ASSOCIATIVE EFFECTS OF UNTREATED AND AMMONIATED WHEAT STRAW AND ALFALFA FED TO SHEEP

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TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Table Page

Chapter II

Chapter III

Table Page

Chapter IV

Table Page

Table Page

Appendix

Table | Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Crop residues are produced in enormous quantities in many areas of the world. These crop residues, which are low in nutritive value, have potential as a feed source for ruminants whose large microbial population enables them to utilize diets of high cellulose content. The main factor limiting the utilization of wheat straw is its low digestibity and crude protein content. The low digestibility has been ascribed to lignin content which is chemically bound with hemicellulose and cellulose and prevents enough swelling of the material to allow digestive enzymes to penetrate and solubilize the cell wall. Therefore, treatment is necessary to increase the exposure of fiber to permit rapid penetration by digestive enzymes.

Physical and chemical treatment of crop residues to improve digestibility has been reviewed by many workers (Al-Rabbat and Heaney, 1978; Horton, 1978; Sundstol et al., 1978; Streeter and Horn, 1980; Zorrilla-Rios et al., 1985). Alkali methods and gaseous ammonia (NH_3) have shown the most promising results. The NH_3 method has some advantages over other alkali methods in that it increases both digestibility and crude protein content and can be carried out under farm conditions.

One of the primary problems concerning the use of roughages is choosing the proper protein supplementation to meet microbial requirements. Alfalfa hay is an important feed ingredient and natural source for supplemental protein and minerals. Therefore, alfalfa may be a good complementary feedstuff to be fed with untreated or ammoniated wheat straw to increase intake and nutritive value by correcting nutrient deficiencies compared with diets containing only low quality roughages (Paterson et al., 1982; Soofie et al., 1982; Brandt and Klopfenstein, 1984; Hunt et al., 1985).

Several workers have indicated an associative effect on dry matter digestibility when roughages of different quality and/or species are fed together (Forbes, 1933; Soofie et al., 1982a; Nelson et al., 1983; Hunt et al., 1985). Paterson et al. (1982) noted a positive associative effect on dry matter digestibility from 50% alfalfa addition to 50% NH_3-treated or untreated corn cobs.

The objective of this study was to determine the effect of combining different proportions of alfalfa hay (ALF) or dehydrated alfalfa pellets (DEHY) with untreated (US) and ammoniated (AS) wheat straw. Diets were fed to wether lambs at restricted and ad libitum levels of feed intake. Measurements included feed intake of total diet; apparent digestibility of dry matter (DMD), organic matter (OMD), crude protein (CPD), neutral detergent fiber (NDFD), kinetics of ruminal liquid and particulate passage and rumen fermentation. The identification of possible associative effects between US or AS and ALF or DEHY on DMD, OMD, CPD and NDFD was determined as a significant difference between observed and calculated digestibilities of the diets.

CHAPTER II

REVIEW OF LITERATURE

Potential Use of Wheat Straw

The energy in agricultural wastes such as wheat straw is poorly utilized by the microbial population in the rumen due to the presence of lignocellulose, whose components are either indigestible (lignin) or act as a barrier between the potentially digestible fractions (cellulose and hemicellulose) and digesting enzymes (Pigden and Heaney, 1969; Pfander et al., 1969).

Physical and/or chemical methods have been developed to treat these poor quality feed materials so that a higher proportion of their potential energy may be released and made available to ruminants (Donefer, 1968; Streeter & Horn, 1980).

Physical Treatments

Grinding and/or pelleting are most important methods to increase feed intake (Van Soest, 1982). With all roughage diets, grinding resulted in an increase in intake, a decrease in digestibility, but at the same time increased the digestible energy intake of the straw because the digested nutrients were utilized more efficiently by the animal (Jackson, 1978). The reduced digestibility found with ground forages is believed to be the result of a faster rate of passage (Minson, 1963). Blaxter et al. (1956) reported data showing the retention time of long roughage was 103 hours. When the same forage was ground through a .60 cm screen, retention time dropped to 72 hours and to 53 hours after grinding through a 0.16 cm screen. The faster rate of passage was associated with decrease in digestibility and an increase in total digestible energy intake which was due to an increase level of feed intake (600 vs 1500 g/d).

Pelleting caused an increase in feed intake, feed efficiency and weight gain but decreased digestibility. Beardsley (1964) showed that grinding and pelleting forages increased feed efficiency by 36%, increased feed intake 25% and increased gain by nearly 100% (daily gain 0.63 vs 1.28). Reducing particle size of the roughage may alter the site of digestion. Pelleting alfalfa shifted the site of gross energy digestion by sheep from the rumen to the small and large intestines (Thomson et al., 1972).

Chemical Treatments

Ammonia treatment of straw has a strong appeal because of the advantages it has over NaOH-treatment. These are: no residual alkali, increased palatability, increased nitrogen content to almost twice the level, and the potential for on-farm treatment (Martynov, 1972; Walker et al., 1974; Solaiman et al., 1979).

Ammoniation increases degradation of lignocellulosic linkages in straw through a swelling action which increases the accessibility of the cell wall to the rumen microbial population. Ammonia solubilizes the 4-O-methyl glucuronic acid and acetyl groups of hemicellulose which breaks the glucuronic acid ester bonds that link the xylan polymers to cellulose and lignin. This allows greater exposure to microbial attack (Tarkow and Feist, 1969).

✳ Three major factors that influence the efficiency 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.

In vitro digestibility of ammoniated wheat straw increased about 1% with each 10% increase in straw moisture content over a range of 10 to 50 percent moisture (Solaiman et al., 1979). Temperature also affects the time needed for optimal ammonia reaction with the straw. Sundstol et al. (1978) have found that at lower temperatures a longer time period is required for high digestible coefficients. Most experiments indicated that there is very little improvement in digestibility resulting from an increase of ammonia level about 3 to 4 percent of dry matter (Sundstol et al., 1979; Borhami and Sundstol, 1982).

One of the problems associated with ammoniated crop residue is the loss of ammonia during application. Sundstol et al. (1978) lost two-thirds of the ammonia nitrogen added at the level of 2 to 4% (W/W) of straw dry matter. Solaiman et al. (1979) lost 59% of the nitrogen added as ammonium hydroxide (3.3 NH_3, W/W) to 45% moisture straw after fifty days exposure in sealed plastic bags.

Ammoniation: Effect on Palatability and Feed Intake

Intake by animals of crop residues is greatly increased by ammoniation. Horton (1979) found that straws from wheat, barley and oats were more palatable when treated with 3.5% anhydrous ammonia. Intake and daily gain of lambs fed wheat straw were increased by 18 and 19%, respectively, by ammoniation. Also, ammoniation increased the consumption of straw fed alone by about 41% (Horton, 1978).

Nelson et al. (1984) reported that the intake of switchgrass and indiangrass hays by steers was increased by ammoniation from 13.5 to 15.1 lb. per day. Herrera-Saldana et al. (1982) observed voluntary intake of DM, OM, CP and IE were increased by ammoniation of wheat straw.

Soofi et al. (1982a) found intakes of DM and cell wall carbohydrates of the whole diet were increased as the percentage of alfalfa increased in the blends. The DM intakes were 53.9, 69.8, 100.9 and 106.2 g $(\text{kg BW}^{.75})^{-1}\text{d}^{-1}$ with SBS, 2 SBS to 1 ALF, 1 SBS to 2 ALF and alfalfa, respectively.

Lambs fed ammoniated cob diets with 30% alfalfa consumed more feed, and gained faster and more efficiently than lambs receiving no alfalfa (Brandt and Klopfenstein, 1983).

Effect of Ammoniation on Digestibility

A great many of in vivo digestibility experiments have been carried out with ammoniated materials. When comparing results from various experiments, a considerable amount of variation is found in range of 5% to 15% digestibility units greater for ammoniated crop residues compared to untreated material. Table I, summarizes some of the results obtained in digestibility experiments in which ammoniated materials have been fed to sheep (Arnason and Mo, 1977).

Horton et al. (1982) reported increases of 15 and 17% for organic matter and neutral detergent fiber digestibilities of straw while crude protein digestibility decreased with ammonia treatment. Ammoniation of corn cobs increased organic matter digestibility in the rumen and total tract, and dietary nitrogen flow at the abomasum (Nelson et al., 1983).

Very little information is available about the value of the added nitrogen to ammoniated residues. Horton et al. (1982) reported that the added nitrogen from ammonia is not well utilized. 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), corn stover (Mowat and Buchanan-Smith, 1978) or soybean residue (Miller et al., 1979). On the other hand, nitrogen digestibility and nitrogen retention data reported by Males and Gaskins (1982) indicate the ammonia added to the straw was absorbed and

TABLE I

IMPROVEMENT IN DIGESTIBILITY OF CROP RESIDUES AS AFFECTED BY AMMONIATION

Crop Residue	Treatment with NH_3	% Dry Matter Digestibility		
		Untreated	Treated	ΔDMD
Wheat Straw[1]	5% anhydrous	36	50	14
Oat Straw[1]	5% anhydrous	47	55	8
Barley Straw[1]	5% anhydrous	43	55	12
Barley Straw[2]	3.5 anhydrous (3 weeks)	47	60	13
Barley Straw[2]	3.5 anhydrous (8 weeks)	47	64	17
Rice Straw[3]	5% aqueous	42	56	14
Maize Stover[4]	5% aqueous	52	60	8
Maize Stover[4]	3% aqueous	52	60	8
Corn Stover[5]	3% anhydrous	44	57	13

[1] Coxworth et al. (1976).

[2] Arnason and Mo (1977).

[3] Guggolz et al. (1971).

[4] Oji et al. (1977).

[5] Paterson et al. (1979).

utilized by lambs. They indicated, however, that the increased nitrogen retention could be due to greater energy intakes provided by supplement, resulting in an increased utilization of the ammonia by rumen microorganisms (Hespell and Bryant, 1979).

Zorrilla-Rios et al. (1985) found ammoniation treatment of wheat straw increased nitrogen intake, apparent digestibility and balance compared to untreated straw.

The Effect of Ammoniation on Ruminal Ammonia-nitrogen and pH

Elevated ruminal ammonia levels for animals fed ammoniated crop residues have been reported by several workers (Al-Rabbat and Heaney, 1978; Horton, 1978; Herrera-Saldana et al., 1982).

Ruminal ammonia nitrogen concentrations in steers were higher when they were fed ammoniated wheat straw compared to untreated wheat straw (14.5 vs 8.4 mg/dl) (Herrera-Saldana., 1982).

Horton (1978) found ruminal ammonia concentration of steers fed either treated straw alone or straw plus barley supplement were quite similar and about seven times greater than untreated straw without supplements. Lower blood urea values for unsupplemented, untreated cereal straws indicated reduced ruminal ammonia concentrations due to the low nitrogen contents of the diet (Horton, 1978).

Pace (1982) also found increase of ruminal ammonia-nitrogen in cows fed ammoniated wheat straw (14.3 vs 10.3 mg/100ml).

Ruminal fluid pH does not appear to be affected by the ammoniation treatment of wheat straw (Horton et al., 1982; Pace, 1982). Zorrilla-Rios et al. (1985) also found the pH values were typical of high roughage diets and were not different with time after feeding, nor among ammoniated and untreated wheat straw. While ruminal NH_3-N was increased ($P<.06$) from 9.1 to 13.0 mg/dl.

The Effect of Voluntary Feed Intake On: Apparent Digestibility

Feed intake is one of the best regulated animal functions. The mechanisms which regulate feed intake appear to be the same mechanisms that control energy exchange (Conrad, 1966).

The two fundamental factors which control voluntary intake (VI) are energy satisfaction and fill limitation (Balch and Campling, 1962; Balker, 1963; Conrad et al., 1964; Montgomery and Baumgardt, 1965; Conrad, 1966; Dinius and Baumgardt, 1970; and Reid et al., 1980).

The energy satisfaction theory implies that ruminant animals eat to meet their energy requirements. Ruminant animals consume a wide range of feeds varying from fibrous crop residues to all-concentrate diets. For diets containing highly digestible feeds, VI is regulated by physiological means (Conrad, 1966).

Blaxter (1950) observed that the amount of feed dry matter consumed increases with increasing concentrations of net energy per Kg dry matter. The VI was positively related to the apparent digestibility of the roughages, which ranged from 38 to 74.2% when fed to cattle and sheep (Blaxter et al., 1961; Blaxter and Wilson, 1962).

The point between bulk limitation of VI and energy regulation is not well defined. Conrad et al. (1964) found that 66.7% digestible dry matter was the lowest energy concentration at which cows regulate their energy intake, whearas Montgomery and Baumgardt (1965) found energy intake of dairy heifers was maintained when the ration was above 56% digestible dry matter.

McCullough and Russel (1962) observed that the influence of digestibility on intake declines when digestibility is above 65%. It may be concluded that with diets consisting entirely of roughages, physical distention of the reticulo-rumen is an important factor in regulating VI (Balch and Campling, 1962). Data suggesting that the VI of roughages is limited by the capacity of the entire digestive tract has been provided by Weston (1966). Blaxter et al. (1961) estimated that the dry matter of the ingesta contained in the total digestive tract of sheep at the end of a meal was similar with three different roughages offered ad libitum. The amount of dry matter in the reticulo-rumen immediately after a meal was measured by Campling et al. (1961). Immediately after the meal, the dry weight of digesta into reticulo-rumen of cows fed hay was 35% greater than those fed oat straw. However, just before the next meal the difference was less than 6 percent.

Freer et al. (1962) have indicated the importance of physical breakdown of ingesta in the reticulo-rumen by the positive correlation between the total time spent eating and ruminating per pound of roughage, and the rate at which digesta leaves the rumen. The efficiency of chewing or rumination by which small particles are produced is likely to influence the rate at which the volume of rumen contents are reduced.

Many workers have reported that the digestibility of long or chopped dry forages fed to sheep and cattle was not affected by level of intake (Hale et al., 1940; Reid and Tyrrell, 1964).

Van Soest (1965) reported that in some forage species (orchardgrass, brome grass, sudangrass) the relation between VI and chemical components is very high, and nutritive value index could be predicted.

In terms of chemical composition, the only consistent effect between VI and digestibility that can be observed for all forages is that of the total fibrous fraction, cell wall constituents. As this fraction increases, VI declines with an increasingly negative slope. In forages with a high cell-wall content, intake is highly correlated with both chemical composition and digestibility of dry matter.

In legumes, the total of cell-wall constituents does not appear to be large enough to inhibit intake, while with low quality roughages (straw) the high cell-wall constituents inhibit intake. The point at which fiber mass appears to become limiting occurs when cell-wall content lies between 50 and 60 percent of forage dry matter (Van Soest, 1965).

Ruminal Turnover

Rumen turnover can be defined as the length of time that the digesta remains in the rumen. Obviously, turnover time varies with the fraction of the digesta considered, level of feed intake, specific gravity, particle size and diet composition (Church, 1979; Van Soest, 1982).

The ruminal contents can be physically divided into solid and liquid phases. The solid fraction contains undegraded and indigestible material, whereas, the liquid fraction contains water, soluble feed components and nutrients made soluble by microorganisms (Evans, 1981). Bacteria in the rumen are associated with both solid and liquid fractions but also with the epithelium of the rumen wall. The latter group contains most of the urease-producing bacteria of cattle (Cheng et al., 1979).

Turnover Rate of Ruminal Solids:

It has been reported that elevation in feed intake increases solid turnover rates with sheep (Minson, 1966). Evans (1981) found a significant relationship between rumen solid turnover rate and level of feed intake, DE level of the diet and the amount of dietary roughage. Varga and Prigge (1982) showed that ruminal solid turnover rates of sheep fed alfalfa and orchard grass hays tends to decrease as level of feed intake increased, but the differences were not significant.

At a given level of digestibility, the VI of legumes was 28% higher than that of equally digestible grasses. This difference was a result of a shorter retention time (17%) and a higher amount of organic matter (14%) in the rumen digesta from legume diets than from grass diets. The weight of wet digesta in the rumen from legumes was 7% lower than from sheep fed on grasses (Thornton & Minson, 1973).

Physical reduction of particle size of feed ingredients has been shown to alter rumen solid turnover rate (Thomson, 1972). Addition of finely ground hay to a long hay diet resulted in the ground hay leaving the rumen faster than the long hay, although when ground hay comprised to the total diet variable results have been obtained.

Liquid Turnover in the Rumen

Probably the most important variable affecting liquid turnover is the level of feed intake (Sutton, 1971). Two different intakes of forage were fed to sheep (Varga and Prigge, 1982). They found there was approximately a two-fold (.072 vs .033h^{-1}) increase in liquid turnover rate at the higher level of intake when averaged over forage species. They suggested that level of feed intake influenced ruminal liquid turnover rate to a greater extent than it affected solid turnover rate.

Staples et al. (1984) used alfalfa haylage: corn silage: corn-soybean meal mix in 45:20:35 dry matter and fed at either 100, 85, 70 or 55% of ad libitum intake to steers. They found the rate dilution markedly decreased (0.094 vs 0.057 h^{-1}) with decreasing feed intake (100% ad libitum to 55% ad libitum).

Other factors may also influence the turnover of the rumen liquid phase. Physical form of the diet has been shown to affect rumen turnover. Under conditions of equal dry matter intake, Putnam et al. (1966) found greater rumen volumes in steers consuming an 89% hay ration than those consuming a 25% hay ration. They also noted an increased saliva flow in steers on the 89% hay ration as compared to those fed the 25% hay ration. This may reflect an increase in the amount of time spent ruminating since saliva flow has been shown to increase with rumination. In animals fed rations consisting primarily of finely ground grains, rumination is markedly decreased.

The increase liquid turnover or dilution rate effectively lowers the concentration of the bacterial population present in the rumen so that they assume a new growth rate which is a function of the new feed rate. Therefore, the net yield of nutrients to the host will be increased (Hungate, 1966).

Isaacson et al. (1975) using continuous mixed cultures of rumen microorganisms, found that at a low dilution rate

(2.0 %/hr) approximately 55% of the energy derived from glucose was used for maintenance of the bacterial population, while at a higher dilution rate (12.0 %/hr) only 15% of the energy was used for maintenance. Therefore, an increased rumen turnover can increase ruminal outflow of bacterial mass which is available to the host for digestion and absorption post-ruminally.

Chemical treatments can influence the ruminal liquid flow. Zorrilla-Rios et al. (1985) found ruminal liquid flow rate ($\%h^{-1}$) increased with ammoniated wheat straw compared to untreated wheat straw (2.97 vs 2.34) ($P<.05$).

Al-Rabbat and Heaney (1978) fed alfalfa untreated straw and ammoniated straw to sheep, the rumen volumes were 4.5, 5.7 and 3.2 l respectively. However differences among means were not significant.

Supplementation of Low Quality Roughages with High Quality Forages

Associative Effects of Feeds on Nutrient Digestion and Utilization

It is untenable to suppose that feeds always retain their individual characteristics when fed in combination with other feeds. Titues (1926) found that the combination of feedstuffs may affect their digestibility and that the effect will depend upon the kinds and amounts of feed combined. In some cases the effect may be almost negligible and in others quite large. Forbes et al. (1943) have stressed the need for practical recognition that the conception of a given feedstuff as characterized by a constant nutritive value, in all rations, is not in accordance with the facts.

Schneider and Ellenberger (1927) found that the digestion coefficients for mixed diets obtained from digestion experiments sometimes are significantly different than those for the weighted sums of the components obtained from published feed tables. Such occurrences are called "associative effects".

Many of these diversions from expected digestibility values may arise from attempts to predict the digestibility of the feed by an indirect method. This procedure involves adding the feed in a considerable amount to a basal diet, the digestibility of which had been previously determined (Mitchell, 1964). The apparent digestibility of the supplemental feed can be readily determined from the digestibility of the combination as compared with the basal diet.

The apparent cause of the associative effects of feeds is usually ascribed to differences in level of feed intake, rate of passage and digestion rate (Rust, 1983). There is some disagreement with respect to this interpretation, and this phenomenon may result from improperly balanced diet, or artifacts of an experimental design (Rust, 1983). Forbes et al. (1943) have theorized that the differences in the diet of the animal, constitute differences in the nutrients presented to the rumen microorganisms. These changes result in differences in the total and relative growth of the various species of microorganisms present and in the digestible constituents of their bodies, and in the digestible products of their vital activities. Thus, the effect of feed combination on apparent digestibility can possess true nutritive significance.

The incidence of associative effects may be beneficial or detrimental, as illustrated by Figure 1, the dashed line represents the expected digestibility if no associative effects occur. The upper and lower solid curves represent "positive and negative" effects, respectively (Van Soest, 1982).

The associative effects of various feed components on the utilization of a number of rations have been studied, and the conclusion reached that the utilization of any feed component is dependent on the degree to which it forms part of a complete and well-balanced ration (Ewing and Wells, 1915; Forbes, 1933). Associative effects may be present when low quality roughages are supplemented with high quality forages. Generally nitrogen supplementation improves the utilization of low quality roughage by increasing total dry matter digestibility and intake. Meeting the nitrogen needs of rumen bacteria is essential in order to achieve a higher rate of fermentation.

Soofi et al. (1982a) used different proportions of soybean stover and alfalfa hay in a sheep digestion trial, and found positive and negative associative effects for intake and digestibility. They concluded that soybean stover at a

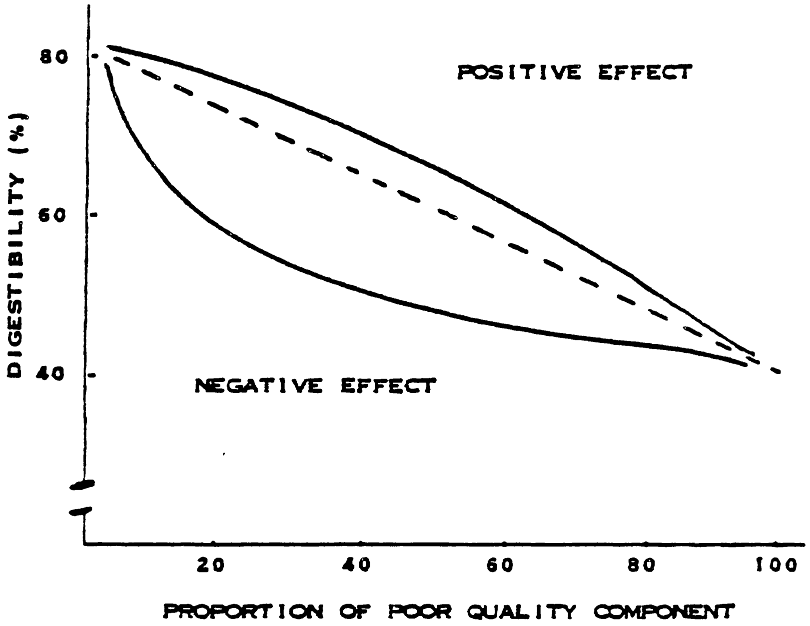

Figure 1. Associative Effects When a Poor Quality Feed is Substituted by a High Quality One (Van Soest, 1982)

level greater than 40 percent of an all forage diet induced negative associative effects when fed to sheep, while dry matter intake was highly and positively correlated (r.96) with dietary addition of alfalfa.

Paterson et al. (1982) found an improvement in dry matter intake by sheep with the addition of alfalfa hay to NaOH-treated corn stalks. In a cattle growth trial, daily gains and feed efficiencies showed positive associative effects from the addition of 50% alfalfa hay to NaOH-treated cobs. Soofi et al. (1982b) reported positive associative effects for intakes and digestibility between different components of NaoH-treated soybean stover and alfalfa hay. The positive associative effects and the beneficial effect of NaOH-treatment were most dramatic with the 2 parts SBS:1 part ALF blended, and nitrogen retention was significantly lower when sheep were fed NaOH-treated SBS compared with other treatments. A quadratic relationship ($P<.08$) was found when different proportions of alfalfa hay were blended with fescue hay and fed ad libitum to lambs. This quadratic effect was observed for DM and NDF digestibility. However, when the intake was restricted to 450 g of DM daily, a linear increase ($P<.05$) in DM digestibility and a linear decrease ($P<.01$) in NDF digestibility was observed with increasing levels of alfalfa (Hunt et al., 1985).

Nelson, et al. (1983) used untreated and ammoniated wheat straw supplemented with alfalfa hay. The results showed that cows fed untreated straw plus 7 lbs. of alfalfa hay lost weight and cows fed ammoniated straw plus 7 lbs. alfalfa hay gained weight. Therefore, the cows fed ammoniated straw responded to alfalfa supplementation.

Brandt and Klopfenstein (1983) reported that calves fed NH_3-treated corn cob residues with 15 and 30% alfalfa hay gained 1.60 and 1.72 lb/day, respectively, compared to 1.40 lb/day by calves fed a 100% alfalfa hay ration. Addition of 15% or 30% of alfalfa or bromegrass hay increased ad libitum intake ($P<.002$) compared to the NH_3- treated corn cob control (Brandt and Klopfenstein, 1984).

Negative associative effects have been reported for grain diets supplemented with alfalfa hay (Forbes et al., 1933). Supplementation of corn silage (7.8% cp) with soybean meal had positive associative effects on feed efficiency and silage consumption in cattle, but no further important effects were observed by raising the soybean meal level beyond 0.45 kg/day (Pendlum et al., 1977).

Robards & Pearce (1975) found that a ration consisting of one part lucerne hay and five parts oaten hay was seven units higher in DM digestibility than expected on the basis of the recorded digestibilities of the two components fed separately to sheep. Similar results were reported by Robards (1971).

Many workers have reported positive associative effects of protein supplementation on dry matter digestibility and feed intake with ad libitum diet of mature Rhodes grass hay fed to sheep (Elliott, 1967); cottonseed hulls by steers (Kropp et al.,1977) and winter-harvested prairie hay (2.3%

protein) fed to steers (Johnson et al., 1981).

As discussed above, the associative effects reported in many trials can be explained by differences in level of feed intake and digestibility of blended feed.

Mitchell (1964) added glucose to a diet containing roughage. The digestibility of both crude fiber and protein by cattle was markedly depressed. The generally accepted reason for these depressing effects is that the rumen microorganism utilized the more readily available carbohydrate so that cellulose and hemicellulose were less extensively fermented if the sugars were present.

Burroughs et al. (1950) added starch and casein to low and high quality roughages. Starch addition inhibited cellulose digestion with low quality roughage but had little effect when added to alfalfa. Addition of casein improved DM digestion of low quality roughage. Starch digestion of a cellulose medium caused a shift in type of cellulolytic bacteria present.

Negative associative effects may be due to acid produced from the fermentation of grain which reduced the pH in the rumen. The microorganisms that digest fiber are very sensitive to the low pH and may be reduced in number and activity (DeHaan et al., 1984).

In summary, utilization of low quality roughage appears to be affected by both the level and kind of supplementation. Most data indicate that positive or negative associative effects result depending on the kind and amount of feeds combined.

Methods of Calulating Digestibility by Difference

Determining the apparent digestibility of nutrients of individual components of mixed diets represents a difficult task (Heavens, 1978). The usual method is to conduct two digestibility trials. In one trial the digestibility of a feed alone (e.g., roughage) is determined first, and in the second the digestibility of combination of the test feed and the roughage is determined. In this subsequent trial the same basal feed plus the new feed are fed together. The total fecal output is measured as usual. On the assumption that the digestibility of nutrients in the first feed remains unaltered, the amount of the nutrients in the feces of the second digestion trial are assumed to represent the same of the original basal portion of the ration and the feed being tested. By determining the differences between the values for the roughage fed alone and for the combination, coefficients for the digestibility of the other feed are calculated by difference (Mead and Goss, 1935).

Schneider and Flatt (1975) suggested that for the most accurate result, it is better to determine the digestibility of the basal ration immediately either before or after the determining of the digestibility of mixed diet by using the same individual animal. This method is more accurate than using the average digestibilities of the basal diet as determined with several trials.

Christensen et al. (1916) also presented such a method estimated algebraically the digestion coefficients of two feeds in rations from the digestibility of the diet with the same feed being fed in different proportions. Another method presented by Carbery and Chatterjee (1936) makes use of simultaneous regression equations. By the regression equations the digestible nutrients can be calculated. The authors compared the differences between observed and calculated digestibility in 18 trials with six animals and in almost all cases the agreement between the two was very good.

Effect of Particle Size Reduction on Intake and Utilization of High Quality Forages

Most studies on changing the physical form of forages have been with hay. Hay can be fed long, chopped, ground or pelleted. Moore (1964) reported that changing the physical form may cause changes in animal response. These changes in animal performance are reflected in changes in feed intake, efficiency of feed utilization, digestibility and rate of passage.

Increased intake appears to be the major factor associated with improved performance observed when long or chopped forages are ground and pelleted. Meyer et al. (1959) observed that the amount of alfalfa required to maintain weight in lambs was the same whether the feed was chopped or pelleted. When chopped alfalfa was fed ad libitum and the intake of pellets controlled to the same amount, gains were almost the same. But when pellets were fed ad libitum intake was increased by 31% and gain 48%.

Weston and Hogan (1967) found that consumption of ground lucerne hay by individual sheep ranged from 136 to 163% of the consumption of chopped hay. The rate of passage of digesta through the reticulo-rumen and the rate of breakdown of digesta in that organ appear to be markedly influenced by the physical form of the diet (Balch, 1950). Grinding lucerne hay greatly decreased flow from the rumen and this reduction was associated with a decrease in the fraction of rumen volume transferred to the omasum per unit time, and an increase in marker retention time (Weston and Hogan, 1967).

Campling et al. (1963) found that ground hay residues had a much shorter time of retention in the alimentary tract than residues of long hay when it was fed to cows, and that the initital excretion of hay particles was faster with ground than with long hay (Balch, 1950). The shorter mean time of retention of ground hay in the gut would be partly responsible for an increased intake of ground relative to long forages. (Blaxter et al., 1956; Meyer et al., 1959).

When ground alfalfa was moistened with water to control dustiness, feed consumption and gains were increased to almost the same level as when pelleted forage was fed. Under conditions of ad libitum feeding, sheep consumed about 50% more when lucerne hay was in a pelleted than a chopped form (Weston and Hogan, 1967).

Many workers have indicated that grinding reduces digestibility of ground hay by cattle (Balch, 1950; Rodrigue and Allen, 1960) and sheep (Blaxter and Graham, 1956; Lloyd et al., 1960). On the other hand, others (Meyer et al., 1959; Wallace and Hubbert, 1959) found no significant differences in digestibility between ground and long hay. Campling et al. (1963) reported that the mean digestibility of ground hay was 19 percentage units lower than that of long hay and the organic matter digestibility of the ground hay was 42.9% compared to 63.6% for long hay fed to cows. The depression in digestibility caused by grinding was most marked for the crude fiber fraction. Blaxter and Graham (1956) reported that the possible cause for the poor digestibility of ground hay may be the more rapid passage.

Ruminants due to their unique physiological characteristics are able to utilize forages of high fiber content and low nutritive value efficiently. Considerable quantities of roughages having low feeding value exist for feeding ruminants. Studies to improve the utilization of low quality roughages, such as cereal residues have been conducted with varying degrees of success.

CHAPTER III

ASSOCIATIVE EFFECTS OF UNTREATED WHEAT STRAW DIETS AND ALFALFA FED TO SHEEP

Summary

Thirty-five wether lambs (22.3 Kg) were individually fed in a restricted and ad libitum fashion in two periods. Intake was restricted in period 1 and ad libitum in period 2. During period ad libitum intake, diets were fed in amounts that resulted in refusals of 5% of amounts offered. Lambs were allowed once a day untreated wheat straw (US) in combination with different proportions of high quality roughages (HQR) as alfalfa hay (ALF) or dehydrated alfalfa pellets (DEHY)(100:0;67:33;33:67 and 0:100 for US:ALF or DEHY), to investigate the effects of combining US with ALF or DEHY in different proportions of the diet on feed intake; apparent digestibility of dry matter (DMD), organic matter (OMD), crude protein (CPD) and neutral detergent fiber (NDFD) and kinetics of ruminal liquid and particulate matter passage.

Apparent digestion coefficients for DM, OM and CP were not affected by level of feed intake. Digestibility of NDF was linearly ($P<.01$) decreased as level of feed intake increased (46.8 vs 39.3%). Particulate turnover time was lin-

early decreased (P<.01) (44.6 vs 40.zh) as level of feed intake increased, and liquid dilution rate (LDR, %/h), liquid rumen volume (LRV, ml) and liquid turnover time (LT, h) were liquid different (P<.02). DEHY had a higher rate of passage (P<.01) of a particulate matter compared to ALF at both levels of feed intake, (5.11 vs 3.69) at restricted feed intake and (4.97 vs 4.17) at ad libitum level of feeding.

Intake of DM, OM, CP and NDF increased linearly (P<.01) with increasing levels of ALF or DEHY in the diets at ad libitum feeding. Digestibility of DM, OM, CP and NDF were linearly increased (P<.01) as the proportion of HQR increased when lambs were fed ad libitum. But when the lambs were restricted to 450 g (as fed) intake daily, a linear increase in DMD, OMD and CPD was observed, and no significant difference was observed with NDFD.

Turnover times of particulate matter were decreased at both levels of intake as the proportion of HQR increased in the diets. Liquid turnover time was not affected by the proportion of HQR in the diets at restricted feeding. While at ad libitum feed intake, liquid turnover time was linearly decreased (P<.03) as HQR proportion increased in the diets. Mean rumen pH differed (P<.02) for both levels of feed intake (6.42 for restricted and 6.17 for ad libitum). Level of HQR caused a significant difference in rumen pH values at 1, 2, 4 and 8 h after feeding at ad libitum feed intake. No significant difference was detected in ruminal ammonia nitrogen (NH_3-N) between both levels of feed intake. Rumen NH_3-N

concentration was linearly increased with the addition of HQR in the diets at 1, 2, 4 and 24 h after feeding at ad libitum level of intake.

Combination of US with ALF or DEHY resulted in a decrease about -3.7 and -.5 units in observed OMD compared to calculated OMD for 67:33 and 33:67 US:ALF, respectively, and -1.7 and -1.0 units for 67:33 and 33.67 US:DEHY, respectively, but these differences were not significant ($P>.05$). A negative associative effect ($P<.05$) on NDFD of the whole diet at ad libitum feeding was observed with 67:33 US:DEHY.

The results of this study demonstrate a positive linear relationship between level of dietary HQR and diet DM and OM consumption, and negative associative effects for the digestibility of NDF of US:DEHY diets with ad libitum intake. Level of feed intake and proportion of substitution of HQR is an important determinant of liquid dilution rate and particulate turnover rate. Thus the differences in rumen pH and NH_3-N concentrations are affected by changes in liquid dilution rates of the rumen.

Introduction

In many areas of the world, cereal straws are becoming important feedstuff for ruminants because other feeds, such as grains and oilseed meals are expensive and less available for animal consumption.

Low digestibility and low voluntary intake of low quality roughages is a consequence of their low protein content and extensive lignification of cell walls. Many methods have been used to improve the nutritive value of roughages. One of the primary problems concerning the use of roughages is proper protein supplementation to meet the requirements of ruminal microbes. Alfalfa hay provides supplemental protein and minerals and is a logical choice for addition to low quality roughages such as wheat straw to increase intake and nutritive value since it corrects nutrient deficiencies of low quality roughages (Paterson et al., 1982; Soofi et al., 1982a; Hunt et al., 1985).

Paterson et al. (1982) reported that dry matter digestibility and performance by steers was greater with a 50% corn cobs -50% alfalfa diet than either 100% corn cobs or 100% alfalfa hay diets. Similarly, Soofi et al. (1982a) found digestibilities of dry matter and cell wall constituents increased as the percentage of alfalfa increased in the diets.

An inverse relationship between feed intake and apparent digestibility has been detected with high concentrate diets and finely ground roughage diets (Reid and Tyrrell, 1964; Reid et al., 1980). However, digestibility was not reduced when intake of long or chopped all-roughage diets was increased (Tyrrell and Moe, 1975).

Varga and Prigge (1982) found no significant effect of level of feeding of a chopped alfalfa diet on apparent digestibilities of organic matter, crude protein and acid detergent fiber. A negative relationship was found between level of feed intake of forage and mean retention time of feed particles in the rumen (Balch, 1950; Blaxter et al., 1956; Minson, 1966; Mudgal et al., 1982). Relationships of intake to ruminal ammonia-nitrogen concentration and liquid dilution rate have been studied by many workers (Hodgson et al., 1976; Varga and Prigge, 1982; Adams and Kartchner 1984). Both levels of feed intake and proportion of high quality roughage (HQR) in the diet influenced liquid dilution rate while ruminal ammonia-nitrogen did not change with level of feed intake as indicated by Varga and Prigge (1982).

The objective of this study was to determine the effect of combining different proportions of alfalfa hay (ALF) or dehydrated alfalfa pellets (DEHY) with untreated wheat straw (US). Diets were fed to wether lambs at restricted and ad libitum levels of feed intake. Measurements included: feed intake of total diet; apparent digestibility of dry matter (DMD), organic matter (OMD), crude protein (CPD), neutral detergent fiber (NDFD), kinetics of ruminal liquid and particulate passage and rumen fermentation. Associative effects between US and HQR on DMD, OMD, CPD and NDFD was also an objective of the experiment, and was calculated as being the difference between observed and calculated digestibilities of the diets. Nutrient digestibilities were calculated as follows:

$$\text{CPND} = \frac{(\text{AxB}) + (\text{CxD})}{\text{E}} \times 100$$

Where:

CPND = Calculated percentage nutrient digestibility.

A = Nutrient intake from straw.

B = Observed nutrient digestibility in 100% straw diet.

C = Nutrient intake from HQR.

D = Observed nutrient digestibility in 100% HQR diet.

E = Total nutrient intake.

Material and Methods

In Vivo Digestibility

Thirty-five wether lambs with an initial weight (mean ± standard deviation) of (22.3 ± 2.3 Kg) were housed in individual 1.5 x 1.5 meter pens with wooden salted floors, stratified by initial body weight, and randomly assigned to seven treatments (5 lambs/treatment) in two periods. Diet intake was restricted in period 1 and ad libitum in period 2. During the period of restricted feeding, all lambs were fed an amount of diet that equals to that consumed by lambs fed 100% untreated wheat straw. During the period of ad libitum access to fed, diets were fed sufficient amounts so that refusals exceeded 5% of amounts. Untreated straw (US) was blended with either alfalfa hay (ALF) or dehydrated alfalfa pellets (DEHY). The ingredient composition of the diets is shown in Table I, and the nutrient composition of the US, ALF and DEHY used in both the restricted and ad libitum periods is shown in Table II. US and ALF were ground through a 1 1/2-inch screen and stored separately until fed. Diet were

TABLE I

INGREDIENT COMPOSITION OF THE DIETS (% AS-FED)

Ingredient	Treatments						
	1[a]	2	3	4	5	6	7
Wheat straw	100	67	33	-	67	33	-
Alfalfa hay chopped	-	33	67	100	-	-	-
Dehydrated alfalfa pellets	-	-	-	-	33	67	100

[a] received 5g urea daily.

TABLE II

NUTRIENT COMPOSITION OF WHEAT STRAW, ALFALFA HAY AND DEHYDRATED ALFALFA PELLETS USED IN BOTH LEVELS OF FEEDING (MEAN ± STANDARD ERROR) (% DM BASIS)

Item %	Number of Samples	Mean ± SE		
		US[a]	ALF[a]	DEHY[a]
Dry matter	7	93.3±.20	90.8±.22	94.0±.23
Organic matter	7	94.2±.23	93.2±.26	89.1±.24
Crude protein	7	4.3±.27	18.1±.28	17.9±.31
Neutral detergent fiber	7	80.2±.64	50.5±.46	50.4±.37
Ash	7	5.8±.12	6.8±.29	10.9±.16

[a] US = Untreated straw; ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

fed once each day. Water was available ad libitum for each lamb throughout the study. All lambs received 45 g of a mineral-vitamin supplement daily (Table III). Lambs that received the 100% US diet also received 5 g urea daily.

Each of the two periods lasted 22 days the preliminary period of 15 days allowed the lambs to adapt to the diets. Feed refusals were weighed daily from days 14 through 20, and an individual collection of total feces were collected on days 16 to 22.

The US, ALF and DEHY offered were sampled daily and composited at the end of each period. A sub-sample representing about 10% of the total daily refusal for each lamb was collected during the seven days of the sampling phase and the seven samples from each lamb were composited at the end of each period. Feces were collected using fecal collection bags. Feces were weighed daily, sampled and composited by using the same procedures as for the refusal feed. All samples were placed in individual plastic bags and refrigrated until processing. All lambs were weighed before and after each period.

Composited fresh and refusal feed samples and feces were weighed and dried at $60^{o}C$ during 48 hours to determine dry matter. Samples were ground through 1 mm screen and stored in plastic bags for later analysis.

Residual dry matter (DM) in feces and feed was obtained by subsequent oven drying at $100^{o}C$ for 24 hours, ash by incineration at $550^{o}C$ for 6 hr, and crude protein (CP) (N x

TABLE III

INGREDIENT[a] COMPOSITION OF MINERAL-VITAMIN SUPPLEMENT

Ingredient	IFN	As-Fed (g)
Dry molasses	4-00-668	20.25
Dicalcium phosphate	6-01-080	18.18
Potassium sulfate[b]	--	4.46
Trace-mineralized salt[c]	--	2.00

[a] Plus Vitamin A, D and E to supply, respectively, 970, 21 and .05 IU/head/day.

[b] 99.0% minimum K_2SO_4.

[c] Trace-mineralized salt composition:

Salt (Nacl)	not more than	97.1%
Manganese (Mn)	not less than	.250%
Iron (Fe)	not less than	.200%
Sulfer (S)	not less than	.030%
Copper (Cu)	not less than	.033%
Cobalt (Co)	not less than	.0025%
Iodin (I)	not less than	.007%
Zinc (Zn)	not less than	.005%.

6.25) by the Macro-Kjeldahl procedure (A.O.A.C, 1975). Neutral detergent fiber (NDF) was determined according to Goering and Van Soest, (1970). Organic matter (OM) of feed and feces was determined by subtracting total ash from DM, (mean ± standard deviation) at the end of the experiment, weights of lambs were (23.0 ± 2.4 Kg).

Data were analyzed using least sequare analysis of variance. Tests were made for linear and quadratic effects on OM intake, dry matter digestibility (DMD), organic matter digestibility (OMD), crude protein digestibility (CPD) and neutral detergent fiber digestibility (NDFD). The contrasts used in comparisons of the treatment means are non-orthogonal (Table IV).

Kinetics of Ruminal Particulate Matter

The lambs used in the in vivo digestibility study also were used to determine the rate of passage of ruminal digesta. The pulse dose procedure with periodical fecal sampling after dosage was used. Rate of passage was measured during both the restricted and ad libitum feeding periods.

Representative samples of US (350 g) and ALF and DEHY (200 g each) were labeled with ytterbium chloride ($YbCl_3$,H_20, 4.05 g) and dysprossium chloride ($DyCl_2$ H_20, 3.75 g), respectively, by the immersion procedure of Teeter et al. (1984). After labeling, feeds were dried to their approximate original DM content.

After a 22-day preliminary period, on day 23, ten grams

TABLE IV

CONTRASTS[a] AMONG TREATMENT MEANS

Contrasts[b]	Treatments						
	1 100:0	2 67:33	3 33:67	4 0:100	5 67:33	6 33:67	7 0:100
ALF vs DEHY[c]	0	1	1	1	-1	-1	-1
LIN 1	0	-1	0	1	-1	0	1
QUAD 1	0	-1	2	-1	-1	2	-1
TYPE*LIN 1	0	-1	0	1	1	0	-1
TYPE*QUAD 1	0	-1	2	-1	1	-2	1
ALF LIN	-3	-1	1	3	0	0	0
ALF QUAD	-1	1	1	-1	0	0	0
DEHY LIN	-3	0	0	0	-1	1	3
DEHY QUAD1	-1	0	0	0	1	1	-1

[a] Definition of Contrasts

ALF vs DEHY	Compares the two sources of high quality roughages regardless of the proportion of substitution of straw. Comparison is treatments 2, 3 and 4 vs 5, 6 and 7.
LIN 1 QUAD 1	Regardless of the sources of high quality roughage, there compare effects due to different proportion of substitution of straw in a linear and quadratic fasion. Take values for treatments 2 & 5, 3 & 6, and 4 & 7.
TYPE*LIN 1 TYPE*QUAD 1	Refers to interactions, linear or quadratics between source of high quality roughage and proportion of substitution, it tests if there is parallelism (either linear or quadratic) among responses with ALF or DEHY at the different proportion of substitution.
ALF LIN ALF QUAD DEHY LIN DEHY QUAD	Linear and quadratic response for each source of high quality roughage, each one at different proportions of substitution. Takes values for treatments 1, 2, 3 and 4 or 1, 5, 6 and 7.

[b] Contrast used for in vivo digestibility and kinetics of rumen liquid are non-orthogonal contrasts.

[c] ALF = Alfalfa hay; DEHY = Dehydrated alfalfa pellets.

of Yb-labelled US (as-fed) containing approximately 162 mg Yb was fed to each lamb on treatments 1, 2, 3, 5 and 6. 10 g of Dy-labelled ALF (as-fed) containing approximately 250 mg Dy was fed to each lamb on treatments 2, 3 and 4 and 10 g of Dy labelled DEHY was fed to each lamb on treatments 5, 6 and 7.

Fecal samples were collected at zero hours (blank) and 24, 48, 72 and 96 hours post dosing. Fecal samples were dried at 60°C for 96 hours, ground through a 2 mm screen, and stored in plastic bags for analysis.

Dry matter of each sample was determined (A.O.A.C. 1975). Fecal samples were prepared for Yb and Dy analysis by digestion of ash residues with a 1:1 v/v mixture of 3 N nitric acid and 3 N hydrochloric acid for 12 hours. After appropriate dilutions, the Yb and Dy concentrations of each sample were determined by atomic absorption spectroscopy using a nitrous oxide flame (Ellis et al., 1982).

Fractional rate of passage of particulate ruminal digesta was assumed to be represented by the slope of the natural log of fecal Yb or Dy concentration vs time. Ruminal turnover time of particulate matter was considered to be the reciprocal of the slope (Weston and Hogan, 1967).

Data were analyzed using least sequare analysis of variance. Tests were made for linear and quadratic effects on rate of passage (%/h) and turnover time (h). The contrasts used in comparisons of the treatment means are non-orthogonal (Table V).

TABLE V

CONTRASTS AMONG TREATMENT MEANS USED IN KINETICS OF PARTICULATE MATTER

Contrasts[a]	Treatments						
	1	2	3	4	5	6	7
Yb labeled:							
ALF vs DEHY[b]	0	-1	-1	0	1	1	0
US[c]/ALF LIN	1	0	-1	0	0	0	0
US/ALF QUAD	-1	2	-1	0	0	0	0
US/DEHY LIN	1	0	0	0	0	-1	0
US/DEHY QUAD	-1	0	0	0	2	-1	0
Dy labeled:							
ALF vs DEHY	0	1	1	1	-1	-1	-1
LIN 1	0	-1	0	1	-1	0	1
QUAD 1	0	-1	2	-1	-1	2	-1
TYPE*LIN 1	0	-1	0	1	1	0	-1
TYPE*QUAD 1	0	-1	2	-1	1	-2	1
ALF LIN	0	-1	0	1	0	0	0
ALF QUAD	0	-1	2	-1	0	0	0
DEHY LIN	0	0	0	0	-1	0	1
DEHY QUAD	0	0	0	0	-1	2	-1

[a] Contrasts are non-orthogonal.

[b] ALF = Alfalfa hay; DEHY = Dehydrated alfalfa pellets

[c] US = Untreated wheat straw.

Kinetics of Ruminal Liquid

The kinetics of rumen liquid were measured in twenty-one of the ruminally cannulated wether lambs described before. Measurements were taken during the restricted and ad libitum feeding periods. After a 10-day adaptation period for each level of feeding, 80 ml of Cr-EDTA (Downes and McDonald, 1964) was ruminally infused into each lamb immediately before the morning feeding (time=0). Rumen samples were taken at 1, 2, 4, 8, 12 and 24 hours post dosing. All samples were centrifuged at 5000 RPM for 30 minutes.

Concentration of Cr in the centrifuged supernatant was determined by atomic absorption spectroscopy using an acetylene air flame.

Liquid dilution rate (LDR, %/h) of rumen fluid was calculated as the slope of the natural log of (Cr) vs time. Rumen liquid volume (RLV, ml) was estimated as the Cr dose divided by the calculated Cr concentration at time zero (antilog of the intercept). Liquid turnover time (LT, h) was estimated as the reciprocal of the fractional dilution rate (LDR; i.e., slope) and liquid flow rate (LFR, ml/h) estimated as the product of volume and fractional dilution rate.

The data were analyzed using least sequare analysis of variance. Tests were made for linear and quadratic effects on LDR, RLV, LT and LFR. The contrasts used in comparisons of the treatment means are non-orthogonal (Table IV).

Ruminal Fermentation

Concomitant with the study of the kinetics of ruminal fluid, estimates of the changes in rumen pH and concentrations of ruminal ammonia-nitrogen (NH_3-N) were made. For this purpose, the same samples obtained to measure Cr concentration.

Ruminal pH was measured immediately after collection. All samples were then centrifuged at 5000 RPM for 30 minutes. One ml of I N HCL was added to 4 ml of suppernatant and then frozen for later NH_3-N analysis. The concentration of NH_3-N in each sample was determined colorimetrically by modification of the procedure of Chaney and Marbach (1962).

Data were analyzed using least sequare analysis of variance. Tests were made for linear and quadratic effects on pH values and NH_3-N concentrations. The contrasts used in comparisons of the treatments are non-orthogonal (Table IV).

Results and Discussion

Level of Feed Intake

Daily intakes of DM, OM, CP and NDF (g/Kg body weight) are shown in Table VI for both restricted and ad libitum periods. Daily intakes of DM, OM, CP and NDF differed between periods (P<.01). The feed intake of DM for treatment 100:0 US:HQR was similar in both periods (17.9 and 17.7 g/Kg BW, respectively). Feed intake of teatments 67:33; 33:67 and 0:100 US:HQR was about 35-55% higher in period 2 comparing

TABLE VI

EFFECTS OF LEVEL OF FEEDING ON DAILY INTAKES (G/KG BODY WEIGHT)

Nutrient	Level of Feeding	
	Restricted	Ad Libitum
Dry matter	18.1^{a}	27.2^{b}
Organic matter	16.7^{a}	25.2^{b}
Crude protein	2.1^{a}	3.5^{b}
Neutral detergent fiber	11.9^{a}	17.0^{b}

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

to period 1, in which the level of feed intake for all treatments was limited to that of lambs fed 100% straw. Both sources of HQR increased DM, OM, CP and NDF intake.

Apparent Digestibility of Total Diet

Apparent digestibilities of DM, OM, CP and NDF of the total diets are shown in Table VII for both periods. There were no significant effects of level of intake on the apparent digestibilities of DM, OM and CP, but a significant reduction in apparent digestibility of NDF was detected.

A reduction in apparent digestibility as level of feed intake increased has not been obtained for all types of diets. It has been observed with mixed, high concentrate diets or finely ground roughage diets (Reid and Tyrrell, 1964; Reid et al., 1980). Tyrrell and Moe (1975) examined the interaction between the level of feed intake and the proportion of concentrate in the diet and indicated that the rate of depression in digestibility is greater for high concentrate diets than for diets high in roughage.

The results of this study agree with those of Varga and Prigge (1982) who found no significant effect of level of feeding (high alfalfa vs low alfalfa intake) on apparent digestibilities of OM, CP and ADF.

Digestibility of NDF was significantly different (P<.01) between the two periods (Table VII). The NDF digestibility was 46.8 and 39.3 for period 1 and 2, respectively. Bull et al. (1979) reported that decreases in rumen fiber digestion that may occur with increased feed intake can be offset by

TABLE VII

EFFECTS OF LEVEL OF FEEDING ON APPARENT DIGESTIBILITIES OF DRY MATTER (DDM), ORGANIC MATTER (DOM), CRUDE PROTEIN (DCP) AND NEUTRAL DETERGENT FIBER (DNDF) (%)

Digestibility, %	Level of Feeding	
	Restricted	Ad Libitum
Dry matter	44.8	43.5
Organic matter	48.6	46.7
Crude protein	49.4	52.0
Neutral detergent fiber	46.8^{a}	39.3^{b}

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

increased postruminal digestion. Thus, the differences in fiber digestibility observed in the present study may be partially attributable to a greater rumen fermentation as digesta stayed in the rumen for a longer time on the restricted level of feeding.

No significant interactions were detected between level of feed intake and diet composition for digestibility of DM, OM, CP, but an interaction ($P<.02$) was observed for NDFD. This interaction is most likely a function of both the rate of digestion of the forage and the rumen retention time. Larger particulate retention time would be expected to result in a slower digestion of NDF. Van Soest (1982) reported that higher intake had a large influence upon the slower digesting cell wall fractions in the diet.

Kinetics of Ruminal Particulate Matter

The results of rate of passage (%/h) and turnover time (h) of Yb which was initially attached to the straw fraction in the diets are shown in Table VIII. The rate of passage of straw was 2.34 and 2.67 %/h, and for turnover time was 44.6 and 40.2 h for period 1 and 2 ($P<.05$), respectively. This represents a 14% increase in rate of passage and 10% decrease in turnover time of digesta of straw as level of feed intake was increased by 30 to 50%. Previously, it was suggested that an increase in rate of passage is accompanied by an increase in voluntary intake (Balch, 1950; Graham and Williams, 1962). In addition, the rate of passage of digesta

TABLE VIII

EFFECTS OF LEVEL OF FEEDING ON RATE OF PASSAGE (%/h) AND TURNOVER TIME (h) OF PARTICULATE MATTER OF UNTREATED STRAW

Item	Level of Feeding	
	Restricted	Ad Libitum
Rate of passage (%/h)	2.34^{a}	2.67^{b}
Turnover time (h)	44.6^{a}	40.2^{b}

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

through the reticulo-rumen and the breakdown of digesta in that organ are important determinants of the efficiency of digestion and the rate of rumen emptying (Balch, 1950).

These results indicate that increased feed intake causes rate of passage to increase and turnover time to decrease, which in general agrees with the results found by workers using roughage diets fed to sheep (Minson, 1966; Grovum and Williams, 1977; Mudgal et al., 1982). The magnitude of differences observed in rate of passage and turnover time may not have been large enough to result in differences in apparent digestibilities of DM, OM, CP and NDF. Differences in the rate of passage as influenced by source of HQR were comparatively small ($P>.2$).

Rate of passage and turnover time of solid particles of high quality roughage in the diets for both periods are shown in Table IX.

Level of feed intake had little effect on rate of passage and turnover time ($P>.2$). Therefore, the differences ($P<.01$) among treatments may be due to the proportion of HQR used in the diets. No significant period X treatment interaction was observed for rate of passage and turnover time. These results agree with those of Varga and Prigge (1982). Although the values are lower than those reported by Varga and Prigge (1982) in lambs fed alfalfa hay (21%) CP at two different levels and the rate of passage was 5.5 and 6.6 %/h. The difference between studies may be due to the quality of roughage used. The alfalfa used in this study contained 18.1% CP.

TABLE IX

EFFECTS OF LEVEL OF FEEDING ON RATE OF PASSAGE (%/h) AND TURNOVER TIME (h) OF PARTICULATE MATTER OF ALFALFA HAY (ALF) OR DEHYDRATED ALFALFA PELLETS (DEHY)

Item	Level of Feeding	
	Restricted	Ad Libitum
Rate of passage (%/h)	3.67	3.97
Turnover time (h)	29.0	26.7

Kinetics of Ruminal Fluid

Rumen liquid volumes (RLV, ml), liquid dilution rates (LDR, %/h), liquid turnovers (LT, h) and liquid flow rates (LFR, ml/h) are shown in Table X.

The RLV decreased by 42.9% ($P<.01$) as DM intake increased from 18.1 to 27.2 g/Kg BW. This result is in agreement with the results reported by Adams and Kartcher (1984) who found RLV decreased linearly ($P<.05$) as forage intake increased from 1.40 to 2.40% of body weight. However, it does not agree with Hartnell and Satter (1979) who reported that RLV increased with increasing DM intake. Hartnell and Satter (1979) indicated that the differences between cows in rumen liquid volume may be due to differences in saliva production.

The LDR increased by 70% ($P<.02$) with increased level of DM intake which is in general agreement with the results of Adams and Kartcher (1984) and Prigge et al. (1984). It does not agree with Hodgson et al. (1976) who found that the level of feed intake had no significant effect on LDR in sheep fed diets containing ground barley, ground hay and ground maize. They indicated that the variations in ruminal volume both between animals and within animals between periods was very wide so that there was little ($P<.05$) change detected with level of feed intake. Increased LDR in the present study may be related to saliva flow. Harrison et al. (1975) reported that the infusion of saliva in the rumen markedly increased LDR.

TABLE X

EFFECTS OF LEVEL OF FEEDING ON RUMINAL LIQUID MEASUREMENTS

Item	Level of Feeding	
	Restricted	Ad Libitum
Liquid dilution rate (%/h)	3.87^{a}	6.57^{b}
Rumen liquid volume (ml)	7273.3^{a}	5089.0^{b}
Liquid flow rate (ml/h)	215.8	254.5
Liquid turnover time (h)	33.7^{a}	20.0^{b}

[ab] Means in the same row with unlike superscript differ (P<.01).

Liquid turnover time (LT, h) decreased by 50% ($P<.01$) as the level of feed intake increased. There was a 1.5 h decrease in LT for each 1 g/Kg BW increase in feed intake. These results are in agreement with the results reported by Adams and Kartchner (1984). Liquid flow rate (LFR, ml/h) was highest for lambs fed ad libitum (27.2 g/Kg BW) and lowest for those fed at restricted levels of feeding (18.1 g/Kg BW). Differences in LFR were not significant ($P>.1$) between the two levels of feeding. No significant period by diet interaction was observed for any of the variables considered.

Rumen Fermentation:

Ruminal pH and ammonia nitrogen (NH_3-N) concentrations are shown in Table XI. Mean rumen pH differed ($P<.05$) for both levels of feed intake (6.42 for restricted vs 6.17 for ad libitum). The results of this study are in agreement with those of Prigge et al. (1984). A drop in pH was observed with time after feeding at ad libitum feed intake from 1 h to approximately 8 h (6.32 to 5.92), to increase again and end up at 24 h at a higher level than 1 h after feeding. Rumen pH values of restricted fed lambs were higher ($P<.05$) at all times after feeding except at 1 h after feeding, where values were similar among levels of feeding. Fluctuations in rumen pH (Table XI) were much greater at ad libitum feed intake, and reached values below 6.0 at 4 and 8 h after feeding. Such low pH values may decrease utilization of the fibrous material by reducing the population or

TABLE XI

EFFECTS OF LEVEL OF FEEDING ON RUMINAL pH AT VARIOUS TIMES AFTER FEEDING

Level of feeding	Time after feeding, h						Mean[a]
	1	2	4	8	12	24	
	Rumen pH						
Restricted	6.30	6.27	6.15^b	6.29^b	6.44^b	7.07^b	6.42^b
Ad libitum	6.32	6.21	5.94^c	5.92^c	6.13^c	6.51^c	6.17^c

[a] Mean rumen pH for each level of feeding.

[bc] Means in the same column with unlike superscript differ ($P<.05$).

activity of ruminal cellulolytic bacteria, which are known to be pH dependent. Hungate et al. (1966) reported that many cellulolytic bacteria cease to grow below 5.5 and the depression in pH values may have influenced the numbers of these organisms within the rumen.

Mean ruminal NH_3-N concentrations (Table XII) over the entire feeding cycle were similar among levels of feeding. The lack of an intake effect on rumen NH_3-N concentrations has been observed previously (Varga and Prigge, 1982; Prigge et al., 1984), and ascribed to differences in liquid flow from the rumen.

Level of feeding had an effect ($P<.01$) on the concentration of NH_3-N in rumen fluid at 1, 2, 4 and 24 hours after feeding, with no differences observed at 8 and 12 hours after feeding. A higher value for restricted levels of feeding at 1 and 2 h post-prandial with a lower value at 4 h after, contrasted with a more steady level found with animals fed ad libitum. The lowest level of NH_3-N was observed at 8 h after feeding, 2.7 vs 3.37 for restricted and ad libitum feeding feeding, respectively. These values are below 5 mg NH_3-N/100 ml rumen fluid which is suggested by Satter and Slyter (1974) as the minimum level needed to support sufficient microbial growth in the rumen.

Rumen NH_3-N concentrations were significantly affected ($P<.01$) by source of HQR at 1 and 12 hours after feeding at ad libitum feed intake.

TABLE XII

EFFECTS OF LEVEL OF FEEDING ON RUMINAL AMMONIA NITROGEN (NH_3-N)CONCENTRATIONS AT VARIOUS TIMES AFTER FEEDING

Level of feeding	Time after feeding, h						Mean[a]
	1	2	4	8	12	24	
	Rumen NH_3-N, mg/100 ml						
Restricted	19.45[b]	20.80[b]	6.65[b]	2.71	8.10	7.85[b]	10.93
Ad libitum	14.30[c]	14.45[c]	16.65[c]	3.37	7.22	10.45[c]	11.07

[a] Mean NH_3-N concentration for each level of feeding.

[bc] Means in the same column with unlike superscript differ ($P<.01$).

Effect of Proportion of High Quality Roughage Substitution in the Diet.

Feed Intake. The results of DM, OM, CP and NDF intake as affected by level of HQR substitution are shown in Table XIII for ad libitum feed intake and the statistical analysis of this data is shown in appendix Table I.

Level of HQR in the diets had little effect (P>.6) on intake of DM and OM at restricted feeding (17.7 and 16.4 g/Kg body weight for DM and OM, respectively). A linear increase (P<.01) in ad libitum intake of DM, OM and CP was found for diets with increased levels of ALF or DEHY.
Paterson et al. (1982); Soofi et al. (1982a) and Hunt et al. (1985) have reported linear increase in DM intake with the addition of legume to low quality roughage diets. Higher intakes by sheep fed more digestible diets might have been due to a shorter retention time and, hence a faster rate of passage through the digestive tract. Thornton and Minson (1972) found a greater voluntary intake of legume compared with grass forage species. The higher intake was highly correlated with shorter ruminal retention time of diets containing legumes. Van Soest (1965) suggested that CWC, which represents the total fibrous fraction of forages limits voluntary intake when present in concentrations more than 55 to 60% of DM. Thus, the greater volunatary intake of legumes may also be related to the lower NDF content of leguminous forages. In this study it appeared that NDF content and rate

TABLE XIII

EFFECTS OF ADDITION OF ALFALFA OR DEHYDRATED ALFALFA PELLETS TO UNTREATED WHEAT STRAW DIETS WHEN FED AD LIBITUM ON DAILY FEED INTAKE (G/KG BODY WEIGHT)

Nutrient	Treatments						
	US:ALF				US:DEHY		
	100:0	67:33	33:67	0:100	67:33	33.67	0:100
Dry matter[a]	17.7	22.9	32.0	33.0	25.3	32.8	32.8
Organic matter[a]	16.7	21.5	29.9	31.6	23.5	29.9	29.4
Crude protein[a]	.9	2.2	4.5	6.3	2.3	4.3	5.7
Neutral detergent fiber[b]	14.1	16.0	19.8	18.2	17.5	19.7	16.5

[a] Linear increase ($P<.01$); 100:0 Wheat straw diet not included in contrast.

[b] Quadratic response ($P<.01$); 100:0 Wheat straw diet not included in contrast.

of passage were the primary factors affecting level of feed intake. Soofi et al. (1982a) found that dietary fiber content was among the primary factors limiting intake by sheep fed soybean stover-alfalfa diets.

Apparent Digestibility

Apparent digestibilities of DM, OM, CP and NDF of the total diets are shown in Tables XIV and XV for restricted and ad libitum intake, respectively, and the statical analysis of these data are in appendix Tables II and III.

Apparent digestibilities of DM and OM were linearly increased ($P<.01$) as levels of ALF or DEHY increased at both levels of feeding. Soofi et al. (1982a) previously found that DM digestibility increased as the percentage of ALF in the blend increased. A quadratic relationship ($P<.05$) was observed between CP digestibility and level of ALF or DEHY with ad libitum feeding. When lambs were restricted to 450 g feed/day, CP digestibility increased linearly ($P<.01$) with increasing levels of ALF or DEHY in the diets. The apparent CP digestibility of US was 6.5% in both periods, which is very low ($P<.01$) compared to apparent CP digestibilities of ALF and DEHY, 72.0 and 70.6%, indicating the positive synergistic effect of increasing protein level on digestibility. This is as expected since apparent CP digestibility generally increases as N intake increases (Guthrie, 1984).

A linear increase ($P<.01$) occurred in NDF digestibility as the level of ALF or DEHY increased in the diet with ad

TABLE XIV

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO UNTREATED WHEAT STRAW DIETS WHEN FED AT RESTRICTED INTAKE ON APPARENT DIGESTIBILITY (%)

	Treatments						
Apparent	US:ALF				US:DEHY		
Dig., %	100:0	67:33	33:67	0:100	67:33	33.67	0:100
Dry matter[a]	38.4	40.9	47.7	53.0	42.4	47.2	51.6
Organic matter[a]	42.3	44.3	51.4	56.9	45.9	50.6	55.1
Crude protein[a]	6.5	42.3	61.1	71.8	43.2	62.1	69.4
Neutral detergent fiber	50.7	45.0	47.7	42.2	47.5	47.9	46.3

[b] Linear increase ($P<.01$); 100:0 Wheat straw diet not included in contrast.

TABLE XV

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO UNTREATED WHEAT STRAW DIETS WHEN FED AD LIBITUM ON APPARENT DIGESTIBILITY (%)

	Treatments						
Apparent	US:ALF				US:DEHY		
Dig., %	100:0	67:33	33:67	0:100	67:33	33.67	0:100
Dry matter[a]	32.0	37.9	47.6	56.2	38.2	48.4	54.1
Organic matter[a]	36.5	41.1	50.9	58.3	41.9	50.7	56.4
Crude protein[b]	6.5	48.5	67.8	72.3	48.0	62.4	71.8
Neutral detergent fiber[a]	38.7	36.3	39.2	48.0	33.6	40.3	43.6

[a] Linear increase ($P<.01$); 100:0 Wheat straw diet not included in contrast.

[b] Quadratic response ($P<.05$); 100:0 Wheat straw diet not included in contrast.

libitum feeding. With restricted feeding, no relationship of intake to NDF digestibility was detected.

Observed and expected digestibilities of DM, OM, CP and NDF for periods 1 and 2 are shown in Tables XVI and XVII. Observed digestibilities of DM and OM for all the treatments did not differ from calculated values in both periods. Observed NDF digestibility was different at a 33% level of ALF and DEHY ($P<.01$ and $P<.05$), respectively, from calculated values. These results are in agreement with the results found by Soofi et al. (1982a).

Feeding US with ALF or DEHY resulted in a tendency toward negative associative effects for DMD, OMD, CPD and NDFD at both levels of feeding, but these results were not ($P>.05$) different (Tables XVI and XVII). The only significant negative associative effect was observed for CP digestibility ($P<.01$) at level of 33% ALF during period 1, and on NDF digestibility at level of 33% DEHY in the diet during period 2. This negative associative effect on NDF digestibility may be due to differences in chemical composition of NDF fraction. Soofi et al. (1982a) found that soybean stover at levels greater than 40% of all forage diets induced negative associative effects when fed to sheep.

Calculated metabolizable energy intake (MEIn) increased as the level of substitution of HQR increased in the diets (Table XVIII). The ME intake of diets containing ALF or DEHY were increased about 745.0 and 770.7 Kcal/day, respectively, as compared to MEIn from a 100% US diet (444.2 Kcal/day).

TABLE XVI

OBSERVED AND CALCULATED DIGESTIBILITIES OF DRY MATTER, ORGANIC MATTER, CRUDE PROTEIN AND NEUTRAL DETERGENT FIBER OF THE TOTAL DIET AT RESTRICTED FEEDING

	Treatments[a]			
	US:ALF		US:DEHY	
	67:33	33:67	67:33	33:67
	- Dry matter digestibility, % -			
observed	40.9	47.7	42.5	47.2
calculated	43.2	48.0	42.8	47.2
difference	-2.3	-0.3	-0.3	0.0
level of sign.	NS	NS	NS	NS
	- Organic matter digestibility, % -			
observed	44.3	51.4	45.9	50.6
calculated	47.1	51.9	46.4	50.6
difference	-2.8	-0.5	-0.5	0.0
level of sign.	NS	NS	NS	NS
	- Crude protein digestibility, % -			
observed	42.3	61.1	43.2	62.1
calculated	52.7	67.5	49.2	62.7
difference	-10.4	-6.4	-6.0	-0.6
level of sign.	.01	NS	NS	NS
	- Neutral detergent fiber digestibility, % -			
observed	45.0	47.7	47.5	48.0
calculated	49.0	46.2	49.6	48.2
difference	-4.0	1.5	-2.1	-0.2
level of sign.	NS	NS	NS	NS

[a] US = Untreated wheat straw; ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

TABLE XVII

OBSERVED AND CALCULATED DIGESTIBILITIES OF DRY MATTER, ORGANIC MATTER, CRUDE PROTEIN AND NEUTRAL DETERGENT FIBER OF THE TOTAL DIET AT AD LIBITUM FEEDING

	Treatments[a]			
	US:ALF		US:DEHY	
	67:33	33:67	67:33	33:67
- Dry matter digestibility, % -				
observed	37.9	47.6	38.2	48.4
calculated	41.3	48.6	40.2	46.9
difference	-3.4	-1.0	-2.0	1.5
level of sign.	NS	NS	NS	NS
- Organic matter digestibility, % -				
observed	41.1	50.9	41.9	50.7
calculated	44.8	51.4	43.6	49.7
difference	-3.7	-0.5	-1.7	-1.0
level of sign.	NS	NS	NS	NS
- Crude protein digestibility, % -				
observed	48.5	67.8	48.0	62.4
calculated	54.1	66.0	52.3	64.8
difference	-5.6	1.8	-4.3	-2.4
level of sign.	NS	NS	NS	NS
- Neutral detergent fiber digestibility, % -				
observed	36.3	39.2	33.6	40.3
calculated	41.5	44.2	40.0	41.5
difference	-5.2	-5.0	-6.4	-1.2
level of sign.	NS	NS	.05	NS

[a] US = Untreated wheat straw; ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

TABLE XVIII

POTENTIAL TO MEET METABOLIZABLE ENERGY REQUIREMENTS FOR MAINTENANCE (MEMt) FOR LAMBS OR EWES, WITH OBSERVED INTAKES OF CALCULATED ME (MEIn), FOR UNTREATED WHEAT STRAW:HIGH QUALITY ROUGHAGE DIETS

		25 Kg Lamb			40 Kg Ewe
Diet[a]	Mein[b] Kcal/day	MEIn/ MEMt[c]	ME Gain Kcal/day	Predicted Gain g/day	MEIn/ MEMt
US/ALF					
100:0	444.2	0.41	--	--	0.37
67:33	726.6	0.67	--	--	0.61
33:67	1300.1	1.21	225.0	20.0	1.09
0:100	1541.6	1.43	446.0	40.0	1.29
US:DEHY					
67:33	786.3	0.73	--	--	.66
33:67	1371.9	1.28	296.0	23.0	1.15
0:100	1486.6	1.38	411.0	38.0	1.24

[a] US = Untreated wheat straw; ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] MEIn = 0.15 DOMD %

DOMD % = % Digestible organic matter in dry matter = $\frac{(\text{Food OM} - \text{Feces OM})}{\text{Food DM}} \times 100$

[c] Ratio = Calculated ME intake / ME maintenance requirement, 25 Kg lamb = 1075.5; 40 Kg ewe = 1195.0 Kcal/day (MAFF, 1977).

The average MEIn of the diets containing DEHY was slightly higher than for the diets containing ALF, 1214.9 and 1189.5 Kcal/day, respectively. The metabolizable energy requirements for maintenance (MEMt) of 25 Kg BW lamb and 40 Kg BW non-pregnant, non-lactating ewes are 1075.5 and 1195.0 Kcal/day, respectively (MAFF, 1977). The MEIn of treatments 100:0 and 67:33 US:HQR did not meet the maintenance requirement of lambs (25 Kg BW) or non-pregnant, non-lactating ewe (40 Kg BW) and the ratio of MEIn/MEMt was less than one. But as the level of HQR was increased in the diets to 67 and 100%, MEIn was sufficient to meet MEMt requirements (Table XVIII). Soofie et al. (1982a) reported that the maintenance requirements of the sheep could be met with 60% ALF and 40% soybean stover.

There was about 224, 446, 296 and 411.0 Kcal/day ME available for gain (ME gain) for diets containing 67 and 100% ALF or DEHY, respectively. Thus lambs fed these diets should gain between 20 to 40 g/day. These results indicate that adding HQR in 67% or more to US diets should increase the nutritional statue of the animals by increasing their MEIn and change ME balance from negative to positive.

Kinetics of Ruminal Particulate Matter

The results of rate of passage and turnover time of straw and high quality roughage are shown in Tables XIX and XX for periods 1 and 2. The statistical analyses of these data are shown in appendix Tables IV and V.

TABLE XIX

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO UNTREATED WHEAT STRAW DIETS WHEN FED AT RESTRICTED INTAKE ON RATE OF PASSAGE (%/h) AND TURNOVER TIME (h) OF RUMINAL PARTICULATE MATTER

Treatments[a]	Rate of Passage[b] (%/h)			Turnover Time[c] (h)		
	US	ALF	DEHY	US	ALF	DEHY
US:ALF						
100:0	1.88	-	-	55.0	-	-
67:33	2.40	2.81	-	43.6	35.9	-
33:67	2.95	3.11	-	34.3	32.5	-
0:100	-	3.69	-	-	27.4	-
US:DEHY						
67:33	2.22	-	3.36	45.3	-	30.8
33:67	2.49	-	3.98	41.5	-	25.9
0:100	-	-	5.11	-	-	21.6

[a] US = Untreated wheat straw; ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] Linear increase ($P<.02$); 100:0 Wheat straw diet not included in contrast.

[c] Linear decrease ($p<.01$); 100:0 Wheat straw diet not included in contrast.

TABLE XX

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO UNTREATED WHEAT STRAW DIETS WHEN FED AD LIBITUM ON RATE OF PASSAGE (%/h) AND TURNOVER TIME (h) OF RUMINAL PARTICULATE MATTER

Treatments[a]	Rate of Passage[b] (%/h)			Turnover Time[c] (h)		
	US	ALF	DEHY	US	ALF	DEHY
<u>US:ALF</u>						
100:0	1.94	-	-	53.1	-	-
67:33	2.82	3.15	-	36.5	33.8	-
33:67	3.46	3.48	-	30.5	29.7	-
0:100	-	4.17	-	-	24.8	-
<u>US:DEHY</u>						
67:33	2.56	-	3.59	39.8	-	28.6
33:67	3.04	-	4.46	35.2	-	22.9
0:100	-	-	4.97	-	-	20.3

[a] US = Untreated wheat straw, ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] Linear increase (P<.01); 100:0 Wheat straw diet not included in contrast.

[c] Linear decrease (P<.01); 100:0 Wheat straw diet not included in contrast.

A linear increase (P<.01) in rate of passage and decrease in turnover time (P<.01) of straw and high quality roughage was observed with increasing levels of ALF or DEHY in the diets of both periods. This response in rate of passage may be explained by the increase in cell solubles present in the diet as ALF or DEHY was added. Smith et al. (1972) reported a faster rate of digestion for legumes compared with grass forages. The faster rate of digestion was associated with the greater content of cell solubles in the legumes. Hunt et al. (1985) studied diets containing 0, 25, 50, 75 or 100% alfalfa with fescue hay by in vitro fermentation. They observed a linear increase (P<.01) in the rate of potentially digestible DM disappearance as the level of alfalfa increased in the diets. The ALF or DEHY had a higher rate of passage compared to 100% US. The rates of passage in period 1 were 1.88, 3.69 and 5.11 (%/h) for US, ALF and DEHY, respectively. At ad libitum intakes, rates of passage were 1.94, 4.17 and 4.97 (h/%) for US, ALF and DEHY, respectively.

Kinetics of Ruminal Fluids

Results of liquid dilution rate (%/h), rumen liquid volume (ml), liquid flow rate (ml/h) and liquid turnover time (h) are shown in Tables XXI, and XXII. The statical analysis of these data are shown in appendix Tables VI and VII. The level of ALF or DEHY in the diets had no significant effect on any of these measurements at restricted levels of feeding.

TABLE XXI

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO UNTREATED WHEAT STRAW DIETS WHEN FED AT RESTRICTED INTAKE ON RUMINAL LIQUID MEASUREMENTS

Items	Treatments[a]						
	US:ALF				US:DEHY		
	100:0	67:33	33:67	0:100	67:33	33.67	0:100
Liquid dilution rate (%/h)	2.49	4.50	2.85	4.85	3.92	5.39	3.08
Rumen liquid volume (ml)	7106	7556	7934	7317	6214	7550	7231
Liquid flow rate (ml/h)	165.3	322.9	148.9	293.8	228.5	251.7	213.9
Liquid turnover time (h)	43.0	23.4	53.3	24.9	27.2	30.0	33.8

[a] US = Untreated wheat straw; ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

TABLE XXII

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO UNTREATED WHEAT STRAW DIETS WHEN FED AD LIBITUM ON RUMINAL LIQUID MEASUREMENTS

	Treatments[a]						
Items	US:ALF				US:DEHY		
	100:0	67:33	33:67	0:100	67:33	33.67	0:100
Liquid dilution rate (%/h)[b]	3.27	5.32	6.46	7.75	4.89	5.40	5.89
Rumen liquid volume (ml)	4359	5796	3700	5420	4837	6132	5375
Liquid flow rate (ml/h)[b]	112.9	282.7	229.8	407.5	234.8	331.5	290.5
Liquid turnover time (h)	38.6	20.5	16.1	13.3	20.6	18.5	18 .5

[a] US = Untreated wheat straw; ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] Linear increase ($P<.05$) as ALF increases in the diet.

During ad libitum feeding, no response due to HQR addition was observed for RLV. Varga and Prigge (1982) found that RLV was not influenced by increasing levels of ALF. LDR, however, was increased ($P<.05$) from 3.27 %/h in lambs fed 100% US to 6.51 %/h in lambs supplemented with ALF. Moreover, LFR increase from 165.3 to 255.2 ml/h ($P<.02$) in lambs fed 100% US vs lambs supplemented with ALF. Liquid turnover time tended to be reduced in lambs supplemented with HQR compared to 100% US. These changes in LDR, LFR and LT may reflect changes in voluntary intake and may be due to increased cell solubles present in the ALF or DEHY as added to the diets. Similar responses have been reported by others (Grovum and Williams, 1977; Mudgal et al., 1982; Varga and Prigge, 1982; Adams and Kartchner, 1984; Prigge et al., 1984).

Rumen Fermentation

The results of pH and NH_3-N concentrations are shown in Tables XXIII, and XXIV, XXV and XXVI. The statistical analysis of these data are shown in appendix Tables VIII, IX, X and XI.

For the combination of US:ALF, there was a linear decrease in pH values at 1 ($P<.05$), 2 ($P<.01$), 4 ($P<.001$) and 8 ($P<.05$) hours after feeding, with opposite trend at 24 ($P<.001$) hours after feeding (Table XXIII), with restricted feeding. Similar results were observed for the combination of US:HQR at ad libitum feeding (Table XXIV). The higher

TABLE XXIII

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO UNTREATED WHEAT STRAW DIETS WHEN FED RESTRICTED ON RUMEN pH.

Treatments	Time after feeding, h					
	1[a]	2[a]	4[a]	8[a]	12	24[b]
	Rumen pH					
US:ALF						
100:0	6.51	6.52	6.46	6.51	6.41	6.59
67:33	6.24	6.39	6.30	6.45	6.46	6.89
33:67	6.35	6.05	5.92	6.18	6.53	7.16
0:100	6.26	6.09	5.92	5.89	6.34	7.34
US:DEHY						
67:33	6.32	6.24	6.01	6.09	6.36	6.99
33:67	6.52	6.32	6.23	6.44	6.42	7.11
0:100	6.40	6.31	6.14	6.42	6.59	7.42

[a] Linear decrease for US:ALF at 1 ($P<.05$), 2 ($P<.01$), 4 ($P<.001$) and 8 ($P<.05$) hours.

[b] Linear increase ($P<.001$); 100:0 Wheat straw diet not included in contrast.

TABLE XXIV

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO UNTREATED WHEAT STRAW DIETS WHEN FED AD LIBITUM ON RUMEN pH.

Treatments	Time after feeding, h					
	1[a]	2[a]	4[a]	8[a]	12	24[b]
	Rumen pH					
<u>US:ALF</u>						
100:0	6.46	6.63	6.39	6.20	6.11	6.11
67:33	6.52	6.30	6.22	6.18	6.24	6.38
33:67	6.52	6.33	6.12	6.08	6.18	6.61
0:100	6.37	6.15	5.78	5.86	6.09	6.76
<u>US:DEHY</u>						
67:33	6.16	6.13	5.70	6.03	6.06	6.54
33:67	6.19	5.98	5.64	5.37	6.10	6.64
0:100	6.08	5.91	5.73	5.76	6.11	6.55

[a] Linear decrease at 1 and 2 ($P<.05$), 4 ($P<.001$) and 8 ($P<.05$) hours; 100:0 Wheat straw diet not included in contrast.

[b] Linear increase ($P<.05$); 100:0 Wheat straw diet not included in contrast.

TABLE XXV

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO UNTREATED WHEAT STRAW DIETS WHEN FED RESTRICTED ON RUMEN AMMONIA NITROGEN (NH_3-N) CONCENTRATION (mg/100 ml).

Treatments	Time after feeding, h					
	1[a]	2	4[a]	8[a]	12	24[b]
	Rumen NH_3-N					
<u>US:ALF</u>						
100:0	27.55	20.00	16.00	7.45	10.55	5.45
67:33	10.10	11.25	3.20	0.55	4.35	6.18
33:67	12.15	26.03	5.45	2.30	8.50	10.35
0:100	22.80	21.40	6.80	4.85	7.85	10.30
<u>US:DEHY</u>						
67:33	13.20	18.75	2.33	0.40	4.35	5.93
33:67	22.78	21.50	2.53	2.28	9.70	6.95
0:100	26.80	20.55	10.35	0.85	11.80	10.45

[a] Linear decrease at 1 ($P<.001$), 4 ($P<.05$) and 8 ($P<.01$); 100:0 Wheat straw diet not included in contrast.

[b] Linear increase ($P<.05$); 100:0 Wheat straw diet not included in contrast.

TABLE XXVI

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO UNTREATED WHEAT STRAW DIETS WHEN FED AD LIBITUM ON RUMEN AMMONIA NITROGEN (NH_3-N) CONCENTRATION (mg/100 ml).

Treatments	Time after feeding, h					
	1[a]	2[a]	4[a]	8[a]	12	24[b]
	Rumen NH_3-N					
<u>US:ALF</u>						
100:0	22.1	22.40	26.70	9.10	13.07	4.20
67:33	3.80	7.55	7.58	2.05	6.15	7.70
33:67	10.10	10.70	11.75	2.75	12.05	8.28
0:100	13.10	14.39	19.60	2.65	9.70	17.25
<u>US:DEHY</u>						
67:33	12.70	6.60	8.60	0.10	2.05	8.70
33:67	17.62	17.95	21.00	3.70	4.83	13.80
0:100	20.59	21.70	20.45	0.90	2.95	13.25

[a] Linear decrease at 1 ($P<.05$), 2, 4 and 8 ($P<.001$); 100:0 Wheat straw diet not included in contrast.

[b] Linear increase ($P<.001$); 100:0 Wheat straw diet not included in contrast.

depression observed in pH values overtime for the US:HQR diets fed ad libitum could upset the utilization of the fibrous material by reducing the population of cellulolytic bacteria. Russell and Dombrowski (1980) reported that use of continuous culture techniques, growth rate sharply declined and, therefore cell yields of pure cultures of four rumen cellulolytic bacteria were reduced at an average pH of 6.3. From this study it seems that the differences in pH values could be related to the amount of fermentable energy available in the rumen at different times after feeding.

Rumen NH_3-N concentrations showed a linear decrease with increasing levels of HQR in the diets at 1 ($P<.05$), and 2, 4 and 8 ($P<.001$) hours after feeding under ad libitum feeding (Table XXVI), and at 1 ($P<.001$), 4 and 8 ($P<.05$) hours after feeding at restricted levels of intake (Table XXV).

Treatments fed ad libitum, the ruminal NH_3-N concentrations tended to peak at 2 to 4 h post-prandial (range 7.6 to 26.7) and were lowest 8 to 12 h after feeding (range .10 to 12.7), and slightly increased at the end of 24 h feeding cycle. During the period of restricted feeding, there was a tendency for a continuous decline in the NH_3-N from 1 h after feeding (range 10.1 to 27.6) to 8 h after (range .40 to 7.45) and to remain relatively low for the rest of the feeding cycle. From these fluctuations in ruminal NH_3-N concentrations with time of sampling, possible periods of shortage of NH_3-N might be expected for ruminal microorganisms especially under diet-regimes based on US fed once a day at restricted levels.

The relatively high level of ruminal NH_3-N during the first 2 h after feeding a restricted amount of US could reflect an uncoupled kind of fermentation taking place within the rumen as the release of energy in the form of volatile fatty acids from the fiber component of the diet would not be expected to occur until approximately 4 to 8 h after feeding. This situation may result in an inefficient use of both energy and nitrogen by rumen microorganisms with detrimental consequences to the host animal. Ruminal NH_3-N concentrations do not directly reflect dietary protein concentrations because rate of liquid flow from the rumen can dilute actual concentrations (Varga and Prigge, 1982).

CHAPTER IV

ASSOCIATIVE EFFECTS OF AMMONIATED WHEAT STRAW AND ALFALFA DIETS FED TO SHEEP

Summary

Twenty-eight wether lambs (26.9 Kg) had ad libitum access to or were individually fed restricted amounts of ammoniated wheat straw and alfalfa diets during 2 periods. Level of feed intake during restricted feeding was 70% of ad libitum intake. Lambs were fed once a day ammoniated wheat straw (AS) in combination with different proportions of high quality roughages (HQR) as alfalfa hay (ALF) or dehydrated alfalfa pellets (DEHY) (100:0; 67:33; 33:67 and 0:100 for AS:ALF or DEHY) to investigate the effects of combining AS with ALF or DEHY in different proportions of the diets on feed intake; apparent digestibility of dry matter (DMD), organic matter (OMD), crude protein (CPD) and neutral detergent fiber (NDFD), kinetics of ruminal liquid and particulate matter passage and rumen fermentation.

Apparent digestion coefficients of DM, OM, and NDF were decreased (P<.0001) as level of feed intake increased. Turnover time of the particulate matter of AS and HQR were decreased by 13 and 10% (P<.05), respectively, as level of

feed intake increased and liquid dilution rate (LDR,%/h), liquid rumen volume (LRV, ml), liquid flow rate (LFR, ml/h) and liquid turnover time (LT,h) were different ($P<.001$). DEHY had a higher rate of passage ($P<.01$) of particulate matter compared to ALF at both levels of feed intake, (5.22 vs 4.28 %/h) and (6.08 vs 4.77 %/h) at restricted and ad libitum feeding, respectively.

Level of feed intake did not affect ($P>.2$) rumen pH. Rumen ammonia nitrogen (NH_3-N) concentrations were decreased ($P<.05$) as level of intake increased. Intake of DM, OM, CP and NDF increased linearly ($P<.001$) with increasing levels of ALF or DEHY in the diets at both levels of feed intake. Digestibility of DM, OM, and CP were linearly increased ($P<.001$) as the proportion of HQR increased in the diets. Digestibility of NDF was linearly ($P<.001$) decreased as level of HQR increased at both levels of intake.

Turnover times of particulate matter of AS and HQR fractions were linearly decreased ($P<.01$) at both levels of intake as the proportion of HQR increased in the diets. Liquid turnover time was not affected by the proportion of HQR in the diets at restricted feeding. While at ad libitum feed intake, liquid turnover time was linearly decreased ($P<.03$) as HQR proportion increased in the diets. No significant difference was detected in rumen pH between both levels of feed intake. Level of HQR caused a significant difference in rumen pH values at 12 ($P<.002$) and 24 ($P<.004$) hours after feeding at restricted intake. Linear and quadratic reponses were observed for ruminal NH_3-N with time after feeding as affected by the proportion of substitution of HQR in the diets.

Combining AS with HQR in different proportions tended to result in positive associative effects for digestibility of DM, OM, CP and NDF at restricted levels of intake. While at ad libitum feeding, significant positive associative effects were observed with AS:ALF (33:67) diet for digestibility of DM, OM, CP and NDF. With the AS:DEHY (67:33) diet, negative associative effects were observed for digestibility of DM ($P<.03$), OM ($P<.02$) and NDF ($P<.01$).

The results of this study demonstrate a positive linear relationship between level of dietary HQR and diet DM and OM consumption, and positive associative effects for digestibility of DM, OM, and NDF of US:ALF diets and negative associative effects for digestibility of DM, OM and NDF of AS:DEHY diets at ad libitum intake. A portion of the difference in apparent digestibility observed between restricted and ad libitum intake of diets may be accounted for by the liquid dilution rate and particulate turnover rate in the rumen as affected by level of feed intake and proportion of substitution of HQR. In addition, ammoniation of wheat straw increased the amount of potentially digestible DM and NDF of wheat straw. This resulted in an increased rate of digestion of total DM in the rumen, and a more rapid rate of particulate passage and increased straw intake.

Introduction

Cereal straws are produced in enormous quantities in many areas of the world. The main factor limiting the utilization of straws are their low digestibility and low crude protein content. Treatments that improve the nutritive value of such feeds should increase energy and dry matter (DM) consumption and improve animal performance. Many methods have been developed to improve the nutritive value of wheat straw. Both physical processing and chemical treatments have been used to improve the feeding value of low quality roughages such as cereal straws (Streeter and Horn, 1980). Anhydrous ammonia (NH_3) has been shown to increase the dry matter digestibility and crude protein of wheat straw and dry matter intake (Al-Rabbat and Heaney, 1978; Sundstol et al., 1978). Alfalfa (ALF) is an important feed ingredient and dietary protein source. Combining ALF with ammoniated straw (AS) can increase the utilization of straw (Nelson et al., 1985).

Soofi et al. (1982b) reported increased intake and digestibility from blending alkali-treated soybean stover with ALF. Nelson et al. (1985) used a combination of 66.7% alfalfa haylage and 31.6% ammoniated straw. They indicated that dry matter intake increased from 4.78 to 5.36 kg/d. Addition of alfalfa to NaOH-treated corn cobs or wheat straw has resulted in positive associative effects on DM digestibility (Maeng et al., 1970; Paterson et al., 1982). Similar responses have been noted by feeding a blend of 2 parts of soybean stover with 1 part of ALF (Soofi et al., 1982b). An inverse relationship between feed intake and turnover time of particulate matter has been observed by several workers (Minson, 1966; Thornton and Minson, 1972; Grovum and Williams 1977; Mudgal et al., 1982). Both levels of feed intake and the proportion of high quality roughages (HQR) in the diet influenced liquid dilution rate (LDR) as previously observed by others (Mudgal et al., 1982; Adams and Kartchner, 1984; Prigge et al., 1984). Adding protein supplements or ALF to prairie hay diets ad libitum had no significant effects on rumen pH in steers (Varga and Prigge, 1982; McCollum and Galyean, 1985). Level of HQR and time after feeding have been shown to alter rumen ammonia nitrogen (NH_3-N) concentrations (Wohlt et al., 1976; Adams and Kartchner, 1984).

The objective of this study was to determine the effect of combining different proportions of alfalfa hay (ALF) or dehydrated alfalfa pellets (DEHY) with ammoniated wheat straw (AS) on feed intake and digestibility of dry matter (DMD), organic matter (OMD), crude protein (CPD), neutral detergent fiber (NDFD), as well as kinetics of ruminal liquid and particulate passage and rumen fermentation by wether lambs.

Associative effects between AS and HQR on DMD, OMD, CPD, and NDFD were determined by calculating the difference between observed and predicted digestibilities of the diets. Predicted nutrient digestibilities were obtained by the following equation.

$$\text{CPND} = \frac{(AxB) + (CxD)}{E} \times 100$$

Where:

CPND = Calculated percentage nutrient digestibility.
A = Nutrient intake from AS.
B = Observed nutrient digestibility in 100% AS diet.
C = Nutrient intake from HQR.
D = Observed nutrient digestibility in 100% HQR diet.
E = Total nutrient intake.

Materials and Methods

Wheat straw was harvested as conventional rectangular bales. It was ammoniated by the stack method (35 g NH_3/Kg of dry matter) as described by Sundstol et al. (1978). All straw used in these studies was from the same harvest. Wheat straw bales were stacked and encased with a polyethylene sheet which was sealed at the base. Anhydrous ammonia (35 g/Kg of dry matter wheat straw) was injected in the stack via a pipe inserted into the stack. Thirty days after ammonia treatment, the stack was opened and excess ammonia was permitted to escape. The ammoniated straw was chopped through a 4.5 cm screen and stored until mixed with ALF or DEHY for each lamb (Table I) immediately before feeding once a day. The ingredient composition of the diets (% as fed) used at both levels of feeding are shown in Table II.

In this experiment, the same procedures and statistical analysis described in the Material and Methods section of Chapter III were used except:

TABLE I

INGREDIENT COMPOSITION OF THE DIETS (% AS FED)

Ingredient	Treatments						
	1	2	3	4	5	6	7
Ammoniated straw	100	67	33	-	67	33	-
Alfalfa hay chopped	-	33	67	100	-	-	-
Dehydrated alfalfa pellets	-	-	-	-	33	67	100

TABLE II

NUTRIENT COMPOSITION OF AMMONIATED STRAW, ALFALFA HAY AND DEHYDRATED ALFALFA PELLETS USED IN BOTH LEVELS OF FEEDING (MEAN ± STANDARD ERROR) (% DM BASIS)

Item %	Number of Samples	Mean ± SE		
		AS[a]	ALF[a]	DEHY[a]
Dry matter	5	91.1±.23	90.6±.20	94.4±.23
Organic matter	5	96.8±.25	92.6±.27	90.0±.19
Crude protein	5	11.4±.31	18.7±.25	21.0±.33
Neutral detergent fiber	5	77.9±.41	52.4±.31	44.9±.39
Ash	5	4.2±.10	7.4±.12	10.0±.21

[a] AS = Ammoniated straw; ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

1) Ammoniated wheat straw (AS) was used instead of untreated wheat straw
2) Twenty-eight wether lambs had an initial weight (mean ± standard deviation) (26.9 ± 3.4 Kg) randomly assigned to seven treatments (4 lambs/treatment).
3) Restricted intake was achieved as 70% of ad libitum intake.
4) For in vivo digestibility, each of two periods lasted 20 days, with a preliminary period from day 1 through 15 for the lambs to adapt to the diets. Individual feed refusals were recorded daily from days 12 through 16, and total feces were collected on day 14 to 18.
5) (Mean ± standard deviation) weights of lambs were (28.4 ± 4.36 Kg).

Results and Discussion

Level of Feed Intake

Significant differences in daily intake of DM, OM, CP and NDF were observed between periods ($P<.0001$) as expected (Table III). Ad libitum intake of DM and OM was higher by about 45% compared to restricted intake.

Improvement in voluntary intake of low quality forage is usually attributed to an increased rate of forage digestion and passage as the results of addition of HQR (Cook, 1981). Ammonia treatment of straws has a positive effect on feed intake by increasing digestibility among other factors.

TABLE III

EFFECTS OF LEVEL OF FEEDING ON DAILY INTAKES (G/KG BODY WEIGHT)

Nutrients	Level of Feeding Restricted	Ad Libitum
Dry matter	27.8^a	40.4^b
Organic matter	25.9^a	37.7^b
Crude protein	4.6^a	6.7^b
Neutral detergent fiber	16.5^a	23.6^b

[a,b] Means in the same row with unlike superscripts differ (P<.0001).

Streeter and Horn, (1984) observed that lambs consumed 22% more ($P<.05$) of ammoniated straw than untreated straw fed either urea or soybean meal based supplements. They indicated that the response was a result of improved digestibility of ammoniated straw. The source of HQR had significant effects ($P<.05$) on DM, OM and CP at both levels of feeding. AS:DEHY diets increased feed intake over AS:ALF diets. This may be because of lower turnover time ($P<.05$) observed with DEHY fraction as compared with ALF.

Apparent Digestibility of Total Diet

Apparent digestibilities of DM, OM, CP and NDF for the total diets is shown in Table IV, for both periods. A significant decrease ($P<.01$) was observed in digestibilities of DM, OM, and NDF of all diets as level of feed intake increased. The depression in apparent digestibilities of DM and OM was about 7 percentage units for ad libitum intake compared with restricted feed intake. This result is in agreement with Prigge et al. (1984). The reduction in DMD for the high level of feed intake has also been reported by Van Soest (1982). The reduction ($P<.001$) in DMD and OMD is probably due to increased rate of passage of ruminal digesta as level of feed intake increased (Blaxter and Graham, 1956; Raymond et al., 1959; Beardsley, 1964).

Level of feed intake had little effect on CP digestibility ($P>.05$). Apparent digestibility of NDF was decreased about 8 percentage units as the level of feed intake in-

TABLE IV

EFFECTS OF LEVEL OF FEEDING ON APPARENT DIGESTIBILITIES OF DRY MATTER (DMD), ORGANIC MATTER (OMD), CRUDE PROTEIN (CPD) AND NEUTRAL DETERGENT FIBER (NDFD),(%)

	Level of Feeding	
Digestibility, %	Restricted	Ad Libitum
Dry matter	51.6[a]	45.0[b]
Organic matter	54.4[a]	47.4[b]
Crude protein	53.7	49.9
Neutral detergent fiber	55.6[a]	47.6[b]

[a,b] Means in the same row with unlike superscripts differ ($P<.0001$).

creased. This result is in agreement with Prigge et al. (1984) and Hunt et al., (1985).

Decreased NDF digestibility may also be due to an increased rate of passage of ruminal particulate matter as the level of feed intake increased (Staples et al., 1964). The differences in NDF digestibility observed in the present study among levels of feeding may be partially attributable to greater fermentation as digesta stayed in the rumen for longer time on the restricted level of feeding. On the other hand, Bull et al. (1979) have indicated that decreases in rumen fiber digestion that may occur with an increase in feed intake can be offset by increased post-ruminal digestion.

No significant interaction was detected between level of feed intake and different level of HQR for digestibilities of DM, OM, CP and NDF. Source of HQR had little effect on digestion coefficients for dietary DM, OM, CP and NDF at either level of feed intake.

Kinetics of Ruminal Particulate Matter

Rate of passage (%/h) and turnover time (h) of AS fraction of the diets are shown in Table V. The level of feed intake had significant effects ($P<.02$) on the rate of passage and turnover time. The average rate of passage of AS fraction was 2.66 and 3.06 %/h, and turnover time was 38.8 and 34.2 h for restricted and ad libitum levels of intake, respectively. These results represent about a 15% increase in rate of passage and 13% decrease in turnover time of digesta of AS

TABLE V

EFFECTS OF LEVEL OF FEEDING ON RATE OF PASSAGE (%/h) AND TURNOVER TIME (h) OF PARTICULATE MATTER OF AMMONIATED STRAW

Item	Level of Feeding	
	Restricted	Ad Libitum
Rate of passage (%/h)	2.66^a	3.06^b
Turnover time (h)	38.8^a	34.2^b

[a,b] Means in the same row with unlike superscripts differ ($P<.02$).

fraction as level of feed intake increased. It has been reported that the elevations in feed intake decreased particulate turnover time (Minson, 1966; Grovum and Williams, 1977). In addition, ruminal turnover time of dietary components are important determinants of the efficiency of microbial growth and the partition of digestion of dietary material between the rumen and post-ruminal tract (Bull et al., 1979; Harrison and McAllan, 1980).

The results of this study indicate that increased levels of feed intake caused an increase in rate of passage and a decrease in turnover time, which is in agreement with the results reported by other workers using all roughage diets fed to sheep (Minson, 1966; Grovum and Williams, 1977; Mudget et. al. 1982).

Rate of passage and turnover time of particulate matter of high quality roughages of the diets for both periods are shown in Table VI.

The level of feed intake had an effect ($P<.05$) on both rate of passage and turnover time of particulate matter of the HQR fraction of the diets. Rate of passage was increased about 12%, while turnover time was decreased by 10% as level of feed intake changed from restricted to ad libitum feeding. These results are in general agreement with results of Balch (1950) and Grovum and Hecker (1973). They indicated that with high intakes of hay dry matter, the passage of hay from the reticulo-rumen was increased rapidly. The turnover time of the HQR fraction of the diet was about 51 and 47% less for

TABLE VI

EFFECTS OF LEVEL OF FEEDING ON RATE OF PASSAGE (%/h) AND TURNOVER TIME (h) OF PARTICULATE MATTER OF ALFALFA HAY (ALF) OR DEHYDRATED ALFALFA PELLETS (DEHY)

	Level of Feeding	
Item	Restricted	Ad Libitum
Rate of passage (%/h)	4.03^a	4.51^b
Turnover time (h)	26.1^a	23.7^b

[a,b]Means in the same row with unlike superscripts differ ($P<.05$).

restricted and ad libitum levels of intake, respectively, than that observed for AS fraction in the diet. Weston (1968) reported that fine particles of straw were retained in the alimentary tract of sheep longer than particles of lucerne hay. Turnover time of feed particles in the rumen are influenced by rate of breakdown by mastication and microbial digestion to a size small enough for passage. These differences in rate of passage and turnover time of AS and HQR in the diets may be partially responsible for the depression in apparent digestibility of DM, OM and NDF observed between restricted and ad libitum feed intake (Balch, 1950).

The source of HQR had little effect (P>.05) on rate of passage and turnover time of particulate matter of the AS fraction of the diet. Rate of passage and turnover time of ALF particulate matter were different (P<.005), as compared with the rate of passage and turnover time of DEHY in the diets. The average rate of passage was faster for DEHY than ALF (3.60 vs 4.47 %/h). These results indicate that the particle size of food has significant effects on rate of passage and turnover time of particulate matter. Campling et al. (1963) reported that ground hay residues had a much shorter time of retention in the alimentary tract than residues of long hay, and the initital excretion of hay particles occurred sooner with ground hay than with long hay (Balch, 1950).

Kinetics of Rumen Liquids

Liquid dilution rates (LDR, %/h), rumen liquid volumes (RLV, ml), liquid flow rates (LFR, ml/h) and liquid turnover times (LT, h) are shown in Table VII.

The LDR increased by 39% ($P<.001$) with increased level of DM intake which is in agreement with the results of Mudgal et al. (1982); Adams and Kartchner (1984) and Prigge et al. (1984). High LDR with increased levels of feed intake may be associated with increased rumination and salivation. Harrison et al. (1975) notes higher LDR with sheep that had received infusion of artificial saliva, as compared with sheep given the same diet without infusions of artificial saliva.

The RLV increased by 16.4% ($P<.001$) as DM intake increased from 27.8 to 40.4 g/kg body weight. This difference in RLV may be partially due to an increase in saliva production as the level of feed intake increased. The results of the present study are in agreement with results of Hartnell and Satter (1979). They indicated that RLV increased ($P<.05$) with increasing DM intake, and that differences between cows in RLV may be due to differences in saliva production (Ulyatte et al. 1967).

LFR increased from 204.6 to 396.0 ml/h ($P<.001$) as intake increased and the LT decreased by 75.4% ($P<.001$). LT decreased a mean of 1.3 h for each 1 g/kg body weight increase in feed intake. These results are in agreement with results of Adams and Kartchner (1984). Changes in LT may reflect changes in voluntary intake. Period by treatment

TABLE VII

EFFECTS OF LEVEL OF FEEDING ON RUMINAL LIQUID MEASUREMENTS

Item	Level of Feeding	
	Restricted	Ad Libitum
Liquid dilution rate (%/h)	4.82^{a}	6.70^{b}
Rumen liquid volume (ml)	5136^{a}	5980^{b}
Liquid flow rate (ml/h)	204.6^{a}	396.0^{b}
Liquid turnover time (h)	25.1^{a}	15.1^{b}

^{a,b}Means in the same row with unlike superscripts differ (P<.001).

interactions were observed for LDR ($P<.05$), LFR ($P<.004$) and LT ($P<.004$). These interactions are most likely a function of both rate of digestion of forage and the proportion of HQR substituted in the diet.

Source of HQR had little effect on any of the rumen liquid measurements discussed above at either level of feed intake.

Rumen Fermentation

Ruminal pH and ammonia nitrogen (NH_3-N) concentrations are shown in Tables VIII and IX. Level of feed intake had no significant effects on rumen pH values (Table VIII). Mean ruminal pH values were 6.37 and 6.29 for restricted and ad libitum feed intake, respectively. The results of this study are in general agreement with the results of Putnam et al. (1966) and Varga and Prigge (1982).

Ruminal pH dropped with time after feeding at both levels of feed intake from 1 h to approximately 8 h after feeding. Restricted feed intake resulted in higher pH values at all times after sampling, but were not significantly different from values of ad libitum feeding except at hours 2 and 24 ($P<.05$). Period by treatment interactions were significant only at hours 2 and 24 ($P<.05$) after feeding. These significant interactions may be due to reduced LDR (Estell and Galyean, 1985).

Mean ruminal NH_3-N concentrations (Table IX) over the entire feeding cycle were different ($P<.01$) between the two

TABLE VIII

EFFECTS OF LEVEL OF FEEDING ON RUMINAL pH AT VARIOUS TIMES AFTER FEEDING

Level of feeding	Time after feeding						
	1	2	4	8	12	24	Mean[a]
	Rumen pH						
Restricted	6.46	6.32[b]	6.19	6.11	6.28	6.86[b]	6.37
Ad libitum	6.35	6.19[c]	6.13	6.09	6.25	6.74[c]	6.29

[a] Mean rumen pH for each level of feeding.

[b,c] Means in the same column with unlike superscripts differ ($P<.05$).

TABLE IX

EFFECTS OF LEVEL OF FEEDING ON RUMINAL AMMONIA NITROGEN (NH_3-N) CONCENTRATIONS AT VARIOUS TIMES AFTER FEEDING

Level of feeding	Time after feeding 1	2	4	8	12	24	Mean[a]
	Rumen NH_3-N, mg/100 ml						
Restricted	22.57[b]	21.43[b]	13.57	6.32	8.33	12.51[b]	14.12[b]
Ad libitum	10.70[c]	15.07[c]	13.25	8.09	7.86	9.35[c]	10.72[c]

[a] Mean NH_3-N concentration for each level of feeding.

[b,c] Means in the same column with unlike superscripts differ ($P<.001$).

levels of intake. The mean of ruminal NH_3-N was decreased by 31.7% as level of feed intake increased. The decrease in ruminal NH_3-N may be due to increased LDR. Kennedy and Milligan (1978) noted lower ruminal NH_3-N concentrations in sheep with faster liquid dilution rates. The amount of NH_3-N produced at both levels of feed intake at all hours after feeding were greater than 5 mg/dl, which has been estimated to be the minimal concentration necessary for a maximal rate of microbial protein synthesis in the rumen (Satter and Slyter, 1974).

Ruminal NH_3-N concentration at various times after feeding was significantly different ($P<.001$) at 1, 2 and 24 hours after feeding. The NH_3-N levels tended to peak at 1 to 4 h post-feeding with lower values at 8, 12 and 24 h after restricted feed intake. Ad libitum feeding resulted in more consistent ruminal NH_3-N concentrations over the entire feeding cycle. In addition, the level of NH_3-N concentrations were not high as observed in restricted feeding. This may be due to higher liquid flow rate associated with higher feed intake which can significantly dilute the actual concentration of rumen NH_3-N.

The relatively high levels of ruminal NH_3-N during the first 2 hours after feeding restricted amounts of AS could reflect uncoupled fermentation taking place within the rumen as the release of energy in the rumen from fermentable OM of the diet would not be expected to occur until approximately 4 to 8 h after feeding. This situation may decrease incorporation of NH_3-N into microbial protein in the rumen. Period * treatment interactions were significant ($P<.001$) at 1 and 24 and ($P<.05$) at 12 hours after feeding. The source of HQR had little effect ($P>.05$) on pH or rumen NH_3-N concentrations at both levels of feed intake.

Effects of Proportion of High Quality Roughage Substitution in the Diet.

Feed Intake

The results of DM, OM, CP and NDF intakes as affected by level of substitution are shown in Table X for ad libitum feed intake, and the statistical analysis is shown in appendix Table XII.

A linear increase ($P<.001$) in DM, OM, CP and NDF intake was observed for diets with increasing levels of ALF or DEHY at ad libitum feed intake. Paterson et al. (1982); Soofi et al. (1982b) have reported a linear increase in DM intake with the addition of alfalfa to alkali-treated low quality roughages. Also Brandt and Klopfenstein (1983) observed that lambs fed ammoniated cob diets with 30% alfalfa hay consumed more feed and gained faster and more efficiently than lambs receiving no alfalfa hay ($P<.001$). The addition of HQR increased the DM intake by 50-60% at both levels of feed intake compared to 100% AS diet.

The increase of DM intake in this study may be due to a shorter retention time resulting from an increase in digest-

TABLE X

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO AMMONIATED STRAW DIETS WHEN FED AT AD LIBITUM FEED INTAKE (G/KG BODY WEIGHT)

Nutrients	Treatments						
	AS:ALF				AS:DEHY		
	100:0	67:33	33:67	0:100	67:33	33.67	0:100
Dry matter[a]	25.1	33.3	42.4	48.2	32.8	48.6	60.7
Organic matter[a]	24.1	31.5	39.6	44.7	30.7	44.4	54.6
Crude protein[a]	2.9	4.7	7.0	9.0	4.9	9.0	12.7
Neutral detergent fiber[a]	19.7	22.9	25.2	25.3	21.5	25.8	27.2

[a] Linear increase ($P<.001$); 100:0 Ammoniated straw diet not included in contrast.

ible nutrients and improved protein quality in the rumen as the proportion of HQR increased in the diets. Thornton and Minson (1972) reported a greater voluntary intake by sheep fed ALF compared with grass forage species. In addition, ammonia-treatment of straw also solubilized hemicellulose which may provide rumen bacteria with greater substrate availability and could explain the increase in DM intake of AS (Saenger et al., 1983).

Horton and Steacy (1979) found that ammoniation increased DM intake of wheat straw per unit metabolic body size by 21% compared with untreated wheat straw fed to steers. In this study, shorter turnover time of particulate matter increased liquid flow rate and effects of ammonia on the fiber fraction to increase potential digestibility of straw cell walls which may explain the increased DM intake.

Apparent Digestibility

Apparent digestibilities of DM, OM, CP and NDF of the total diet are shown in Tables XI and XII, for restricted and ad libitum intakes, respectively. The statistical analysis of this data is shown in appendix Tables XIII and XIV.

Apparent digestibility of DM, OM, and CP were linearly increased (P<.001) as levels of ALF or DEHY increased in the diets at both levels of intake. Apparent digestibility of DM of 100% AS was 40.8 and 35.4% at restricted and ad libitum feeding, respectively. The addition of 33 and 67% of HQR to AS increased apparent digestibility of DM of the total diet to 48.1 and 54.5% at restricted and 40.5 and 49.6% at

TABLE XI

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO AMMONIATED STRAW DIETS WHEN FED RESTRICTED ON DIGESTIBILITY (%)

Apparent Dig., %	Treatments						
	AS:ALF				AS:DEHY		
	100:0	67:33	33:67	0:100	67:33	33.67	0:100
Dry matter[a]	40.8	47.3	52.0	57.7	48.8	57.0	56.9
Organic matter[a]	45.8	50.7	54.3	58.9	52.0	58.6	58.2
Crude protein[a]	30.6	48.1	62.4	70.7	51.7	63.0	64.7
Neutral detergent fiber[b]	58.7	58.3	52.8	53.0	59.2	56.3	48.6

[a] Linear increase (P<.001); 100:0 Ammoniated straw diet not included in contrast.

[b] Linear decrease (P<.001); 100:0 Ammoniated straw diet not included in contrast.

TABLE XII

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO AMMONIATED STRAW DIETS WHEN FED AD LIBITUM ON APPARENT DIGESTIBILITY (%)

	Treatments						
Apparent Dig., %	AS:ALF				AS:DEHY		
	100:0	67:33	33:67	0:100	67:33	33.67	0:100
Dry matter[a]	35.4	43.0	49.2	47.7	37.7	50.1	53.7
Organic matter[a]	39.9	46.2	51.2	49.1	40.5	51.2	54.2
Crude protein[a]	25.1	47.3	61.8	64.3	44.1	57.2	61.8
Neutral detergent fiber[b]	52.9	52.1	48.6	39.7	44.9	46.6	43.2

[a] Linear increase ($P<.001$); 100:0 Ammoniated straw diet not included in contrast.

[b] Linear decrease ($P<.05$); 100:0 Ammoniated straw diet not included in contrast.

ad libitum feeding. Paterson et al. (1982) reported that addition of 50% alfalfa hay to sodium hydroxide-treated cobs increased DM digestibility by 8 percentage units to 62.4%. Soofi et al. (1982b) reported that significant (P<.005) increase in DM digestibility occurred when alkali-treated soybean stover (SBS) was blended with alfalfa hay.

Apparent digestibility of OM was increased (P<.001) linearly as level of HQR increased in the diets. Addition of HQR to diets of sheep apparently provides a more favorable environment for microorganisms in the rumen, and hence, increases digestion of all nutrients which increases digestibility of DM and OM. The linear increase (P<.001) in CP digestibility also reflects the positive synergistic effect of increasing protein levels on CP digestibility. This is expected since apparent digestibility of CP generally improves as nitrogen intake increases (Guthrie, 1984). The average CP digestibility for 100% AS diets was 29.7% compared to 67.5 and 63.3% for ALF and DEHY, respectively, at both levels of feed intake.

Digestibility of NDF decreased (P<.001) linearly as the level of ALF or DEHY increased in the diets at both levels of feed intake. These results are in agreement with those of Hunt et al. (1985) who reported a linear decrease (P<.01) in NDF digestibility with each incremental addition of ALF. The decrease observed in NDF digestibility with addition of HQR in this study may be due to higher NDF digestiblity observed with 100% AS than with either HQR. Resistence of alfalfa NDF to digestion may be associated with the greater lignin content of the alfalfa NDF fraction. (Brandt and Klopfenstein, 1984).

Associative effects differed with HQR source and level of feed intake (Tables XIII and XIV). At restricted feed intake, addition of ALF to AS tended to result in positive associative effects on digestibility of DM, OM, CP and NDF of the whole diets, but these effects were not significant ($P<.2$). Diets of AS:DEHY (33:67) resulted in significant positive associative effects on digestibility of DM ($P<.01$), OM ($P<.02$) and CP ($P<.02$) (Table XIII).

With ad libitum feed intake, substitution of AS by DEHY resulted in negative associative effects on digestibility of DM, OM and NDF of the whole diet (Table XIV). These negative associative effects may be the result of higher feed intake and faster rate of passage observed with DEHY. Minson (1962) reported that pelleting may be associated with higher intake and rate of passage reduces digestibility of roughage. Diets of AS:ALF (33:67) resulted in positive associative effects for digestibility of DM and OM ($P<.02$), CP ($P<.03$) and NDF ($P<.08$). These results are in general agreement with those of Soofi et al (1982b), who observed significant positive associative effects in DM digestibility between different components of alkali-treated soybean stover and alfalfa hay fed to sheep.

Paterson et al. (1982) reported positive associative effects from addition of 50% alfalfa hay to NaOH-treated cobs

TABLE XIII

OBSERVED AND CALCULATED DIGESTIBILITIES OF DRY MATTER, ORGANIC MATTER, CRUDE PROTEIN AND NEUTRAL DETERGENT FIBER OF THE TOTAL DIET AT RESTRICTED LEVEL OF FEEDING

	Treatments[a]			
	AS:ALF		AS:DEHY	
	67:33	33:67	67:33	33:67
	- Dry matter digestibility, % -			
observed	47.3	52.0	48.8	57.0
calculated	46.4	52.0	46.3	51.7
difference	0.9	0.0	2.5	5.3
level of sign.	NS	NS	NS	.01
	- Organic matter digestibility, % -			
observed	50.7	54.3	52.0	58.6
calculated	50.0	54.4	49.8	54.0
difference	0.7	-0.1	2.2	4.6
level of sign.	NS	NS	NS	.02
	- Crude protein digestibility, % -			
observed	48.1	62.4	51.7	63.0
calculated	48.4	61.4	47.2	57.8
difference	-0.3	1.0	4.5	5.2
level of sign.	NS	NS	.06	.02
	- Neutral detergent fiber digestibility, % -			
observed	58.3	52.8	59.2	56.3
calculated	57.3	55.2	56.5	53.2
difference	1.0	-2.4	2.7	3.1
level of sign.	NS	NS	NS	NS

[a] AS = Ammoniated wheat straw; ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

TABLE XIV

OBSERVED AND CALCULATED DIGESTIBILITIES OF DRY MATTER, ORGANIC MATTER, CRUDE PROTEIN AND NEUTRAL DETERGENT FIBER OF THE TOTAL DIET AT AD LIBITUM LEVEL OF FEEDING

	Treatments[a]			
	AS:ALF		AS:DEHY	
	67:33	33:67	67:33	33:67
	- Dry matter digestibility, % -			
observed	43.0	49.2	37.7	50.1
calculated	40.0	44.1	42.4	49.1
difference	3.0	5.1	-4.7	1.0
level of sign.	NS	.02	.03	NS
	- Organic matter digestibility, % -			
observed	46.2	51.2	40.5	51.2
calculated	43.2	46.3	45.1	50.4
difference	3.0	4.9	-4.6	0.8
level of sign.	NS	.02	.02	NS
	- Crude protein digestibility, % -			
observed	47.3	61.8	44.1	57.2
calculated	44.6	56.6	44.6	56.2
difference	2.7	5.2	-.5	1.0
level of sign.	NS	.03	NS	NS
	- Neutral detergent fiber digestibility, % -			
observed	52.1	48.6	44.9	46.6
calculated	48.9	44.9	50.3	46.6
difference	3.2	3.7	-5.4	0.0
level of sign.	NS	.08	.01	NS

[a] AS = Ammoniated wheat straw; ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

fed to steers. The positive associative effects observed in this study may be related to the beneficial effects of ammonia treatment. This suggests that intake and digestibility of wheat straw when fed to sheep as a major part of an all-roughage diet, would be enhanced by ammoniation.

Calculated metabolizable energy intake (MEIn) increased as level of substitution of HQR increased in the diets (Table XV). The average MEIn intake of the diets containing AS:DEHY was higher by about 10.4% compared to MEIn of AS:ALF diets. This was due to the higher intake of AS:DEHY diets. All combinations of AS:HQR resulted in MEIn sufficient to meet maintenance ME requirements (MEMt) of lambs (25 kg BW) or non-pregnant, non-lactating ewes (40 kg BW). The lambs fed AS:HQR would be expected to gain from 15 to 188 g/day (Table XV). Treating wheat straw with ammonia increased energy availability (Nelson et al., 1985). Al-Rabbat and Heaney (1978) fed ammoniated wheat straw to sheep, and reported that ammoniation increased energy fermentability in the rumen, expressed in terms of either concentrations or rates of production of VFA's, which were comparable in magnitude to those obtained with sheep fed grain or alfalfa hay rations. Horton and Steacy (1979) observed that feeding ammoniated straw instead of untreated straw resulted in an increase about 13% in feed consumption and 7% in ration dry matter digestibility. Digestible energy intake increased from .201 to .253 Mcal/kg$^{.75}$/day.

TABLE XV

POTENTIAL TO MEET METABOLIZABLE ENERGY REQUIREMENTS FOR MAINTENANCE (MEMt) FOR LAMBS OR EWES, WITH OBSERVED INTAKES OF CALCULATED ME (MEIn), FOR AMMONIATED WHEAT STRAW:HIGH QUALITY ROUGHAGE DIET

Diet[a]	MEIn[b] Kcal/day	25 Kg Lamb MEIn/ MEMt[c]			40 Kg Ewe MEIn/ MEMt
			ME Gain Kcal/day	Predicted Gain g/day	
AS/ALF					
100:0	769.6	0.72	--	--	0.64
67:33	1190.2	1.11	114.7	15	1.00
33:67	1864.1	1.73	788.6	56	1.56
0:100	2103.2	1.95	1027.7	85	1.76
AS:DEHY					
67:33	1058.8	0.98	--	--	0.89
33:67	2313.5	2.15	1238.0	106	1.94
0:100	3209.8	2.98	2134.3	188	2.69

[a] AS = Ammoniated wheat straw; ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] MEIn = 0.15 DOMD %

DOMD % = % Digestible organic matter in dry matter = $\frac{\text{(Food OM - Feces OM)}}{\text{Food DM}} \times 100$

[c] Ratio = Calculated ME intake / ME maintenance requirement, 25 Kg lamb = 1075.5; 40 Kg ewe = 1195.0 Kcal/day (MAFF, 1977).

Kinetics of Ruminal Particulate Matter

Rate of passage and turnover time of ammoniated straw and high quality roughages are shown in Tables XVI and XVII for restricted and ad libitum intakes, respectively. The statistical analysis of these data are shown in appendix Tables XV and XVI.

Rate of passage increased ($P<.001$) linearly and turnover time decreased ($P<.01$) for AS and HQR with increasing levels of ALF or DEHY in the diets at both levels of intake. The increase observed in rate of passage in this study may be due to an improved rumen environment from increased amounts of amino acids and cell solubles from added ALF or DEHY to AS. added to AS. In addition, ammoniation would result in an incease in both potential digestibility and rate of cell wall digestion (Dunlop and Kellaway, 1980).

Ellis (1978) suggested that supplementation of nitrogen to low protein forages would increase rate of forage digestion and particulate passage. Turnover time was higher ($P<.05$) for 100% AS compared to 100% ALF or DEHY at both levels of intake. The difference in turnover time may be partially due to digestible organic matter intake. Thornton and Minson, (1973) found retention time of organic matter in the rumen was highly correlated ($r= .88$) with daily intake of digestible organic matter in sheep fed grasses and legumes.

Kinetics of Ruminal Liquids

Liquid dilution rates (LDR, %/h), rumen liquid volumes

TABLE XVI

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO AMMONIATED STRAW DIETS WHEN FED AT RESTRICTED INTAKE ON RATE OF PASSAGE (%/h) AND TURNOVER TIME (h) OF RUMINAL PARTICULATE MATTER

Treatments[a]	Rate of Passage[b] (%/h)			Turnover Time[c] (h)		
	AS	ALF	DEHY	AS	ALF	DEHY
AS:ALF						
100:0	2.13	-	-	47.5	-	-
67:33	2.64	3.10	-	38.5	32.6	-
33:67	3.24	3.41	-	31.7	29.9	-
0:100	-	4.28	-	-	24.1	-
AS:DEHY						
67:33	2.52	-	3.62	40.0	-	28.0
33:67	2.91	-	4.58	35.1	-	22.9
0:100	-	-	5.22	-	-	19.2

[a] AS = Ammoniated wheat straw; ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] Linear increase ($P<.001$); 100:0 Ammoniated straw diet not included in contrast.

[c] Linear decrease ($P<.01$); 100:0 Ammoniated straw diet not included in contrast.

TABLE XVII

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO AMMONIATED STRAW DIETS WHEN FED AT AD LIBITUM INTAKE ON RATE OF PASSAGE (%/h) AND TURNOVER TIME (h) OF RUMINAL PARTICULATE MATTER

Treatments[a]	Rate of Passage[b] (%/h)			Turnover Time[c] (h)		
	AS	ALF	DEHY	AS	ALF	DEHY
AS:ALF						
100:0	2.42	-	-	41.4	-	-
67:33	3.27	3.40	-	32.8	29.9	-
33:67	3.66	3.74	-	28.3	27.1	-
0:100	-	4.77	-	-	21.6	-
AS:DEHY						
67:33	3.02	-	3.72	34.2	-	27.3
33:67	3.39	-	5.34	29.7	-	19.6
0:100	-	-	6.08	-	-	16.8

[a] AS = Ammoniated wheat straw; ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] Linear increase ($P<.001$); 100:0 Ammoniated straw diet not included in contrast.

[c] Linear decrease ($p<.01$); 100:0 Ammoniated straw diet not included in contrast.

(RLV, ml), liquid flow rates (LFR, ml/h) and liquid turnover times (LT, h) are shown in Tables XVIII and XIX. The statistical analysis of these data are shown in appendix Tables XVII and XVIII. Level of ALF or DEHY in the diets had no significant effect on any of the measurements at restricted levels of intake.

With ad libitum feeding, RLV did not change with HQR addition to the diet. Varga and Prigge (1982) also reported that RLV was not influenced by adding ALF to the diets. However, LDR increased ($P<.05$) from 6.01 in lambs fed 100% AS to 7.53 and 9.00 %/h in lambs fed 100% ALF or DEHY, respectively. Moreover, LFR was increased ($P<.05$) from 403.8 to 422.9 and 487.6 ml/h with 100% ALF or DEHY diets. Liquid turnover time tended to be reduced in lambs supplemented with HQR compared to 100% AS. These changes in LDR, LFR and LT may reflect changes in voluntary intake and increased nitrogen and cell solubles from ALF or DEHY added to the diets. Similar results have been reported by others (Mudgal et al. 1982; Varga and Prigge, 1982; Adams and Kartchner, 1984).

Rumen Fermentation

Ruminal pH and NH_3-N concentrations are shown in Tables XX, XXI, XXII and XXIII, and the statistical analysis of these data can be seen in appendix Tables XIX, XX, XXI and XXII.

Rumen pH was decreased ($P<.05$) linearly with HQR supplementation at 2 h after feeding, but increased linearly with

TABLE XVIII

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO AMMONIATED STRAW DIETS WHEN FED AT RESTRICTED INTAKE ON RUMINAL LIQUID MEASUREMENTS

Items	Treatments[a]						
	AS:ALF				AS:DEHY		
	100:0	67:33	33:67	0:100	67:33	33.67	0:100
Liquid dilution rate (%/h)	5.00	5.71	6.65	5.24	5.48	2.57	3.07
Rumen liquid volume (ml)	5532	5361	4619	5070	4442	5714	5209
Liquid flow rate (ml/h)	273.9	289.8	245.7	226.3	238.8	135.1	147.9
Liquid turnover time (h)	20.2	18.5	18.8	22.4	18.6	42.3	35.2

[a] AS = Ammoniated wheat straw; ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

TABLE XIX

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO AMMONIATED STRAW DIETS WHEN FED AT AD LIBITUM INTAKE ON RUMINAL LIQUID MEASUREMENTS

Items	Treatments						
	AS:ALF				AS:DEHY		
	100:0	67:33	33:67	0:100	67:33	33.67	0:100
Liquid dilution rate (%/h)[b]	6.01	6.73	6.31	7.53	5.68	7.72	9.00
Rumen liquid volume (ml)	6784	6096	6215	6085	5434	5534	5705
Liquid flow rate[b] (ml/h)	403.8	409.1	386.0	422.9	295.3	422.4	487.6
Liquid turnover time (h)[c]	16.8	14.9	16.1	14.4	18.4	13.1	11.7

[a] AS = Ammoniated wheat straw; ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] Linear increase ($P<.05$); 100:0 Ammoniated straw diet not included in contrast.

[c] Linear decrease ($P<.03$) as DEHY increase in the diet.

TABLE XX

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO AMMONIATED STRAW DIETS WHEN FED RESTRICTED ON RUMEN pH

	Time after feeding, h					
Treatments[a]	1	2[b]	4	8	12[c]	24[c]
	Rumen pH					
AS:ALF						
100:0	6.49	6.38	6.26	6.14	6.29	6.54
67:33	6.62	6.49	6.28	5.98	6.14	6.65
33:67	6.52	6.29	6.25	6.07	6.05	6.61
0:100	6.33	6.23	6.13	6.30	6.52	7.23
AS:DEHY						
67:33	6.47	6.37	6.24	6.09	6.21	6.82
33:67	6.40	6.28	6.11	6.06	6.25	6.94
0:100	6.41	6.18	6.08	6.12	6.52	7.26

[a] AS = Ammoniated straw; ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] Linear decrease ($P<.05$); 100:0 Ammoniated straw diet not included in contrast.

[c] Linear increase at 12 and 24 ($P<.001$) hours after feeding; 100:0 Ammoniated straw diet not included in contrast.

TABLE XXI

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO AMMONIATED STRAW DIETS WHEN FED AD LIBITUM ON RUMEN pH

	Time after feeding, h					
Treatments[a]	1	2	4	8	12	24
	Rumen pH					
AS:ALF						
100:0	6.45	6.24	6.17	6.09	6.15	6.51
67:33	6.51	6.20	6.19	6.16	6.23	6.64
33:67	6.38	6.19	6.10	5.96	6.30	6.75
0:100	6.32	6.18	6.01	6.10	6.26	7.04
AS:DEHY						
67:33	6.26	6.20	6.08	6.08	6.30	6.97
33:67	6.19	6.06	6.01	6.02	6.31	6.70
0:100	6.37	6.27	6.29	6.19	6.21	6.57

[a] AS = Ammoniated straw; ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

TABLE XXII

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO AMMONIATED STRAW DIETS WHEN FED RESTRICTED ON RUMEN AMMONIA NITROGEN (NH_3-N) CONCENTRATION (Mg/100 ml)

	Time after feeding, h					
Treatments[a]	1[b]	2	4[c]	8	12[d]	24[d]
	Rumen NH_3-N					
AS:ALF						
100:0	13.71	12.45	9.80	4.55	4.35	5.80
67:33	19.40	20.90	14.85	5.50	5.20	10.75
33:67	20.45	21.95	17.10	12.35	10.85	13.91
0:100	15.85	24.90	12.35	7.85	13.00	16.12
AS:DEHY						
67:33	31.15	21.11	15.95	4.35	4.50	9.22
33:67	26.95	23.40	12.15	3.25	4.81	12.20
0:100	30.50	25.32	13.80	6.40	15.59	19.65

[a] AS = Ammoniated straw; ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] Linear decrease ($P<.05$) for AS:DEHY.

[c] Quadratic response ($P<.05$); 100:0 Ammoniated straw diet not included in contrast.

[d] Linear increase ($P<.01$); 100:0 Ammoniated straw diet not included in contrast.

TABLE XXIII

EFFECTS OF ADDITION OF ALFALFA HAY OR DEHYDRATED ALFALFA PELLETS TO AMMONIATED STRAW DIETS WHEN FED AD LIBITUM ON RUMEN AMMONIA NITROGEN (NH_3-N) CONCENTRATION (Mg/100 ml)

	Time after feeding, h					
Treatments[a]	1[b]	2	4[d]	8	12	24[e]
	Rumen NH_3-N					
AS:ALF						
100:0	10.55	17.41	9.30	8.45	8.70	6.20
67:33	10.40	16.50	17.15	9.20	6.35	6.45
33:67	12.00	17.30	17.85	11.00	12.60	10.60
0:100	10.80	13.75	13.40	10.40	7.90	16.25
AS:DEHY						
67:33	14.20	20.65	17.85	6.65	7.65	8.20
33:67	11.55	12.62	12.30	3.90	4.40	9.85
0:100	5.45	7.30	4.90	7.00	7.45	7.90

[a] AS = Ammoniated straw; ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] Linear decrease ($P<.05$) for AS:DEHY.

[d] Quadratic response ($P<.05$); 100:0 Ammoniated straw diet not included in contrast.

[e] Linear increase ($P<.001$) for AS:ALF.

HQR level at 12 and 24 ($P<.001$) hours after feeding (Table XX), with restricted intake. With ad libitum access to feed, rumen pH at various sampling times was little effect ($P>.05$) by addition of HQR. Values ranged from a low of 5.96 to a high 7.04. McCollum and Galyean (1985) reported no differences between rumen pH of steers fed prairie hay with or without protein supplementation. Likewise, Varga and Prigge (1982) found that ruminal pH was not affected by increasing levels of ALF in the diets.

Reduction of rumen pH below 6.3 may decrease utilization of fibrous material by reducing the population or activity of cellulolytic bacteria. Russell and Dombrowksi (1980) reported that the numbers of four rumen cellulolytic bacteria were reduced when pH fell below 6.3. The differences in pH values observed in this study are presumably the result of VFA production from fermentation energy available in the rumen at different times after feeding.

Linear and quadratic responses to HQR level were observed in ruminal NH_3-N concentrations with time after feeding (Tables XXII and XXIII). At restricted feeding, ALF substitution produced linear ($P<.001$) increase at 12 and 24 h and quadratic ($P<.05$) at 4 hours after feeding. With ad libitum feeding, HQR substitution had a linear increase in ruminal NH_3-N at 24 ($P<.01$) hour post-prandial, and quadratic response ($P<.05$) at 4 h post-prandial.

Level of DEHY in the diets had linear decrease at 1 ($P<.05$) hour after feeding at restricted intake. At ad libitum feeding, DEHY substitution had a linear decrease in ruminal NH_3-N at 1 ($P<.05$) hour after feeding.

Concentrations of ruminal NH_3-N ranged from 9.8 to 30.5 and 5.45 to 20.65 mg/100 ml at 1 to 4 hours after feeding for restricted and ad libitum feeding, respectively. Concentrations of ruminal NH_3-N was observed at 8 to 12 hours after feeding. The range was 3.25 to 15.59 and 3.90 to 12.6 mg/100 ml for restricted and ad libitum feed intake, respectively. From these fluctuations in the concentration of NH_3-N within the rumen, it could be suspected that possible periods of shortage of nitrogen for microorganisms could have especially at 8 to 12 h after feeding. These results indicate that rumen NH_3-N was affected by proportion of substitution of HQR and time after feeding. Adams and Kartchner, (1984) also observed that the concentration of rumen NH_3-N was affected by level of forage intake and time after feeding.

The relatively high levels of ruminal NH_3-N during the first 2 h after feeding a restricted amount of AS:HQR reflects an uncoupled kind of fermentation taking place within the rumen as the release of energy in the form of volatile fatty acids from the fiber component of the diet would not be expected to occur until approximately 4 to 8 h after feeding. Mehrez and Orskov (1978) suggested a need for synchronization between rumen NH_3-N and energy availability in the rumen. Knowledge of these types of processes allow for possible implementation of means of manipulating ruminal fermentation to improve efficiency of animal production.

CONCLUSIONS

1. These experiments indicated that ammoniation of wheat straw increased CP content (4.3 vs 11.3%), DM intake (17.7 vs 21.3 g/Kg BW) and digestibilities of DM, OM, CP and NDF by 2.9, 3.5, 21.4 and 11.1 percentage units, respectively, averaged across level of feed intake.

2. Up to the level of substitution of 67% HQR and 33% wheat straw, a linear increase in voluntary intake of OM was observed with both US and AS diets.

3. Digestibility of DM and OM increased linearly for both US and AS diets as the proportion of substitution of HQR increased.

4. The increased DM intakes and apparent digestibility of DM and OM, as the proportion of substitution of HQR increased, resulted in an increased nutritional status of animals by increasing their ME intake from negative to positive balance. The break-point of ME balance was different for US and AS diets, and its magnitude was also related to the source of HQR in the case of AS diets. For US diets and both sources of HQR, it was not until a level of 67% of HQR was included in the diet,

that ME intake exceeded the maintenance ME requirement. In contrast, ME balance was positive with 33% HQR substitution for AS.

5. Ammoniation of wheat straw itself resulted in a similar ME balance as that observed with US diets and 33% HQR, a 33% sparing effect of HQR by ammoniation of straw Thus a higher level of production could be expected from offering AS plus HQR. A mature non-pregnant non-lactating ewe could be maintained with a diet of 67:33% AS:ALF, while with US diets a ratio of 33:67% would be required.

6. The associative effects observed between wheat straw and source of HQR varied depending on the type of straw and HQR used. With US, ALF produced negative associative effects for DM, OM and NDF digestibility of the total diet. On the other hand, a positive associative effect for DM, OM and NDF digestibility was observed with AS diets. DEHY depressed the digestibility of NDF of the total diet for both types of straw. Therefore under these conditions, diets of 67:33% AS:ALF seemed to be utilized more efficiently than the same level of AS:DEHY diet at both levels of feed intake.

7. Treatment with anhydrous ammonia increased the level of potentially digestible nutrients. This increased the rate of digestion of total dry matter in the rumen and resulted in a more rapid rate of passage and hence,

greater straw intake at both levels of feeding. On the other hand, substitution of HQR caused a linear increased rate of passage and decreased turnover time of particulate matter in the rumen.

8. Liquid dilution rate and liquid flow rate were increased with AS:HQR diets as compared to US:HQR diets at ad libitum intake (6.70 vs 6.57 %/h) and (396.0 vs 254.5 ml/h) for liquid dilution rate and liquid flow rate, respectively. Liquid turnover time was decreased by 33% in both levels of feed intake for AS:HQR diets as compared to US:HQR diets.

9. Ruminal NH_3-N concentrations of lambs fed AS diets fluctuated less over the 24-hour feeding cycle and were highest at 8 h after feeding, as compared with US diets (7.2 vs 3.0 mg/100 ml) at both levels of feed intake. Ruminal pH of lambs fed US based diets decreased below 6.0 at 4 and 8 h after feeding at the ad libitum level of feed intake. In contrast ruminal pH values of lambs fed AS diets were higher than 6.0 at all sampling times after feeding.

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APPENDIX

TABLE I

CONTRASTS[a] AMONG TREATMENT MEANS OF DAILY INTAKE[a] (G/KG BODY WEIGHT) OF DM, OM CP AND NDF AT AD LIBITUM FEEDING

Contrasts	DIDMBW	DIOMBW	DICPBW	DINDFBW
ALF vs DEHY[b]	NS[c]	NS	NS	NS
LIN 1[d]	.01	.01	.01	NS
QUAD 1[d]	.01	.01	NS	.01
TYPE*LIN 1	NS	NS	NS	NS
TYPE*QUAD 1	NS	NS	NS	NS
ALF LIN	.01	.01	.01	.01
ALF QUAD	NS	NS	NS	NS
DEHY LIN	.01	.01	.01	NS
DEHY QUAD	.02	.02	NS	.01

[a] DIDMBW = Daily intake of dry matter as g/Kg body weight.
DIOMBW = Daily intake of organic matter as g/Kg body weight.
DICPBW = Daily intake of crude protein as g/Kg body weight.
DINDFBW = Daily intake of neuteral detergent fiber as g/Kg body weight.

[b] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[c] NS, (P>.05).

[d] 100:0 Wheat straw diet not included in contrast.

TABLE II

CONTRASTS AMONG TREATMENT MEANS OF APPARENT DIGESTIBILITY OF DM, OM, CP AND NDF AT RESTRICTED FEEDING

Contrasts	DMD	OMD	CPD	NDFD
ALF vs DEHY[a]	NS[b]	NS	NS	NS
LIN 1[c]	.01	.01	.01	NS
QUAD 1[c]	NS	NS	NS	NS
TYPE*LIN 1	NS	NS	NS	NS
TYPE*QUAD 1	NS	NS	NS	NS
ALF LIN	.01	.01	.01	.04
ALF QUAD	NS	NS	.01	NS
DEHY LIN	.01	.01	.01	NS
DEHY QUAD	NS	NS	.01	NS

[a] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] NS, ($P>.05$).

[c] 100:0 Wheat straw diet not included in contrast.

TABLE III

CONTRASTS AMONG TREATMENT MEANS OF APPARENT DIGESTIBILITY OF DM, OM, CP AND NDF AT AD LIBITUM FEEDING

Contrasts	DMD	OMD	CPD	NDFD
ALF vs DEHY[a]	NS[b]	NS	NS	NS
LIN 1[c]	.01	.01	.01	.01
QUAD 1[c]	NS	NS	.05	NS
TYPE*LIN 1	NS	NS	NS	NS
TYPE*QUAD 1	NS	NS	NS	NS
ALF LIN	.01	.01	.01	.03
ALF QUAD	NS	NS	.01	NS
DEHY LIN	.01	.01	.01	NS
DEHY QUAD	NS	NS	.01	NS

[a] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] NS, $(P>.05)$.

[c] 100:0 Wheat straw diet not included in contrast.

TABLE IV

CONTRASTS AMONG TREATMENT MEANS OF RATE OF PASSAGE AND TURNOVER TIME OF RUMINAL PARTICULATE MATTERS OF UNTREATED STRAW AT BOTH LEVELS OF FEEDING[a]

Contrasts	Rate of Passage (%/h)		Turnover Time (h)	
	REST	AD LIB	REST	AD LIB
ALF vs DEHY[b]	NS[c]	NS	NS	NS
Straw/ALF LIN	.01	.01	.01	.01
Straw/ALF QUAD	NS	NS	NS	NS
Straw/DEHY LIN	.02	.02	.02	.01
Straw/DEHY QUAD	NS	NS	NS	NS

[a] REST = Restricted; AD LIB = Ad libitum.

[b] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[c] NS, $(P>.05)$.

TABLE V

CONTRASTS AMONG TREATMENT MEANS OF RATE OF PASSAGE AND TURNOVER TIME OF RUMINAL PARTICULATE MATTERS OF ALF OR DEHY AT BOTH LEVELS OF FEEDING[a]

	Rate of Passage (%/h)		Turnover Time (h)	
Contrasts	REST	AD LIB	REST	AD LIB
ALF vs DEHY[b]	.02	.02	.02	.02
LIN 1[d]	.01	.01	.01	.01
QUAD 1[d]	NS[c]	NS	NS	NS
TYPE*LIN 1	NS	NS	NS	NS
TYPE*QUAD 1	NS	NS	NS	NS
ALF LIN	.02	.04	.02	.02
ALF QUAD	NS	NS	NS	NS
DEHY LIN	.01	.01	.01	.04
DEHY QUAD	NS	NS	NS	NS

[a] REST = Restricted; AD LIB = Ad libitum.

[b] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[c] NS, (P>.05).

[d] 100:0 Wheat straw diet not included in contrast.

TABLE VI

CONTRASTS AMONG TREATMENT MEANS OF RUMINAL LIQUID MEASUREMENTS[a] AT RESTRICTED FEEDING

Contrasts	LDR (%/h)	RLV (ml)	LFR (ml/h)	LT (h)
ALF vs DEHY[b]	NS[c]	NS	NS	NS
LIN 1[d]	NS	NS	NS	NS
QUAD 1[d]	NS	NS	NS	NS
TYPE*LIN 1	NS	NS	NS	NS
TYPE*QUAD 1	NS	NS	NS	NS
ALF LIN	NS	NS	.01	NS
ALF QUAD	NS	NS	NS	NS
DEHY LIN	NS	NS	.03	NS
DEHY QUAD	NS	NS	NS	NS

[a] LDR = Liquid dilution rate.
RLV = Rumen liquid volume.
LFR = Liquid flow rate.
LT = Liquid turnover time.

[b] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[c] NS, ($P>.05$).

[d] 100:0 Wheat straw diet not included in contrast.

TABLE VII

CONTRASTS AMONG TREATMENT MEANS OF RUMINAL LIQUID MEASUREMENTS[a] AT AD LIBITUM FEEDING

Contrasts	LDR (%/h)	RLV (ml)	LFR (ml/h)	LT (h)
ALF vs DEHY[b]	NS[c]	NS	NS	NS
LIN 1[d]	NS	NS	NS	NS
QUAD 1[d]	NS	NS	NS	NS
TYPE*LIN 1	NS	NS	.01	NS
TYPE*QUAD 1	NS	NS	NS	NS
ALF LIN	.05	NS	.01	.02
ALF QUAD	NS	NS	NS	NS
DEHY LIN	NS	NS	NS	NS
DEHY QUAD	NS	NS	NS	NS

[a] LDR = Liquid dilution rate.
RLV = Rumen liquid volume.
LFR = Liquid flow rate.
LT = Liquid turnover time.

[b] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[c] NS, $(P>.05)$.

[d] 100:0 Wheat straw diet not included in contrast.

TABLE VIII

CONTRAST AMONG TREATMENT MEANS OF RUMEN pH AT VARIOUS TIMES AFTER FEEDING AT RESTRICTED LEVEL OF INTAKE

Contrasts	Time after feeding, h					
	1	2	4	8	12	24
	Rumen pH					
ALF vs DEHY[a]	NS[b]	NS	NS	NS	NS	NS
LIN 1[c]	NS	NS	NS	NS	NS	.0003
QUAD 1[c]	NS	NS	NS	NS	NS	NS
TYPE*LIN 1	.02	.04	.04	.03	NS	NS
TYPE*QUAD 1	NS	NS	NS	NS	NS	NS
ALF LIN	.05	.001	.01	.05	NS	.0005
ALF QUAD	NS	NS	NS	NS	NS	NS
DEHY LIN	NS	NS	NS	NS	NS	.0003
DEHY QUAD	NS	NS	NS	NS	NS	NS

[a] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] NS, (P>.05).

[c] 100:0 Wheat straw diet not included in contrast.

TABLE IX

CONTRAST AMONG TREATMENT MEANS OF RUMEN pH AT VARIOUS TIMES AFTER FEEDING AT AD LIBITUM LEVEL OF INTAKE

Contrasts	Time after feeding, h					
	1	2	4	8	12	24
	Rumen pH					
ALF vsDEHY[a]	NS[b]	.05	NS	NS	NS	NS
LIN 1[c]	.05	.05	.001	.05	NS	.05
QUAD 1[c]	NS	NS	NS	NS	NS	NS
TYPE*LIN 1	NS	NS	NS	NS	NS	NS
TYPE*QUAD 1	NS	NS	NS	NS	NS	NS
ALF LIN	.02	.04	.003	.05	NS	.003
ALF QUAD	NS	NS	NS	NS	NS	NS
DEHY LIN	.01	.002	.04	.05	NS	.03
DEHY QUAD	NS	NS	NS	NS	NS	NS

[a] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] NS, (P>.05).

[c] 100:0 Wheat straw diet not included in contrast.

TABLE X

CONTRAST AMONG TREATMENT MEANS OF RUMINAL AMMONIA NITROGEN (NH_3-N) CONCENTRATIONS AT VARIOUS TIMES AFTER FEEDING AT RESTRICTED LEVEL OF INTAKE

Contrasts	Time after feeding, h					
	1	2	4	8	12	24
	Rumen NH_3-N					
ALF vs DEHY[a]	NS[b]	NS	NS	NS	NS	NS
LIN 1[c]	.002	NS	.04	.01	NS	.02
QUAD 1[c]	NS	.04	NS	NS	NS	NS
TYPE*LIN 1	NS	NS	NS	NS	NS	NS
TYPE*QUAD 1	NS	NS	NS	NS	NS	NS
ALF LIN	.002	NS	.05	NS	NS	.03
ALF QUAD	NS	NS	.02	.02	NS	NS
DEHY LIN	.02	NS	NS	.03	NS	NS
DEHY QUAD	NS	NS	.0001	NS	NS	NS

[a] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] NS, (P>.05).

[c] 100:0 Wheat straw diet not included in contrast.

TABLE XI

CONTRAST AMONG TREATMENT MEANS OF RUMINAL AMMONIA NITROGEN (NH_3-N) CONCENTRATIONS AT VARIOUS TIMES AFTER FEEDING AT AD LIBITUM LEVEL OF INTAKE

Contrasts	Time after feeding, h					
	1	2	4	8	12	24
	------------- Rumen NH_3-N -------------					
ALF vs DEHY[a]	.01	NS[b]	NS	NS	.001	NS
LIN 1[c]	.05	.001	.001	.001	NS	.001
QUAD 1[c]	NS	NS	NS	NS	NS	NS
TYPE*LIN 1	NS	NS	NS	NS	NS	NS
TYPE*QUAD 1	NS	NS	NS	NS	NS	NS
ALF LIN	.0009	.01	.02	.001	NS	.0001
ALF QUAD	NS	NS	NS	NS	NS	NS
DEHY LIN	.009	.007	NS	.002	.007	.0001
DEHY QUAD	NS	NS	NS	NS	NS	NS

[a] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] NS, (P>.05).

[c] 100:0 Wheat straw diet not included in contrast.

TABLE XII

CONTRASTS AMONG TREATMENT MEANS OF DAILY INTAKE[a] (G/KG BODY WEIGHT) OF DM, OM CP AND NDF AT AD LIBITUM FEEDING

Contrasts	DIDMBW	DIOMBW	DICPBW	DINDFBW
ALF vs DEHY[b]	.01	.02	.0001	NS[c]
LIN 1[d]	.0001	.0001	.0001	.02
QUAD 1[d]	NS	NS	NS	NS
TYPE*LIN 1	.02	.02	.0001	NS
TYPE*QUAD 1	NS	NS	NS	NS
ALF LIN	.0001	.0001	.0001	.01
ALF QUAD	NS	NS	NS	NS
DEHY LIN	.0001	.0001	.0001	.001
DEHY QUAD	NS	NS	.03	NS

[a] DIDMBW = Daily intake of dry matter as g/Kg body weight.
DIOMBW = Daily intake of organic matter as g/Kg body weight.
DICPBW = Daily intake of crude protein as g/Kg body weight.
DINDFBW = Daily intake of neuteral detergent fiber as g/Kg body weight.

[b] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[c] NS, (P>.05).

[d] 100:0 Wheat straw diet not included in contrast.

TABLE XIII

CONTRASTS AMONG TREATMENT MEANS OF APPARENT DIGESTIBILITY OF DM, OM, CP AND NDF AT RESTRICTED FEEDING

Contrasts	DMD	OMD	CPD	NDFD
ALF vs DEHY[a]	NS[b]	NS	NS	NS
LIN 1[c]	.0001	.0002	.0001	.0001
QUAD 1[c]	NS	NS	NS	NS
TYPE*LIN 1	NS	NS	NS	NS
TYPE*QUAD 1	NS	NS	NS	NS
ALF LIN	.0001	.0001	.0001	.003
ALF QUAD	NS	NS	NS	NS
DEHY LIN	.0001	.0001	.0001	.0001
DEHY QUAD	.03	.05	.0007	.02

[a] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] NS, (P>.05).

[c] 100:0 Wheat straw diet not included in contrast.

TABLE XIV

CONTRASTS AMONG TREATMENT MEANS OF APPARENT DIGESTIBILITY OF DM, OM, CP AND NDF AT AD LIBITUM FEEDING

Contrasts	DMD	OMD	CPD	NDFD
ALF vs DEHY[a]	NS[b]	NS	NS	NS
LIN 1[c]	.001	.001	.001	.05
QUAD 1[c]	NS	NS	NS	NS
TYPE*LIN 1	NS	NS	NS	NS
TYPE*QUAD 1	NS	NS	NS	NS
ALF LIN	.003	.02	.0001	.008
ALF QUAD	NS	NS	.002	NS
DEHY LIN	.0001	.0002	.0001	.008
DEHY QUAD	NS	NS	.02	NS

[a] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] NS, (P>.05).

[c] 100:0 Wheat straw diet not included in contrast.

TABLE XV

CONTRASTS AMONG TREATMENT MEANS OF RATE OF PASSAGE AND TURNOVER TIME OF RUMINAL PARTICULATE MATTERS OF AMMONIATED STRAW AT BOTH LEVELS OF FEEDING[a]

Contrasts	Rate of Passage (%/h)		Turnover Time (h)	
	REST	AD LIB	REST	AD LIB
ALF vs DEHY[b]	NS[c]	NS	NS	NS
Straw/ALF LIN	.003	.003	.01	.01
Straw/ALF QUAD	NS	NS	NS	NS
Straw/DEHY LIN	.03	.05	.01	.02
Straw/DEHY QUAD	NS	NS	NS	NS

[a] REST = Restricted; AD LIB = Ad libitum.

[b] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[c] NS, $(P>.05)$.

TABLE XVl

CONTRASTS AMONG TREATMENT MEANS OF RATE OF PASSAGE AND TURNOVER TIME OF RUMINAL PARTICULATE MATTERS OF ALFALFA OR DEHY AT BOTH LEVELS OF FEEDING[a]

	Rate of Passage (%/h)		Turnover Time (h)	
Contrasts	REST	AD LIB	REST	AD LIB
ALF vs DEHY[b]	.007	.007	.005	.006
LIN 1[c]	.001	.0005	.0008	.0002
QUAD 1[c]	NS[d]	NS	NS	NS
TYPE*LIN 1	NS	NS	NS	NS
TYPE*QUAD 1	NS	NS	NS	NS
ALF LIN	.03	.04	.01	.008
ALF QUAD	NS	NS	NS	NS
DEHY LIN	.005	.001	.009	.001
DEHY QUAD	NS	NS	NS	NS

[a] REST = Restricted; AD LIB = Ad libitum.

[b] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[c] 100:0 Wheat straw diet not included in contrast.

[d] NS, $(P>.05)$.

TABLE XVII

CONTRASTS AMONG TREATMENT MEANS OF RUMINAL LIQUID MEASUREMENTS[a] AT RESTRICTED FEEDING

Contrasts	LDR (%/h)	RLV (ml)	LFR (ml/h)	LT (h)
ALF vs DEHY[b]	NS[c]	NS	NS	NS
LIN 1[d]	NS	NS	NS	NS
QUAD 1[d]	NS	NS	NS	NS
TYPE*LIN 1	NS	NS	NS	NS
TYPE*QUAD 1	NS	NS	NS	NS
ALF LIN	NS	NS	NS	NS
ALF QUAD	NS	NS	NS	NS
DEHY LIN	NS	NS	.01	.01
DEHY QUAD	NS	NS	NS	NS

[a] LDR = Liquid dilution rate.
RLV = Rumen liquid volume.
LFR = Liquid flow rate.
LT = Liquid turnover time.

[b] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[c] NS, $(P<.05)$.

[d] 100:0 Wheat straw diet not included in contrast.

TABLE XVIII

CONTRASTS AMONG TREATMENT MEANS OF RUMINAL LIQUID MEASUREMENTS[a] AT AD LIBITUM FEEDING

Contrasts	LDR (%/h)	RLV (ml)	LFR (ml/h)	LT (h)
ALF vs DEHY[b]	NS[c]	NS	NS	NS
LIN 1[d]	.05	NS	.006	NS
QUAD 1[d]	NS	NS	NS	NS
TYPE*LIN 1	NS	NS	NS	NS
TYPE*QUAD 1	NS	NS	NS	NS
ALF LIN	NS	NS	NS	NS
ALF QUAD	NS	NS	NS	NS
DEHY LIN	.02	NS	.03	.03
DEHY QUAD	NS	NS	.03	.03

[a] LDR = Liquid dilution rate.
RLV = Rumen liquid volume.
LFR = Liquid flow rate.
LT = Liquid turnover time.

[b] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[c] NS, (P<.05).

[d] 100:0 Wheat straw diet not included in contrast.

TABLE XIX

CONTRAST AMONG TREATMENT MEANS OF RUMEN pH AT VARIOUS TIMES AFTER FEEDING AT RESTRICTED LEVEL OF INTAKE

Contrasts	Time after feeding, h 1	2	4	8	12	24
	--------------		Rumen pH			--------------
ALF vs DEHY[a]	NS[b]	NS	NS	NS	NS	NS
LIN 1[c]	NS	.03	NS	NS	.002	.004
QUAD 1[c]	NS	NS	NS	NS	.02	.04
TYPE*LIN 1	NS	NS	NS	NS	NS	NS
TYPE*QUAD 1	NS	NS	NS	NS	NS	NS
ALF LIN	NS	NS	NS	NS	NS	.001
ALF QUAD	NS	NS	NS	NS	.004	.03
DEHY LIN	NS	NS	NS	NS	NS	.004
DEHY QUAD	NS	NS	NS	NS	NS	NS

[a] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] NS, (P>.05).

[c] 100:0 Wheat straw diet not included in contrast.

TABLE XX

CONTRAST AMONG TREATMENT MEANS OF RUMEN pH AT VARIOUS TIMES AFTER FEEDING AT AD LIBITUM LEVEL OF INTAKE

Contrasts	Time after feeding, h					
	1	2	4	8	12	24
	Rumen pH					
ALF vs DEHY[a]	NS[b]	NS	NS	NS	NS	NS
LIN 1[c]	NS	NS	NS	NS	NS	NS
QUAD 1[c]	NS	NS	NS	NS	NS	NS
TYPE*LIN 1	NS	NS	NS	NS	NS	.04
TYPE*QUAD 1	NS	NS	NS	NS	NS	NS
ALF LIN	NS	NS	NS	NS	NS	NS
ALF QUAD	NS	NS	NS	NS	NS	NS
DEHY LIN	NS	NS	NS	NS	NS	NS
DEHY QUAD	NS	NS	NS	NS	NS	NS

[a] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] NS, (P>.05).

[c] 100:0 Wheat straw diet not included in contrast.

TABLE XXI

CONTRAST AMONG TREATMENT MEANS OF RUMINAL AMMONIA NITROGEN (NH_3-N) CONCENTRATIONS AT VARIOUS TIMES AFTER FEEDING AT RESTRICTED LEVEL OF INTAKE

Contrasts	Time after feeding, h					
	1	2	4	8	12	24
	------------- Rumen NH_3-N -------------					
ALF vs DEHY[a]	NS[b]	NS	NS	NS	NS	NS
LIN 1[c]	NS	NS	NS	NS	.001	.0001
QUAD 1[c]	NS	NS	.008	NS	NS	NS
TYPE*LIN 1	.02	NS	NS	NS	NS	.04
TYPE*QUAD 1	NS	NS	NS	NS	NS	NS
ALF LIN	NS	.003	NS	NS	.01	.001
ALF QUAD	NS	NS	.02	NS	NS	NS
DEHY LIN	.04	.002	NS	NS	.008	.001
DEHY QUAD	NS	NS	NS	NS	NS	NS

[a] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] NS, ($P>.05$).

[c] 100:0 Wheat straw diet not included in contrast.

TABLE XXII

CONTRAST AMONG TREATMENT MEANS OF RUMINAL AMMONIA NITROGEN (NH_3-N) CONCENTRATIONS AT VARIOUS TIMES AFTER FEEDING AT AD LIBITUM LEVEL OF INTAKE

Contrasts	Time after feeding, h 1	2	4	8	12	24
	------------- Rumen NH_3-N					-------------
ALF vs DEHY[a]	NS[b]	NS	NS	NS	NS	NS
LIN 1[c]	.03	NS	NS	NS	NS	.009
QUAD 1[c]	NS	NS	.008	NS	NS	NS
TYPE*LIN 1	.02	NS	NS	NS	NS	.006
TYPE*QUAD 1	NS	NS	NS	NS	NS	NS
ALF LIN	NS	NS	NS	NS	NS	.004
ALF QUAD	NS	NS	.03	NS	NS	NS
DEHY LIN	.03	.05	NS	NS	NS	NS
DEHY QUAD	NS	NS	.03	NS	NS	NS

[a] ALF = Chaffed alfalfa hay; DEHY = Dehydrated alfalfa pellets.

[b] NS, (P>.05).

[c] 100:0 Wheat straw diet not included in contrast.

2

VITA

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