ($P<.10$) and nitrogen retention ($P<.002$) of the straw during baling. The effect of crimping was not significant ($P>.10$). Mean crude protein content of the ammoniated straw after storage (i.e., 59 days after baling) ranged from 5.84 to 7.28 percent, and was significantly

Table 1. Analyses of non-treated and ammoniated (1.7 percent NH_3 on DM basis) wheat straw

Wheat straw:	Non-treated	Ammoniated			
		Non-crimped		Crimped	
Surfactant[a]:		–	+	–	+
Number of bales	7	7	7	7	7
Sampling time					
After baling					
Bale wt, lb	447	563	540	409	504
Bale DM, %	93.1	87.6	85.4	85.8	86.1
Crude protein[b], %	3.06	6.24	7.24	7.13	7.46
N retention[c], %	—	41	52	37	51
After storage[d]					
Bale wt, lb	440	526	500	382	471
Bale DM, %	93.8	92.9	92.0	93.5	92.7
Crude protein[e], %	2.82	6.09	6.41	5.84	7.28
N retention[f], %	—	39	41	26	49
IVDMD[g]	35.2	37.1	39.2	40.9	37.8

[a]Super Kem Flak Liquid. Kemin Industries, Inc. Des Moines, Iowa.

[b]Significant surfactant effect ($P<.10$).

[c]Nitrogen retention during application =

$$\frac{\text{Increase N content of bale}}{\text{Amount of } NH_3\text{–N added}} \times 100$$

Significant surfactant effect ($P<.002$).

[d]59 days after baling.

[e]Significant surfactant effect ($P<.004$) and surfactant by crimping interaction ($P<.06$).

[f]Nitrogen retention after storage =

$$\frac{\text{Increased N content of bale}}{\text{Amount of } NH_3\text{–N added}} \times 100$$

Significant surfactant effect ($P<.0001$) and surfactant by crimping interaction ($P<.0004$).

[g]*In vitro* dry matter digestibility.

Significant surfactant by crimping interaction ($P<.018$).

increased ($P<.004$) by addition of surfactant. The effect of surfactant on the crude protein content of straw was greater for the crimped straw, which was increased by 1.44 percentage units. Mean IVDMD of ammoniated straw after storage ranged from 37.1 to 40.9 percent (Table 1). Crimping or addition of surfactant did not ($P>.10$) increase IVDMD of ammoniated straw. The mean IVDMD (38.8) of ammoniated wheat straw of all four treatments was greater ($P<.01$) than that of non-treated straw (35.2). The magnitude of the increase in IVDMD of ammoniated straw (about 10 percent) was considerably less than the improvement of about 33 percent observed in previous studies (Solaiman *et al.*, 1979 and Horn *et al.*, 1979) in which wheat straw was treated with 3.5 percent ammonia. This reduced response in IVDMD due to ammoniation would be attributable to the lower level of ammonia (i.e., 1.7 percent of straw DM) that was applied.

Prairie hay

Results of the analyses of prairie hay are shown in Table 2. The crude protein content and IVDMD of prairie hay were increased from about 4.7 to 13.9 percent ($P<.0001$) and 46.2 to 49.3 percent ($P<.10$), respectively. The prairie hay was treated with a greater amount of ammonia (7.6 percent NH_3 on a DM basis) than planned due to a malfunction of the ammonia flow meter. Therefore, retention of the added nitrogen was less (i.e., 26 percent) than that observed for wheat straw. Three of the seven ammoniated bales showed clear evidence (i.e., odor and darkened color) of mold growth when they were sampled after storage, which would be attributable to the greater than anticipated amount of water that was added. The ammoniated hay contained about 29 percent water (Table 2) after baling. The small improvement in IVDMD due to ammoniation would be attributed to loss of the more digestible nutrients during heating of the hay which accompanies mold growth. While we have not conducted studies with different levels of water applied to prairie hay, the water content after baling probably should not exceed 24 percent.

Ammoniation of hay that has become too mature prior to baling, and therefore is of low quality, appears to be an alternative for improving its nutritive value. Penetration of grass hay by aqua-ammonia appears to be less of a problem than with wheat straw since it does not have a slick surface.

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Table 2. Analyses of prairie hay

	Non-treated		Ammoniated[a]	
Sampling time:	After baling	After storage[b]	After baling	After storage[b]
Number of bales	5	5	7	7
Bale wt, lb	796	744	872	732
Bale DM, %	87.8	93.2	71.3[c]	84.6[c]
Crude protein, % of DM	4.41	5.02	13.92[d]	13.81[d]
N retention, %	—	—	26	26
IVDMD[e]	—	46.2	—	49.3[f]

[a]7.6% NH_3 on a DM basis.
[b]32 days after baling.
[c]Significantly ($P<.0002$) less than non-treated hay.
[d]Significantly ($P<.0001$) greater than non-treated hay.
[e]*In vitro* dry matter digestibility.
[f]Significantly ($P<.10$) greater than non-treated hay.

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Effect of Source of Supplemental Protein and Level of Supplement on Voluntary Intake and Performance of Lambs Fed Ammoniated Wheat Straw Silage[1]

C. L. Streeter, G. W. Horn, D. G. Batchelder and G. Manor[2]

Story in Brief

Wheat straw was chopped, moistened to 38 percent dry matter (DM), ammoniated with 8.4 percent w/w anhydrous ammonia and stored in an Ag-Bagger. The resultant "ammoniated straw silage" was individually fed *ad lib* to lambs with a negative control supplement containing only molasses and minerals, two levels of a soybean meal-based supplement or two levels of a corn gluten meal-based supplement. Lambs fed the negative control supplement consumed 2.48 percent of their body weight as straw DM and lost 0.07 lb/day. Source of supplemental protein did not affect (P>.05) gain or straw consumption. Level of supplement increased (P<.01) gains but did not affect (P>.05) ammoniated straw DM consumption. Lambs fed the ammoniated straw silage and 0.44 lb/day of a 36-percent crude protein-soybean meal supplement ate more (P<.01) and gained faster (P<.01) than the control lambs. The ammoniated straw silage contained 2.10 percent of the DM as free ammonia, which was 56.8 percent of the total nitrogen. Acid detergent fiber-bound nitrogen represented 19.7 percent of the total nitrogen. The cellulose content of the silage was 47.3 percent of the DM and was 60 percent digestible *in vivo* when fed with the low level of the soybean meal supplement. The hemicellulose content of the silage was 9.7 percent and was completely digested.

Introduction

Dry treatment of crop residues with anhydrous ammonia has been reported to improve digestibility and voluntary consumption by ruminant animals (Streeter and Horn, 1980). However, few ammoniation studies have been conducted with crop residues that have been moistened to a dry matter (DM) content of 30 to 40 percent so

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