EFFECTS OF AMMONIATION AND SOURCE OF SUPPLEMENTAL PROTEIN ON UTILIZATION OF WHEAT STRAW BY CATTLE AND SHEEP

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TABLE OF CONTENTS

LIST OF TABLES

Table Page

FIGURE

CHAPTER I

INTRODUCTION

In 1980, world cereal grain production was 1.57 billion metric tons (FAO, 1981). This would produce an estimated 2.3 billion metric tons of residues (Tindall et al., 1980), and does not even consider residues from non-grain crops such as soybeans and cotton. In the United States alone, 270 million metric tons of grain were produced, leaving an estimated 378 million metric tons of aftermath in the field (FAO, 1981).

Wheat straw produced in North America accounted for as much as 76 million metric tons of the total residuum, with Oklahoma as the third largest producer of the grain in the United States (USDA, 1980). This harvest aftermath has great potential as a feed source for ruminant animals whose large microbial population present in their rumen enables them to utilize diets with a high cellulose content. However, due to the maturity of the plant at harvest, crop residues have a high cell wall content and are characterized by low crude protein and low digestibility. This meager digestibility has been ascribed to lignin or silica chemically bonding with hemicellulose and cellulose and preventing enough swelling of the material to allow

cellulytic enzymes to penetrate (Tarkow and Feist, 1969) and solublize the cell wall fractions.

The amelioration of harvest residue digestibility requires both economic and energy expenditures. These costs may be in the form of mechanical processing, heat and pressure treatment, or chemicals. Processing of cereal straws has been reviewed by many workers (Capper et al., 1977; Jackson, 1977; Wilson and Brigstocke, 1977; Han, 1978b; Wilkinson, 1978; Klopenstein et al., 1978; Kohler et al., 1979; Streeter and Horn, 1980) with the general concensus that chemical as opposed to mechanical treatment of crop residues is more effective in improving digestibility. Mechanical processing includes increasing accessibility of the cell wall contents by physically changing the size or structure through grinding, pelleting, electron irradiation, or steam and pressure treatment. Chemical treatment changes the structure of the plant material through chemical reaction, allowing better utilization of the material by ruminant animals. Although a multitude of chemicals have been tested for their potential to increase crop residue digestibility, relatively few have proven to have merit.

Chemical treatments generally take the form of saccharification, swelling or dilignification (Streeter and Horn, 1980), and of these alkaline swelling appears to be employed most often (Klopfenstein, 1978). Alkali treatment of lignocellulosic wastes affects the cell wall constituents, rendering them more soluble (Tarkow and Feist, 1969). While

use of sodium, calcium, potassium and ammonium hydroxides have recently been extensively reviewed by Klopenstein (1978), Streeter and Horn (1980), Hartley (1981), and Coxworth et al. (1981), the ease of use and availability of anhydrous ammonia for on-farm residue treatment precludes their usage in the United States.

Using ammonia to improve straw for animal consumption is not a new concept. In the early 1900's Lehman (1905) patented a procedure to treat straw and wood pulp with ammonia. Many trials of straw ammoniation were conducted in the 1950's and 60's using liquid ammonia on square bales of straw enclosed in a plastic sheet (Arnason and Mo., 1977). Ammoniation of crop residues has numerous advantages over other types of chemical treatments. All chemical treatments previously discussed, are capable of increasing the digestibility of cellulosic wastes. However, ammonia has the added benefit of doubling the crude protein content (Sundstol et al., 1978) and increasing the palatability of cereal straws (Horton, 1978, 1979).

Utilization of lignocellulose wastes for animal agriculture depends on many cultural, economic, meteorological and geographical factors. Availability of more conventional forage sources and current prices of those forages compared to the availability and prices of crop residues and their chemical benefactors will continue to moderate the use of crop residues well into the 21st century.

CHAPTER II

REVIEW OF LITERATURE

Protein Supplementation of Crop Residues

Supplementation Effects

Voluntary intake of low quality roughages is usually below the maintenance requirement of ruminant animals, with nitrogen being the nutrient most limiting in forages with less than about 5% crude protein (NRC, 1976). The ability to take advantage of low quality roughages such as crop residues by ruminants is dependent on ruminal microbial activity. Early work (Burroughs et al., 1950c, 1950d; Shrewsbury et al., 1942; Hemsly and Moir, 1963; Weston, 1967) indicated that lignocellulosic wastes have inadequate nitrogen to enable maximum microbial growth.

The addition of supplemental nitrogen to low quality roughage diets has shown many positive effects (Kropp et al., 1977; Andrews et al., 1972; Crabtree and Williams, 1971; Lyons et al., 1970). However, the amount of ammonia that can be utilized in the rumen depends on the number of bacteria present and their rate of growth. Any ammonia that is formed in the rumen and not used will be absorbed and eventually converted into urea by the liver. Therefore, it

is important to know the concentrations of ammonia that will support maximum microbial growth and decrease the loss of ammonia. Most researchers cite the data of Satter and Slyter (1974) and Satter et al. (1979) which indicates that any ruminal ammonia concentrations above 5 mg/100ml is associated with an increased loss of feed-nitrogen. It should be noted, however, that conflicting findings exist concerning the optimum ammonia concentration in rumen contents. Mehrez et al. (1977), Kang-Meznarich and Broderick (1981) and Wallace (1979) reported data that indicated ruminal ammonia was efficiently utilized up to a level of 22 mg NH_3/100ml of ruminal fluid. Ruminant digestion may show considerable wastage in a situation in which more nitrogen is absorbed than synthesized by the rumen microbes resulting in a net loss of dietary protein. Further studies are urgently needed, as this is a question of great practical importance.

Source of Protein

Cereal grains, high protein supplements, alfalfa hay, urea, and various green forages have all shown favorable influences on the digestibility of low-grade roughages (Burroughs and Gerlaugh, 1949; Burroughs et al., 1949a, 1950a, 1950d; Lyons et al., 1979; Coombe and Tribe, 1960; Kropp et al., 1977; Andrews et al., 1972; Barry and Johnstone, 1976; Robards and Pearce, 1975). Crabtree and Williams (1971) reported an increase in low levels of

concentrate (up to 25% of total diet) increased the intake of low quality hay and oat straw, but higher levels of concentrates tended to increase roughage intake.

Urea and other sources of non-protein nitrogen (NPN) have shown variable effects on intake and digestibility of low utility forages. Weston (1967) and Faichney (1968) have shown positive responses to supplemental nitrogen for increasing straw intake and weight gains. Fishwick et al. (1973) fed cubes of a straw-molasses-urea mixture and increased straw intake by about 20 percent. Kendall et al. (1980a) found that barley soaked in urea, fed once daily, increased straw intake by 20 percent, but when urea was supplied in a protein block very little advantage was noted. Bass et al. (1973), using biuret, increased low quality roughage intake and apparent digestibility of cellulose.

Not all research has shown increases in intake with nitrogen. Results reported by Kay et al. (1968) found no advantages in intake of straw with supplementation of either urea or barley. O'Donovan (1968) saw no effect of spraying straw with urea and Sharma et al. (1972a, 1972b) did not increase intake of straw when barley meal was already added. Joyce (1975), using a barley straw base, saw no effect from urea supplementation on weight change, but found the total weight loss was reduced when barley or corn were used as an energy protein source. This variation in response to NPN supplementation is dependent on the nitrogen content of the roughage and energy supply to the rumen microbial population

for efficiency of utilization.

Morris (1966), Crabtree and Williams (1971), Andrews (1972) and Fishwick (1973) have all reported that maximum intake of cereal residues is achieved when supplemented with small amounts of a starch-type carbohydrate in addition to nitrogen, regardless of the form of that supplemental nitrogen (NPN vs Protein). However, these energy containing supplements may be expensive to buy, store and feed and can decrease intake of low quality roughages (Holder, 1962; Langlands, 1969). High nitrogen forages (i.e., alfalfa and wheat pasture) which usually are abundant in the great plains, are an alternative to conventional supplementation, and these high-protein forages would be a cheap, plentiful source of supplemental nitrogen and energy. Grazing experiments have demonstrated that small quantities of fresh forage will improve animal performance (Willoughby, 1959; Norman and Stewart, 1967 and Norman, 1968).

In a drylot experiment, Barry and Johnstone (1976) fed leucerne hay (18.1% CP) or autumn pasture, which was cut fresh daily and contained 23.2% crude protein, as protein supplements. These high-nitrogen forages increased straw and digestible energy (DE) intake and decreased live weight loss. Although grain supplementation produced greater intakes of straw and DE and prevented weight loss, the high-protein forages were still of considerable value as supplements. When fed at a digestible organic matter intake level of 20% of maintenance, the high nitrogen

forages increased DE intake and were still low enough to prevent a substitution of high nitrogen forage intake for roughage intake as described by Crabtree and Williams (1971) or Andrews et al. (1972).

Increased digestibility is a main factor in supplementation of low quality roughages. Robards and Pearce (1975) found dry matter digestibility of a diet consisting of one part alfalfa hay and five parts oat hay to be seven units higher than the digestibility of the two components fed separately, when incorporated into a management program based on low quality roughages. Any benefit seen from this type of digestibility interaction relies on frequent supplementation, as more frequent feeding results in higher intakes as well as greater weight gains (Robards, 1970; Robards and Pearce, 1975). Coleman and Wyatt (1982) have also shown a depression in total dry matter intake and low quality roughage intake when small grains forages were fed at four-day intervals, as compared to daily feeding or even feeding on alternate days. This contrasted with their comparison of cottonseed meal in which they found no effect of supplementation frequency. It was suggested, however, that the depression in dry matter intake on the four day intervals with small grains forage were more a function of bulk intake of the small grains forage and the percent of total dietary DM provided by it, than an effect of feeding frequency per se. Therefore, to achieve an optimum supplementary effect, access to high nitrogen forage must be

fairly frequent, preferably one hour per day (Miller et al., 1965). Economics render this type of practice unfeasible in more extensive operations.

Another consideration in utilization of high nitrogen roughages for supplementation is their physical form and the effect of grinding, heat and pressure on digestibility. This change in forage form not only improves intake, weight gain and efficiency of feed utilization, but also changes the sites of digestion from the rumen to the lower tract (Coelho da Silva et al., 1972a, 1972b). Hogan and Lindsay (1980) evaluated the digestibility of non-ammonia nitrogen (NAN) of four forage diets which covered a wide range of protein content and organic matter digestibility and found them to be reasonably consistent between diets. These digestibilities of NAN in the small intestine were similar to those of fresh forages as described by MacRae and Wyatt (1974), but were much lower than that of forages dried at high temperatures (Coelho da Silva et al., 1972a, 1972b). These results suggested that digestion of protein from forages subjected to high temperatures and pressures more closely resembles that observed with concentrate diets (Faichney and White, 1979).

Ammoniation

Effects of Ammoniation on Straw Characteristics

Cereal straws potentially represent a vast energy source

for ruminant animals. These residues are composed mainly of cell wall polysaccharides that are poorly degraded by the microflora of the rumen. Cellulose, hemicellulose and lignin are the major components of the cell walls, along with silica and small amounts of pectin and protein. Cellulose is formed by polymers of B-1, 4-linked glucose units laid down in layers of parallel fibers (Preston, 1979) and hemicellulose, which contributes to cement the cellulose fibers, consists mainly of xylan, a polymer of B-1, 4-linked xylose units with arabinofuranosyl, 4-O-methylglucuronosyl, acetyl and substituted cinnamyl substituents (Wilkie, 1979). Lignin is formed in the secondary portion of the cell wall as the plant reaches maturity and is a phenolic polymer containing phenylpropane structural units and can comprise over 25 percent of the dry weight of the cell wall (Freudenberg, 1965). Breakdown of plant cell walls by the rumen microbial population is inhibited by the binding of the cellulose and hemicellulose by lignin which cannot be degraded by any bacteria in the rumen (Lechtenburg et al., 1974). Lignin along with silica contribute to the structural rigidity of plants and these associations are responsible for much of plant cell wall resistance to microbial digestion.

Ammonia increases degradation of lignocellulosic wastes through a swelling action which increases the accessibility of the cell wall to the rumen microbial population. Ammonia solublizes the 4-O-methyl glucuronic acid and acetyl groups of hemicellulose, this breaks the glucuronic acid ester

bonds which link the xylan polymers to cellulose and lignin, allowing greater exposure to microbial enzymatic attack (Tarkow and Fiest, 1960). Solaiman et al., (1979) treated straw with ammonia hydroxide at a level equal to 3.3% ammonia of the dry weight of the straw and analyzed the various fiber fractions for changes in solubility and digestibility. Hemicellulose and neutral detergent fiber (NDF) were decreased by 42.7 and 8.6 percent, respectively. The digestibility of the hemicellulose actually decreased with chemical treatment due to the large amount that was solublized, while the cellulose digestion increased from 38.7 to 71.4 percent by addition of NH_4OH. Horton et al. (1982), comparing ammoniated straw that had been either shredded or pelleted, found a 16 percentage unit increase in organic matter digestibility and a decrease in crude protein digestibility, especially with the pelleted ammoniated diet. The lowered crude protein digestibility is comparable to those reported by Garrett et al. (1974) and percentage unit increase in organic matter digestibility is almost identical to another trial with wheat straw by Horton and Steacy (1979). Ammoniation increased the degradation of NDF, ADF and cellulose in the pelleted ration and gave evidence that hemicellulose was solublized by treatment with anhydrous ammonia.

Three major factors that influence the efficacy of ammoniation of cereal straws are (1) the moisture content of the straw, (2) the temperature of the material under

treatment and (3) the level of ammonia applied to the dry weight of the straw. Moisture contents varying from 7.5 up to 50 percent have been reported as ideal for straw ammoniation (Waiss et al., 1972; Solaiman et al., 1979; Sundstol et al., 1978; Borltami and Sundstol, 1982). Temperature influences the amount of time necessary for optimal ammonia reaction with the straw. Kernan et al. (1977) and Sundstol et al. (1979) have reported that at lower temperatures longer treatment time is required for higher digestibility coefficients. The effect of treatment time also changes with the level of ammonia injected (Sundstol et al., 1978; Waagepeterson and Thomsen, 1977; Borhami and Sundstol, 1982). However, Waagepeterson and Thomsen (1977) indicated that increasing the ammonia level from 4.4 to 5.5 percent was without benefit if the time of treatment was sufficiently long.

Table I presents the conditions which have been recommended by different authors to maximize the nutritive value of low quality roughages treated with ammonia. Borhami and Sundstol (1982) found that aqueous ammonia was more efficient in improving the nutritive value of low moisture straw. Sundstol (1979) attributed the additional water in aqueous ammonia as the benefactor, since no additional effect was denoted when treating high moisture straw.

Genus and variety are other factors which affect improvement of cereal straws through ammoniation. While it is generally accepted that there are differences in feeding

TABLE I

OPTIMAL CONDITIONS RECOMMENDED TO OBTAIN MAXIMAL DIGESTIBILITY OF CEREAL STRAWS BY AMMONIATION

Ammonia Type	Ammonia Level (% of straw DM)	Temperature (°C)	No. Days	Moisture (%)	Reference
Anhydrous	2.5 - 4.0	> 30 30-15 15-5 > 5	> 7-28 28-56 56	at least 25-30	A
Aqueous	3.3	21-23	1-10	54	B
Anhydrous	2.6 5.9	62 30	4 3-7	30 30	C
Aqueous	5.0	Ambient	30	30	D
Anhydrous	3.5	20 10 0	15 30 60	15 15 15	E
Aqueous	4.0	17	42	7.5	F
Anhydrous	2.0 4.0	17 17	42 42	10 7.5	F
Anhydrous	3.0 3.0	14° 14°	30	11.6 11.6	G

A Sundstol et al., 1978
B Solaiman et al., 1979
C Waagepeterson and Thomsen, 1977
D Waiss et al., 1972
E Kernan et al., 1977
F Borhami and Sundstol, 1982
G Lawlor et al., 1981

value of wheat, oat and barley straws, there is a lack of information characterizing the nutrient composition differences between cultivars. Thomas et al. (1979), analyzing untreated straw, found no differences within genre in crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) or lignin of five varieties of barley straw or seven varieties of wheat straw. Kernan et al. (1979), on the other hand, found small but significant differences in CP and DOM between cultivars and Horton and Steacy (1979) noted large variation in CP and crude fiber of the varieties within each cereal genus. These disparities in crude protein and digestibility within family contribute to irregularities when ammonia is applied to the straw.

Horton and Steacy (1979) applied anhydrous ammonia at 3.5 percent of the dry weight of straw and noted an increase in CP content of about 160% in wheat and oat straws. Barley straw produced more mutable results with CP increases ranging from 50 to 270 percent between varieties. These workers felt that since treatment conditions were the same for all cultivars, determinants other than temperature, treatment duration, ammonia level and moisture content of the straw influence nitrogen retention with anhydrous ammonia application. Although Kernan et al. (1979) conducted their trials at different locations and times, ammoniation tripled wheat straw crude protein and doubled that of barley and oats, even though significant CP differences occurred within variety at several crop locations.

Regardless of the initial crude protein, ammoniation at least doubled and often tripled crude protein content of all crops and varieties reported. The final total improvement in crude protein and digestibility remains based on the initial quality of the straw. Plant breeding programs are well established for improving grain yields, disease resistance and grain quality while ignoring the feeding value of the lignocellulosic harvest remnant.

Effects of Ammoniation on Animal Performance and Other Physiological Parameters

Augmentation of digestibility and crude protein content of lignocellulosic wastes are only two constituents which are enhanced by ammoniation. Palatability, and therefore intake and animal performance, show great improvement as exemplified by Armason and Mo (1977), Oji et al. (1977) and Hertel et al. (1979). Intake and daily gains of lambs fed wheat straw were increased by 18 and 91 percent, respectively, by ammoniation. A Nebraska group (Asadpour and Klopenstein, 1970; Paterson et al., 1970b), utilizing wheat straw treated with ammonium hydroxide, saw even greater intake with lambs by increasing intake 31 percent and average daily gain by 91 percent.

Horton (1978) found that ammoniation increased consumption of straw fed alone by about 41%. However, when straw was fed with a supplement, intakes were quite similar

between untreated and ammoniated straw. This is not surprising since steers were allowed to eat 3.6 kg DM of concentrate each day. Similar results were reported by Horton and Holmes (1976), feeding barley straw ad libitum with supplements ranging from 1.5 to 7.5 kg/day. In a more recent experiment, Horton and Steacy (1979) fed a concentrate supplement at 1% of steer body wt. and reported ammoniation increased straw consumption 19%. Horton et al. (1982) reported an increase in straw intake of 12% and an increase in organic matter digestibility of 15% by ammoniation. Streeter et al. (1980) reported no advantage in gain of steers fed ammoniated wheat straw although intakes were increased by 14% over untreated straw. However, the straw in this trial was ammoniated during baling and this method is not as effective in increasing the in vitro dry matter digestibility of straw as the stack method (Horn et al., 1981; Sundstol et al., 1978). Rissanen et al. (1981) reported a small increase in live weight gain of steers fed ammoniated barley straw, even though intakes of treated and untreated straws were the same.

Garrett et al. (1979) showed a 130 percent increase in average daily gain with a 15 percent increase in intake of ammonia treated rice straw when fed to growing calves, and increase in both variables of 52 and 8%, respectively, with the same treatment fed to lambs. Rice straw intakes of steers in this experiment were 9290 g/day when fed at 72% of the total diet. Horton (1979) and Arnason and Mo

(1977) reported straw intakes of 2010 g/day and 4100 g/day, respectively, for wheat and barley straw when fed at 50 and 30% of the diet, respectively. Horton (1979) showed no increase in intake or gain while Arnason and Mo (1977) reported increases of 36 and 25%, respectively. Males and Gaskins (1982) reported increases in intakes of 90% for an ammonia plus water ensiled wheat straw and 65% for "stack method" ammoniated straw fed to growing heifers.

The intake and performance results cited from the previous data give rise to the question of the value of the added nitrogen in the ammoniated residues. Very little information is available on this practical aspect of crude protein digestibility and nitrogen retention comparisons between treated and unammoniated harvest leftovers. Horton et al. (1982) recently reported increases of 15 and 17% for organic matter and neutral detergent fiber digestibilities of straw, while crude protein digestibility decreased with ammonia treatment, indicating that the added nitrogen received from ammonia is not well utilized. Oji et al. (1977) produced similar results and indicated a Maillard reaction product that occurs due to a condensation of the aldehyde fraction of amino-sugars will have decreased nitrogen availability. Numerous workers have noted similar findings with little or no difference in nitrogen retention of animals fed barley straw (Arnason and Mo., 1977), wheat straw (Al-Rabbatt and Heaney, 1978), soybean residue (Miller et al., 1979) or corn stover (Mowat and

Buchannan-Smith, 1978).

More recent work, however, has shown contrasting results. Saenger et al. (1982) found dry matter intake and digestibility of ammoniated corn stover (C-NH_3) superior to that of untreated corn stover supplemented with soybean meal (CS) or urea (CU) unsupplemented, or untreated corn stover (NC). Nitrogen retention of ammoniated corn stover was slightly greater than CU but not significantly so, and both of these were vastly improved over CS with NC having nitrogen retention values 5 times less than C-NH_3. These workers indicated that the nitrogen added during ammonia treatment was used with the same efficiency as the nitrogen from soybean meal or urea supplements. Since ammoniation alters the carbohydrate fraction of the forage fiber (Tarkow and Feist, 1969), then utilization of the nitrogen from ammoniated residues should be increased because NH_3 is released slightly before or concurrently with energy from the more readily available carbohydrates. Herrera-Saldana et al. (1982) reported crude protein digestion coefficients of 31.8, -48.0 and -38.5 for ammoniated wheat straw (NH_3-WS), untreated wheat straw (WS) and untreated wheat straw supplemented with feather meal (FM-WS) respectively. These authors could not explain the negative digestion coefficients for FM-WS and WS. Ruminal ammonia values of 14.5, 8.4 and 12.4 mg/dl for NH_3+WS, WS and FM+WS, respectively, were significantly different. Ruminal ammonia values did not indicate the same differences between

treatments that were suggested by the crude protein digestion coefficients. Nitrogen digestibility and nitrogen retention data reported by Males and Gaskins (1982) indicate that ammonia added to the straw was absorbed and utilized by lambs. They indicated, however, that the increased nitrogen retention could be due to greater energy intakes provided in the supplement, resulting in an increased utilization of the ammonia by rumen microorganisms (Hespell and Bryant, 1979). These later works were conducted with a small number of animals which may have accounted for some of the differences they reported.

Elevated ruminal ammonia levels for animals fed ammoniated straws and low quality roughages have also been reported by Horton (1978) and Al-Rabbat (1978). Horton (1978) found ruminal ammonia concentrations of steers fed either treated straw alone or straw plus a barley-based supplement were quite similar and about seven times greater than untreated straw without supplements. Al-Rabbatt and Heaney (1978) reported ruminal ammonia values as mg of NH_3 per kg of whole rumen digesta (WRD) and found ruminal ammonia values to be much greater than the increase in nitrogen intake accounted for. This indicates the ammonia was retained in the form of ammonia salts in the ammoniated wheat straw.

Horton (1978) noted consistently lower blood urea values for unsupplemented, untreated cereal straws and suggested these lower values indicate reduced ruminal

ammonia concentrations due to the low nitrogen contents of the diet. These workers also reported elevated plasma urea values when ammoniated straw was fed without supplement and speculated this was due to low nitrogen utilization since a "normal" blood urea level was achieved when a supplement was fed with either straw treatment. This would indicate that the increased nitrogen present is optimally employed when energy is available. Herrera-Saldana et al. (1982) presented plasma urea data with much lower values but the same general trend. The plasma urea nitrogen was greatest for steers fed ammoniated straw and lowest for untreated straw, while a protein type supplement fed with untreated straw increased plasma urea nitrogen close to the level obtained with ammoniated straw. However, maximum usage of ruminal ammonia and the level of plasma urea nitrogen depends greatly on the concentration needed for maximum microbial synthesis and the level of carbohydrate-type energy source. Both of these factors need to be more clearly defined.

Rumen fluid pH does not appear to be affected by the type of straw fed (Horton et al., 1978; Horn et al., 1982) although lower values are seen for untreated straw rations. Al-Rabbatt and Heaney (1978) Horton (1978) and Herrera-Saldana et al. (1982) have reported that total volatile fatty acid (VFA) concentrations also to be unaffected by diet when NH_3 straw versus untreated straw is fed. Al-Rabbat and Heaney (1978) noted a difference in molar

percentages of two of the fatty acids. Butyrate (11.7%) contributed a greater proportion of the total VFA's with acetate (73.1%) being the apparent source. Comparing VFA molar proportions of lambs fed ammoniated wheat straw to alfalfa, steamed wood, wheat straw or a grain-alfalfa ration, Al-Rabbatt and Heaney (1978) reported acetate values of 83.7, 84.4, 83.9 and 76.6%, respectively, and butyrate values of 3.2, 1.8, 4.2 and 7.9%, respectively. This apparent conversion could occur through reversal of the B-oxidation or the malonyl-CoA pathways (Baldwin, 1965; Leng, 1970) as a result of more fermentable energy being available. Males and Gaskins (1982) reported ammonia treatment of wheat straw caused a shift in the proportion of VFA to a lower concentration of acetate and a higher concentration of propionate. Morris and Mowat (1980), feeding ammonia treated corn cobs, noted a similar shift to higher ruminal propionate concentrations.

CHAPTER III

THE EFFECT OF AMMONIATION OF WHEAT STRAW ON INTAKE, DIGESTIBILITY AND PERFORMANCE OF NONPREGNANT, NONLACTATING BEEF COWS

Summary

The effects of ammoniation of wheat straw on intake, digestibility, ruminal fluid and blood plasma parameters were evaluated in an in vivo digestion trial with cows. Wheat straw was treated with 37 g NH_3/kg wheat straw dry matter (DM). Forty-eight mature nonpregnant, nonlactating Hereford cows weighing 369±24 kg were randomly allotted to one of three treatments and allowed to graze dormant native range (Treatment 1) or have ad libitum access in drylot to untreated wheat straw (Treatment 2) or ammoniated wheat straw (Treatment 3). Weight changes and body condition scores (9 point scale) were evaluated. All cows were individually fed .95 kg/day of a cottonseed based supplement that supplied .32 kg of crude protein. Ammoniation increased straw crude protein content from 4.2 to 8.7% of DM and increased in vitro dry matter digestibility (IVDMD) 32% (40.9 to 53.9%). Weight gains and condition score changes of cows on range and cows fed untreated or ammoniated straw

were, respectively: .24, .04 and .18 kg/day and +.48, +.05 and +.12 condition score units. Using acid-insoluble ash (AIA) as an internal marker, digestibility and straw intake increased, respectively, from 65.4 to 72.8% and 2.48 to 2.92% of cow weight by ammoniation. These unrealistically high values were attributed to sorting of straw by the cows and consumption of straw of different AIA content than straw obtained for analysis prior to feeding. Intakes of straw, calculated from in vivo DMD estimates from IVDMD values were 1.50 and 1.81% of cow weight. Regardless of which procedure was used to estimate straw intake, ammoniation increased intake (kg straw DM/100 kg body wt) about 20%. Concentrations ot total volatile fatty acids (VFAs) of cows fed ammoniated straw (77.3 vs 104.4 umoles/ml) were lower than those of cows fed untreated straw. Ruminal ammonia (14.3 vs 10.3 mg/100 ml, $P<.01$) and total soluble carbohydrate concentrations (9.4 vs 8.2 mg/100 ml, $P<.05$) were increased by ammoniation.

Plasma urea and albumin concentrations were not affected ($P>.05$) by treatment, but concentrations of total protein in plasma of cows fed ammoniated straw were slightly increased ($P<.05$). These results indicate that utilization of ammoniated wheat straw would be an alternative feeding strategy for wintering cows by producers faced with inadequate amounts of range forage. (KEY WORDS: WHEAT STRAW, AMMONIATION, COWS).

Introduction

For every metric ton of wheat produced in North America, almost one and one-half metric tons of wheat straw is left in the field as potential feedstuff for ruminant animals (Anderson, 1978). However, the digestibility and crude protein content of wheat straw are generally too low to maintain even mature nonproductive ruminants without supplementary protein. Because of the low feeding value of crop residues, many chemical and physical alterations to improve energy efficiency, consumption and animal performance have been tested.

Chemical treatment of low quality roughages has produced favorable results, with much of the attention being focused on various alkalis, such as sodium hydroxide, which has been shown to increase digestibility, intake and animal performance (Ololade et al., 1979; Klopenstein et al., 1972). However, the sodium may place a physiological stress on the animal as large quantities are consumed with the residue and must be excreted in the urine (Maeng et al., 1971). Also, over a period of time this practice could lead to an accumulation of sodium in the soil.

Anhydrous ammonia has recently received a great deal of attention and has been shown to improve digestibility and intake of poor quality roughages while also increasing the crude protein content (Al-Rabbat and Heaney, 1978; Horton, 1978; Sundstol et al., 1978; Kerman et al., 1979; Herrera-Saldana et al., 1982; Males and Gaskins, 1982).

Ammoniation of crop residues has the potential of reducing the chemical cost of treatment, increasing the crude protein content of treated residues and is not a source of chemical pollution.

Beef producers, when faced with declining or inadequate amounts of winter pasture need optional roughage resources to maintain their beef cow herds. Therefore, the objectives of this trial were to compare the performance of cows fed treated and untreated wheat straw in drylot to that of cows wintered on dormant native range. Effects of ammoniation of wheat straw on body weight and condition changes and ruminal fluid and blood plasma constituents of nonpregnant, nonlactating cows in drylot were also studied.

Materials and Methods

Forty-eight (48) nonpregnant, nonlactating Hereford cows that were five years old and weighed 369±24 kg were stratified by weight and randomly assigned to three treatments with two replications per treatment. The cows grazed dormant native range pasture (Treatment 1) or had ad libitum access in drylot to either untreated wheat straw (Treatment 2) or ammoniated wheat straw (Treatment 3).

The wheat straw was ammoniated by the "stack method" similar to that described by Sundstol et al. (1978). Two separate stacks of 28 large round bales per stack were ammoniated. The bales of straw (two rows of fourteen bales placed end-to-end per row) were rolled onto one edge of a

12.2 x 30.5 meter sheet of black plastic (.20 mm thick). The remaining free portion of the plastic sheet was pulled over the bales and the edges were rolled together and sealed. The ends of the stack were tied off with nylon cord after a 12.7 mm (O.D.) black pipe had been placed in the stack. Anhydrous ammonia (3.7% w/w of straw DM) was injected into the sealed stack through the pipe that open-ended into an empty oil drum in the middle of the stack. Since the straw was ammoniated during cool weather of the fall, the stack remained sealed for 30 days after injection of ammonia.

Untreated and ammoniated bales of straw were sampled to depths of 42 cm with a forage probe immediately prior to placing the bales in the panel-type feeders. Samples were composited across weeks within months and stored in double plastic bags in a freezer until analysis were completed. Crude protein content of the samples was determined by the macro-Kjeldahl procedure prior to drying to avoid loss of ammonia. In vitro dry matter digestibility (IVDMD) was determined by the Tilley and Terry (1963) procedure with urea (.5 g/liter) added to the buffered rumen fluid (1 part strained rumen fluid: 1 part McDougall's buffer, 1948) and a 24 h acid-pepsin digestion phase. Residual DM was collected by use of a Buchner funnel fitted with pre-weighed, oven-dried Whatman No. 4 filter papers.

Cows of all treatments were individually fed .95 kg/day of a supplement that contained 34% crude protein. Ingredient

composition of the supplement is shown in Table II. The cows were weighed after being held off feed and water for 24 h on days 0, 16, 46 and 58 of the 58-day trial and assigned a body condition score of 1 to 9 (1 = very thin, 9 = very fat) on days 0 and 58. Daily weight gains of the cows were calculated by (1) dividing the difference of final and initial body weights by number of days and (2) regression of body weight on days of the trial.

Voluntary consumption of wheat straw by the cows in drylot was measured during days 28 through 42 of the trial. Cows were fed 11.6 g chromic oxide in their daily allotment of supplement during 10-day preliminary and 5-day fecal collection periods. Fecal samples were collected from the rectum each time the cows were fed supplement and were composited across days, within cows, on an equal wet weight basis for drying at 60 C and subsequent analyses. Fecal outputs were estimated by chromium dilution. Yearling Hereford steers (249±7.6 kg) which were fitted with fecal collection bags and harnesses, were used to correct fecal outputs of cows for recovery of chromium. At the start of the preliminary period, three steers were placed in one pen of each group of cows fed untreated or ammoniated straw and were fed the same amount of chromic oxide containing supplement as the cows. Acid-insoluble ash (AIA) was used as an internal marker and the AIA content of the feces, straw, and supplement was used to calculate straw intake. Fecal AIA concentrations were corrected for fecal recovery of AIA of

TABLE II

COMPOSITION[A] OF SUPPLEMENT FED TO COWS

Ingredient	% As-Fed
Cottonseed Meal	90.5
Molasses	3.1
Calcium Carbonate	2.7
Dicalcium Phosphate	1.2
Trace Mineralized Salt	2.5

[A]Plus Vitamin A, 26,217 IU/KG of supplement.

94.2% obtained in previous straw feeding trials with lambs. The 2N HCl procedure (Van Keulan and Young, 1977) was used for analysis of AIA.

Ruminal fluid samples were taken by aspiration from the rumen and blood samples were obtained from the jugular vein of all cows fed wheat straw on day 56 of the trial. Samples were obtained about 22 h after feeding supplement, but cows had access to straw up to the time of sampling. The pH of ruminal fluid samples was measured immediately after collection. The samples were then strained through cheese cloth and 50-ml aliquots were acidified with 1 ml of 20% H_2SO_4; and placed on ice. One-milliliter aliquots of the acidified ruminal fluid samples were diluted to 50 ml with freshly distilled water, and 1 ml of the diluted samples was analyzed for ammonia using the phenolnitroprusside and alkaline-hypochlorite reagents of Chaney and Marbach (1962). Soluble carbohydrate concentrations of rumen fluid samples were determined by modification of the procedure of Johnson et al. (1966). Aliquots (.5 ml) of rumen fluid were added to reaction tubes containing 1.5 ml of distilled water. One ml of phenol reagent and 5 ml of concentrated sulfuric acid were added to each tube, mixed and allowed to set at room temperature for 10 min. The tubes were then mixed a second time and incubated at 30 C for 20 min. before measuring absorbance at 490 nm. Glucose was used as the standard. Five-milliliter aliquots of the strained ruminal fluid were prepared for VFA analysis by deproteinization

with 1 ml of 25% (w/w) meta-phosphoric acid that contained 2-ethylbutyric acid as an internal standard. Samples were centrifuged at 25,000 x g for 20 minutes and the supernatant portions were refrigerated until analyzed for VFA by gas chromatography. Column packing and gas flow rate were the same as those reported by Hinman and Johnson (1974).

Plasma of the blood samples was separated by centrifugation and frozen until analyzed for urea, total protein and albumin. Plasma samples were incubated with buffered urease (Fawcett and Scott, 1960; Searcy et al., 1961) and then analyzed for ammonia using the reagents of Chaney and Marbach (1962). The biuret (Gornall et al., 1949) and bromcreasol green[1] procedures, respectively, were used to determine total plasma protein and albumin concentrations.

Data were analyzed by analysis of variance procedures for a completely random design (Steel and Torrie, 1960). Differences among treatment means were tested for significance by Duncan's Multiple-range test only if the preliminary F test was significant.

Results and Discussion

Crude protein content and IVDMD of untreated and ammoniated straw are shown in Table III. Crude protein content of straw DM was increased from 4.2 to 8.7% by ammoniation. Ammonia nitrogen was 37.7% of the total

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[1]Sigma Technical Bulletin No. 630. Sigma Chemical Co., P.O. Box 14508, St. Louis, MO 63178 USA.

TABLE III

COMPOSITION OF UNTREATED AND AMMONIATED WHEAT STRAW

Item	Untreated Straw	Ammoniated Straw	SEM
Crude Protein, %DM	3.8	8.5	2.74
Pepsin Insoluble N, % of Total N	57.6	34.5	3.42
NH_3-N, % of Total N	--	37.7	.360
NH_3-N Recovery[B], %	--	23.4	--
ADF[D]-N, % of Total N	--	34.0	1.01
% of Increased N	--	16.6	.076
Soluble CH_2O, %	.999	1.443	.114
IVDMD[C], %	40.9	53.9	.572

[A] 3.7% NH_3 of Straw DM.

[B] $\frac{\text{Increased N Content of Straw in Stack}}{\text{Amount of } NH_3 \text{ Added}} \times 100$

[C] In Vitro Dry Matter Digestibility

[D] Acid Detergent Fiber

nitrogen in the ammoniated straw. Calculated recovery of ammonia injected into the two stacks was only 23.4±3.7%, which was lower than the 33% reported by Sundstol et al. (1978) and 40% reported by Horn et al. (1981a) for wheat straw treated with aqua-ammonia (1.7% NH_3 w/w of straw DM) during baling of large round bales. Loss of ammonia through small punctures in the plastic, which is an important practical problem with ammoniation by the stack method, may have attributed to the low recovery of ammonia. Depending on the extent to which the low recovery of ammonia was due to loss of ammonia on the straw, it may be possible to use lower levels of ammonia in ammoniation of crop residues by the stack method. The total soluble carbohydrates in the wheat straw increased 44% (.999 vs 1.443%, Table II) and the IVDMD of wheat straw was increased about 32% (53.9 vs 40.9%, Table II) by ammoniation.

Body weight gains and condition score changes of the cows are shown in Table IV. Cows on native range gained .24 kg/day and improved in body condition by about .5 units. Cows fed untreated wheat straw essentially maintained body weight and condition. Saenger et al. (1982) feeding corn stover to pregnant beef cows, found that only cows fed ammoniated corn stover supplemented with corn were able to gain weight and maintain their body condition. Cows fed untreated corn stover plus a supplement of corn, soybean meal or urea all lost weight and decreased in condition score. Gains of cows fed ammoniated wheat straw in drylot

TABLE IV

MEAN BODY WEIGHT GAINS AND CONDITION SCORE CHANGES OF COWS

Item	Native Range	Untreated Straw	Ammoniated Straw	SEM
No. of Cows	16	16	16	---
Initial Cow Weight, Kg	366.2	366.9	371.2	---
Weight Gains				
Kg/Day[C]	.24[A]	.04[B]	.18[A]	.040
Kg/Day[D]	.25[A]	-.01[B]	.18[A]	.081
Condition Score				
Initial	4.94	4.97	5.00	.112
Final	5.42	5.02	5.12	.091
Change	+.48	+.05	+.12	---

[AB] Means with a common superscript are not different ($P<.05$).

[C] Calculated by difference of $\frac{\text{final-initial wt.}}{\text{No. of Days}}$

[D] Calculated by regression of wt. on days on trial.

were similar to those of cows that grazed native range, but the cows did not improve in condition as much as cows on native range. Part of the improved condition of the range cows may have been due to the consumption of cool-season annual grasses that remained green during the extremely mild winter. Standard errors of the mean weight gains of the cows calculated by regression were twice as great as those for gains calculated by difference to nonlinearity of gains early in the trial.

Digestibility and intake of wheat straw DM, calculated using AIA as an internal marker, were increased, respectively from 65.4 to 72.8% and 2.48 to 2.92% of cow body weight by ammoniation (Table V). These unrealistically high values are probably due to sorting of straw by the cows and consumption of straw of different AIA content than the samples of straw obtained with the forage probe prior to feeding. Failure to account for AIA content of orts has been identified (Block et al., 1981) as a problem where AIA is used as a marker. This was not really possible in the present study where cows had ad libitum access to large round bales of straw in panel-type feeders. Herrera-Saldana et al. (1982) feeding wheat straw to steers, also found great variability in AIA concentrations and declined use of the AIA data.

Intakes of straw, calculated in vivo DMD estimates from IVDMD values were 1.50 and 1.81% of body weight (Table IV) and much more realistic. Irrespective of which

TABLE V

EFFECT OF AMMONIATION ON INTAKE AND DIGESTIBILITY OF WHEAT STRAW BY COWS IN DRYLOT

	Untreated Straw	Ammoniated Straw	SEM
No. of cows	15	14	--
Method of estimating in vivo digestibility (and/or intake of straw)			
AIA[b]			
Straw DM digestibility, %	65.4	72.8	1.397
Straw intake			
Kg DM/day	9.06	11.07**	1.369
Dg DM/100 Kg body wt	2.48	2.92*	.133
IVDMD[c]			
Straw DM digestibility[d], %	47.0	55.6	--
Straw intake			
Kg DM/day[e]	5.57	6.88**	--
Kg DM/100 Kg body wt	1.50	1.81**	--

[a]Data of 1 and 2 cows fed untreated and ammoniated straw, respectively, were deleted because of extremely high fecal AIA concentrations.

[b]Straw intake, Kg DM/day = $\frac{\text{Acid-insoluble ash (AIA) in feces from straw, KG}}{\text{AIA content of straw, \% of DM}}$

[c]In vitro dry matter digestibility.

[d]Calculated from regression equation of Oh et al. (1966): In vivo DMD, % = 16.7 + .74 (IVDMD)

[e]Straw intake, KG/day = $\frac{\text{Fecal output (KG) corrected for CR recovery and indigestibility of supplement}}{1 - (\text{in vivo DMD}/100)}$

* $P < .05$.
** $P < .01$.

procedure was used to estimate straw intake, ammoniation increased intake of straw (kg DM/100 kg body wt) about 20% which is in agreement with other studies (Horton and Steacy, 1979; Saenger et al., 1982) relative to ammoniation of crop residues.

Effect of ammoniation of wheat straw on ruminal fermentation and VFA concentrations of cows fed in drylot is shown in Table VI. Concentration of total ruminal volatile fatty acids (VFAs) of cows fed ammoniated straw (77.3 vs 105.4 umoles/ml) was lower than that of cows fed untreated straw. Since intake of straw was increased by ammoniation, the decreased total VFA concentrations may indicate that ruminal digestion of straw was decreased by ammoniation. Berger et al. (1979) reported that ruminal digestion of "potentially digestible fiber" of NaOH-treated corn cobs by lambs decreased with greater than 2% of NaOH in the diet. Similar data have not been reported for ammoniated crop residues but would be of particular concern since reduced ruminal fermentation would decrease utilization of NH_3-N present in ammoniated residues. Another explantion for the decreased total VFA concentration would be the result of dilution by the greater amount of straw that was consumed by cows fed ammoniated straw.

Other than the small increase in the molar proportion of butyric acid of cows fed ammoniated straw, the molar proportions of VFAs were similar and were not affected ($P>.05$) by treatment.

TABLE VI

EFFECT OF AMMONIATION OF WHEAT STRAW ON RUMINAL FERMENTATION AND VFA CONCENTRATION

Item	Untreated Straw	Ammoniated Straw	SEM
Total VFA, Umoles/Ml	105.4	77.3*	.869
VFA Molar Proporations			
Acetic	74.7	77.3	.491
Propionic	17.0	16.9	.285
Acetic: Propionic Ratio	5.5	4.4	.104
Butyric	6.0	6.7*	.184
Valeric	.38	.43	.047
Isovaleric	.91	.81	.070

*P<.05.

Ruminal ammonia concentrations (Table VII) of cows fed ammoniated wheat straw were increased ($P<.01$). This would be expected since a large portion (i.e., 24% to 79%) of the increased N content of ammoniated residues is in the form of ammonia (Waagepetersen and Thomsen, 1977; Solaiman et al., 1979; Streeter et al., 1981a, 1981b). Herrera-Saldana et al. (1982) reported quite similar ruminal ammonia values for steers fed ammoniated and untreated wheat straw. However, the crude protein digestion coefficient for the untreated straw was a negative value which the authors could not explain.

Total soluble carbohydrate concentration of ruminal fluid of cows fed ammoniated straw was slightly ($P<.05$) increased. Hespell (1979) reported that K_s values[2] of 6 to 100 umolar have been found for soluble sugar of ruminal fluid and(or) bacterial growth media. The soluble carbohydrate concentrations may limit growth of ruminal bacteria of ruminants fed low-quality roughages such as crop residues. Chemical treatments that increase availability of sugar moities of hemicellulose and cellulose may increase bacterial growth rates by increasing the amount of soluble carbohydrates available for growth. Tarkow and Fiest (1969) showed that ammonia reacts with the 4-O-methyl glucuronic acid and acetyl groups of the xylan polymer, hemicellulose.

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[2]Concentration of a growth limiting nutrient that permits bacteria to grow at 50% of maximal growth rate. A 10-fold increase in the K_s value will allow a growth rate of 99% of maximal rate.

TABLE VII

EFFECT OF AMMONIATION OF WHEAT STRAW ON RUMINAL FLUID AND BLOOD PLASMA CONSTITUENTS

Item	Untreated Straw	Ammoniated Straw	SEM
Rumen Fluid pH	7.34	7.39	.045
Ruminal NH_3, mg/100 ml	10.3	14.3**	.815
Ruminal Soluble CH_2O, mg/100 ml	8.2	9.4*	.438
Blood Plasma Constituents			
Urea, mg/100 ml	8.9	9.6	.549
Total Protein, g/100 ml	7.7	8.1*	.137
Albumin, g/100 ml	4.9	5.2	.201

**P<.01.
* P<.05.

Solaiman et al. (1979) found that 42.7% of the hemicellulose of wheat straw was solubilized by treatment with ammonia (3.3% w/w of straw DM).

Plasma urea nitrogen concentrations (Table VI) were similar to those reported by Horton (1978) for steers fed ammoniated and untreated with supplementation, but were not statistically different ($P>.05$). Plasma albumin was not affected by treatment ($P>.05$). Jordan and Swenson (1979), Claypool et al. (1980) and Treacher et al. (1976) all reported that the percent crude protein in the ration did not affect albumin concentrations in blood serum. Payne et al. (1970), however, reported Hypoalbuminaemia in cows with low intakes of crude protein and Hyperalbuminaemia in cows with high intakes of crude protein. The concentration of albumin in serum is inversely related to the number of services required per conception (Rowlands et al., 1977). Total protein concentrations in plasma of cows fed ammoniated straw were slightly increased ($P<.05$), however.

Low crude protein and low digestibility of wheat straw restrict utilization by ruminant animals. Treatment with anhydrous ammonia increases dry matter digestibility and provides additional crude protein resulting in greater dry matter intake, as was demonstrated in this trial. With this increase in intake and digestibility, more energy was made available and weight gains of cows fed ammoniated straw were similar to those of cows grazing native range forage, while cows fed untreated straw maintained body

weight and condition. These results indicate that utilization of ammoniated wheat straw would be an alternative feeding strategy for wintering cows by producers faced with inadequate amounts of dormant native range.

CHAPTER IV

EFFECT OF SOURCE OF SUPPLEMENTAL CRUDE PROTEIN ON INTAKE AND DIGESTIBILITY OF WHEAT STRAW BY LAMBS

Summary

Thirty lambs with a mean initial weight of 38.8±1.9 kg were housed in individual pens and fed untreated chopped wheat straw ad libitum and either soybean meal (SBM), dehydrated alfalfa pellets (DEHY) or harvested wheat forage in amounts to supply 60 g of supplemental crude protein per day. Straw dry matter (DM) intake was greatest for lambs supplemented with SBM (1.26 percent of body weight). Intake of straw by lambs fed DEHY (1.12 percent of body weight) was slightly lower than lambs fed SBM. Supplementation with wheat forage decreased ($P<.05$) straw consumption as compared with lambs supplemented with SBM and DEHY. Total feed intake was highest for lambs supplemented with DEHY ($P<.05$). Dry matter digestibility of wheat straw was 37.2, 36.4 and 49.2 percent, respectively, for lambs supplemented with SBM, DEHY and wheat forage. The decreased straw consumption of lambs supplemented with wheat forage would be of concern in situations where an abundant supply of straw or other low quality roughage was to serve as the base of the feeding

program. In these situations, supplemental protein should enhance intake and utilization of the low-quality roughage.

Introduction

The effects of protein supplementation in increasing consumption and digestibility of low quality roughages by ruminants are well known (Lyons et al., 1970; Crabtree and Williams, 1971; Andrews et al., 1972). While oilseed meals such as cottonseed and soybean meal are commonly used as sources of supplemental protein, they may be expensive to buy, store and feed. High nitrogen forages are an alternative to conventional supplementation.

Wheat forage commonly contains 25 to 30 percent crude protein (DM basis) during the normal grazing period of November 15 to March 15. Utilization of wheat forage to supplement low-quality roughages would be particularly appropriate since large amounts of wheat pasture are grown on the southern Great Plains. The objective of this study was to determine the effect of three sources of supplemental crude protein (soybean meal, dehydrated alfalfa pellets and wheat forage) on intake and dry matter digestibility of chopped wheat straw by lambs.

Material and Methods

Thirty wether and ewe lambs with a mean initial weight of 38.8±1.9 kg were randomly assigned, within sex, to three treatments. The lambs were housed in individual pens with

a 1.5 x 1.5 meter wooden slat floor space and allowed ad-libitum access to chopped wheat straw. Supplements of either soybean meal (SBM), dehydrated alfalfa pellets (DEHY) or wheat forage were fed to supply 60 g crude protein (CP) per day. Wheat forage was analyzed daily for dry matter and crude protein content and the amount fed was adjusted to meet CP requirements. Supplement DM Intake and Composition of Ingredients are shown on Table VIII. Wheat forage was harvested in early April with a small pull-type flail harvester. After harvesting, the forage was placed in large plastic bags (11.3±2.0 kg/bag), excess air was pressed out and the bags were sealed. The bagged forage was stored in a walk-in freezer at -2°C and fed as needed during the trial.

Samples of wheat straw and the three sources of supplemental protein were collected daily and composited over 5-day intervals during the trial and analyzed for dry matter and crude protein. The wheat straw contained 4.3 percent crude protein and had an in vitro dry matter digestibility (IVDMD) of 3.74 percent. The trial included a ten day preliminary period for the lambs to adapt to the diets and a thirteen day period in which straw consumption was measured. Total fecal excretion of five lambs per treatment was measured during the last five days of the trial by use of total fecal collection bags.

Dry matter digestion coefficients of wheat forage and dehydrated alfalfa pellets were obtained by feeding an

TABLE VIII

SUPPLEMENT DM INTAKE AND COMPOSITION OF INGREDIENTS

	SBM	DEHY	Wheat Forage
Supplement DM Intake (g)	120.0	340.0	280.0
Trace Mineralized Salt (g)	10.0	10.0	10.0
Dicalcium Phosphate (g)	13.2	13.3	11.8
Limestone (g)	7.8	0.0	6.2
Vitamin A + D Premix[A] (g)	.5	.5	.5
Wheat Midlings (g)	18.5	26.2	21.5

[A]Vitamin A + D 30,000 IU/g

additional five lambs per supplement for a period of ten days with total fecal output collected the last four days. The supplements were fed at a level of 1.6 percent of lamb body weight. All fecal samples were weighed daily to determine total fecal output and a 5 percent aliquot was taken and composited across days, dried in a 60°C oven and analyzed for dry matter. The TDN value of 81 percent was used as the dry matter digestion coefficient of SBM (NRC, 1976). Straw dry matter digestibility was calculated by "difference" as described by Schneider and Flatt (1975).

The data were analyzed by analysis of variance procedures. Duncans multiple range test was used to test differences among treatment means for significance.

Results and Discussion

Dry matter, crude protein content and dry matter digestibility of the three supplements are shown in Table IX. The wheat forage was harvested at the three-joint, pre-boot stage of maturity. Therefore, its crude protein content and digestibility were lower than that expected with wheat forage grazed during the "normal" November 15 to March 15 grazing period.

Total DM intake expressed as a percentage of body weight is presented in Figure 1. Dry matter consumption of supplements followed an inverse pattern of amount of crude protein expressed as a percent of dry matter. This would be expected since a lower percent crude protein supplement

TABLE IX

DRY MATTER (DM), CRUDE PROTEIN AND DM DIGESTIBILITY OF SUPPLEMENTS

	Source of Supplemental Crude Protein			
	Soybean Meal	Dehydrated Alfalfa Pellets	Wheat Forage	SEM
Intake, g DM/day	120	340	280	---
No. of Samples	5	5	5	---
Dry matter, %	88.1	91.4	23.6	.275
Crude protein, % of DM	47.7	16.9	20.7	5.697
Dry matter digestibility, %	81.0[a]	60.1[b]	64.5[b]	2.045

[a]From TDN value of SBM of 81% (NRC).

[b]From lamb digestion trial.

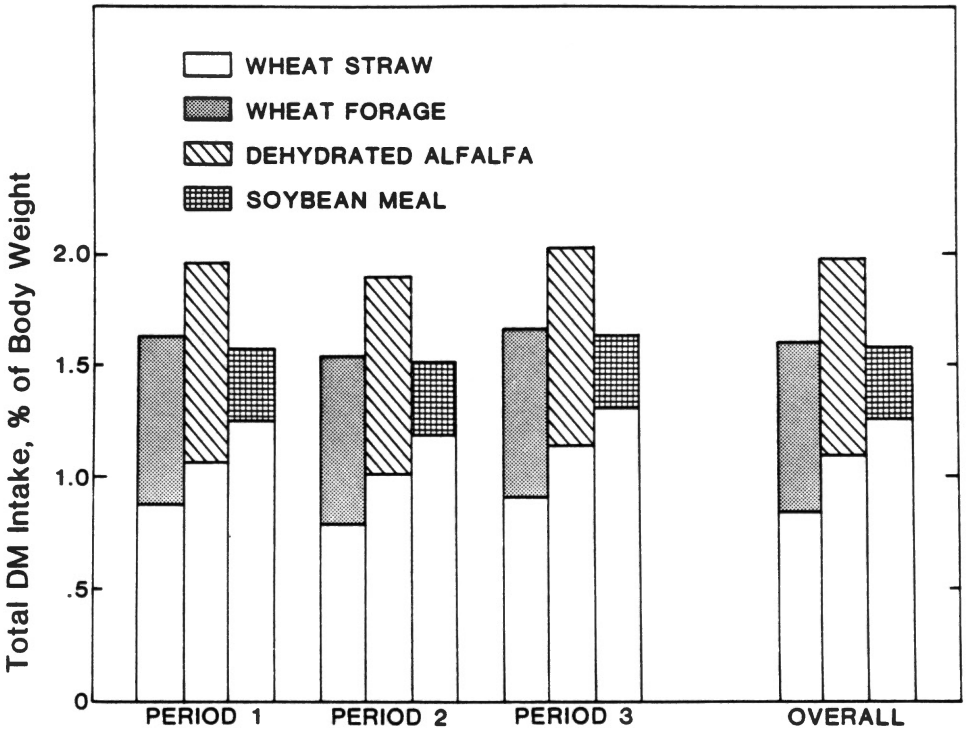

Figure 1. Total DM Intake. Period 1, 2 and 3 Relate to Days 11-15, 16-20 and 21-23 of the 23-Day Trial. Overall is Days 11-23.

would require greater amounts to reach the 60 gram per day goal. Supplement consumption was greatest for lambs fed DEHY (.89% of body wt) followed closely by wheat forage (.74% of body wt), while SBM DM intake was only .32% of body weight. Wheat straw dry matter intake was consistent within treatment (Fig 1) throughout the trial, and was greatest for lambs fed soybean meal (1.26% of body wt., Table III). Intake of straw by lambs fed DEHY (1.12% of body wt., Table III) was slightly lower than lambs fed SBM. Faichney and White (1979) have suggested that high nitrogen forages that have been subjected to high temperatures and pressures have digestibility patterns that more closely resemble concentrate diets than forage diets. Wheat forage decreased ($P<.05$) straw consumption as compared with lambs supplemented with SBM or DEHY.

One possible explanation for the increased straw intake of lambs supplemented with SBM would be that the lambs were eating to fulfill their energy requirements since the supplements were not iso-caloric. The decreased consumption of straw noted with wheat forage supplementation may be the result of a substitution effect. Minson and Milford (1967) found that increasing the ratio of green feed to low quality roughage tended to convert the forage from a supplement that stimulated to a substitute that reduced poor quality roughage intake. Bulk fill may be another effect causing the lambs fed wheat forage to feel satiated and decrease consumption of wheat straw. Total feed intake (Table X)

TABLE X

FEED DRY MATTER (DM) INTAKE AND DM DIGESTIBILITY OF WHEAT STRAW

	Source of Supplemental Crude Protein			
	Soybean Meal	Dehydrated Alfalfa Pellets	Wheat Forage	SEM
Supplemental Crude Protein, g/head/day	60	60	60	---
Lamb Weights, kg				
Initial	39.0	39.1	38.2	.593
Final	37.9	38.6	37.8	.527
Feed DM Intake				
Supplement, g/day	120	340	280	---
Wheat Straw g/day	480[a]	430[a]	320[b]	30.970
% of body wt	1.26[a]	1.12[a]	.84[b]	.084
Supplement Plus Wheat straw, % of body wt	1.58[a]	2.02[b]	1.59[a]	.086
Straw DM Digestibility, %	37.2[a]	36.4[a]	49.2[b]	1.788
Total Digestibile DM Intake, g/day[c]	278.4	353.8	319.6	---

[ab]Means in the same row with different superscripts are different ($P<.05$).

[c] Estimated from TDN values of sheep NRC, 1975.

was 1.58, 2.02 and 1.59 percent of lamb body weight for SBM, DEHY and wheat forage, respectively, with DEHY producing a significantly greater ($P<.05$) intake.

Digestibility of straw DM (Table III) was similar (37.2 and 36.4, respectively) for lambs supplemented with SBM and DEHY and was highest (49.2 percent) for lambs fed wheat forage. Some of the improvement in straw DM digestibility of lambs supplemented with wheat forage would be attributable to the lower wheat straw intakes.

Robards and Pearce (1975) found dry matter digestibility of a diet containing one part alfalfa hay and 5 parts oat hay to be seven units greater than the average digestibility of the two hays fed separately. However, to benefit from this type of digestibility interaction would require frequent feeding as reported by Robards (1970). Coleman and Wyatt (1982) found that feeding harvested small grains forages at four-day intervals decreased total intake and intake of low quality roughages when compared to daily or alternate day feeding. Miller et al. (1965) has suggested that animals have one hour per day access to high nitrogen forage to achieve an optimum supplementary effect. Such practices would be limited due to the additional labor, cost and management required.

The decreased straw consumption of lambs supplemented with wheat forage would be of concern in situations where an abundant supply of straw or other low quality roughage was to serve as the base of the feeding program. In these

situations, supplemental protein should enhance intake and utilization of the low quality roughage. If adequate amounts of low quality roughage were not available, the reduction in consumption of straw by wheat forage supplementation would be of less concern.

CHAPTER V

ANHYDROUS AMMONIA TREATMENT OF WHEAT STRAW AND ITS EFFECT ON INTAKE, DIGESTIBILITY AND PERFORMANCE OF BEEF STEERS

Summary

The effects of anhydrous ammonia treatment of wheat straw on intake, digestibility and average daily gain were studied in an in vitro digestion trial with yearling steers. Wheat straw was treated with 35 g NH_3kg wheat straw dry matter (DM). Forty-four yearling steers weighing 233±20 kg were randomly assigned to one of four treatments. Steers were individually fed 1.44 kg/day of a supplement designed to provide supplemental crude protein (CP) at a level of .54, .45 or .36kg/head/day. The steers also had ad libitum access in drylot to either untreated wheat straw or ammoniated straw. Ammoniation increased straw CP content from 6.03 to 13.56% of DM and increased in vitro dry matter digestibility (IVDMD) 29% (33.78 to 43.60%). Average daily gains were .26, .28, .24 and .57 kg for steers on Treatments 1, 2, 3 and 4, respectively. Intakes of straw were increased ($P<.05$) from 1.7 to 2.2% of steer body weight. Concentrations of total volatile fatty acids (VFAs) of steers fed

ammoniated straw were higher (34.42 vs 40.57 umoles/ml) than steers fed untreated straw. Ammoniation of straw increased ($P<.01$) the molar proportion of acetate and decreased ($P<.05$) the proportion of propionate. Ruminal ammonia (12.33 vs 22.24 mg/ml, P .001) and total soluble carbohydrate concentrations (11.06 vs 16.19 mg/100 ml, $P<.001$) were increased by ammoniation. These results indicate that anhydrous ammonia treatment of wheat straw could provide an emergency source of energy and crude protein when conventional sources are unavailable.

Introduction

In the United States an estimated 76 million metric tons of wheat straw were produced and Oklahoma ranks third in tons of production (USDA, 1980). Straw had a high cellulose content and is a potential feedstuff for ruminant animals. However, due to low crude protein content and poor dry matter digestibility only a small proportion of straw is harvested for animal consumption.

A wide variety of chemical and physical alterations have been attempted to improve the feeding value of wheat straw with chemical methods producing the most promising results (Campling and Freer, 1966; Klopfenstein, 1978; Horton et al., 1982). Chemical treatment of crop residues with anhydrous ammonia has received the most attention recently since it may be done on the farm with materials that are easily obtained. Treatment with ammonia has the

added advantage of increasing the crude protein content of the straw.

Oklahoma cattlemen will winter more than a million head of stocker cattle on wheat pasture during even the least productive years. Wheat pasture may become unavailable for grazing due to a lack of sufficient moisture and inadequate plant growth or snow covering of the plant parts during an extreme winter. During these unproductive years cattlemen need optional sources of protein and carbohydrates to maintain their stockers and try to produce some gains. Feeding large amounts of grain and buying additional roughage can put an economical hardship on the producer.

The objectives of this trial were to compare the performance of steers fed ammoniated straw and supplemental crude protein (CP) at a level of .45 kg/head/day, to steers fed untreated straw and supplemental CP levels of .54, .45 and .36 kg/head/day. The effect of ammoniation of wheat straw on ruminal fluid constituents and straw intake and digestibility were also studied.

Materials and Methods

Forty-four yearling steers weighing 233±20 kg were randomly assigned to one of four treatments. The steers were obtained from two different sources and were composed of mixed British breeds. The steers were individually fed 1.44 kg/day (dry matter [DM] basis) of corn and soybean meal based supplements (Table XI). Supplements were

TABLE XI

COMPOSITION[A] OF SUPPLEMENTS[B]

	Untreated Straw			Ammoniated Straw
Supplemental Crude Protein, kg/hd/day	.54	.45	.36	.45
Ground Shelled Corn	20.4	36.8	53.2	36.8
Soybean Meal	73.9	57.5	41.1	57.5
Dicalcium Phosphate	4.3	4.3	4.3	4.3
Trace Mineralized Salt	1.4	1.4	1.4	1.4

[A]Plus Vitamin A, 12,568 IU/kg of supplement.

[B]% As Fed.

designed to supply Crude Protein (CP) at a level of .54, .45 or .36 kg/head/day. The steers also had ad libitum access in drylot to either untreated wheat straw or ammoniated straw.

Wheat straw was ammoniated by the "stack method", a process developed in Europe and described by Sundstol et al. (1978). Twenty-eight large round bales (413±41 kg) were placed in two rows of fourteen on the edge of a 12.2 x 30.5 meter sheet of black plastic (.20 mm thickness). The remainder of the plastic sheet was pulled over the bales and the edges were sealed with tape and tightly rolled next to the stack. Bags filled with sand and loose dirt were used to weight the edges to prevent unrolling. One end of the stack was tied closed with nylon cord after a pipe (12.7 mm outside diameter) was placed in the stack to open-end into one-half of a fifty-five gallon metal drum (split long ways) in the middle of the stack. Anhydrous ammonia (3.5% w/w of straw DM) was injected into the stack from a portable anhydrous ammonia tank hooked to the pipe apparatus. The stack remained sealed for thirty days after ammoniation, then was uncovered to allow the effluvium to dissipate.

Supplement samples were taken daily, stored in plastic bags and composited within each mixture feeding period. Untreated and ammoniated bales of straw were sampled to depths of 42 cm with a forage probe immediately prior to placing bales in panel-type feeders. Samples were stored in double plastic bags in a freezer and composited across

months for analysis. Straw samples were ground with dry ice through a wiley mill and stored in a freezer until analysis were completed. Crude protein content of the samples were determined by the macro-Kjeldahl procedure prior to drying to avoid loss of ammonia nitrogen. In vitro dry matter digestibility (IVDMD) was determined by the Tilley and Terry (1963) procedure. Urea (.5 g/liter) was added to the buffered rumen fluid (1 part strained rumen fluid:1 part McDougall's buffer, 1948), followed by a 24 hour acid-pepsin digestion phase. Dry matter residue was collected in a Buchner funnel fitted with pre-weighed, oven-dried Whatman No. 4 filter paper. Straw samples were analyzed for pepsin insoluble nitrogen and ammonia nitrogen (Horwitz, 1975). Soluble carbohydrate content of the wheat straw was determined using a 5 g (wet wt) straw sample homogenized in 45 ml of distilled water. The supernatant was drawn off and 2 ml was diluted with distilled water to 100 ml. Two ml of the diluted supernatant was used for analysis in the procedure described by Johnson et al. (1966).

Steers on all treatments were weighed after being held off feed and water for twenty-four hours on days 0, 28, 70 and 100 of the 100 day trial. Average daily gains (ADG) of the steers were calculated by dividing the difference of final and initial body weights by number of days.

Voluntary consumption of wheat straw was measured for steers on Treatment 2 (.45 kg CP/hd/day and untreated wheat straw) and Treatment 4 (.45 kg CP/hd/day and ammoniated

wheat straw) during days 57 through 67 of the trial. Steers were fed 6 g chromic oxide daily in their supplement during an 8 day preliminary and a 5 day fecal collection period. During the fecal collection period, fecal samples were collected from the rectum when steers were fed supplement. Samples were composited across days, within steers, on an equal wet weight basis for drying at 60°C and subsequent analysis.

Ruminal fluid samples were taken via a stomach tube from steers on Treatment 2 and Treatment 4 on day 72 of the trial. Samples were obtained about 20 hours after feeding supplement, but steers had free access to straw up to the time of sampling. The pH of ruminal fluid samples was measured immediately after collection. The samples were then strained through four layers of cheese cloth and 50 ml aliquots were acidified with 1 ml of 20% H_2SO_4 and placed on ice. Ruminal fluid ammonia concentration was determined by using the Chaney and Marbach (1962) procedure with one ml aliquots of the acidified rumen fluid diluted to 50 ml with distilled water. One ml of the diluted samples was analyzed for ammonia using phenolnitroprusside and alkaline-hypochlorite reagents. Soluble carbohydrate concentrations of rumen fluid samples were determined by modification of the procedure of Johnson et al. (1966). Rumen fluid (.5 ml) was added to reaction tubes with 1.5 ml of distilled water. Phenol reagent (1 ml) and concentrated sulfuric acid (5 ml) were added to each tube, mixed and allowed to set at

room temperature for ten minutes. After a second mixing the tubes were incubated in a water bath at 30°C for twenty minutes before measuring absorbance at 490 nm. Glucose was used as the standard.

Five ml aliquots of the acidified ruminal fluid were prepared for Volatile Fatty Acid (VFA) analysis by deproteinization with 1 ml of 25% (w/w) meta-phosphoric acid that contained 2-ethylbutyric acid as an internal standard. Samples were centrifuged at 25,000 x g for 20 minutes and the supernatant portion was drawn off and refrigerated until analyzed for VFA by gas chromatography. Column packing and gas flow rate were the same as those reported by Hinman and Johnson (1974).

Data were analyzed by analysis of variance procedures for a completely random design (Steel and Torrie, 1960). Differences among treatment means were tested for significance by Duncans Multiple-range test where appropriate.

Results and Discussion

Crude protein content and daily intakes of the supplements are shown in Table XII. Average crude protein contents were 38.5, 31.8 and 24.8% for supplements 1, 2 and 3, respectively. Average daily intakes were 1.42, 1.43 and 1.47 kg for each of the three supplements, respectively.

Crude protein content, nitrogen parameters, soluble carbohydrate concentrations and IVDMD of the untreated and ammoniated straw are shown in Table XIII. Crude protein

TABLE XII

SUMMARY OF SUPPLEMENT INTAKE AND CRUDE PROTEIN (CP) LEVEL (DRY MATTER BASIS)

Supplemental CP/hd/day		.54 kg CP/hd/day		.45 kg CP/hd/day		.36 kg CP/hd/day	
Mix No.	Number of Days Fed	1		2		3	
		Intake (kg/day)	CP (%)	Intake (kg/day)	CP (%)	Intake (kg/day)	CP (%)
1	23	1.35	40.2	1.47	30.8	1.50	24.4
2	22	1.49	36.49	1.43	31.6	1.53	23.8
3	24	1.40	38.8	1.41	32.2	1.37	26.6
4	22	1.42	38.3	1.40	32.5	1.47	24.7
5	9	1.41	38.5	1.40	32.4	1.51	24.2
	Total Days			Weighted Average			
	100	1.42	38.5	1.43	31.8	1.47	24.8

content of straw DM was more than doubled by ammoniation with an increase from 6.03 to 13.56%. Pepsin insoluble nitrogen (47.15 vs 31.52% of total nitrogen, Table XIII) accounted for 19% of the increased nitrogen in the ammoniated straw while ammonia nitrogen (5.78 vs 34.52% of total nitrogen, Table XIII) comprised 57.53% of the increased nitrogen in the ammoniated straw. Recovery of ammonia (Table XIII) injected into the sealed stack indicates that 34% was bound to the straw. Sundstol et al. (1978) and Waagepetersen and Vestergaard Thomsen (1977) report similar nitrogen recovery values, but results can be quite variable. Lawlor and O'Shea (1979) reported nitrogen recoveries of greater than 50% while Herrera-Saldana (1982) recovered only 18% of the nitrogen injected into a sealed stack. Total soluble carbohydrates in the wheat straw were increased 74% (.927 vs 1.614%, Table XIII) by ammoniation.

Steer body wt gains and average daily gains are shown in Table XIV. Steers fed ammoniated straw had more than doubled daily gains ($P<.01$) than steers fed untreated straw, regardless of supplement crude protein level. Weight gains of steers fed untreated wheat straw were not different from each other. Horton et al. (1982), feeding wheat straw at 40% of the total diet, increased average daily gains of feeder steers from .83 to 1.13 kg/day by ammoniation, an increase of 36%.

Wheat straw DM intakes, calculated from fecal production using chromix oxide as a marker and in vitro DM

TABLE XIII

COMPOSITION OF UNTREATED AND AMMONIATED WHEAT STRAW

	Untreated Straw	Ammoniated Straw	SEM
Samples Per TRT	4	4	---
Crude Protein, % DM	6.03	13.56	.184
Pepsin Insoluble N, % of Total	36.80	31.52	7.593
% of Increased N	---	27.37	8.653
NH_3-N, % of Total[A]	5.78	34.52	1.470
% of Increased N	---	57.49	1.766
ADF-N, % of Total N	31.10	22.41	6.680
% of Increased N	---	15.12	4.223
NH_3-N Recovery[B], %	---	34.37	---
Soluble CH_2O, %	.927	1.614	.081
IVDMD[C], %	33.78	43.60	5.167

[A] 3.5% NH_3 w/w of straw DM

[B] $\frac{\text{Increased N Content of Straw in Stack}}{\text{Amount of } NH_3 \text{ Added}} \times 100$

[C] In Vitro Dry Matter Digestibility

TABLE XIV

EFFECT OF AMMONIATION OF WHEAT STRAW AND SUPPLEMENT CP LEVEL ON AVERAGE DAILY GAIN OF STEERS

	Untreated Straw			Ammoniated Straw	SEM
Supplemental Crude Protein, % of DM	38.5	31.8	24.8	31.8	---
Supplemental Crude Protein, kg/hd/day	.54	.45	.36	.45	---
No. of Steers	11	11	10[c]	11	---
Initial wt, kg	234.3	232.5	234.2	230.9	5.323
Final wt, kg	260.0[a]	260.4[a]	258.5[a]	288.0[b]	10.213
Average Daily Gain, kg	.26[a]	.28[a]	.24[a]	.57[b]	.042

[ab]Means in the same row with different superscripts differ ($P < .01$).

[c] 1 steer deleted due to negative wt. gains.

digestibilities, are shown in Table XV. Fecal production was increased significantly ($P<.05$) from 2.8 to 3.3 kg DM/day by ammoniation of wheat straw. The respective intakes of steers fed ammoniated straw were increased ($P<.01$) 37% (4.3 to 5.9 kg DM/day and intake of straw DM as a percent of steer body weight were increased ($P<.05$) 27% (1.708 vs 2.171 kg DM/100 kg steer body weight). This increase in dry matter intake (kg/day) is similar to those reported by Horton et al. (1982), Garrett et al. (1974) and Males and Gaskins (1982). Other researchers have reported intake to be increased by ammoniation by 13% or more (Herrera-Saldana et al., 1982 and Saenger et al., 1982).

Effect of ammoniation of wheat straw on VFA concentrations of steers fed ammoniated or untreated straw are shown in Table XVI. Total ruminal volatile fatty acid concentrations of steers fed untreated straw were lower than that of steers fed ammoniated straw (34.42 vs 40.57 umoles/ml). Such low total VFA concentrations are uncommon, however Herrera-Saldana et al. (1982) reported similar results for steers fed wheat straw diets. These authors suggested that the additional nitrogen added to the straw was insufficient for adequate rumen fermentation. However, ruminal ammonia concentrations in the Herrera-Saldana study were above the 5 mg NH_3-N/100 ml of ruminal fluid recommendation offered by Satter and Slyter (1974). This would indicate that additional energy in the form of readily available carbohydrates would have been the limiting factor (Barry and

TABLE XV

EFFECT OF AMMONIATION ON INTAKE AND DIGESTIBILITY OF WHEAT STRAW BY STEERS

	Untreated Straw	Ammoniated Straw	SEM
No. of Steers	11	11	---
Straw IVDMD[A], %	33.78	43.60	5.167
Straw Intake			
Kg DM/day	4.315	5.925**	.298
Kg DM/100 kg body wt.	1.708	2.171*	1.34
Fecal Production (kg)	2.857	3.42*	1.82

**P<.01
* P<.05
[A]In Vitro Dry Matter Digestibility.

TABLE XVI

EFFECT OF AMMONIATION OF WHEAT STRAW ON RUMINAL FERMENTATION AND VOLATILE FATTY ACID (VFA) CONCENTRATION

	Untreated Straw	Ammoniated Straw	SEM
Total VFA (umoles/ml)	34.42	40.57**	.045
VFA Molar Proportions			
Acetic	68.24	71.33**	.755
Propionic	17.35*	15.71	.413
Acetic:Propionic	3.97	4.60**	.151
Butyric	8.53	8.13	.262
Valeric	.82	.82	.120
Isovaleric	2.77**	2.12	.147

* $P < .05$

** $P < .01$

Johnstone, 1976). Ammonia nitrogen should not have been a factor in the present trial. Ammonia treatment of the straw resulted in an increased ($P<.01$) proportion of acetate and a lower proportion of propionate ($P<.05$). The acetate:propionate ratio was increased ($P<.01$) from 3.97 to 4.60%. This data is in direct conflict with that reported by Males and Gaskins (1982) who found a decrease in the acetate concentration and in increase in the propionate concentration when ammoniated straw was fed to sheep.

Ruminal ammonia concentrations of (Table XVII) steers fed ammoniated wheat straw were increased ($P<.001$) from 12.3 to 22.2 mg NH_3/100 ml of ruminal fluid. Mehrez et al. (1977) reported that ruminal ammonia is efficiently utilized up to 22 mg NH_3/100 ml of ruminal fluid. This could indicate that ammonia nitrogen is a limiting factor in the ruminal fermentation of the untreated straw, but does not explain the low total VFA concentrations of the ammoniated straw diet. Total soluble carbohydrate concentration (Table XVII) of ruminal fluid of steers fed ammoniated straw was increased ($P<.001$) from 11.06 to 16.19 mg/100 of ruminal fluid. If soluble carbohydrates availability is a limiting factor for growth of ruminal bacteria, chemical treatments that decrease the cell wall resistance to microbial digestion should increase bacterial growth rates. Ammonia has been demonstrated to break the glucuronic acid ester bonds that cement cell wall constituents together and allows swelling and increased accessibility of the cell

TABLE XVII

EFFECT OF AMMONIATION OF WHEAT STRAW ON RUMINAL FLUID pH AND CONCENTRATIONS OF AMMONIA AND SOLUBLE CARBOHYDRATES

	Untreated Straw	Ammoniated Straw	SEM
Rumen Fluid pH	7.27	7.28	.010
Ruminal NH_3 (mg/100 ml)	12.33	22.24*	.950
Ruminal Soluble Carbohydrates (mg/100 ml)	11.06	16.19*	.570

*P <.001.

components to microbial digestion (Wang et al., 1964; Tarkow and Fiest, 1969).

Although total VFA's were lower than expected, ammoniation of straw increased ruminal fluid ammonia and soluble carbohydrate concentrations. Steers fed ammoniated straw had doubled daily gains over steers fed untreated straw regardless of level of CP supplementation. Since intake of wheat straw is limited by its low digestibility and crude protein content should result in an increased rate of removal of rumen contents and increased intake. With an increase in both intake and digestibility and crude protein, more energy and crude protein are made available for steer gains.

Results of this trial indicates that anhydrous ammoniation increases digestibility, intake and crude protein content of wheat straw and improves steers gains in drylot. Anhydrous ammonia treatment of wheat straw can be conducted on the farm and could provide an emergency source of energy and crude protein when conventional sources are unavailable.

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VITA

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