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Increased costs of production have caused livestock producers to reduce feed costs whenever possible. Low quality crop residues, because of their availability, receive attention and offer considerable potential for reducing feed costs for cattle producers; however, because they are low in digestibility, intake by livestock is reduced.

Treatment of low quality crop residues with anhydrous ammonia improves digestibility or total digestible nutrients (TDN) and increases consumption of these forages. The positive effects of ammonia treatment on digestibility and intake of low quality forages make them a viable possibility in feeding programs.

Anhydrous Ammonia Treatment

Type of Forages to Consider: Ammoniation is a procedure designed to increase energy availability of low quality forages. Forages to consider for treatment include: wheat straw, barley straw, oat straw, very mature, low quality warm or cool season grasses, com stover and milo stover. Most forages that are less than five percent crude protein and 45 percent TDN on a dry matter basis are candidates for ammonia treatment. Treatment of medium- to high-quality forages with anhydrous ammonia results in only small changes in digestibility and intake, and may cause toxicity problems when fed.

Moisture Content of Forages: The moisture content of the forage to be ammoniated is important. The anhydrous ammonia combines with the moisture in the forage to form ammonium hydroxide. The ammonium hydroxide reacts on fiber components of the forage to cause an increase in digestibility. Ideally, best results of ammonia treatment occur when the forage is greater than 10 percent moisture.

Ammoniation of forages less than 10 percent moisture results in smaller increases in forage intake and digestibility.

Ways to ensure moisture in the forage to be treated include:

1. bale the forage shortly after harvest, or
2. bale the forage in early morning or late evening when there is dew on the forage.

Procedure for Anhydrous Ammonia Treatment: The ammoniation procedure is relatively simple and easy to accomplish. The stack of forage must be totally covered and sealed with plastic to make an airtight environment for the anhydrous to be added into. A few simple steps routinely used to ensure successful treatment include:

1. Determine the amount and approximate weight of residue or forage to be treated in each stack, and the availability of plastic in your area. Most farm supply stores and lumberyards sell various sizes of plastic, with the largest being 40 by 100 feet. If possible, locate stacks in an area with some protection from strong prevailing wind, good drainage, and near where it will be fed.

2. Disk an area to loosen the top one to three inches of soil for anchoring the plastic cover. If 40 by 100 feet of plastic is used, blade a space about 15 feet wide and 80 feet long to provide a surface for the bales and loose soil to later cover and seal the plastic.

3. Stack residue to be treated on the smooth area. If big round bales are used, stack them in a triad (two bales on the bottom and one bale on top) or in a pyramid (three bales on the bottom, two bales on the second row and one on top). Size of the bales and plastic dictates the method of stacking. If the plastic is 40 by 100 feet, there is usually enough room for 11 to 13 bales per row. Leave about two inches between each set of bales so as much of the bale as possible is exposed to anhydrous ammonia.

4. Cover stacked residue with new six to eight millimeter black plastic and seal the edge of plastic with the excess loose soil. Leave a small space to insert a pipe for adding anhydrous about the midpoint of the stack.

5. Insert a pipe 6 to 10 feet in length on the ground at the midpoint of the stack. Seal plastic with dirt around the pipe and connect the pipe to the hose on the anhydrous nurse tank. An adaptor is required that usually can be acquired from the supplier of the anhydrous. A shut-off valve on the pipe helps eliminate the backflow of anhydrous when disconnecting the adaptor after treatment is completed.

6. Add 60 pounds of anhydrous per ton of dry forage (3 percent; refer to worksheet for calculations).

Table I. Temperature — length of time forage needs to be sealed

Temperature at Ammoniation	*Minimum Time to be Sealed*
above 86° F	1 week
59-86° F	1 to 4 weeks
below 59° F	4 to 8 weeks

7. Turn on anhydrous slowly, until the plastic balloons slightly, then shut off the flow of anhydrous. Go around the stack and check for minor tears in the plastic, or leaks around the edges of the stack. If there are tears in the plastic, cover them with duct tape. After checking for and taping any

holes, add the remainder of anhydrous until the desired amount has been added. Do not add anhydrous so fast the plastic balloons. Total time to treat the residue will be about eight to 10 minutes per ton of residue — a 30 ton stack requires about five hours.

8. Turn off valve after treatment is complete, and remove pipe. Re-seal the area where the pipe was removed.

9. The rate at which the reaction occurs is temperature dependent (*Table I*). The cooler the outside temperature, the longer the residue needs to remain sealed.

10. Open one end of the stack three to five days prior to feeding to permit dissipation of the remaining anhydrous gas.

Table II. Average dry matter and moisture content of forages[a]

Forage[b]	*Percent Moisture*	*Percent Dry Matter*
Wheat straw	11	89
Oat straw	8	92
Barley straw	9	91
Milo stover	15-40	60-85
Com stover	15-30	70-85
Very mature bromegrass hay	11	89
Very mature big bluestem hay	12	88

[a]NRC, 1984, Sixth Edition
[b]All forages are sun-cured

Safety Precautions: Remember anhydrous ammonia is dangerous. If misused it can burn skin, eyes or throat, can explode and bum, and is maintained under pressure. Suggested safety precautions include:

1. Wear goggles, rubber gloves and protective clothing.
2. Work upwind when releasing anhydrous ammonia.
3. Have fresh water available to wash off any anhydrous ammonia that comes in contact with skin.
4. Check valves, hoses and tanks for leaks.
5. Check plastic cover over stack for leaks.
6. **Do not** smoke near anhydrous ammonia.
7. Keep children away from treatment area.

Remember, anhydrous ammonia is corrosive to most metals.

Worksheet to Determine the Amount of Anhydrous to Add

To calculate the amount of anhydrous needed, you need to know the approximate weight of the bales and the moisture content of the residue.

Weigh two to three bales to determine an approximate weight Average moisture and dry matter content of some residues are listed in *Table II*, and can be used if moisture content is not known.

The following calculations illustrate, using the percent gauge on the nurse tank, when to shut off the flow of anhydrous ammonia into the residue stack.

Method: For this method, one needs to know:

a. approximate weight of bales.

b. net full weight of anhydrous tank.
c. approximate dry matter content of residue.
d. tank gauge reading.

Need: 60 pounds of anhydrous ammonia per ton of dry matter of residue.

(1)_____ number of bales x (2)_____ pounds per bale x (3)_____ dry matter content of the residue = (4)_____ pounds of residue dry matter to be ammoniated.

(4)_____ ÷ 2,000 pounds per ton = (5)_____ tons of residue dry matter to treat with ammonia.

(5)_____ x 60 pounds of anhydrous per ton = (6)_____ pounds of anhydrous needed to treat residue.

Net weight (in pounds) of anhydrous ammonia tank (7)_____ at (8)_____ percentage of fullness read from the temperature pressure compensating regulator gauge on the anhydrous tank.

(7)_____ ÷ (8)_____ = (9)_____ pounds of anhydrous per each percentage unit on gauge.

(6)_____ ÷ (9)_____ = (10)_____ percentage units needed to complete anhydrous treatment.

(8)_____ — (10)_____ = (11)_____ is the final reading on the percentage fullness gauge when treatment is complete; therefore, shut the flow of anhydrous ammonia off when the tank gauge reads (11)_____.

Example:
(1) *39* number of bales x (2) *950* pounds per bale x (3) *.90* dry matter content of the residue = (4) *33,345* pounds of residue dry matter to be ammoniated.

(4) *33,345* ÷ 2,000 pounds per ton = (5) *16.7* tons of residue dry matter to treat with ammonia.

(5) *16.7* x 60 pounds of anhydrous per ton = (6) *1,002* pounds of anhydrous needed to treat residue.

Net weight (in pounds) of anhydrous ammonia tank (7) *4,420* at (8) *85* percentage of fullness read from the temperature pressure compensating regulator gauge on the anhydrous tank.

(7) *4,420* ÷ (8) *85* = (9) *52* pounds of anhydrous per each percentage unit on gauge.

(6) *1,002* ÷ (9) *52* = (10) *19.3* percentage units needed to complete anhydrous treatment.

(8) *85* — (10) *19.3* = (11) *65.7* is the final reading on the percentage fullness gauge when treatment is complete; therefore, shut the flow of anhydrous ammonia off when the tank gauge reads (11) *66*.

Forage Quality Changes

The digestibility and quality of crop residues is low because of an increase in cell wall components of the plant caused by greater maturity at harvest. Low digestibility slows down the rate of passage of the feed through the digestive tract of livestock, reducing the amount of forage that can be consumed. Ammonia treatment of forages with high cell wall content increases the digestibility and the intake of these feeds.

Digestibility: Ammoniating low quality forages increases digestibility 10 to 15 percent (*Table III*). The increase in digestibility is a result of the water and ammonia combining to cause breakdown of the fiber components of the forage. The ammoniation process essentially pre-digests the fiber so when animals consume the treated forage, breakdown of tough fiber components already has started and total digestibility is increased. An increase in digestibility means an increase in available energy content of the residue.

Table III. Change in forage digestibility, intake and crude protein after ammonia treatment

	Digestibility (%)		Crude Protein (%)		Increase In
Forage	Untreated	Treated	Untreated	Treated	Intake (%)
Wheat straw	39	48	3.7	9.7	18
Corn stover	48	56	6.2	11	22
Milo stover	46	61	5.4	17	NA
Switchgrass	46	55	5.6	14.5	6
Big Bluestem	53	59	5.6	17	10
Soybean straw	41	47	4.9	14	16

[a]Studies from Nebraska, Kansas, Oklahoma, Indiana, Missouri, Illinois, Arkansas, Guelph and Saskatchewan.

Animal Intake: In feeding trials using ammoniated residues, animal intake increased as much as 22 percent (*Table III*). These data indicate ammoniated residues are readily consumed if the material is allowed to "air out" three to five days prior to feeding.

The increase in intake of ammoniated residues is primarily due to the increase in digestibility; however, a portion of the increase in animal intake may be attributed to an increased palatability of ammoniated residues.

Increased intake of ammoniated residues allows animals to do a better job of meeting their protein and energy requirements by eating more feed.

Crude Protein: Crude protein content of residues increases after ammoniation (*Table III*). Ammonia (NH_3) contains nitrogen, and when residues are treated with anhydrous ammonia, the nitrogen component is attached to the fiber parts of the residue. Crude protein analysis measures the amount of

nitrogen (N compounds) in a sample whether it be from "true" plant source or added nitrogen compounds (NPN) such as ammonia.

Although the crude protein in ammoniated residues increases, not all that added nitrogen may be used by the animal. Rumen microorganisms use a portion of the additional nitrogen from ammonia treatment because of the increased energy from the treated straw and from any added energy sources.

For example, before ammoniation, crude protein content of a forage may be four percent; after ammoniation treatment the crude protein may be 10 percent. The ration should be balanced using about seven percent crude protein because that is the maximum amount residual ammonia the microorganism can use. Any additional protein should be supplied from high bypass sources.

Research indicates the increase in digestibility and intake of the ammoniated forage allows a mature gestating cow to consume more total protein and energy compared to untreated forage.

Preservation: Anhydrous ammonia applied at the 3 per-cent level acts as an excellent fungicide. As stated previously, moisture is essential for the ammoniation process. It is important to have the moisture content of the residue to be treated greater than 10 percent, and preferably around 15 — 20 percent.

Baled or stacked forages with high moisture content are excellent environments for molds. Anhydrous ammonia inhibits mold growth.

Animal Performance

Beef Cows: Research data indicates gain is greater for cattle eating ammoniated versus non-ammoniated residues (*Table IV*). Increased gain is due to increased digestibility and, subsequently, intake of the treated compared to the non-treated residue. Ammoniated residues appear to fit best as a feed source for mature gestating cows prior to calving. Nutrient requirements of replacement heifers and cows after calving are high, and treated residues need to be supplemented with protein and energy.

Supplementation for Beef Cows: When feeding treated residues to brood cows prior to calving, pay particular attention to hod~ condition. If cattle lose weight and body condition, the treated residue needs to be supplemented. As an example, a time when ammoniated residues may need to be supplemented with energy could be during extended periods of low temperatures and wind chill.

Mature gestating cows fed ammoniated straw will respond to alfalfa hay supplementation (*Table IV*).

Table IV. Effect of ammonia treatment of straw on intake and performance of gestating beef cows[a]

Treatment	*Daily Intake (lb)*	*Daily Weight Change (lb)*
Straw + 7 pounds of Alfalfa	14.8	-.27
Treated straw + 7 pounds of Alfalfa	19.7	.4
Treated straw	26.1	.1

[a]Ward et al., 1982

Supplementing Cows Fed Ammoniated Residues: Forage ammoniation increases the nitrogen content of the roughage as indicated by the increase in percent crude protein (*Table III*). The nitrogen of the

treated forage represents a readily available source of ammonia for rumen bacteria, and may meet the nitrogen requirement for optimum rumen fermentation.

When the animal's protein requirements are high, as during lactation, nitrogen needed by rumen bacteria can be supplied using ammoniated forages and by supplementing with a protein source (corn gluten meal, blood meal, feather meal, distillers grain) that is not digested in the rumen (bypass protein) but is digested in the small intestine to meet the remaining protein need. Animal performance may be enhanced because of the amino acid profile supplied by bypass protein reaching the small intestine.

A trial conducted at Nebraska shows lactating beef cows fed treated straw and supplemented with a protein (corn gluten meal, blood meal) that escapes (bypass) rumen breakdown performed similarly to cows supplemented with soybean meal. Because of the high bypass qualities of corn gluten meal and blood meal, the amount of supplement is reduced (by 1/4 to 1/2).

If a rumen bypass protein source could be purchased at a price that reduces overall feed costs because a smaller amount is needed compared to an all natural plant protein source, a producer should consider the bypass protein source and expect no decrease in performance.

When feeding ammoniated forages to beef cows, provide cows access to a mineral mix containing adequate salt, phosphorus and vitamin A. The mineral mix can be provided "free-choice" in loose or block form.

Feeding Method For Cows: Three to five days before feeding ammoniated forages, open up one end of the stack and allow any ammonia remaining to escape. Ammoniated forages can be fed three different ways. First, they can be fed loose, scattered on the ground. This method lends itself to the greatest amount of feeding losses. Second, they can be fed free choice, in slant bar bale feeders. And third, they can be ground and fed in bunks or inverted tractor tires.

Weaned Calves and Replacement Heifers Fed Ammoniated Forages: Harvested ammoniated crop residues can be used in rations for weaned calves. Depending on the percentage of ammoniated residue used in the ration, daily gain of .5 to 1.8 lb can be achieved. Ammoniating the crop residue increases calf performance compared to rations that contain untreated residue.

Supplementing Calves Fed AmmonIated Residues: Because of the high protein requirement of growing cattle, it is doubtful microbial synthesis of protein can meet animal needs while animals are eating low-quality roughage diets. Treatment of residues with anhydrous ammonia increases the amount of available energy and could provide nitrogen for microbial protein synthesis.

In Oklahoma studies, steers fed ammoniated straw and corn (6.5 lb/h/day) had gains similar to those fed untreated straw, corn (5.0 lb/h/day) and 1.3 pounds of soybean meal. So there appears to be a protein sparing effect of ammoniated forages.

Recent research indicates that when supplementing ammoniated residues with protein, that protein should be of the type (blood meal, corn gluten meal, distillers' grain, feather meal) that escapes digestion in the rumen. The ammonia from the treated residue and the portion of the supplement digested in the rumen would be used to meet the needs of the rumen microbes. The remaining protein would be digested in the small intestine, providing more protein and allowing for better calf performance.

Feeding Method for Growing Calves: Ammoniated residues may be deficient in both protein and energy in growing rations, depending upon the desired rate of gain. Ammoniated residues can be ground

and incorporated easily into a complete ration. There is an added cost for grinding and mixing, but it is a convenient way to assure protein and energy supplements are consumed with the straw.

Recent Nebraska research shows calves will gain at least 1/2 lb/h/day if the straw is fed in slant bar feeders in the long form, and a high bypass protein source fed separately.

Cost of Ammoniation

Four items need to be considered when determining the cost of ammoniating low quality forages: cost of anhydrous ammonia, plastic, quality and form of low quality forage available, and labor. In 1988, estimated costs to treat wheat straw were anhydrous ammonia @ $8-$12 per ton of residue; plastic (6 mil., 40' by 100') @ $4-$6 per ton of residue; residue @ $8-$10 per ton of residue; for a total that ranges between $24 to $35 per ton.

When should a producer consider treating residue and using this forage in a feeding program? Let's assume mid-bloom alfalfa is $50/ton and is 58 percent TDN (energy), while untreated wheat straw is 40 percent TDN (energy). Assume ammoniation increased the digestibility or TDN 15 percent; therefore, treated wheat straw would have a TDN value of 46 percent.

$$\frac{\text{46\% TDN for ammoniated straw}}{\text{58\% TDN for mid-bloom alfalfa}} \times \$50/\text{ton} = \$39.66/\text{ton alfalfa.}$$

In this situation, if a producer could buy and ammoniate wheat straw for less than $39.66/ton, he should consider this management practice to supply energy for his cattle.

Toxicity with Ammoniated Medium to High Quality Roughage

Toxicity has been reported in cattle consuming ammoniated medium to high quality roughage. Neurological signs of toxicity include hyperexcitability, circling, convulsions and sometimes death.

Toxicity appears to occur when livestock are fed ammoniated forage sorghum, hybrid sudan, early harvested small grain (wheat, oat, barley) hay, immature brome and fescue hays.

The toxicity also can occur in only the calves nursing cows fed ammoniated medium to high quality forages. The toxic problem in calves is the result of a compound passed through the dams via the mill: and the dam may not be visibly affected by the treated residue.

To date, no cases of toxicity have been reported with livestock fed ammoniated low quality roughage such as wheat, barley and oat straw, com Stover, and very mature cool or warm season grass hay. Management practices to consider to avoid toxicity include:

1. Ammoniate only low quality roughage.
2. Anhydrous ammonia should be added at a rate of 3 percent (60 pounds of anhydrous per ton of dry matter or crop residue).
3. Do not ammoniate medium to high quality hays.

If toxicity occurs in calves or cows avoid working the cattle and remove treated forage for two to three days. After two to three days, begin feeding cattle half ammonia-treated forages and half untreated

forage to eliminate the toxic condition.

Adding Liquid Supplements to Low-Quality Forages

As mentioned previously, ammoniation increases digestibility, intake and palatability of low quality forages. Experiments have been conducted to determine if injecting or spraying liquid (molasses) protein (non-protein nitrogen, urea) supplements on low quality roughage would result in the same positive effects as ammoniation of these roughages. Research conducted in Nebraska, Canada, Missouri and North Carolina indicates that adding liquid protein supplements to low quality forages ***does not*** increase digestibility, intake and gain of animals.

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