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WEIGHT CHANGE, INTAKE AND DIGESTION OF ALFALFA HAY AND WHEAT STRAW BY KARAKUL, RAMBOUILLET AND ST. CROIX

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WEIGHT CHANGE, INTAKE AND DIGESTION OF ALFALFA HAY AND WHEAT STRAW BY KARAKUL, RAMBOUILLET AND ST. CROIX

by

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STATEMENT BY AUTHOR

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ABSTRACT

An experiment was conducted to determine the weight changes, intake and digestion of alfalfa hay and wheat straw by Karakul, Rambouillet and St. Croix sheep. All the breeds gained weight on alfalfa and lost weight on wheat straw. Feed intake (g/da) was significantly ($P<.05$) different, in the order: Rambouillet > Karakul > St. Croix; but intake per unit of body weight was similar within diets for all breeds. Feed intake was higher for alfalfa than for wheat straw diets. Digestibility of dietary components was similar for sheep breeds. The average digestibility of dry matter was 56.5% and 42.8%, organic matter; 57.8% and 46.6%, crude protein; 62.9% and 27.6%, ADF; 43.5% and 49.1%, and hemicellulose; 44.0% and 54.5% for alfalfa and wheat straw respectively. Forty eight hour, in vitro dry matter disappearance was 70.5%, 69.5% and 73.4% for alfalfa, wheat straw and supplemented wheat straw, respectively.

CHAPTER 1

INTRODUCTION

In many parts of the world, poor-quality roughages, low in nitrogen are the only food available to the grazing animal, especially during the dry season. In India (Coombe, 1981), it has been estimated that dry roughages, predominantly cereal straws, provide over 50% of the energy in the annual feed supply. With an increasing proportion of the land being converted to farming crops, the ranges of the third world countries are shrinking (Kesteven, 1975). Crop by-products are becoming more and more important in livestock production. Various studies have shown that, properly supplemented, these roughages can be used successfully as a major component of ruminant diets, particularly at or slightly above maintenance feeding levels (Coombe, 1981). During recent years, the possibilities of using non-protein nitrogen supplements has aroused much interest; of the compounds considered, urea has predominated mainly because of its high nitrogen content and its low cost.

It is well established that alfalfa and most pasture and crop legumes have a much higher nutritive value than straws (Oh, Weir and Longhurst, 1971; Egan et al., 1975; and Conrad, Pratt and Hibbs, 1964).

In 1880 a remark was made about diets of sheep: "Weeds, grasses, shrubs, roots, cereals, leaves, barks, and even in times of scarcity, fish and meats all furnish a subsistence to this wonderful animal" (Pope, 1958). Bishop (1984) also remarked that sheep can produce lean and tender meat exclusively from pasture land and crop residutes such as corn stover; however, cattle usually require some grain to attain comparable meat quality. The demand for mutton is increasing, especially in Moslem communities where religious festivals require the meat of sheep (Adu and Nguere, 1979).

The Rambouillet breed of sheep, formerly called the French Merino, originated at Rambouillet, France (Briggs, 1980). However, the improved breeding stock that formed the foundation of the American Rambouillet flocks came from Germany. The importations of this breed to America began in 1840. It became very popular in the west and the rams were used to replace Merino rams on the western ranges. The modern Rambouillet is a large, rugged breed of sheep. The rams are particularly impressive with strong, wide heads, and well-balanced horns that curve backward and outward from the head. Though they have a good mutton conformation, Rambouillets are known for their high-quality fine wool. They are adaptable to various climatic and forage conditions, but are most adapted to temperate climates.

Karakul is a fur-bearing breed of sheep native to the country of Bokhara, which lies between Turkestan and Afghanistan in central Asia (Briggs, 1980). It originated from the crossing of the long-tailed black Danabar sheep and an early native sheep called Arabi. The first importation of Karakuls to the United States took place in 1909. The modern breed is of medium size and has a long and narrow face, with long and drooping ears. Its body conformation is inferior to that of mutton breeds. Their back is usually uneven and the sheep have steep rumps that end in a broad, fat tail, which is used as a nutrient reserve in the desert country. The chief virtue of the Karakul sheep is its ability to produce salable fur pelts from baby lambs. This breed of sheep is extremely hardy and parasite-resistant. It is best adapted to an intermediate climate between temperate and tropical climatic extremes.

The St. Croix breed is a hair sheep from the U.S. Virgin Island of St. Croix. The St. Croix sheep were brought to the Americas by the Spaniards and Portuguese from their country or North Africa. They were first introduced into the United States in the 1960's. They have a precocious puberty, a near year-round breeding season, breed back soon after lambing, and a high prolificacy (Foote, Evans and Gebrelul, 1982). This breed of sheep is adapted to subtropical climates and are capable of survival on poor-quality roughages.

The purpose of this experiment was to compare the three breeds, originating from different climatic regions, in their ability to digest alfalfa and wheat straw, and their response to supplementation of straw with molasses and urea.

Since the three breeds of sheep originated in different environmental conditions, they are expected to differ in their efficiency of feed utilization, mainly because, having different mature sizes, their growth patterns are different. Therefore, their efficiency of of tissue deposition may be different, and this difference is expected to result in differences in the efficiency of feed utilization (Notter, Ferrell and Field, 1984).

CHAPTER 2

LITERATURE REVIEW

Ruminants in livestock production are sustained on a variety of feeds. Their ability to digest cellulose and other structural polysaccharides has caused man for many years to expect these animals to convert cellulosic waste materials into useful products (Coombe, 1981). These animals are raised on feeds ranging from good-quality alfalfa to cereal straws. It is important to know the nutritive value of these feeds for livestock production. The nutritive value of feedstuffs is determined by the intake and digestibility of the feeds, or by the response in weight gain by the animals.

A tremendous amount of research has focused on assessing the nutritive value of livestock feeds. Messenger, Donald and Brown (1971) found that adult Merino wethers grazed on wheat stubble lost weight at the rate of 90g/day. Allden (1981) stated that the lack of energy and nitrogen deficiency were the most important problems in tropical pastures, or in temperate regions when legumes are absent from the sward. Norman (1963) working in a subtropical environment, observed a linear relationship between the amount of crude protein fed as a supplement and the liveweight change in cattle. Addition of lucerne to spear grass increased the intake and dry matter digestibility of the grass, showing that lucerne had a complementary nutritive value (Siebert and

Kennedy, 1972). Minson and Milford (1967) showed that dry matter digestibility of lucerne was much higher than that of Pangola grass. Egan et al. (1975) reported that alfalfa yielded 50% more amino acids at the duodenum of sheep than wheat straw, and its organic matter was better digested. Addition of alfalfa to soybean stover increased the dry matter digestibility of the stover (Soofi, Fahey and Berger, 1983). Oh, Weir and Longhurst (1971) found that the relative value of the feeds they studied was alfalfa > corn stalks > rice straw > barley straw.

The chemical composition of roughages has been used to estimate their nutritive quality, in combination with feed intake. Ulyatt, Blaxter and McDonald (1967) found feed intake of roughages to be directly related to the crude protein content. Forbes, Rees and Boaz (1967) showed the same relationship. Intake was found to be a better indicator of nutritive value than the chemical composition or the TDN content of roughages (Crampton, Leister and Lloyd, 1957). Conrad, Pratt and Hibbs (1964) reported that forage cell-wall constituents, when they represent more than 50% of the dry matter, have the highest correlation with feed intake. They also determined three classes of factors affecting intake:

1) Inhibitory or toxic substances that impair the taste.

2) Factors associated with plant maturity, such as lignin which when associated with fiber mass is digested more slowly and results in rumen fill, therefore, reduces intake.

3) In high-quality feeds where the fiber fraction is small, the feed intake is limited by the physical factors of the forages.

Robles et al. (1981) observed that, as the cell-wall concentration increased, the feed intake decreased as a result of rumen fill. Allinson and Osbourn (1970) concluded that the undigested residues of cell-wall constituents contributed to ruminal ballast and influenced voluntary feed intake.

Intake, in turn, is influenced by the rate of passage: the higher the rate of passage, the greater the voluntary feed intake (Jones, 1972; Laredo and Minson, 1973; Blaxter, Wainman and Wilson, 1961).

The digestibility of the various components of feeds is the main factor influencing their nutritive value. Digestibility reflects the nutritive availability of the different chemical fractions of roughages (Van Soest, 1965). In general, the dry matter digestibility of forages is directly related to the crude protein content (Robles et al., 1981), the difference in the available carbohydrate content of the diets (Fonnesbeck, Christiansen and Harris, 1981), and the digestibility of cellulose (Robles, Belyea and Martz, 1981). Lignin was found to be a poor indicator of forage digestibility (Fahey, McLaren and Williams, 1979), though it is quite indigestible (Ferguson, 1942). The fiber fractions are associated with lignin (Donefer, Crampton and Lloyd, 1960; and Allinson and Osbourn, 1970), and delignification greatly increases dry matter and fiber digestion (Van Soest, 1967; and Chandra and Jackson, 1971). Silica content of feeds depresses digestion of organic matter (Smith, Nelson and Boggino, 1971; Goering and Van Soest, 1970).

Because in vivo experiments are tedious and require much feed, in vitro methods have been developed to estimate the digestibility of roughages. Tilley and Terry (1963) observed that in vitro procedures yielded a more accurate estimate of digestibility than chemical methods. These procedures are, therefore, a valuable laboratory method for estimating the digestibility of herbage. Many correlations have been developed to relate the in vitro results to the in vivo digestion. Wilkins and Grim (1966) found the correlation to be 0.94 for the dry matter digestibility in vivo with the organic matter digestibility in vitro and 0.95 with the cellulose digestion in vitro. Johnson et al. (1962) found a correlation between cellulose digestibility in vivo and in vitro of 0.95 for legumes and 0.86 for grasses, in 12 hours.

Cellulose digestibility in vitro was more highly correlated with cellulose and dry matter digestibility in vivo (Hershberger et al. 1959; LeFevre and Kamstra, 1960). However, the correlation is different for each class of forage (Johnson et al. 1964, 1962). Cellulose digestion in vitro can be predicted from the lignin content of forages. The correlation is highest for grasses (Tomlin, Johnson and Dehority, 1965).

The best incubation time for the prediction of the dry matter or cellulose digestibility in vivo is 12 hours, in vitro cellulose digestion (Hershberger and Hartsook, 1970; Johnson et al. 1962; Donefer, Crampton and Lloyd, 1960).

Baker et al. (1959) showed that cellulose is composed of both crystalline and amorphous structures. The greater the degree of crystallinity of cellulose, the slower the rate of microbial degradation. The size of the glucose chains also influences the digestion of celluloses.

The source of the inoculum used for in vitro fermentation is also important. Gallinger and Kercher (1964) found that significantly more dry matter and organic matter from alfalfa disappeared from the nylon bag when the fistulated steers were fed alfalfa hay than when fed alfalfa hay plus barley. Van Dyne and Weir (1964) observed that in vitro cellulose digestion of animals fed alfalfa was higher for alfalfa and lower for solka-floc (96.6% cellulose) than that of the inoculum from animals fed range forage of a lower quality. To best estimate the digestibility of a forage, the inoculum should come from an animal fed the feed to be analyzed. They also found differences between inoculum from cattle and sheep.

Although in vitro studies are related to in vivo values, Meyer et al. (1971) suggested that further digestion beyond a rumen microbial fermentation is necessary to estimate in vivo forage digestibility.

In many areas around the world, straws are fed to ruminants. These straws are high in fiber and low in protein and constitute submaintenance rations for animals consuming them (Coombe and Tribe, 1960). Supplementation of these rations with urea and a source of available energy can prevent or reduce the weight loss by the animals.

Urea causes a shortening of the mean retention time of straw in the digestive tract, resulting in an increased voluntary feed intake, due to an increased cellulose digestion (Coombe and Tribe, 1960). Beames (1960) found that urea and molasses increased the dry matter intake and body weight gain in animals grazing a low-quality pasture. Meiske et al. (1955) found that urea increased the efficiency of feed utilization in lambs. However, two to three weeks are required for the animals to become fully adapted to the non-protein nitrogenous compounds (Repp, Hale and Burroughs, 1955).

Increasing the level of urea in the diet increases its utilization to a maximum, where it reaches a plateau (Belasco, 1954; Coombe, 1959; Hume, Moir and Somers, 1970) and is followed by a decline in utilization, sometimes having a toxic effect at high levels (Martin et al. 1981).

The addition of urea to a diet improves low-quality roughages because nitrogen is the most limiting factor in the utilization of those feeds to ruminant animals (Coombe, 1981). The cellulolytic bacteria in the rumen which depend on the nitrogen for growth are inhibited by the deficiency of crude protein (Moir and Harris, 1962; Egan and Moir, 1965). The addition of urea supplies the necessary nitrogen to the bacteria in the form of ammonium ions (Briggs, 1967) which are then incorporated into protein by the microbial population of the rumen. However, a source of readily available carbohydrates is needed for the efficient utilization of urea (Reid, 1953; Herrera-Saldana, 1982; Mills et al., 1944).

Natural proteins have been shown to be superior to urea and molasses (Pope, 1958; Williams, Whiteman and Tillman, 1969; Mercer, Allen and Miller, 1980; and Kropp et al. 1977), because urea and molasses do not meet the nutrient requirements of the micro-organisms. Bentley et al. (1954) showed that microbes required minerals, vitamins and other unidentified factors not contained in molasses or urea. Leibholz (1980) found that the replacement of meat meal by urea reduced the flow of nitrogen to the duodenum and the apparent absorption of amino acids in the intestines. The sulfur amino acids were also deficient, though molasses contains some minerals and sulfur (Hemsley, 1964; Rush, Johnson and Totusek, 1976).

Cattle utilize urea in the diets better than sheep. Addition of sulfates to sulfur-deficient diets increased their utilization by sheep (Thomas et al., 1951). Bruggenmann and Giesecke (1967) showed that the strains of rumen bacteria which require branched-chain volatile fatty acids for growth incorporate reasonable amounts of ammonia nitrogen into their cell protein. These fatty acids are produced by the deamination of the respective amino acids, and become limiting if dietary protein is replaced by urea. Addition of starch to cellulose-urea diets seems to overcome the limitation.

Response to urea in roughages also depends on the crude protein content of those feeds (Hamilton, Robinson and Johnson, 1948; Tillman, Gallup and Woods, 1957). Urea is hydrolyzed rapidly and often is absorbed or excreted before it is utilized efficiently by the rumen microorganisms (Blake, Salter and Smith, 1983; Drori and Loosli, 1961).

With an *in vitro* fermentation of more than 12 hours, the dry matter disappearance of supplemented straw is high (Belasco, 1954) because the ammonia is not absorbed or passed down to the rest of the digestive tract. Therefore, it is available to microbes for a longer period than it actually is *in vivo*, and the microorganisms can utilize it more effectively. Thus, urea appears to be superior to natural proteins for cellulose digestion *in vitro*, whereas in the rumen, urea is absorbed rapidly.

Heat stress, usually has a negative effect on ruminants. Ames (1979) showed that heat stress increased the basal metabolic heat production and decreased feed intake accompanied by an increase in the retention time of the feed in the digestive tract (Christopherson and Kennedy, 1983). This was caused by a reduced motility of the reticulo-rumen (Yousef, 1985). The change in motility was a result of a reduced thyroid activity (Curtis, 1983; and Yousef, 1985), and the subsequent decrease in thyroid hormone secretion. There is, therefore, a reduced basal metabolic rate. The digestibility of roughages increases with warmer temperatures. Exposure to heat and solar radiation increases the animal respiration rate which provides an evaporative cooling to prevent an increase in rectal temperature (El-Sheikh et al. 1981b). Curtis (1983) reported that heat exposures elevated body-core temperature in ruminants.

Breeds have been reported to differ in their resistance to environmental stresses, because they have different fasting metabolisms (Blaxter, Clapperton and Wainman, 1966). El-Sheik et al. (1981a) found that foreign breeds were less adapted to heat than local ones in Egypt and that heat affected the intake of feeds. This response of different breeds of sheep is expected to result in a difference in the intake and digestibility of roughage components. Khalil and Morad (1977) found that the intake per 100 kg of body weight varied with breed. However, the effect of temperature was not of primary concern in this experiment.

CHAPTER 3

MATERIALS AND METHODS

Three breeds of sheep, Rambouillet, Karakul and St. Croix, with four mature animals per breed (2 years old), were placed in individual pens at the Campbell farm, University of Arizona. Numbers from 1 to 4 were assigned to sheep of each breed at random. The animals were fed once daily at 8:00 A.M. for a 21-day preliminary period to establish a uniform feed intake. The quantity of feed given was adjusted so that about 10% was left over. Feed refusals were weighed back once each week.

Alfalfa cubes (alf), wheat straw (ws) obtained from the University feedlot and wheat straw supplemented with urea and molasses (ws+s) were fed *ad libitum*. The liquid supplement (298g) consisting of 43.7% water, 41.7% molasses and 14.6% urea was mixed with the daily ration of wheat straw in the feed bunk, so that the animal received 124.3 gms of molasses and 43.5 gms of urea per day. Water was available *ad libitum*.

The experiment began March 9, 1984 and continued over three periods consisting of a 21-day preliminary adjustment followed by a 6 or 5-day collection period. At least one sheep of each breed received one of the three diets each period and each animal was fed each of the diets over the experiment, one diet each period (Table 1).

Table 1. Experimental design.

Sheep Breed	Animal #	Alf	WS	WS + S
Rambouillet	1	Pd1	Pd2	Pd3
	2	Pd2	Pd1	Pd3
	3	Pd3	Pd2	Pd1
	4	Pd1	Pd3	Pd2
Karakul	1	Pd1	Pd2	Pd3
	2	Pd2	Pd1	Pd3
	3	Pd3	Pd2	Pd1
	4	Pd1	Pd3	Pd2
St. Croix	1	Pd1	Pd2	Pd3
	2	Pd2	Pd1	Pd3
	3	Pd3	Pd2	Pd1
	4	Pd1	Pd3	Pd2

When two animals of the same breed received the same diet (which occurred for each breed, each period since we had four sheep per breed and three diets), the average value of the two was used for statistical analyses. Therefore, the experiment was analyzed as a 3x3x3 factorial.

The feed refusals were cleaned out of the bunks once a week, weighed and sampled for analysis of their chemical composition. Samples of feed and refusals were dried in a forced air oven at 60° F for at least 48 hours before they were ground for analyses. The sheep were weighed just before the experiment started, then they were weighed weekly and at the end of each period.

The collection was made every day of the collection period with brooms and brushes and the manure was stored in buckets. At the end of the collection period, the floor was scraped very closely so that as much as possible was collected and weighed, then sampled, dried and analyzed for chemical composition. The last feed refusal was weighed at the end of the collection period.

Metabolism crates were not available.

Intake was determined by subtracting the feed refusals from the feed given during the week.

The chemical composition of the alfalfa and the wheat straw used was determined. The composition of the supplemented wheat straw diet was variable since the amount of supplement fed to each animal was constant while the feed intake was different for each animal. The liquid supplement consisted of 41.7% crude protein equivalent, 30.1% dry matter, 87.4% organic matter and had an energy content of 3331 cal/gm of dry matter.

Feed refusals of each animal were combined for each period for chemical analyses. The difference from feed composition and feed refusals was used to calculate nutrient digestibilities.

The apparent digestibility of the various fractions was determined using the formula:

$$\frac{\text{conc}_1 \text{ of X (\%) x Intake (lbs) - conc}_2 \text{ of X (\%) x Feces (lbs.)}}{\text{conc}_1 \text{ of X (\%) x Intake (lbs.)}}$$

X = nutrient considered

conc_1 = concentration in the dry feed

conc_2 = concentration in the dry feces

Chemical Analysis:

The method for protein was essentially a scaled down version of a normal Kjeldahl procedure (AOAC, 1976). Duplicate .5 gm samples were weighed into 25 mm x 200 mm pyrex test tubes with 1.0g K_2SO_4, 0.1g Na_2SeO_3 and 10 ml concentrated H_2SO_4. Samples were digested at about 400° C on a block digester until they turned a clear amber color. The tubes were removed from the block digester and placed in test tube racks to cool. The digestate was then quantitatively transferred to a 100 ml volumetric flask, diluted to the mark with distilled water and transferred to polyethelene bottles. Small subsamples were taken from the bottles and passed into an auto-analyzer. The output was recorded on a graph with a series of peaks corresponding to standard nitrogen samples. Using the ratio of the peak heights of the known and unknown samples, the nitrogen concentration was determined, in ppm. Using the formula:

$$\% \text{ crude protein} = \frac{\text{ppm} \times 10^{-2} \times 6.25}{\text{sample weight}}$$

The air-dried samples were dried in a vacuum oven overnight at 100° C to determine the absolute dry matter content. The organic matter content of the samples was determined by the difference between dry samples and the residue after the samples were ashed overnight at 600° C. The permanganate lignin, cellulose and silica method of Goering and Van Soest (1970) was used for forage fiber analysis. Acid detergent fiber (ADF), neutral detergent fiber (NDF), lignin, cellulose and silica were determined. Hemicellulose was the difference between the NDF and the ADF. It is assumed that the NDF is the cell-wall constituents of the forages. In vitro digestion was determined following the procedures described by Goering and Van Soest (1970). The fiber fractions were expressed as a percent of the dry matter.

CHAPTER 4

RESULTS AND DISCUSSION

The chemical composition of alfalfa and wheat straw is presented in Table 2. Wheat straw was higher in fiber and lower in crude protein than alfalfa. They were similar in dry matter. When supplemented the wheat straw diet had a crude protein equivalent similar to or greater than that of alfalfa.

The initial weight of the animals is presented in Table 3. The animals were all fed alfalfa before the experiment started and were in good body condition. The Rambouillet sheep were much bigger than the Karakul and St. Croix sheep. Two of the St. Croix were comparable to the Karakul, but the other two were relatively smaller in size.

Feed Intake

The total intake of dry matter is presented in Table 4A and the intake per 100 kg of live body weight is given in Table 4B. The total intake of all three diets was directly related to the body size of the animals. The Rambouillet sheep consumed significantly more dry matter when they were fed alfalfa cubes than Karakul, which had a significantly greater intake than St. Croix. On wheat straw diets, the trend was similar, though the differences were not significant. These results can be explained by the fact that the energy requirement

Table 2. Chemical composition of the feeds.

Component		ALF Pd1	ALF Pd2	ALF Pd3	WS Pd1	WS Pd2	WS Pd3
Crude protein	(%)	15.4	19.2	15.7	6.9	6.0	5.8
Dry matter	(%)	95.2	96.0	97.2	95.7	96.9	97.2
Ash	(%)	9.9	11.7	14.1	12.6	15.0	15.6
Organic matter	(%)	90.1	88.3	85.9	87.4	85.0	84.4
ADF	(%)	36.2	29.7	33.5	37.6	46.0	46.0
Lignin	(%)	9.4	9.1	9.2	6.6	7.9	8.1
Cellulose	(%)	24.4	20.0	19.9	23.8	31.9	30.4
Silica	(%)	2.4	0.6	4.4	7.2	6.2	7.4
NDF	(%)	47.5	36.0	39.8	55.3	65.3	64.6
Hemicellulose	(%)	11.3	6.3	6.3	17.7	19.2	18.6

Table 3. Initial weight of the animals (kg).

Animal #	Rambouillet	Karakul	St. Croix
1	117.9	66.7	71.2
2	108.4	77.6	50.3
3	106.1	78.5	65.3
4	104.8	78.9	79.4

Table 4A. Total daily dry matter intake (kg).

	Alf Period				WS Period				WS + S Period			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
Rambouillet	3.05	3.28	3.11	3.15a	1.29	0.96	0.63	0.96bd	1.78	1.32	0.60	1.23b
Karakul	2.32	2.75	2.85	2.64b	1.14	0.64	0.33	0.70d	0.92	1.03	0.18	0.71d
St. Croix	2.01	1.96	1.84	1.94c	0.78	0.96	0.64	0.79d	0.92	0.69	0.54	0.71d
Average				2.58b				0.82d				0.88d

ab Means in the same row or column with different subscripts are significantly different ($P < .05$).

Table 4B. Relative daily intake/100 kg of live weight (kg).

	Alf Period 1	2	3	Average	WS Period 1	2	3	Average	WS + S Period 1	2	3	Average
Rambouillet	2.77	2.92	2.77	2.82a	1.31	0.96	0.64	0.97b	1.73	1.37	0.60	1.23b
Karakul	2.97	3.40	3.49	3.29a	1.60	0.93	0.47	1.00b	1.41	1.50	0.29	1.07b
St. Croix	3.08	2.97	2.85	2.97a	1.21	1.55	0.86	1.21b	1.47	1.10	1.03	1.20b
Average				3.03a				1.06b				1.17b

a,b Means in the same row or same column with different subscripts are significantly different ($P < .05$).

of adult animals is closely related to body weight (Church, 1979a). The capacity of the reticulo-rumen will also influence how much feed an animal can eat, since sheep generally consume roughages to achieve a constant fill of their rumen (Ulyatt, Blaxter and McDonald, 1967). Crampton, Lister and Lloyd (1957) and Williams and Miller (1965) also found that differences in the level of intake of roughages depended upon body weight. However, with wheat straw this trend was not apparent. The St. Croix sheep tended to consume more than the Karakul which were larger. Supplemented wheat straw was consumed to a similar extent by Karakul and St. Croix, but Rambouillet consumed significantly more.

Many other factors regulate the voluntary intake of roughages by ruminants including type and level of production, individuality of the animals, environmental conditions, the health of the animals and stress (Church, 1979a). But the single most important factor would be the type of feed. Intake of alfalfa was significantly greater than that of wheat straw. Wheat straw intake was less than the supplemented wheat straw, though not significantly. Feed quality and nutrient adequacy largely govern intake. Alfalfa in this experiment had a crude protein of 16.8% compared to an average of 6.2% for wheat straw. Ulyatt, Blaxter and McDonald (1967) and Blaxter, Wainman and Wilson (1961) showed that a good quality roughage was consumed to a greater extent than a lower quality one. The quality is usually reflected in the crude protein content. Messenger, Donald and Brown (1971) believed that nitrogen deficiency was the primary limiting factor in the utilization of low quality roughages. The rate of dry matter digestion in turn affects the rate of passage of the digesta (Jones, 1972). By reducing the retention time in the reticulo-rumen, more space is available for additional intake. The satiety signals relating to fill come from the reticulum (Grovum, 1979). Therefore, the rate of passage from the reticulum to the omasum is critical in regulating feed intake. Weston and Hogan (1968) also found that with low quality ryegrass (6% crude protein) feed intake was limited by the resistance of the hay to passage from the rumen.

The content and digestibility of the fiber fractions also affect the voluntary intake. Van Soest (1965) showed that with low quality roughages, the factor limiting intake was the fiber content. Fiber makes up the least digestible part of the feed and, therefore, acts mostly as a ballast in the rumen. Its digestibility will also affect the rate of passage and, therefore, the voluntary intake. Van Soest (1965) found that if the cell-wall constituents, represented by NDF, contribute more than 50% of the dry matter (which is the case for wheat straw but not for alfalfa), the correlation between the total fiber fraction and intake is high. Thus, the intake of alfalfa would be expected to be greater than that of wheat straw. Robles et al. (1981) found that as the cell-wall content of forages increases, the level of intake and digestibility decreases.

The digestion rate of cellulose is highly correlated with voluntary intake (Donefer, Crampton and Lloyd, 1959). Fahey et al. (1980) showed that different sources of celluloses had different digestibilities. Robles, Belyea and Martz (1981) also showed that the extent and rate of cell-wall digestion was related to the rate of passage of food through the reticulo-rumen. In vitro studies by Burroughs et al. (1950) indicated that the cellulose of alfalfa was more digestible by sheep than that of wheat straw. From these results, alfalfa would be expected to be consumed to a greater extent than wheat straw.

Palatability, often referred to as acceptability also controls intake of roughages. Greenhalgh and Reid (1971) reported that the palatability of wheat straw can be enhanced by supplementation resulting in a higher voluntary intake.

Addition of urea and molasses to wheat straw was expected to result in an increased voluntary intake, even though Loboto and Pearce (1980) and Entwistle and Knights (1974) reported that this type of supplementation is not equally palatable to all animals. Nolan et al. (1975) found that when offered in the liquid form, urea and molasses supplements were consumed at rates varying from 5 to 500 ml/day. In this experiment, some of the animals consumed the wheat straw and tended to avoid the supplement. Many workers, however, have found that urea either sprayed alone (Herrera-Saldana, 1982) or in combination with molasses (Tulloh, Watson and Burnell, 1963; Hemsley, 1964) increased voluntary intake by grazing animals.

In this experiment, the supplementation of wheat straw with urea and molasses increased the voluntary intake only slightly for Rambouillet and Karakul (not significant). The intake of supplemented wheat straw by St. Croix sheep was slightly reduced. These results are in agreement with the findings by Church and Santos (1981) with cattle. However, the level of urea and molasses also affects the intake. Belasco (1954) and Coombe (1959) found that urea addition at increasing levels to poor quality roughages increased intake to a maximum followed by a depression.

Feed intake is better expressed as the relative intake per unit of body weight for animals of different size. When expressed as the amount per 100 kg of body weight, the trend was the same as that of absolute values for the difference between the forages. Among breeds, however, there was no significant difference in intake per unit of body weight.

The period when the experiment took place had a significant effect on the intake of the wheat straw and the supplemented wheat straw. As the experiment progressed toward the hot weather (Table 5), the intake of the lower quality feeds was depressed. This effect agrees with the observation by Church (1979b) that heat stress will reduce intake of low quality forages.

Weight Changes of the Animals

The weight changes of the animals when switching diets is presented in Table 6A. Since the animals were all fed alfalfa before the experiment started, in the first period, dietary changes were from alfalfa to either wheat straw or wheat straw, supplemented. Relative changes of body weight in percents are presented in Table 6B. This

Table 5. Temperatures during the collection periods (° C).

	Pd 1		Pd 2		Pd 3	
Day	Max	Min	Max	Min	Max	Min
1	23.3	13.3	27.2	8.3	38.3	26.1
2	27.2	10.0	27.8	12.2	36.1	22.8
3	19.4	10.6	28.9	12.8	36.1	22.2
4	21.1	6.7	31.7	14.4	36.1	22.2
5	24.4	7.2	33.3	16.7	33.9	21.1
6	29.4	7.2				
Average	24.1	9.3	29.8	12.9	36.1	22.9

method of expressing the weight changes is more appropriate for comparison of animals of different weights.

When switched from wheat straw plus supplement to alfalfa, the animals gained weight in the order of Karakul > Rambouillet > St. Croix. Alfalfa, therefore, had a much better feeding value than the supplemented wheat straw. Rambouillet and Karakul changed from wheat straw plus supplement to alfalfa and gained weight in the same order during period 2 and period 3, while St. Croix gained less weight during period 3, which was the hotter weather. The environment may have affected the appetite of St. Croix sheep to a greater extent when switched to a high quality diet.

Table 6A. Weight changes of animals (kg).

Breeds	Period 1 ALF -> WS	Period 1 ALF -> WS+S	WS -> WS+S Period 2	WS -> WS+S Period 3	WS+S -> ALF Period 2	WS+S -> ALF Period 3	ALF -> WS Period 2	ALF -> WS Period 3
Rambouillet	-10.9	-7.2	+4.5	-3.6	+ 9.5	+10.0	-9.5	-15.9
Karakul	-6.8	-7.2	-1.8	-8.2	+15.4	+12.7	-9.5	-15.4
St. Croix	-6.8	-4.5	-0.4	-11.3	+7.2	+0.4	-1.8	-11.3

Table 6B. Relative weight changes of animals (%).

	Period 1 ALF -> WS	Period 1 ALF -> WS+S	WS -> WS+S Period 2	WS -> WS+S Period 3	WS+S -> ALF Period 2	WS+S -> ALF Period 3	ALF -> WS Period 2	ALF -> WS Period 3
Rambouillet	-10.0	-6.2	+4.6	-3.5	+9.1	+9.8	-8.5	-12.0
Karakul	-8.8	-9.8	-2.6	-11.7	+22.8	+18.4	-12.0	-19.1
St. Croix	-9.6	-8.2	-0.7	-18.4	+12.8	+0.7	-2.8	-13.3

When switching diets from alfalfa to wheat straw or supplemented wheat straw, the animals lost weight rapidly. From literature, supplementation of low quality roughages with urea and molasses has reduced weight loss (Coombe and Tribe, 1960; McInnes and Mangelsdorf, 1966). Coombe (1981) stated that this type of supplement would reduce weight loss or maintain the body weight. This effect was observed in this experiment with Rambouillet and St. Croix sheep. Karakuls lost about the same weight when switched to wheat straw as they did when switched to supplemented wheat straw.

When the animals went from alfalfa to wheat straw during period 2 and period 3, the relative weight loss was even greater. Again, St. Croix were most affected during the third period. During the second period, weight loss for St. Croix was minimal, indicating that even though this breed may be more sensitive to environmental heat, it does better under thermally neutral conditions when changed to wheat straw.

When the animals went from wheat straw to supplemented wheat straw, weight was expected to increase, but this response was observed with Rambouillet only in period 2. There was a slight weight loss in the other two breeds, and during period 3 they all lost considerable weight, St. Croix being, once more, the most affected by the heat.

Alfalfa was better than wheat straw, or supplemented wheat straw.

Alfalfa has been known for a long time to be a good forage for livestock. Franklin, McInnes and Briggs (1967) found that it could be used by Merino sheep as a protein supplement. This was also observed by Minson and Milford (1967). In this experiment, intake of alfalfa was significantly higher than that of the other two diets for all breeds of sheep.

Digestibilities

Dry Matter Digestibility

The results for the dry matter digestibility are given in Table 7. There was no significant difference between breeds. The dry matter digestion of alfalfa was significantly greater than that of wheat straw, but not different from that of the supplemented diet which was not significantly different from the wheat straw. The supplemented diet was, therefore, in between, with alfalfa being highest. The results agree with those found by Robles, Belyea and Martz (1981) who obtained a dry matter digestibility of alfalfa leaves and stems (17% crude protein) of 55%. Ferguson (1942) found the dry matter digestibility of wheat straw to be about 48% higher than that measured here. Foot and Romberg (1965) also reported that the dry matter digestibility of lucerne was higher than that of oat straw. A study in many laboratories (Donefer, 1966) obtained a dry matter digestibility for alfalfa with 18% crude protein to average about 60%. The dry matter digestibility seems to be a function of the crude protein content. This theory is supported by Sutton and Vetter (1971) who found the digestibility of

Table 7. Dry matter digestibility (%).

	Alf Period				WS Period				WS + S Period			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
Rambouillet	47.53	53.84	63.08	54.82a	58.89	50.50	16.84	42.08ab	55.84	60.41	39.41	51.89b
Karakul	65.86	55.49	60.56	60.64a	57.96	36.32	26.43	40.24ab	60.22	49.33	28.18	45.91b
St. Croix	59.69	53.88	48.56	54.04a	63.08	43.42	31.40	45.97ab	59.04	48.63	28.32	45.33b
Average				56.50a				42.76ab				47.71b

a,b Means on the same row or column with different subscripts are significantly different ($P < .05$).

dry matter for alfalfa with 21% crude protein to be 64% and that with 19% crude protein to be 63%.

When looking at the breeds within one type of feed, even though the difference was not significant, alfalfa was better digested by Karakul. Rambouillet had only slightly greater digestibility than St. Croix. St. Croix were the most affected by the heat in the third period. Karakuls were only slightly affected and Rambouillets did better during the hottest period. With wheat straw Rambouillets were the most affected by the third period, but all three breeds had a decreased dry matter digestibility. This depression in the utilization could have been caused by the low intake level of straw during the hottest period. With the supplemented wheat straw, digestibility still tended to decrease with the progressing periods, but the effect was less accentuated. Wheat straw was better utilized by St. Croix, followed by Rambouillet.

Rambouillet responded to the supplementation better than Karakul which did better than St. Croix (not significantly). The latter did not respond at all in terms of dry matter digestibility to the supplement. The depressed intake of wheat straw and supplemented wheat straw observed during period 3 may be due to the heat of the environment which according to Christopherson and Kennedy (1983), affects slowly fermented diets to a greater extent. In general, when intake is decreased, the dry matter digestibility increases because of a longer retention time (Coombe and Tribe, 1963). But in this case, intake was low and the endogenous secretions must have contributed to the low value observed in apparent dry matter digestibility.

Supplementing wheat straw with urea and molasses increased dry matter digestibility, as found by Beames (1960), Hemsley (1964) and Redman, Kellaway and Leibholz (1980). Dry matter digestion is closely related to the digestibility of the various fractions of the feeds.

Organic Matter Digestibility

The organic matter digestibility of the diets is presented in Table 8. It followed the same pattern as dry matter digestibility. There was no significant difference between the breeds, but alfalfa was significantly greater than wheat straw and the supplemented diet was in between, not significantly different from either diets. The organic matter digestion of the supplemented diet, however, was very close to that of alfalfa. Alfalfa still proved to be superior to wheat straw. The values for alfalfa are similar to those found by Sutton and Vetter (1971) of about 59%. The value reported by Ferguson (1942) for wheat straw, however, was higher (52%) as compared to the 47% determined in this experiment. The low value may have been caused by the importance of endogenous secretions to apparent digestion due to low intake levels, especially during the last period of the experiment.

While St. Croix showed a decrease in the organic matter digestibility with each period for alfalfa, Rambouillet showed an increase and Karakul showed a decrease during the second period followed by a slight increase during the last period. When they consumed wheat

Table 8. Organic matter digestibility (%).

	Alf Period 1	2	3	Average	WS Period 1	2	3	Average	WS + S Period 1	2	3	Average
Rambouillet	48.36	56.24	66.76	57.12a	63.15	55.16	20.44	46.25ab	58.14	65.02	45.02	56.06b
Karakul	66.09	54.12	61.36	60.52a	59.61	39.00	36.66	45.09ab	64.58	52.33	64.51	60.47b
St. Croix	60.46	55.92	50.46	55.61a	65.07	46.95	33.50	48.51ab	64.41	55.09	32.08	50.53b
Average				57.75a				46.62ab				55.70b

a,b Means in the same row or column with different subscripts are significantly different ($P < .05$).

straw, the organic matter digestion of all breeds decreased by period. Rambouillet were the most affected, followed by St. Croix. Karakul digested alfalfa best over the three periods, followed by Rambouillet and then St. Croix. However, St. Croix utilized wheat straw better, followed by Rambouillet and then Karakul.

The organic matter digestibility of Karakul was greater for supplemented wheat straw, followed by Rambouillet. The supplementation of straw with urea and molasses usually increases the organic matter digestibility (Tillman, Gallup and Woods, 1957; Redman, Kellaway and Leibholz, 1980; and Klopfenstein et al., 1972).

The various fractions of the organic matter and their digestibilities contribute to total utilization. Egan et al. (1975) found that the completely digested fractions made up 16% of the organic matter in wheat straw, and 27% of that in alfalfa. They had a great effect on the difference in the utilization of these two diets. The organic matter digestibility is also highly correlated with the crude protein, cell-wall constituents, acid detergent lignin and silica content of the feeds (Smith, Nelson and Boggino, 1971).

Crude Protein Digestibility

The results of the crude protein digestibility are given in Table 9. There was no significant difference between the breeds of sheep. However, the crude protein of alfalfa was significantly more digestible than that of wheat straw, and that of the supplemented wheat straw exceeded both, due to NPN in the supplement, though it was not

Table 9. Crude protein digestibility (%).

	Alf Period				WS Period				WS + S Period			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
Rambouillet	66.98	69.34	72.26	69.53a	45.68	28.83	-25.00	16.50b	66.32	76.60	75.57	72.83a
Karakul	73.77	69.72	61.30	68.26a	49.26	22.37	28.83	33.49b	68.76	78.16	73.86	73.59a
St. Croix	58.84	68.84	24.75	50.81a	60.05	28.56	10.15	32.92b	80.17	78.30	62.23	73.57a
Average				62.87a				27.64b				73.33a

a,b Means in the same row or column with different subscripts are significantly different ($P < .05$).

significantly different from that of alfalfa. The dietary crude protein digestibility is directly related to the crude protein content of the roughages. This correlation was verified by a number of workers. Fonnesbeck, Christiansen and Harris (1981) found this relationship to be true with alfalfa and grasses. Sundstol, Coxworth and Mowat (1978) found the digestibility of crude protein in wheat straw to be low. It is, therefore, reasonable to associate the crude protein content of roughages with their nutritive quality. Fonnesbeck, Christiansen and Harris (1981) stated that the crude protein and the available carbohydrates are most related to the digestibility of roughages. These are the major soluble nutrient components of feedstuffs. As a result, high protein roughages fed as a protein supplement increase the digestibility of the low quality forages (Minson and Milford, 1967; Church and Santos, 1981).

Rambouillet utilized the crude protein of alfalfa better than Karakul, and St. Croix utilized it the least. The utilization by St. Croix was also considerably decreased during the third period, showing, once more, the sensitivity of St. Croix to heat (Table 5). Karakul were affected less, and Rambouillet, not at all.

With wheat straw, Rambouillet were the most affected by the heat, and the crude protein digestibility during the third period was negative, which can be explained by the fact that there was more endogenous secretions than crude protein actually digested. St. Croix utilized the crude protein of wheat straw best.

The protein of supplemented wheat straw was equally digested by all three breeds, and there was no change in period three, as the digestibility was similar over all periods for Rambouillet and Karakul, with only a slight decrease for St. Croix. The crude protein digestibility of this feed was higher than that of alfalfa. Urea is readily hydrolyzed into ammonia in the rumen (Briggs, 1967). Since urea ammonia is not associated with protein or the fibrous fractions of the feeds, its hydrolysis is almost complete (Wanapat, Erickson and Slanger, 1982).

The crude protein digestibility, however, causes some problems. The true digestibility is almost always higher than the apparent digestibility (Van Soest, 1967; Holter and Reid, 1959). Furthermore, crude protein is digested both in the rumen and the large intestine. However, the microbial protein formed in the large intestine is not available to the animal because it is excreted and does not have a chance to be digested (Hoover, 1978), and yet, it contributes to the apparent digestibility. In addition, synthesis of amino acids such as methionine and arginine in the hindgut reduces the estimate of their digestibility, whereas destruction of isoleucine, leucine, valine and lysine increases their digestibility. Endogenous secretions could also be significant with low quality feeds. Because of all these facts, the apparent crude protein digestibility of forages is difficult to interpret.

Acid Detergent Fiber (ADF) Digestibility

The ADF digestibility is given in Table 10. There were no significant differences between either breeds or diets. However, ADF

Table 10. Acid detergent fiber digestibility (%).

	Alf Period				WS Period				WS + S Period			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
Rambouillet	33.94	38.28	51.88	41.37	49.89	47.79	10.78	36.15	47.73	54.50	27.29	43.17
Karakul	52.12	35.60	48.18	45.30	51.14	26.76	17.56	31.82	51.91	40.89	2.78	31.86
St. Croix	51.49	40.38	39.34	43.74	57.77	38.85	17.35	37.99	43.28	40.38	5.79	29.82
Average				43.47				35.32				34.95

in alfalfa had a higher digestion than that of wheat straw. The lack of significance was due to the wide variations within periods. Karakul utilized ADF best, followed by St. Croix, then Rambouillet, with alfalfa. With wheat straw, St. Croix utilized the ADF best, followed by Rambouillet. Rambouillet responded more to supplementation with molasses and urea, but on the average, there was no effect on the ADF digestibility.

With alfalfa, the digestibility of ADF increased by period for Rambouillet, whereas that of St. Croix decreased while Karakul results were mixed. Again, St. Croix digestion was most affected in period three. With wheat straw, Rambouillet were most affected by the hottest period (Table 5), followed by St. Croix. During the third period, St. Croix and Karakul had low ADF digestion. This decrease was also due to the depressed level of intake in the third period.

Acid detergent fiber in association with the other fiber fractions has been used as an indicator of the nutritive value of forages (Van Soest, 1965) because some of its fractions are lowly or almost indigestible; such fractions are silica and lignin (Smith, Nelson and Boggino, 1971). Therefore, fiber digestibility, which reflects the availability of forage soluble fractions is important.

It is well documented that the digestibility of the fibrous fractions differs from feed to feed. Foot and Romberg (1965) found that the digestibility of the various fiber fractions of alfalfa was higher than that of oat straw for sheep. The values for the ADF digestibility in the present experiment are similar to those found by Donefer (1966) of 48% for alfalfa having an 18% crude protein content. Barnes (1968) found an ADF digestibility for alfalfa to be 44%, similar to the results of this experiment. Robles et al. (1981) reported that diets containing different concentrations of crude protein had ADF digestibility positively correlated with the crude protein content. From these results, it appears that the ADF digestibility is higher with higher quality forages. Fahey and McLaren (1979) found that lignin which is considered indigestible and sometimes used to predict the nutritive value of forages is digested to an extent, both in the rumen and in the large intestine. The digestibility of lignin, which is a fraction of ADF was 5.8% for alfalfa and - 10.7% for wheat straw. The negative value may have resulted from artifact lignin formed in the gastro-intestinal tract. The lignin in wheat straw is, therefore practically undigested. The degree to which ADF is digested depends on the lignification of the fiber fraction. There is more lignification in wheat straw than there is in alfalfa. The ADF digestibility, therefore, contributes to the nutritive value of roughages. The results with the supplementation do not agree with those found by Hemsley (1964) showing an increase in crude fiber digestion, though not significant. Church and Santos (1981) showed the same tendency. Thus, the effect of urea and molasses is minimal on ADF digestibility.

Neutral Detergent Fiber (NDF) Digestibility

The results of the NDF digestibility for the various roughages by the different breeds are presented in Table 11. There was no significant difference among either breeds or diets. However, with alfalfa,

Table 11. Neutral detergent fiber digestibility (%).

	Alf Period				WS Period				WS + S Period			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
Rambouillet	37.58	38.20	49.36	41.71	61.32	52.51	12.32	42.05	51.99	61.21	34.69	49.30
Karakul	56.71	38.11	45.39	46.74	52.92	33.47	27.78	38.06	56.94	43.53	17.10	39.19
St. Croix	53.30	37.72	38.27	43.10	59.79	41.90	29.65	43.78	54.74	45.24	11.93	37.30
Average				43.85				41.30				41.93

Karakul utilized the NDF best, followed by St. Croix. The effect of the periods followed the same pattern as that of ADF digestibility, for all three diets. With alfalfa, the NDF digestibility increased from the first to the third period for Rambouillet. Karakul showed mixed results and St. Croix sheep NDF digestibility was lower in period 2 then remained constant in the third period. With wheat straw, the NDF digestibility was higher for St. Croix, followed by Rambouillet. From period one to period three, all three breeds had reduced NDF digestibility. The third period affected Rambouillet most. Karakul and St. Croix were similar.

The NDF digestibility found by Robles, Belyea and Martz (1981) of 44% for alfalfa was similar to that determined in this experiment. That reported by Soofi et al. (1981) of 50% was a little higher. Foot and Romberg (1965) found the digestibility of lucerne NDF to be only slightly higher than that of wheat straw.

Neutral detergent fiber estimates the cell-wall constituents (Van Soest, 1967). The difference between NDF and ADF is hemicellulose. There was a larger difference between alfalfa and wheat straw for ADF digestibility, yet the NDF digestibility was similar. This can only mean that the hemicellulose in wheat straw is digested to a greater extent than that of alfalfa or to a similar extent, but wheat straw had a higher content. The NDF content of alfalfa is much lower than that of wheat straw. Conrad, Pratt and Hibbs (1964) reported that when the cell-wall constituents represented more than 50% of the dry matter of forages, the NDF content is most negatively correlated with dry matter intake. The NDF in wheat straw averaged over 60% while that of alfalfa was only slightly over 40%. The NDF digestibility of wheat straw, nearing that of alfalfa, can be explained by a longer retention time in the reticulo-rumen. The NDF digestibility does not account for the difference in the over-all dry matter digestibility of alfalfa and wheat straw.

Cellulose Digestibility

The results of cellulose digestibility are presented in Table 12. There was no significant difference among either breeds or diets. However, the cellulose in alfalfa was slightly higher in digestibility than that of wheat straw. Karakul utilized the cellulose in alfalfa best, followed by St. Croix, which decreased with each successive period. Cellulose digestibility in alfalfa by Rambouillet increased by periods and that by Karakul was mixed. Thus, with alfalfa, St. Croix were negatively affected by period. With wheat straw, Rambouillet were the most affected. The cellulose digestibility decreased for Rambouillet and St. Croix from period one to period three. All three breeds responded positively to supplementation of straw with urea and molasses.

The digestibility of cellulose is closely associated with the dry matter digestibility of roughages (Allinson and Osburn, 1970). That is because cellulose is different for each feedstuff, and the availability of cellulose largely contributes to the over-all digestibility of the roughages. Van Soest (1967) reported that the cell-wall

Table 12. Cellulose digestibility (%).

	Alf Period				WS Period				WS + S Period			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
Rambouillet	40.39	48.52	57.41	48.77	67.95	60.39	26.54	51.63	54.63	68.20	48.23	57.02
Karakul	61.12	44.15	56.48	53.92	59.57	39.25	42.32	47.05	65.44	56.64	34.21	52.10
St. Croix	58.74	51.82	44.90	51.82	64.21	51.37	30.30	48.63	64.42	59.18	31.35	51.65
Average				51.50				49.10				53.59

constituents of grasses were more digestible than those of legumes. The difference may be due to the degree of branching of the glucose units contained in the cellulose. Amos, Evans and Burdick (1976) found the digestibility of cellulose in high-quality forages to be higher than that of low-quality ones. Fahey et al. (1980) reported that the cellulose from different sources had different digestibilities. Fonnesbeck, Christiansen and Harris (1981) showed that cellulose in orchardgrass and smooth brome hay was better digested than that of alfalfa.

Cellulose digestibility was estimated by Robles, Belyea and Martz (1981) to be 54%, similar to the value found in this experiment for alfalfa. Sutton and Vetter (1971) found it to be 59%, and Barnes (1968) reported a 52% digestibility for cellulose. Wilkins and Grimes (1966) showed a 46% cellulose digestibility in wheat chaff.

In vitro cellulose digestibility studies have been reported and found to be very useful in predicting the digestibility of other roughage components *in vivo*. Tomlin, Johnson and Dehority (1965) concluded that cellulose digestion *in vitro* was highly correlated with the nutritive value index of forages, which is the product of the digestible energy of a feed and the relative intake of that feed. Karn, Johnson and Dehority (1967) found it to be highly correlated with *in vivo* dry matter, cellulose, and energy digestion. The rate of cellulose digestion can be used as a measure of bacterial activity (Bentley et al., 1954), therefore, the presence of nitrogen which is necessary for bacterial growth in the rumen will influence the cellulolytic activity. Coombe (1981) stated that nitrogen deficiency was the primary limiting factor in the utilization of cellulose. This may explain the differences in its utilization in wheat straw and alfalfa. But the differences found in this study were not significant. Cellulose digestion is also affected by its lignification (Hemsley, 1964; Van Soest, 1967), which will determine its availability.

Many workers have shown that the cellulose in all roughages is digestible, and that the rate of digestion is the factor that affects its in vivo digestibility (Donefer, Crampton and Lloyd, 1959; McAnally, 1942). The conditions in the rumen, the nitrogen, and mineral content of the diet, and the lignification of the cell-wall constituents will affect the rate of cellulose digestion (Burroughs et al. 1950). The rate of cellulose digestion, in turn, affects the rate of passage which has been shown to be directly related to voluntary feed intake (Robles, Belyea and Martz, 1981).

Generally, addition of urea and molasses to low-quality forages increases the digestion of cellulose by supplying the rumen with nitrogen and minerals. Coombe and Tribe (1960) reported an increase in voluntary feed intake; Belasco (1954), Coombe and Tribe (1963) and Harris and Mitchell (1941) found the same response with supplementation of wheat straw with urea and molasses. In this experiment, the increase was not significant.

Cellulose digestibility is, therefore an important factor in estimating the nutritive value of a roughage, the rate of digestion being critical.

Hemicellulose Digestibility

The results for the hemicellulose digestibility are presented in Table 13. There was no significant difference between breeds, but there was between diets. Wheat straw was not significantly different from alfalfa in hemicellulose digestion. However, that of supplemented wheat straw was significantly higher than that of alfalfa. There was no significance between wheat straw and supplemented wheat straw.

Hemicellulose is the fraction of the forage cell-wall constituents that is soluble in acid detergent (Goering and Van Soest, 1970). It is part of the nitrogen-free extract (NFE), which represents the soluble fraction of roughages (Fonnesbeck, Christiansen and Harris, 1981). These workers also reported that hemicellulose was the most nutritive fraction of the cell-wall constituents. The differences found here might be caused by the differences in the rate of passage of the diets, alfalfa passing faster than wheat straw. Burdick and Sullivan (1963) showed that the ease of solubilization and/or hydrolysis of the hemicellulose was also positively correlated with dry matter and cellulose digestibility.

Karakul sheep utilized the hemicellulose of alfalfa best, followed by Rambouillet, then St. Croix. The last two were similar. Rambouillet utilized that of wheat straw best, followed by St. Croix,

Table 13. Hemicellulose digestibility (%).

	Alf Period				WS Period				WS + S Period			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
Rambouillet	48.40	37.27	39.26	41.64a	86.48	63.87	16.24	55.53ab	62.14	77.35	52.23	63.91b
Karakul	72.42	47.60	32.83	50.95a	57.32	49.84	52.14	53.10ab	69.16	50.40	49.26	56.27b
St. Croix	59.75	25.08	33.36	39.40a	65.19	49.44	49.64	54.76ab	80.13	57.76	26.49	54.79b
Average				44.00a				54.46b				58.32b

a,b Means in the same row or column with different subscripts are significantly different (P < .05).

then Karakul, but the differences were small. With alfalfa, the hemicellulose digestibility decreased in period two, then slightly increased in period three for Rambouillet and St. Croix and Karakul sheep had a decrease from period one to period three. Karakul was most affected by the third period, followed by St. Croix. With wheat straw, the hemicellulose digestibility by Rambouillet decreased steadily from period one to period three. St. Croix had a decrease in period two and there was no change in period three. Karakul had mixed results.

Supplementation with urea and molasses increased the digestibility of the hemicellulose in wheat straw, though not significantly. The same response was obtained with cellulose.

Cellulose, hemicellulose and lignin are closely associated in roughages (Fonnesbeck, Christiansen and Harris, 1981). Their combined digestibilities, which represent the NDF digestibility largely reflect the availability of the nutrients in the fiber fractions.

In Vitro Dry Matter Digestibility

The standard method of *in vitro* digestibility of forages as described by Goering and Van Soest (1970) consisted of the use of rumen fluid from a fistulated steer fed alfalfa, fermentation for 48 hours. The dry matter disappearance was found to be 69.5, 70.5 and 73.4% for wheat straw, alfalfa and supplemented wheat straw, respectively. Wheat straw and supplemented wheat straw were significantly different, but alfalfa was not significantly different from either.

The supplementation with urea and molasses, therefore, increased *in vitro* dry matter disappearance over 48 hours which represents the maximum potential digestibility. This result can be explained by the fact that when nitrogen is supplied to a low-nitrogen roughage in the rumen, the number of cellulolytic bacteria increases, and the digestion of the cellulose is improved (Henderickx, 1967). Nitrogen was found by Coombe (1981) to be the limiting factor in the utilization of low-quality roughages.

However, the results here cannot be interpreted as related directly to *in vivo* rumen digestion for many reasons:

A) The inoculum came from the rumen of a steer, and many workers have found the ruminal digestion of cattle and sheep to be different for various roughages. Alexander et al. (1962) reported that grass hay of low-protein content was digested by sheep better than by cattle. Poppi, Minson and Ternouth (1981) found that cattle were more efficient in digestion of dry matter and NDF of grasses than sheep. Bird (1974) showed the same results with cereal roughages. The crude protein digestibility of low-protein roughages was greater by sheep, and that of high-protein roughages was greater by cattle (Lippke, 1980). Forbes (1950) also found with forages with over 15% crude protein that cattle and sheep were similar digesters of the protein in roughages; however, cattle almost always digest the dry matter in forages better than sheep (Blaxter, Wainman and Davidson, 1966; Buchman and Henken, 1964). Therefore, in the *in vitro* estimation of dry matter disappearance for sheep diets, the values with cattle inoculum would overestimate those expected with inoculum from sheep. Cattle also respond to nitrogen supplementation better than sheep (Bird, 1974). All these results suggest that the rumen microorganisms of cattle may utilize the nutrients in forages better than those of sheep (Playne, 1978) and cattle inocula should not be used for *in vitro* evaluation of sheep diets.

B) The *in vitro* dry matter disappearance is not directly related to the dry matter digestibility of roughages. Karn, Johnson and Dehority (1967) reported a correlation of only 0.65 between the two. In this experiment, the nutritive value of alfalfa is much higher than that of wheat straw; yet, the *in vitro* dry matter disappearance of the two was similar.

C) The feed the donor animal was on when the inoculum was taken also affects the *in vitro* dry matter disappearance. Reid, Jung and Murray (1964) showed that *in vitro* digestibility was higher with inoculum from hay than from fresh grass, and Gallinger and Kercher (1964) found that significantly more dry matter disappeared from the nylon bag when the fistulated steers were fed alfalfa hay than when fed alfalfa hay plus barley. Bezeau (1965) reported differences in dry matter disappearance of alfalfa hay and grass hays with different sources of inoculum. In this experiment, the results of alfalfa are more valid because inoculum was from alfalfa fed animals.

D) Another reason *in vitro* dry matter disappearance was not an appropriate comparison is that the rate of digestion of roughages *in vivo* is not the same (Table 14). This fact is reflected in the difference in the rate of passage of food in the gastro-intestinal tract and in the difference in the voluntary intake of various feeds (Laredo and Minson, 1973; Poppi, Minson and Ternouth, 1981; Siebert and Kennedy, 1972). From the intake data, alfalfa would be expected to have a faster rate of passage. With *in vitro* studies, Hershberger and Hartsook (1970) found that maximum fermentation of alfalfa occurred between 5 and 11 hours. Foot and Romberg (1965) showed that alfalfa had a much higher nutritive value than most straws. Burroughs et al. (1950) found that with a 36-hour incubation time, the cellulose of alfalfa was digested much more efficiently than that of wheat straw. These results suggest that alfalfa is fermented at a faster rate than straw, then fermentation levels off (Figure 1). Wheat straw is fermented more gradually and in 48 hours enough of it is fermented to almost equate the fermentation of alfalfa. A 48 hour *in vitro* fermentation may approximate potential digestion rather than *in vivo* values.

Table 14. Rate of dry matter disappearance *in vitro* (%).

Incubation Time (Hours)	Alfalfa	Wheat Straw
4	58.4	35.1
8	60.4	36.4
16	64.0	46.4
48	72.0	66.1

Most researchers found the rate of cellulose digestion *in vitro* to be a better indicator of roughage nutritive value and dry matter digestibility (Karn, Johnson and Dehority, 1967; Tomlin, Johnson and Dehority, 1965; and Hershberger et al., 1959), the appropriate incubation time was about 12 hours (Laredo and Minson, 1975; Donefer, Crampton and Lloyd, 1959; 1960).

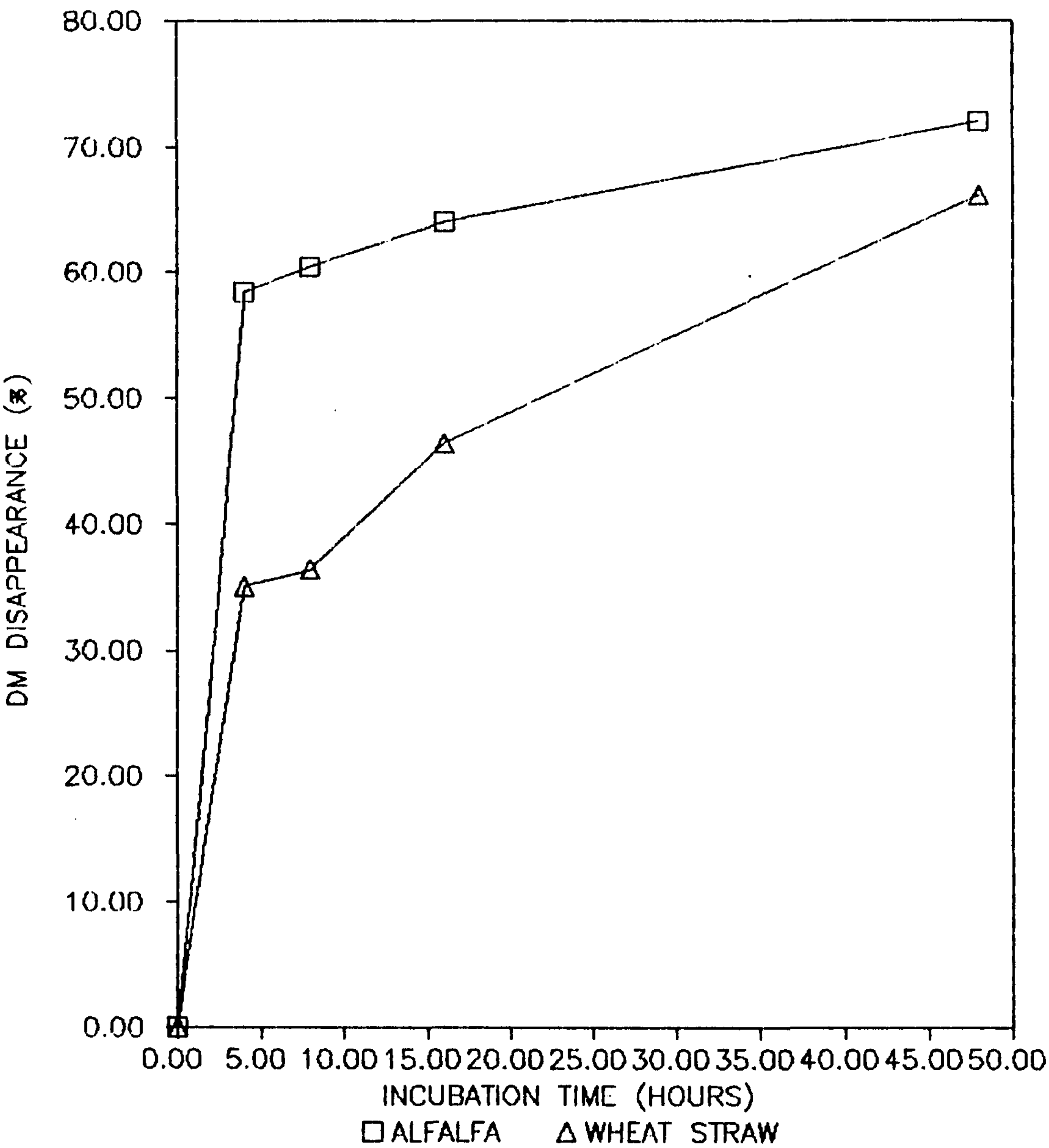

Figure 1. *In vitro* fermentation curve of alfalfa and wheat straw.

CHAPTER 5

CONCLUSIONS

The soluble carbohydrates and other readily available nutrients in feedstuffs are digested almost completely by sheep and other ruminants. The fibrous fractions, however, are only partially digested. The most important fraction of fibers is cellulose. Its digestibility, which depends on its association with hemicellulose, lignin and cell-wall nitrogen, determines the nutritive value of roughages. Alfalfa has more nitrogen and soluble carbohydrates than wheat straw and its cellulose and lignin are more digestible. Therefore, alfalfa is more readily digested than wheat straw, and will pass through the digestive tract faster. Cellulose can be broken down to a high degree by the rumen microorganisms when favorable growth conditions are present. However, the rate of digestion depends on lignification. The cellulose in wheat straw is not retained long enough in the digestive tract to be acted upon efficiently by the microorganisms (Burroughs et al., 1950; McAnally, 1942). Addition of urea and molasses provides the nitrogen and the energy necessary for the growth of the cellulolytic rumen microorganisms, resulting in increasing the rate of cellulose digestion. However, urea is hydrolyzed rapidly and lost by absorption and subsequent excretion (Drori and Loosli, 1961). Utilization of feedstuffs supplemented with urea and molasses is, therefore, less efficient than that of feedstuffs supplemented with natural proteins.

Sheep consume roughages to achieve a maximum fill of their reticulo-rumens. The faster the digesta passes through this compartment, the higher the voluntary feed intake of sheep. Feed intake of alfalfa is higher than that of wheat straw. The feed intake, along with the crude protein and the cell-wall content, can be used to predict the nutritive value of roughages.

When using *in vitro* techniques to estimate the digestibility of feeds, the cellulose digestion at about 12 hours is more closely related to *in vivo* results. Addition of urea and molasses resulted in a greater improvement in digestibility *in vitro* than it did *in vivo* in this experiment.

The environment, here reflected in the periods from March to June had a significant effect on intake and therefore, on the digestibility of the wheat straw and the supplemented wheat straw especially. The effect on alfalfa was minimal. The Rambouillet breed tended to be affected the most when consuming wheat straw, while St. Croix was affected the most when consuming alfalfa. Karakul had mixed results.

Alfalfa produced a considerable weight gain in all breeds, and wheat straw and supplemented wheat straw caused a great loss in weight in all three breeds. Alfalfa is, therefore, a much better quality feed than wheat straw, even when the latter is supplemented with urea and molasses.

Intake of feed, in absolute terms, was directly related to the body weight of the animals. However, the intake per 100 kg of live body weight was similar for all three breeds.

Karakul tended to digest the dry matter, organic matter, ADF, NDF, cellulose, and hemicellulose of alfalfa the most, followed by Rambouillet, then St. Croix. With wheat straw, St. Croix utilized dry matter, organic matter, ADF and NDF the most, followed by Rambouillet, then Karakul. Crude protein of alfalfa was better digested by Rambouillet and Karakul, and that of wheat straw was better utilized by Karakul and St. Croix. The cellulose and hemicellulose of wheat straw was better digested by Rambouillet, followed by St. Croix. The differences were not significant.

Karakul and Rambouillet seemed to utilize the alfalfa better than St. Croix, and St. Croix and Karakul to digest the wheat straw better than Rambouillet.

Based on this experiment, wheat straw can provide nutrients only for a sub-maintenance in sheep. It has to be supplemented, if it is fed to sheep.

There were differences in breeds of sheep utilization of good and poor quality forage. There was a tendency for greater utilization by the St. Croix of a low-quality diet of wheat straw, whereas Rambouillet were superior in the utilization of the alfalfa diet (high quality).

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