EFFECTS OF FEEDING LOW-QUALITY ROUGHAGES

ON PERFORMANCE AND WHEAT FORAGE

UTILIZATION OF STOCKER CATTLE

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CHAPTER I

INTRODUCTION

Low-quality roughages (LQR) such as wheat straw are commonly fed to stocker cattle[a] grazing wheat pasture. Reasons cited by producers for feeding low-quality roughages to cattle on wheat pasture include the following: (1) extension of wheat pasture, (2) a means of slowing rate of passage and thereby increasing the efficiency of utilization of "washy" wheat forage, (3) for heat (e.g., to increase the heat of ruminal fermentation) and (4) to reduce the incidence of bloat. Perhaps the most important question relative to the feeding of low-quality roughages to wheat pasture stockers is what effect it may have on wheat forage intake and stocker weight gains. If, for example, .91 to 1.36 kg of wheat straw were substituted for wheat forage on an equivalent-weight basis, stocker daily weight gains would be reduced by as much as .21 kg/day (.96 versus .75) as indicated in table 1. On the other hand, if the intake of wheat forage is not limited by the capacity of the rumino-reticulum and by the rate of disappearance of digesta from this organ (bulk-fill concept; Balch and Campling, 1962; Troelsen and Campbell, 1968), then the intake of LQR should not reduce wheat forage intake and rate of gain.

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[a]Young or recently weaned animals which are grown to heavier weights, usually on pasture, before being placed in the feedlot.

Intake of high quality feedstuffs with dry matter digestibilities greater than about 66 percent, generally is not limited by passage rate or indigestible bulk in the digestive tract (Blaxter et al., 1961; Conrad et al., 1964; Forbes et al., 1969).

TABLE 1. CALCULATED DAILY WEIGHT GAINS OF WHEAT PASTURE STOCKERS[a]

	All wheat forage	Wheat forage + .91 kg straw	Wheat forage + 1.36 kg straw
Daily gains, kg	.96	.82[b]	.75[b]
Change from "all wheat forage", kg	----	.14	.21

[a]Calculated for a 200 kg steer with a total dry matter intake (wheat forage alone or wheat forage plus straw) of 3 percent of body weight.

The following energy densities (Mcal/kg DM) were used:

	$NE_{main.}$	NE_{gain}
Wheat forage	1.51	0.92
Wheat straw	1.03	0.19

[b]Calculated on basis of equivalent weight substitution of straw DM for wheat forage DM.

From a dry matter digestibility point of view, the bulk-fill concept of feed intake regulation would not be expected to regulate wheat forage intake by stocker cattle since the estimated in vivo dry matter digestibility of wheat forage will commonly be in the range of 75 to 85 percent (Horn et al., 1977). The high water content of wheat forage, however, might limit wheat forage dry matter intake. Dodsworth and Campbell (1952 and 1953) have suggested that the performance of animals fed largely on "succulents" is likely to be affected by the dry matter percentage of the diet insofar as high performance can only be expected if the dry matter percentage of the diet as a whole is maintained above some critical level. In the studies of Dodsworth (1954), sheep fed 19.46% dry matter silage consumed 16.7% more dry matter and 19.8% more starch equivalent than sheep fed 15.85% dry matter silage. However, the critical level of dietary dry matter content and possible effects on dry matter intake has not been precisely defined.

In regard to the effect of feeding LQR on weight gains of wheat pasture stockers limited data is available. In the "limit grazing small grain pastures" studies conducted at the Samuel Roberts Noble Foundation, stockers grazed small grain pastures for various periods of time each day and had ad libitum access to grass hay when not on small grain pastures. In this four year study, the daily gains (kg) of stockers which grazed continuously, or restricted to grazing four h, two h, or one h per day on small grain pastures were, respectively, 1.00, .59, .60 and .38 (Altom, 1978) In studies conducted by Davis et al. (1973) daily gains of steer calves grazed on wheat pasture and an adjacent milo stalk field were decreased by 0.13 kg/day (.71 vs .58) when compared to gains of steers grazing wheat pasture only. However, the wheat pasture stocking rate was increased from 1 steer per 1.66 ha to 1 steer per 1.29 ha of wheat pasture for the steers having access to the milo stalk field. The substitution of 20% wheat straw into high-corn silage diets decreased steer daily gains by 0.21 Kg (1.12 vs 0.90) in studies conducted by Lesoing et al. (1978). One to 1.4 kg of straw dry matter would constitute 17 to 23 percent of the total dry matter consumed by a 200 kg steer with a dry matter intake of 3 percent of body weight. The results of these studies indicate that any management practice which would allow stocker cattle to substitute a LQR for high-quality wheat forage would decrease stocker weight gains. However, no data are presently available from which to evaluate the practice of feeding LQR to wheat pasture stockers.

Meyer et al. (1956) and Hull et al. (1957) reported that feeding 1.36 to 2.27 kg of either oat hay or sudan grass hay "effectively controlled" bloat in steers grazing the young, lush regrowth of alfalfa. Other studies have shown that the inclusion of scabrous material, such as prairie grass hay, in the ration of cattle strengthened ruminal motility and decreased the incidence of bloat (Colvin et al., 1958b); and that the feeding of 0.75 kg of oat hay per 100 kg of body weight (the night before a morning feeding of fresh-cut alfalfa tops) increased eructation efficiency (Colvin et al., 1958a). The practice of feeding LQR to wheat pasture stockers therefore, can be based on some sound principles, and may reduce the incidence of bloat by (1) maintaining or reinforcing normal ruminal motility and eructation and (2) physically preventing the formation of a frothy, glutinous mass within the rumen. However, no research data are available concerning the influence of LQR on bloat of stocker cattle grazing wheat pasture.

CHAPTER II

REVIEW OF LITERATURE

Factors Associated with the Utilization of Small Grains (Wheat) Forage by Stocker Cattle

Steer Performance Versus Changes In Forage Growing Conditions

In years favorable to the growth of winter wheat pasture, more than 1.5 million stocker cattle graze wheat pastures in Oklahoma. The usual wheat pasture grazing period is from November 1 to March 15. Graze-out programs will extend the grazing period into May, however. Weight gains of stockers grazed on wheat pasture will generally range from .57 to .90 kg per head per day. However, gains greater than 1.25 kg per head per day have been observed. Gains of this magnitude are indicative of the high quality forage found in small grains pasture.

Wyatt (1977) reported that small grains forage provides an excellent source of nutrients for cattle, and usually contains 25 to 30% crude protein and 65 to 75% TDN on a dry matter basis. Under dry land conditions, forage yields of 2240 to 5600 kg of dry matter per hectare are common with production potentials of 224 to 560 kg of beef per hectare.

The chemical composition of wheat forage grown in Oklahoma for the months of the normal wheat pasture growing season is presented in table 2.

TABLE 1. AVERAGE DRY MATTER, CRUDE PROTEIN (DM BASIS) AND IVDMD[a] OF OKLAHOMA WINTER WHEAT PASTURE

	Dry Matter		Crude Protein			IVDMD[a]
Year:	1940-41[b]	1977-78[c]	1940-41[b]	1974-75[d]	1977-78[c]	1974-75[d]
November	31.5	24.2	22.7	--	21.9	--
December	30.6	35.3	20.2	--	20.1	--
January	32.7	41.0	21.9	27.1	21.2	62.2
February	37.0	--	19.3	22.5	--	76.0
March	28.0	35.0	24.2	25.3	24.4	81.5
April	25.3	18.7	25.5	--	29.6	--

[a]IVDMD = in vitro dry matter digestibility.

[b]McMillen and Langham, 1942.

[c]Frost, 1978.

[d]Horn et al., 1976.

In general, the dry matter percentage in wheat forage increases from November to January and (or) February and then declines. By April wheat forage dry matter tends to be around 20 to 25% and typically lower than the wheat forage dry matter observed during the first part of the grazing season. Crude protein content of wheat forage as a percentage of dry matter is fairly constant during the first part of the grazing season. A slight decline in crude protein may be observed during the period of winter dormancy (late January and February). By March and April wheat forage crude protein generally reaches its maximum and can comprise over 31% or of the total dry matter (Horn et al., 1974). In vitro dry matter digestibility, tends to follow a pattern similar to crude protein, reaching maximum levels (75 to 80%) after the period of winter dormancy. However, Horn et al. (1981) reported digestibilities of wheat forage that were greater than 80% in periods prior to and after winter dormancy.

Steer weight gains measured at different time periods during the grazing season have been reported by McMillen and Langham (1942) for steers grazing wheat pasture and by Elder (1967) for steers grazing small grains pasture. McMillen and Langham (1942) reported gains of .40 kg per head per day for steers grazing wheat pasture during the period of winter dormancy. Weight gains exceeded .70 kg per head per day during the lush spring growing period (March to mid-April). Elder (1967) reported gains of over 1.0 kg per head per day during the periods prior to and after winter dormancy. The greatest gains (1.12 kg per head per day) were obtained in the month of April on well fertilized pastures. Gains during the period of slow winter growth averaged .58 kg per head per day and over the entire grazing season were .68 kg per head per day. These studies were conducted on pastures planted with a mixture of wheat, rye, oats and vetch. On the average, pasture stocking rates were .38 head per hectare at the start of the grazing period (November), reduced to .24 head per hectare by February and increased to .45 head per hectare by mid-April. Lower weight gains were observed during the period of winter dormancy, even though adjustments in stocking rates were made based upon the availability of forage.

These data suggests that the weight gains of steers grazing small grains pasture depend on forage availability and quality. For producers who maintain constant stocking rates on small grains pastures, a depression in steer performance would result during the period of winter dormancy, provided stocking rates were such that available forage was adequately utilized during the periods prior to and after winter dormancy. The quality (crude protein and digestibility) of small grains pastures, although very high when compared to most other forages, influences steer weight gains. During periods of lush growth (i.e. after period of winter dormancy) gains of steers grazing small grains tend to be greater than gains during previous periods.

Effect of Forage Moisture Level on Forage Intake and Utilization

The effect of forage moisture level on forage intake has been examined mainly with ruminants fed mainly grass and legume silages. Dodworth and Campbell (1952 and 1953) fed sheep grass silage or grass silage with water added. Dry matter levels of consumed silage ranged between 16.85% and 22.66%. Intakes of silages on a wet basis were similar indicating forage dry matter intake was limited by the quantity of moisture consumed. Wetter silages had lower digestibilities (69.8 vs 73.7%). However, only two sheep per treatment were used in these studies and no statistical analysis of data was conducted. Dodsworth

(1954) fed three sheep per treatment grass silage containing 15.9 or 19.5% dry matter. Daily dry matter intake was lower (919 vs 787g) for sheep rceiving the low dry matter silage. The digestibility of the control silage was slightly higher (72.8%) compared to the low dry matter (69.8%) silage.

In studies conducted by Campling and Balch (1961) addition of 45.4 kg of water to the contents of the rumino-reticulum, did not affect voluntary hay intake of Friesian and Shorthorn cows. Also, in studies conducted by Gharib et al. (1970) daily gains of crossbred Charolais steers fed a ration containing 60% water were not significantly different from steers fed the same ration with no added water (12% moisture). Feed dry matter intake was only slightly decreased (7.5 versus 7.9 kg/day).

In studies conducted by Thomas et al. (1961) with alfalfa silages and Ward et al. (1966) with sorghum silages, positive correlations ($r =$ .71 to .95) were found between dry matter intake of silage and dry matter content. However, Thomas et al. (1961) found no difference ($P >$ .05) in dry matter intake of fresh (18 to 54% dry matter) versus dried (90% dry matter) silage. Thomas et al. (1961) concluded that differences in dry matter of forage at ensiling results in differences in fermentation; the end products of which are major determinants of the amount of silage consumed rather than the moisture content of the silage per se. Ward et al. (1966) suggested that the mechanism of feed intake depression associated with high-moisture silage appears to involve organic acid concentrations. The lower pH, together with the lower dry matter concentration of high-moisture silage, indicates a proportionately greater concentration of volatile fatty acids per unit of dry matter.

Other studies conducted by Lake et al. (1973) compared the intake and performance of steers fed fresh forage (22% dry matter) or dried (81% dry matter). Two 30-day trials were conducted utilizing 22 yearling steers. Forage was harvested daily from an irrigated pasture (mixture of orchard grass, smooth brome and alfalfa) and fed immediately or dried to be fed the next morning. Daily dry matter intakes were similar (7.85 versus 7.89 kg). Average daily gains were slightly greater ($P > .05$) for steers fed the dried forage (.99 versus .93 kg). However, apparent dry matter digestibility of forage was similar (59.3 versus 59.1%).

The above data refute the concept that the dry matter content of forages effect forage dry matter intake. Differences in forage dry matter intake are most likely associated with differences in structural characteristics which influence rate of digestion in and rate of passage from the rumen. In the case of silages, fermentative characteristics are most likely the major determinants in dry matter intake.

Factors Associated with Bloat of Steers Grazing Wheat Pasture

Frothy bloat is a major herd health problem of stocker cattle grazed on wheat pasture. Stocker death losses due to bloat are believed to be about 2.5 percent of total stockers, and have been as high as 20% on some wheat pastures. Some basic points relative to the etiology and prevention of frothy bloat in wheat pasture stockers are as follows: (1) Bloat occurs when the rate of removal of rumen fermentation gases through the esophagus is less than the rate of production. This may result from an increased rate of production of gases, or from impaired function of the rumen, cardia or esophagus. (2) Rumen fermentation gases may become entrapped in ruminal fluid froth or foam and cannot be eructed regardless of the functionality of the rumen and other digestive organs. (3) The chemical composition of wheat forage changes depending upon environmental growing conditions, stage of wheat plant growth or maturity, fertility level, etc; and, therefore, would be expected to effect the degree or likelihood that a stable ruminal foam would be formed when wheat forage is grazed by stockers. The major factors contributing to the occurrence of frothy bloat of stocker cattle on wheat pasture are (1) wheat forage intake, (2) rate of ruminal digestion of wheat forage, (3) level of crude protein and dry matter in wheat forage, and (4) grazing behavior of steers on wheat pasture.

Wheat forage intakes required to support the observed daily gains of stockers on pasture are high. Based on the net energy values for wheat forage given in table 1 and the NRC nutrient requirements of Beef Cattle (1976) wheat forage intakes (dry matter basis) of 2.4 to 2.7% of body weight are required to support a gain of .9 kg for a 250 kg steer grazing wheat pasture. This same steer would consume on the average over 21 kg of wet forage daily to support the specified gain, assuming the wheat forage is 30% dry matter.

The role of ruminal digestion, as a factor which may influence wheat forage intake, has not been quantitated. Horn (1974) suggested that the rate of ruminal digestion of wheat forage is very rapid and this coupled with the high forage intakes mentioned above are conducive to the production of extremely large volumes of rumen fermentation gases. In the event that the animal is unable to eructate these gases, due to an impaired rumen function or entrapment of gases in ruminal fluid of froth, bloat would result.

Another factor associated with bloat of wheat pasture stockers is the level of crude protein and dry matter in the wheat forage. Levels of these components in wheat forage have been shown previously in table 2. A possible relationship between the incidence of bloat in wheat pasture stockers and the crude protein content and other nitrogen containing fractions of wheat forage has been suggested by Bartley, Barr and Mickelsen (1975).

Results of analyses of wheat forage samples collected during the spring of 1973 from Oklahoma wheat pastures where (1) bloat was not observed and (2) bloat was frequently observed and (or) stockers had very recently died of bloat have been reported by Horn et al. (1977). Forage samples from bloat-provocative pastures contained less dry matter and total fiber (neutral-detergent fiber). The concentrations of crude protein and soluble nitrogen fractions (total soluble N, soluble protein N) of forage samples from bloat provocative pastures were all significantly greater ($P < .05$).

How dry matter content of wheat forage influences bloat is not completely known, although, the incidence of bloat on bloat-producing legume pastures is greater on more succulent forage. Similarly, it would be expected that the incidence of bloat in stockers on wheat pasture would increase with increasing forage water content as water content reflects stage of forage maturity and the presence of foam stabilizing chemical components. Also, wheat pasture stockers may be unable to eructate ruminal fermentation gases in the presence of excessive amounts of liquid digesta in the rumen.

A final factor believed to be associated with bloat in wheat pasture stockers is changes in grazing behavior, which occurs most often in these cattle in response to the movement of weather fronts through the area (Horn et al., 1976). A period of little or no grazing followed by a period of very active grazing would be conducive to the bloating of cattle.

Effects of Feeding Low-Quality Roughage to Cattle Grazing High-Quality Forage

Bloat

Studies reported by Cole et al. (1943) and Cole and Kleiber (1945) have demonstrated that feeding dairy cattle sudan grass hay or allowing cattle to graze sudan pasture overnight would prevent bloat in cattle grazing immature alfalfa pasture. Cows needed to consume greater than 7 kg of sudan daily for complete protection against bloat. However, Hull et al. (1957) effectively controlled bloat in steers by feeding 1.4 to 2.3 kg sudan grass hay per head per day prior to grazing alfalfa. Hogg and Barrentine (1951) reduced the incidence of bloat in the morning grazing period, but not in the afternoon, by prefeeding 2.3 kg hay. If ad libitum access to hay was permitted, prior to grazing, more effective control of bloat was achieved. They suggested that hay or grain feeding twice a day could control bloat.

In studies where dry roughage other than sudan hay was fed to cattle on bloat provocation pastures, Mead et al. (1944) reported that barley straw fed at 1.5 kg per head per day was ineffective in preventing bloat in dairy cattle grazing alfalfa pastures. In contrast, Meyer et al. (1956) reported that oat hay fed overnight at 1.4 to 2.3 kg per head was effective in preventing bloat in steers grazing alfalfa pastures. In these studies it was not necessary to feed oat hay to steers on a dry alfalfa hay diet. This is consistent with the concept that water content of succulent bloat-provocative forages contributes to the incidence of bloat. However, daily gains of steers fed the dry alfalfa hay were significantly lower ($P < .05$; .76 vs. 82 kg) than gains of steers receiving fresh-cut alfalfa. Ittner et al. (1954) fed out hay at 1.2 kg per head per day to steers grazing or being fed alfalfa. They indicated that bloat was never a problem in any of the treatments, but that two pasture lots required slightly more hay to maintain firm feces and to preclude the danger of bloat. The above studies would suggest that in the case of steers grazing bloat-provocative pastures, dry roughage fed at 1.2 to 2.3 kg per head per day aids in reducing the incidence of bloat.

Other means of controlling bloat have been attempted by Cole et al. (1945) and Davis et al. (1973) where cattle were allowed to simultaneously graze adjoining pastures of bloat-provocative and non-bloat-provocative forages. Cole et al. (1945) reported that heifers, having access to alfalfa on one end and Sudan on the other, did not extensively graze the alfalfa until the sudan was almost depleted. In contrast, David et al. (1973) grazed steer calves on adjacent wheat pasture and milo stalk fields and effectively utilized the wheat pasture, although daily gains were slightly depressed (.58 vs .71 kg) when compared with gains of steers grazing wheat pasture only.

The mechanism by which dry roughage aids in preventing bloat has been studied by Colvin et al. (1958a). They reported that feeding cows and steers .75 kg of oat hay per 100 kg of body weight the night before a morning feeding of fresh-cut alfalfa increased eructation efficiency. Colvin et al. (1958b) further reported the scabrous material in the diet is necessary to maintain the tonic activity of the central pool of motor neurons responsible for proper rumen motility. Similar conclusions were reached by Schak and Amadon (1928). Other researchers have indicated that feeding a dry, lower quality roughage reduces the incidence of bloat in cattle utilizing high-quality, bloat-provocative pastures by (1) maintaining or reinforcing normal ruminal motility and eructation (Cole et al. 1942) and (2) physically preventing the formation of a frothy glutinous mass within the rumen (Clark and Quin, 1945).

Performance

In early studies (Meyer et al., 1953; Ittner et al., 1954; Meyer et al., 1956; Hull et al., 1957), steers were assigned to different alfalfa production systems and were fed levels of Sudan hay or oat hay between 1.3 and 4.8 (usually less than 1.7) kg per head per day. In general weight gains of steers were not significantly ($P>.05$) affected by level of sudan or oat hay fed. On the average, steers consuming the higher levels of Sudan or oat hay achieved gains equal to or slightly greater than gains achieved by steers consuming lower levels of Sudan or oat hay.

Based on alfalfa pasture studies, Cole and Kleiber (1945) concluded that, in general, feeding sudan hay stimulated alfalfa intake

(9.2 vs. 8.4 kg, as is basis) of dairy cows and that feeding hay, even at levels of consumption above 7 kg per head daily, did not reduce intake of alfalfa. Alfalfa intakes were estimated from the weight change during a 2 h grazing period.

In regard to studies conducted with cattle grazing wheat pasture, McMillen and Warren (1942) reported that steers and heifers fed dry sumac cane free choice on wheat pasture consumed .41 kg cane per head per day and out-performed steers grazing only wheat pasture (.70 vs. .67 kg per head per day). In a four-year study (Altom, 1978), stockers grazed on small grains pastures continuously, or were restricted to four, two or one h grazing daily. Stockers had ad libitum access to grass hay when not on small grains pastures. Daily gains were 1.00, .59, .60 and .38 kg per head for steers on the respective treatments. Davis et al. (1973) reported also that gains of steer calves grazed on wheat pasture and an adjacent milo stalk field were decreased by 18% (.71 vs. .58 kg per day) when compared to daily gains of steers grazing wheat pasture only. However, stocking rate on the wheat pasture was increased by 22% (1.66 vs. 1.29 ha per steer) by steers utilizing the milo stalk field.

In summary data would suggest that dry low-quality roughage consumed by stocker cattle grazing wheat pasture has no have an adverse affect on total beef production per hectare. If daily gains of steers grazing wheat pasture are depressed by feeding a low-quality roughage, although data is inconclusive regarding this (in some cases gains were increased), a corresponding increase in stocking rate would offset the losses in weight gain attributed to the low-quality roughage.

Models for Quantification of Rate of Passage of Digesta Through the Ruminant Gastrointestinal Tract

Although the term rate of passage has been used interchangeably with rate of flow, rate of transport and turnover rate, it has come to be defined as the time required for a quantity (weight or proportion of digesta from a given meal to pass a specific point along the alimentary tract (Balch and Campling, 1965 and Kotb and Luckey, 1972). Numerous factors can alter rate of passage of digesta through the gastrointestinal tract. These include the following: (1) Level of intake and types of feed in the diet (Blaxter et al., 1955; Lambourne, 1957a and b; Graham and Williams, 1962; Coombe and Kay, 1965; Grovum and Hecker, 1973; Grovum and Williams, 1973a; Evans et al., 1973; Ulyatt and Macrae, 1974; Teeter, 1981), (2) particle size and density of feedstuffs (Balch and Kelly, 1950; Campling and Freer, 1962; Evans et al., 1973; Ellis, 1978; Mertens and Ely, 1979), (3) degree of mastication (Welch and Smith, 1969 and 1970, Troelsen and Bell, 1969), (4) rate of digestion (Waldo, 1972; Mertens, 1973 and 1977; Ellis, 1978) and (5) age, weight and sex of animal (Dawson, 1972; Kass et al., 1980). Other less defined factors include interactions among different feeds in the diet with each other and the rumen microbial population. Of the above mentioned factors, rate of digestion or particle size reduction, particularly in all-forage diets, exerts the greatest influence on rate of passage and has been studied in great detail (Waldo, 1972; Ellis, 1978; Mertens and Ely, 1979).

In an attempt to quantitate rate of passage and/or rate of digestion of ingested feedstuffs, several models have been proposed (Blaxter et al., 1956; Brandt and Thacker, 1958; Hungate, 1966; Matis, 1972; Waldo, 1972; Grovum and Williams, 1973c; Ellis, 1978; Ellis et al., 1979; Mertens, 1973 and 1977; Mertens and Ely, 1979). From these models, two general types emerge.

The first type represents the rate of passage of digesta, based upon the appearance of a marker or label (administered to the animal as a single pulse dose) in the feces. This type of model illustrated by Blaxter et al. (1956), Brandt and Thacker (1958), Matis (1972), Grovum and Williams (1973c) and Ellis et al. (1979) suggest that the fecal excretion curve represents a sequential two compartment flow process. Brandt and Thacker (1958) suggested that one pool is the reticulo-rumen while the other pool is the remaining part of the gastrointestinal tract. Coombe and Kay (1965) and Grovum and Williams (1973 b and c) arrived at similar conclusions and have some evidence which suggests the cecum and proximal colon comparise the second pool. Hungate (1966), Matis (1972) and Ellis et al. (1979) proposed similar two-pool models but indicated that the first pool contained the coarse particles to be ruminated and the second pool was the material capable of leaving the rumen without further change in particle size. Of these models, those utilized by Grovum and Williams (1973c) and Ellis et al. (1979) have become most widely accepted to represent rate of passage of digesta through the gastrointestinal tract based upon the fecal excretion data. These two models will be discussed in more detail later in this thesis.

A second type of model, which has more recently been developed, attempts to assess the disappearance of fibrous constituents from the digestive tract of the ruminant. These models (Waldo, 1972; Ellis, 1978; Mertens, 1973 and 1977; Mertens and Ely, 1979) partition the dynamic process of fiber dissappearance into various components: (1) potential or maximum extent of digestion (2) rate of particle size reduction and/or digestion, (3) digestion lag and (4) rate of passage. Although it is not the intent of this paper to characterize the kinetics of fiber digestion a brief discussion of these models is presented below.

Models of Fiber Digestion and Passage in the Ruminant Animal

Waldo (1972) proposed a model for cellulose disappearance from the rumen. The model divides cellulose into two components: potentially digestible and indigestible. Indigestible cellulose is that component never digested even, if it were retained in the rumen for an infinite time period. Assuming that substrate supply is limiting, rate of digestion of the digestible fraction and rate of passage of the digestible and indigestible fractions are assumed to display first-order kinetics. Therefore, the disappearance of cellulose from the rumen would be described by the following differential equations:

$$\frac{dA}{dt} = - k_1A - k_2A \qquad (1)$$

$$\frac{dB}{dt} = - k_2B \qquad (2)$$

where A is the quantity of potentially digestible cellulose in the rumen; B is the quantity of indigestible cellulose in the rumen; k_1 is the cellulose digestion rate constant; k_2 is the cellulose passage rate constant; and t is the time elapsed. Solving these two differential equations and adding the terms of the two solved equations together, the portion of a cellulose meal (f) remaining at time t is obtained and equal to:

$$f = ae^{-(k_2 + k_2)t} + be^{-k_2 t} \tag{3}$$

where a is the fraction of total cellulose which is the potentially digestible and b is the fraction of total cellulose which is indigestible. The problem with this model is that it does not incorporate all components of fiber into the model and it ignores the digestion lag in the rumen which is normally associated with fibrous diets.

Mertens (1973), ignoring rate of passage, proposed five different models for cell wall digestion which were based upon rates of dry matter disappearance in vitro. Mertens determined that two of these models adequately described the kinetics of cell wall digestion. Both models assumed that digestion was preceded by a discrete lag phase and thereafter followed first-order kinetics. The difference in these two models, as described by Mertens, is that one assumes only a single potentially digestible fraction was present in cell walls whereas the other assumes two potentially digestible fractions a fast and a slow digesting fraction were present in cell walls. Both models assume an indigestible fraction is present in cell walls.

Mertens (1977) expanded the later model (fast and slow digesting fraction) to include rate of passage from the rumen. This model effectively separates ruminal disappearance of fiber into four components: digestion rate, digestion lag, potential extent of digestion and passage rate. The problems associated with this model are that it fails to account for the rate of particle size reduction, the differential digestion associated with particles of different sizes and rate of passage for particles of different sizes. These problems were partially resolved in a subsequent model proposed by Mertens and Ely (1979). This model is described by 20 differential equations, whereby, rates of particle size reduction, passage and digestion have been integrated into a complete model of fiber disappearance throughout the digestive tract. Rate constants representing digestion in the rumen and in the lower intestinal tract of fast- and slow-digesting small, medium and large particles are assigned to the respective components. Constants representing rate of particle size reduction in and passage from the rumen and out of the gastrointestinal tract are also assigned to the fast-digesting, slow-digesting and indigestible fractions. This model, although complex, is probably the most accurate representation of the kinetics of fiber digestion and rate of passage in the ruminant. One disadvantage of this model, over simpler models, is the large number of rate constants (13 in total) that need to be determined and amount of computation required to accurately predict fiber disappearance (digestibility and passage) in the ruminant. The biological validity of this model remains to be determined since the accurate quantitation of all these rate constants is questionable. Simpler models offer the advantage of pooling some of the digestion and passage rate constants.

Ellis (1978) has taken this approach in outlining a model for the determination of intake and digestibility of grazed forages. In his model, the forage diet is partitioned into indigestible cell wall components (CWCi), potentially digestible cell wall components which are digested (DCWCd) or not digested due to rate of passage (UCWCd), digestible cell contents (DCC) and undigested cell contents (UCC). The UCC component of the forage is assumed to include endogenous counterparts derived from both the animal and the gastrointestinal microbes which collectively represent a fecal quantity of 10 to 12% of dry matter intake (Van Soest, 1967). One rate constant (k_d) collectively represents the rate of digestion (fraction per day) of DCWCd and DCC and another rate constant (k_p) represents the rate of passage (fraction per day) of UCWCd and UCC. The fill of undigested dry matter (UDMF) is equal to the dry matter excreted in the feces (UDME) minus endogenous cell contents (ECC) and undigested microbial mass (UMM) all divided by k_p:

$$UDMF = [UDME-(ECC + UMM)]/k_p \tag{4}$$

Therefore, UDMF x k_p equals the daily dry matter intake (I) times the fraction of intake undigested. The fraction of I which is undigested is a function of both k_p and k_d and is equal to $kp/(k_p + k_d)$. Therefore I x $[k_p/(k_p + k_d)]$ equals UDMF x k_p. If it is assumed that daily voluntary intake of forages is limited by the physical processing capacity of the gastrointestinal tract (rate of digestion and passage), then daily voluntary intake (DVI) can be expressed as follows:

$$DVI = [UDMF \times k_p]/[k_p/(k_p + k_d)] \tag{5}$$

or

$$DVI = [UDMF \times (k_p + k_d)] \tag{6}$$

Rate constants used in this model are expressed in terms of the fraction digested or passed per day and that the magnitude of these constants (i.e., .70 to .90) is greater than the magnitude of rate constants which are normally expressed on a fraction per hour basis. The relative meaning is the same.

The advantage of Ellis' Model over other models is the simplified approach taken in developing it. It has much greater practical application, in that it attempts to quantitate voluntary intake of cattle in a grazing situation, a measurement that would aid producers as well as researchers in determination of stocking rate and need for supplemental nutrients.

The disadvantages of this model, however, are that it must be assumed that: (1) voluntary intake is limited by total fill of cell wall (CW) constituents, (2) CW constituents of all forage species (processed and unprocessed) occupy the same space and, therefore, are similar in density and volume characteristics, and (3) the rate of passage and digestion of the various cell wall components, although not similar, can be pooled and represented by one value, respectively. Ellis concedes that this model requires further refinement and that quantitative information relative to the relationships between chemical and physical degradation of forage tissue and the relationship between bulk fill and total CW components (and particles derived therefrom) is needed.

Although the above models attempt to describe the digestive process of the ruminant, none have been applied to practical forage-beef production systems. Each contains vital components needed in a suitable model. The lack of additional data and complete knowledge as to what components must be included in the model requires further research. In addition to the needed research indicated by Ellis (1978), other areas where information is needed are as follows: (1) the interaction of cell wall components (i.e., hemicelluse, cellulose and lignin) with the rate of particle size reduction and passage of the cell wall and individual components of the cell wall, (2) the interactions of the animal and its rumen microbial population with forage species fed individually or as mixtures, (3) the effect of grazing intensity and forage selectivity on overall forage utilization, and (4) determination of factors associated with plant species which are preferentially selected by the grazing ruminant animal. Although quantity and composition of cell walls in forage must be a factor in forage selection and utilization, these are probably not the only factors. Further research relative to what specific chemical and other physical factors affect forage utilization is warranted.

Models for Quantification of the Rate of Passage of Digesta Based Upon Fecal Excretion Data

The concentration of marker (administered as a pulse dose, orally or via rumen cannula) in feces collected over time is illustrated in figure 1. Assuming the rate of removal of marker from the reticulo-rumen is exponential with time, then the plot of the natural logarithm (Ln) of marker concentration vs time will be illustrated by a curve similar to the curve shown in figure 2. Brandt and Thacker (1958) and later Grovum and Williams (1973c) and Hartnell and Satter (1979 a and

b) fitted the data representing the fecal excretion curve to the following equation:

$$y = Ae^{-k_1(t-TT)} - Ae^{-k_2(t-TT)} \quad t>TT \quad (7)$$

$$y = 0 \quad t \leq TT \quad (8)$$

where y is the fecal marker concentration; A is a biologically undefined constant; k_1 is the turnover rate constant associated with pool of ruminal contents; k_2 is the turnover rate constant associated with pool of contents of the hindgut or cecum and proximal colon; t is the time post-dosage of marker; and TT is the time of first appearance of marker in feces.

In regard to the rate constants, k_1 and k_2 , Grovum and Williams (1973c) reported that k_1 was the rate-constant associated with the rate of passage of marker from the reticulo-rumen, since the difference between the half-life ($T_{1/2}k_1 = .693/k_1$) of Cr in reticulo-rumen liquor and in feces of sheep was not significant ($P>.05$). Furthermore Grovum and Williams (1973c), with limited data, hypothesized that k_2 reflects the rate of passage of digesta from the cecum and proximal colon, since the $T_{1/2}k_2$ of Cr-EDTA injected in the rumen, was 60 to 76% (average 66%) of the $T_{1/2}k_2$ of Cr-EDTA injected into the abomasum. Both $T_{1/2}k_2$ values were calculated from fecal data.

Hungate (1966), however, has suggested that the rumen is made up of two pools. Coarse particles requiring further reduction in particle size constitute one pool. The rate-constant k_2 could then represent the rate of particle size reduction and (or) the rate of passage of these particles into the pool of smaller particles. The rate of passage of small particles out of reticulo-rumen would be represented by k_1 as suggested by Grovum and Williams (1973c).

More recently, Ellis et al. (1979) suggested that the fecal excretion curve could be best represented by a two compartment, sequential time dependent-time independent model. This model was based upon a previous model developed by Matis (1972), whereby the first compartment was represented by a sequence of smaller subcompartments. The rate of passage of particles from the first compartment to the second compartment was considered to be time dependent. The equation for the time-dependent time-independent model is as follows:

$$y = k_o e^{-k_1(t-T)} \left(\frac{k_1{}^2\ (t-T)}{k_2-k_1} - \frac{k_1{}^2}{(k_2-k_1)^2} \right) + k_o e^{-k_2(t-T)} \left(\frac{k_1}{k_2-k_1} \right)^2 \qquad t>T \tag{9}$$

$$y = 0 \qquad t \leq T \tag{10}$$

where y is equal to the fecal marker concentration; k_o is the initial concentration of marker in the independent compartment; k_1 is the time dependent rate-constant (analogous to the rate constant, k_2, in the model utilized by Grovum and Williams (1973c)); k_2 is the time independent rate-constant (analogous to the rate constant, k_1, in the model utilized by Grovum and Williams (1973c)); t is time post-dosage of marker; and T is the time of first appearance of marker in feces. In this model it is assumed that the time-dependent compartment is associated with the large particle pool and (or) particles which occupy the upper strata of the rumen and have not been thoroughly mixed with the particles and liquid occupying the remainder of the rumen. The

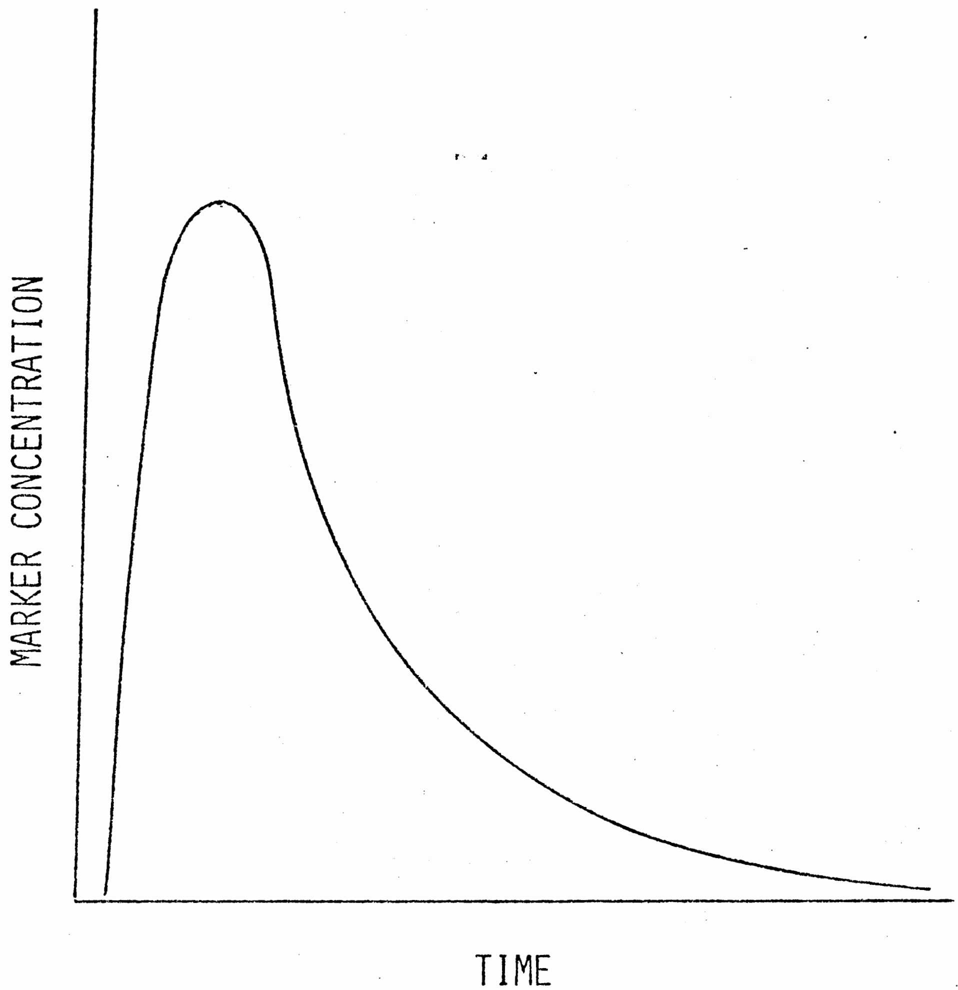

Figure 1. Fecal excretion curve.

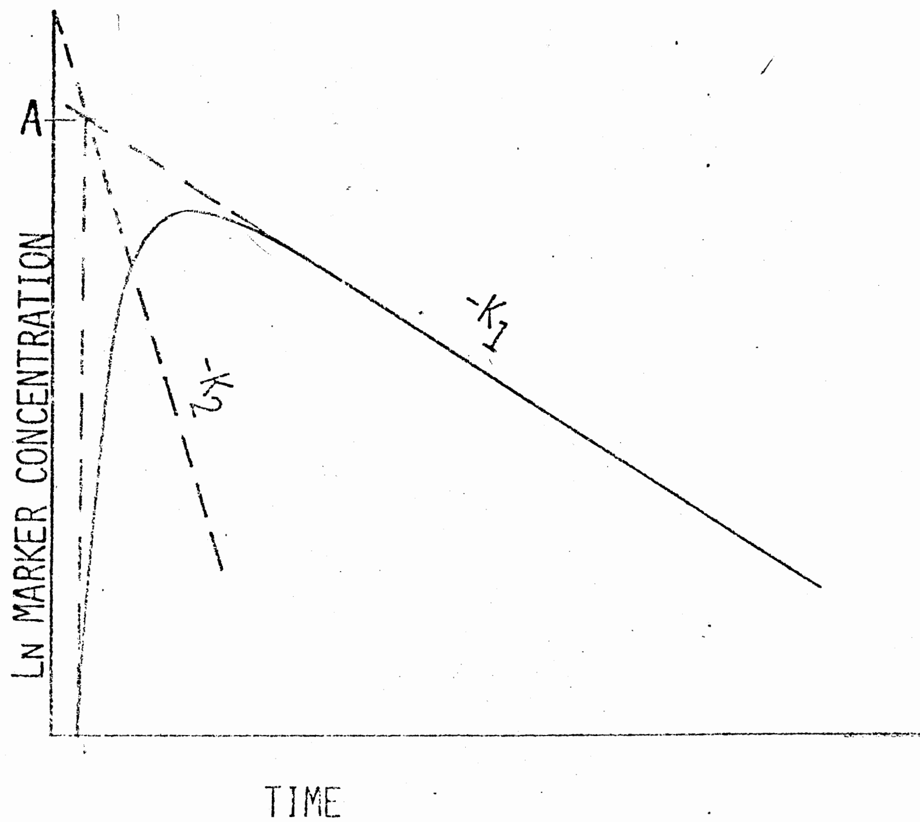

Figure 2. Natural logarithm (Ln) of marker concentration of fecal excretion curve.

time independent compartment is the pool of digesta in the reticulo-rumen capable of passing through the reticulo-omasal orifice.

The advantage of this model over other models is that it provides an equal or superior fit to data points along a fecal excretion curve and a more rapid convergence is obtained when fitting data to the model using computer programs such as the non-linear regression program of the Statistical Analysis System (SAS). Another advantage of this model over other models is that daily fecal output from the animal can be estimated. This is accomplished by first estimating the gastrointestinal tract fill of undigested dry matter (UDMG):

$$UDMG = \frac{\text{amount of marker administered (g)}}{k_o \text{ (g marker/g feces)}} \quad (11)$$

The daily fecal output of undigested dry matter (UDMF) is then determined by the following equation:

$$UDMF = UDMG \times k_2/hr \times 24\ hr \quad (12)$$

Previous research by Ellis et al. (1977) utilizing eight cows has shown that the estimated UDMF, based upon the sequential time dependent-time independent model, averaged 1.026 ± .015 (mean ± S.D.) of fecal output determined by total collection. Data from 23 sheep fed 10 different forages estimated UDMF to be 1.017 ± .008 of total collected feces (Ellis et al., 1980). In five trials, utilizing 110 head of cattle Delaney et al. (1981) reported that UDMF values ranged from .70 to 1.28 of total feces collected. The large variation observed in this study was attributed to an inaccurate quantitation of the marker administered to the animal (K. R. Pond, personal communication).

Also, in this study fecal outputs were determined by the single dose marker technique, using the time dependent-time independent model, and were compared to estimates of fecal outputs which were determined by more conventional daily administration of marker methods. In conventional methods a marker is administered to the animal daily via supplement or bolus. Once an assumed equilibrium is established, fecal output can be estimated by dividing the daily quantity of marker administered by the average concentration of marker in fecal grab samples. In this study the range in predicted versus observed fecal outputs (.64 to 1.22) was as large as the range of values determined by the single pulse dose technique. The advantage of the single dose marker technique is that less labor and time is required for marker administration and establishment of equilibrium. In addition, rate of passage through the gastrointestinal tract and total tract fill can be estimated. However, the continuous dosing method offers the advantage of obtaining an estimate of fecal output from each grab sample, while the single dose marker technique requires a large number (10 to 15) of fecal grab samples to adequately estimate the parameters desired. It should be noted that in four of the five trials reported by Delaney et al. (1981), eight or less grab samples were obtained (per animal) for the estimates of fecal output. Limited data would, thus far, indicate that more studies are needed to assess the accuracy of the single dose marker technique (using the time dependent-time independent model) for estimating fecal output.

Rare Earth Elements as Particulate Phase Markers

Faichney (1975), MacRae (1974) and Kotb and Luckey (1972) presented criteria for effective nutritional markers. The ideal nutritional marker should: be inert with no toxic, physiological or psychological effects; be strictly non-absorbable; not affect or be affected by the gastrointestinal tract or its microbial population; mix intimately with material it is meant to mark and remain uniformly distributed in the digesta; have qualities which allow precise quantitative measurements. Numerous studies (Kyker and Anderson, 1956; Kyker, 1962; Huston and Ellis, 1968; Ellis and Huston, 1968; Miler and Byrne, 1970; Miller et al., 1971; Luckey et al., 1975a and b; Lascano et al., 1979; Leverette et al., 1977; Teeter, 1981) conducted with the lanthanide series (rare earth metals) of elements have demonstrated that they possess many of the desirable qualities of a particulate phase marker. Hutcheson et al. (1975 a and b) and Luckey et al. (1975a and b) in studies with monkeys and mice demonstrated that survival, growth rate and reproduction performance were not altered by administration of rare earth metals and that the metals were, largely, nonabsorbable. Fecal recovery ranged from 99 to 107% of dosage.

In studies conducted using the rare earth elements Cerium and Dysprosium Ellis (1968), Ellis and Houston (1968) and Houston and Ellis (1968) demonstrated complete recovery of the metal in the feces and that the metal was in continued association with particulate matter in digesta and feces. However, in studies conducted by Teeter et al. (1979), Ellis et al. (1981) and Teeter (1981) it was determined that the binding capacity of ytterbium (Yb) is limited and that the more fibrous feedstuffs tend to bind a greater quantity of Yb (Ellis et al., 1981; Teeter, 1981). Teeter (1981) found that even at low levels of marker concentration in various feedstuffs a small proporation (0-6%) of Yb is readily exchangeable. Hartnell and Satter (1979a) sprayed the rare earth elements, samarium, cerium and lanthanum, (approximately 1 gram of element per kg) on feed and determined that 92.6% and 99.2% of these elements remained associated with labeled grain and hay particles, respectively, after a 24 hr in vitro incubation period. Using fistulated cows these same researchers determined that as much as 10.1% of the rate earth elements applied to feedstuffs migrated to particulate fractions other than the one on which it was originally applied.

The nature and extent of migration of an elemental markers (rare earths) from one feed component to another will depend upon the quantity of the element applied, the binding affinities of the feed components for the element, the association of the element with both the particulate and liquid phase, the affect of digestion on disrupting the molecular structure contributing to the binding force and/or capacity and method of application of marker or element to the feed (Teeter, 1981). Two methods of rare earth marker application to feedstuffs have been proposed. Ellis (personal communication) has recommended spraying a solution of the rare earth (5-10g per animal) on the feedstuffs to be labeled. Teeter (1981) recommended submerging feedstuffs to be labeled into a solution of the rare earth element then rinsing the material over an extended period of time to remove much of the marker which is not tenaciously bound to the feedstuffs. The later method reduces the potential for migration of the marker to other feed components in the digesta. With the spraying method migration of marker appears more likely and initially would be to a feed components with smaller dimensions than the feed components it was originally attached, due to a greater surface area to volume ratio. The result would be a faster estimated rate of passage for the labeled feedstuffs. The disadvantage of the immersion technique (Teeter, 1981) is that it allows greater opportunity for binding of the marker to soluble cell contents. The effect would be minimal, provided the bound soluble fractions were rinsed away. However, if ingested, a similar error in estimated rate of passage would occur, as with the spraying technique.

The data presented above indicates that rare earth elements, as external markers, have potential utility in studies related to measurements of intake, fecal output, rate of passage and rate of digestion of feeds and feed components. Although extensive studies have been conducted concerning the nature and extent of binding of rare earth elements by feedstuffs, further data is needed to verify what effect the method of binding and quantity of marker bound or administered to the animal has on estimating fecal output and passage rate parameters.

Chromium-mordant as a Particulate Phase Marker

Chromium sesquioxide (Cr_2O_3) has been used extensively as a particulate phase marker for measuring the rate of passage of solid material through the gastrointestinal tract. Being insoluble (Kotb and Luckey, 1972) in the liquid phase of digesta and assumed to be associated with the solid material, Cr_2O_3 has become a standard for use as an external particulate phase marker. However, recent workers (Bull et al., 1979) suggest that, although Cr_2O_3 is associated with particulate matter, caution should be exercised with its use, since the passage rate of particulate matter as measured by Cr_2O_3 will be limited to the passage rate of Cr_2O_3. This suggests that the rate of passage of Cr_2O_3 can be independent and different from the rate of passage of the particulate matter. Therefore, the accuracy of the particulate phase passage rate measured with Cr_2O_3 is questionable.

One solution to this problem was suggested by Balch et al. (1957). They suggested that Cr_2O_3 be given in a form in which feed is carried into the rumen and developed chromium-impregnated paper strips. administration of such paper to the animal depicts the consumption of feed material by animals grazing pastures. Ideally, the paper could be cut or designed to have approximately the same physical dimensions as the type of forage material the animal is consuming. However, the Cr-impregnated paper has chemical and other physical properties which differ from the consumed forage, thus rates of rumination and particle size reduction differ from those of consumed forage. Consequently, as a particulate phase marker, Cr-impregnated paper has a similiar disadvantage as Cr_2O_3, in that its rate of passage may differ from the rate of passage of ingested feedstuffs.

With the development of the detergent system for fiber analysis (Goering and Van Soest, 1970), Martz et al. (1974) and Uden et al. (1980) have outlined procedures for complexing Cr with cell walls (NDF) of forages. The resulting Cr-mordant fiber has many properties similar to those of the original forage fiber and passage rate estimates based upon Cr-mordant may be similar to those of the forage studied and somewhat more accurate than the passage rates determined from Cr_2O_3 and

Cr-impregnated paper.

With proper preparation the Cr is tightly bound to be fibrous constituents and, consequently, any errors in passage rate estimates due to marker migration, are eliminated. Because of this, Cr-mordant has become a substitute for rare earth metals as particulate phase markers. Weiss et al. (1978), McDonnell et al. (1981) and Pond et al. (1981) have found Cr-mordant suitable for use in passage rate studies.

The greatest disadvantage of Cr-mordant when compared to rare earth elements, is its effect on digestibility. Uden et al. (1980) determined that when Cr is attached to fiber at levels greater than 8% the fiber becomes virtually indigestible. Although application of rare earth elements to fibrous material will depress digestibility, the effects of rare earth elements on digestibility is probably less (Ellis et al., 1981). The effects of the change in digestibility, associated with both the Cr-mordant and rare earth elements, on rate of particle size reduction and passage of fibrous constituents is not known. Although recent studies have addressed questions, relative to the differences in rates of passage and stability of Cr-mordant versus rare earth-labeled feedstuff (Pond et al., 1981; Uden et al., 1980), no data has adequately characterized the effects of the application of these elements on the properties of the labeled material once it is consumed by the animal.

CHAPTER III

EFFECT OF FEEDING LOW-QUALITY ROUGHAGES ON WEIGHT GAINS AND INCIDENCE OF BLOUT OF STEERS GRAZING WHEAT PASTURE

Summary

Studies were conducted over a three-year period to compare live and carcass weight gains and incidence and severity of bloat of steers grazing wheat pasture and fed no supplemental low-quality roughage or having wheat straw (WS) or sorghum-sudan hay (SS) available ad libitum. Mean WS and SS daily intakes (.100 and .247 kg DM) were low, although live weight gains were greater ($P \leq .10$) for steers fed WS in the periods of grazing following the winter wheat dormant stage. Overall grazing periods weight gains were similar ($P > .05$), however. Bloat was exhibited by steers during a two week period in the first year only. The mean steer days of bloat and bloat scores were for control, WS-fed and SS-fed steers 9.5 and 1.2, .5 and .5, and 2.0 and 1.0. Although, somewhat inconclusive data suggest that WS and SS are effective in decreasing the incidence and severity of wheat pasture bloat. Characteristics of wheat forage which affected LQR intake the most were availability, in vitro dry matter digestibility and acid detergent fiber.

(Key Words: Bloat, Weight Gains, Low-Quality Roughage, Wheat Pasture).

Introduction

Millions of cattle are graze winter wheat pastures of the southern great plains from November to the middle of March. Grazing can be extended to the end of May, however, with forfeit of the grain crop. Daily gains of .68 to .91 kg are common but are not without risk, however. Death losses due to bloat are believed to average 2 to 3 percent per year.

Low quality roughages (LQR), such as wheat straw (WS) or sorghum-sudan hay (SS) are frequently provided for cattle grazing wheat pasture. It is commonly believed that cattle will consume .8 to 1.2 kg LQR daily and that the LQR slows the passage rate of "washy" wheat forage and, thereby, improves its utilization and reduces the incidence of bloat. Data are not available relative to the effect of LQR on wheat pasture bloat, although studies with alfalfa have shown that daily intakes of 1.3 to 4.8 kg dry roughage, such as sudan grass (Cole and Kleiber, 1945; Hull et al., 1957) or oat hay (Meyer et al., 1956), were effective in controlling legume bloat. However, Meyer et al. (1956) indicated that it was not necessary to feed oat hay to steers on a dry alfalfa diet. This would incidate that the water content of succulent bloat-provocative forages is a factor contributing to the incidence of bloat. Colvin et al. (1958 a and b) found that scabrous material in the diet strengthened rumen motility, increased eructation efficiency and, thereby, aided in reducing the incidence of bloat. Coarse oat hay increased ($P < .05$) rumen contraction frequency and amplitude of steer calves fed a grain-based diet (Colvin and Daniels, 1965), although only the amplitude was increased ($P < .05$) when an alfalfa tops diet was fed (Colvin et al., 1978).

Results of a three-year study that was conducted to determine the effect of feeding LQR on weight gains and the incidence and severity of bloat of steers grazing wheat pasture are presented in this paper. Also, the relationship between LQR intake and wheat forage availability and composition was evaluated.

Experimental Procedures

Fifty-Six (1978-79), 57 (1979-80) and 72 (1980-81) fall-weaned Hereford and HerefordxAngus steer calves, with mean ±SE weights of 165±10, 158±9 and 192±6 kg for the three years, respectively, were randomly assigned to six groups. Steers were allotted to two blocks of wheat pasture with three treatments per block. Two groups of steers grazed clean-tilled wheat pasture and four groups of steers grazed wheat pasture and had ad libitum access to wheat straw (WS) or sorghum-sudan hay (SS). Due to a shortage of wheat pasture during the 1979-80 grazing season, only one group of steers was placed on the WS treatment. Steers of each treatment group were rotated among the pastures within each block at two-week intervals.

Intakes of WS and SS were measured at two-week intervals from the difference in initial and final weight of the portable feeders used for feeding the LQR. New WS and SS was sampled and added to or replaced old WS and SS at the time feeder weights were taken. A mineral mixture consisted of two-thirds salt and one-third ground limestone was available free-choice. When of snow and (or) ice cover restricted grazing of wheat forage, alfalfa hay was fed to all groups of steers. All steers were observed twice daily throughout the trial and assigned a zero to three[a].

Initial, intermittent and final shrunk live weights were measured following an overnight interval without access to feed or water. Weights were taken to coincide with major changes in climatic growing conditions for wheat, and therefore major changes in wheat forage quality and (or) maturity. Mean weight gains were thus determined for the following four periods and corresponding dates (averaged across years): (I) fall grazing period prior to winter wheat dormancy stage (November 23 to January 11); (II) grazing period during winter dormancy of wheat (January 12 to February 20); (III) lush spring growing period following dormancy (February 21 to March 24); and (IV) period of advancing maturity and declining quality (March 25 to April 27).

Data were obtained for period IV only in 1979-80 and 1980-81. In 1979-80 data were obtained in period IV because bloat was not observed for any of the steers in that year previous to this period and because in the previous year the greatest incidence of bloat was observed at the very end of the grazing period, at which time steers were scheduled to be removed from the wheat pasture. In 1980-81, steers were grazed on wheat pasture only during period IV due to droughty summer and fall conditions and a lack of wheat forage during the normal wheat pasture grazing season. Carcass weight gains were obtained in 1978-79 and 1979-80. Carcass gains were calculated from the mean dressing percentages (shown in table 3 of Appendix) of an initial slaughter group of

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[a]0 - no visible signs of bloat
1 - slight distention of left side
2 - marked distention of left side
3 - left and right sides distended

four steers and final slaughter groups of three steers randomly selected from each treatment group.

Available wheat forage of all pastures were estimated by hand clipping three randomly selected one-half square meter plots of wheat forage to a height of 2 to 4 cm at 2- to 4-week intervals throughout the study. A separate hand-clipped sample, 10 to 15 cm in length was clipped from the terminal end of randomly selected plants for laboratory analysis. Samples of wheat forage, WS and SS were analyzed for crude protein (Horwitz, 1975). Cell wall content (NDF) and acid detergent fiber (ADF) were determined by methods described by Goering and Van Soest (1970). In vitro dry matter digestibility (IVDMD) was determined by modified procedures of Tilley and Terry (1963). IVDMD procedural modifications consisted of adding 1.0g of urea per liter of buffer plus rumen fluid, acidifying with 2.4 N HCL after the incubation in buffered rumen fluid and filtering contents of the digestion tubes through Whatman No. 4 qualitative filter paper following 24 hr pepsin digestion.

Treatment effects on daily gains were compared using the General Linear Models (GLM) and Least Squares Means procedures of the Statistical Analysis System (Barr et al., 1979). Differences in incidence and severity of bloat were tested using GLM procedure and Duncan's multiple range test. Bloat data were analyzed using the mean steer days of bloat (incidence) and mean bloat score (severity) within each treatment of each block of only animals in which bloat was observed. Effect of wheat forage characteristics (availability, IVDMD, dry matter, crude protein, NDF and ADF) on WS and SS intake were determined by multiple regression analysis using GLM procedures. Effects of year, period, treatment (WS and SS), individual wheat forage characteristic and two- and three-way interactions on WS and SS intake were tested using GLM procedures.

Results and Discussion

The mean wheat forage availability, composition and IVDMD are presented in table 1 for the four grazing periods of this study. Wheat forage composition and yield data, relative to individual dates of each year, are presented in table 1 of Appendix. An expected decline in forage availability was observed in the period of winter wheat dormancy (Period II). This was followed by a gradual increase in Period III and a sharp increase in forage availability in Period IV. Crude protein and IVDMD tended to be lower in both periods II and IV and peaked in period III. Dry matter content peaked in period II. Similar trends in wheat forage crude protein and dry matter content have been shown by McMillen and Laugham (1942) and Frost (1978). NDF and ADF content peaked in period II and again in period IV. Similar trends in wheat forage NDF, ADF and IVDMD have been shown by Horn et al. (1974 and 1977).

The IVDMD and composition of WS and SS that were fed are presented in table 2 and is representative of the type and composition of LQR commonly fed to steers grazing wheat pastures. LQR consumption is presented in table 3. In the Appendix (table 2) is shown the mean LQR intake for each period within each year. Consumption of WS tended to decline over the normal wheat pasture growing season (periods I, II, and III) but rose slightly in period IV. This rise was due to the higher than average (.142 vs. .088 kg) WS intake for steers which

TABLE 1. AVAILABILITY AND COMPOSITION OF HAND-CLIPPED WHEAT FORAGE

Period	Available Forage, kg DM/ha	Dry Matter, (DM),%	CP[a],%	NDF[a],%	ADF[a],%	IVDMD[a],%
November 23 to January 11 (I)[bc]	799	28.0	23.8	48.8	22.0	73.2
January 12 to February 20 (II)[bc]	365	33.0	23.8	59.4	26.0	69.8
February 21 to March 24 (III)[bc]	523	26.9	26.4	52.1	21.5	76.1
March 25 to April 27 (IV)[bd]	1664	23.8	19.8	58.1	27.7	69.9

[a]CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; IVDMD = in vitro dry matter digestibility. All values are expressed as a percent of dry matter.

[b]Dates are approximate (averaged across years) but deviate only 3 to 7 days from actual dates within the individual years.

[c]Composition of forage determined from samples clipped during the 1978-79 and 1979-80 grazing season.

[d]Composition of forage determined from samples clipped during the 1979-80 and 1980-81 grazing season.

TABLE 2. MEAN COMPOSITION OF WHEAT STRAW AND SORGHUM-SUDAN HAY FED TO STEERS GRAZING WHEAT PASTURE

Roughage	Dry Matter,%	CP[a],%	NDF[a],%	ADF[a],%	IVDMD[a],%
Wheat Straw	89.3	3.6	86.2	57.0	27.4
Sorghum-Sudan Hay	90.3	8.5	74.1	43.2	48.8

[a]CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; IVDMD = in vitro dry matter digestibility. all values are expressed as a percent of dry matter.

TABLE 3. MEAN ± SE LOW-QUALITY ROUGHAGE INTAKES (KG DRY MATTER/HEAD/DAY) OF STEERS GRAZING WHEAT PASTURE

	Wheat Straw	Sorghum-Sudan Hay
No. of Steers	55	65
Period		
November 23 to January 11 (I)[ab]	.120 ± .044	.225 ± .072
January 12 to February 20 (II)[ab]	.090 ± .011	.248 ± .034
February 21 to March 24 (III)[ab]	.076 ± .030	.241 ± .043
November 23 to March 24 (I-III)[bd]	.100 ± .023	.247 ± .045
% Metabolic BW[e]	.180 ± .040	.450 ± .078
March 25 to April 27 (IV)[ac]	.088 ± .032	.199 ± .024

[a]Dates are approximate (averaged across years) but deviate only 3 to 7 days from actual dates within the individual years.

[b]Data obtained during the 1978-79 and 1979-80 grazing season.

[c]Data obtained during the 1979-80 and 1980-81 grazing season.

[d]Average low-quality roughage consumed over the typical wheat pasture grazing season.

[e]Low-quality roughage intake expressed as a percent of metabolic body weight ($wt^{.75}$, k_g).

were placed on trial for period IV only (1980-81) and had not previously grazed wheat pasture. Consumption of SS peaked in periods II and III and then declined in period IV. It should be noted that in the 1978-79 wheat pasture grazing season alfalfa hay had to be fed to all treatment groups for 8 days in period I and 22 days in period II because of snow and/or ice cover on wheat forage. Figures 1 and 2 show the LQR intake over the 1978-79 and 1979-80 grazing seasons. From these figures it is evident that LQR intake tended to be quite variable. Although, over periods I, II and III the average WS (.100 kg/head/day) and SS (.247 kg/head/day) intakes were similar to the average WS and SS intakes within these periods (table 3). The magnitude of these intakes are much less than the intakes of WS and SS commonly stated by producers and much less than the amount of roughage fed to steers and cows in previously mentioned studies (Cole and Kleiber, 1945; Hull et al., 1957; Meyer et al., 1956). The manner in which roughage intakes were measured was not stated in these studies, however. Mean daily intakes of .41 Kg (as is basis) were observed by McMillen and Langham (1942) for five steers fed sumac cane free-choice on wheat pasture. This is slightly higher but in close agreement to the SS intake observed for steers grazing wheat pasture in this study.

Live and carcass average daily gains (ADG) are shown in table 4. Interactions between years and treatments were not significant ($P > .05$) within periods or overall periods; therefore, data was pooled across years. ADG of steers within each period of each year is shown in table 3 of Appendix. Live ADG were greater ($P \leq .10$) for steers fed WS during the final two periods of the trial. However, live ADG steers during the November 23 to March 24 grazing period and carcass ADB were

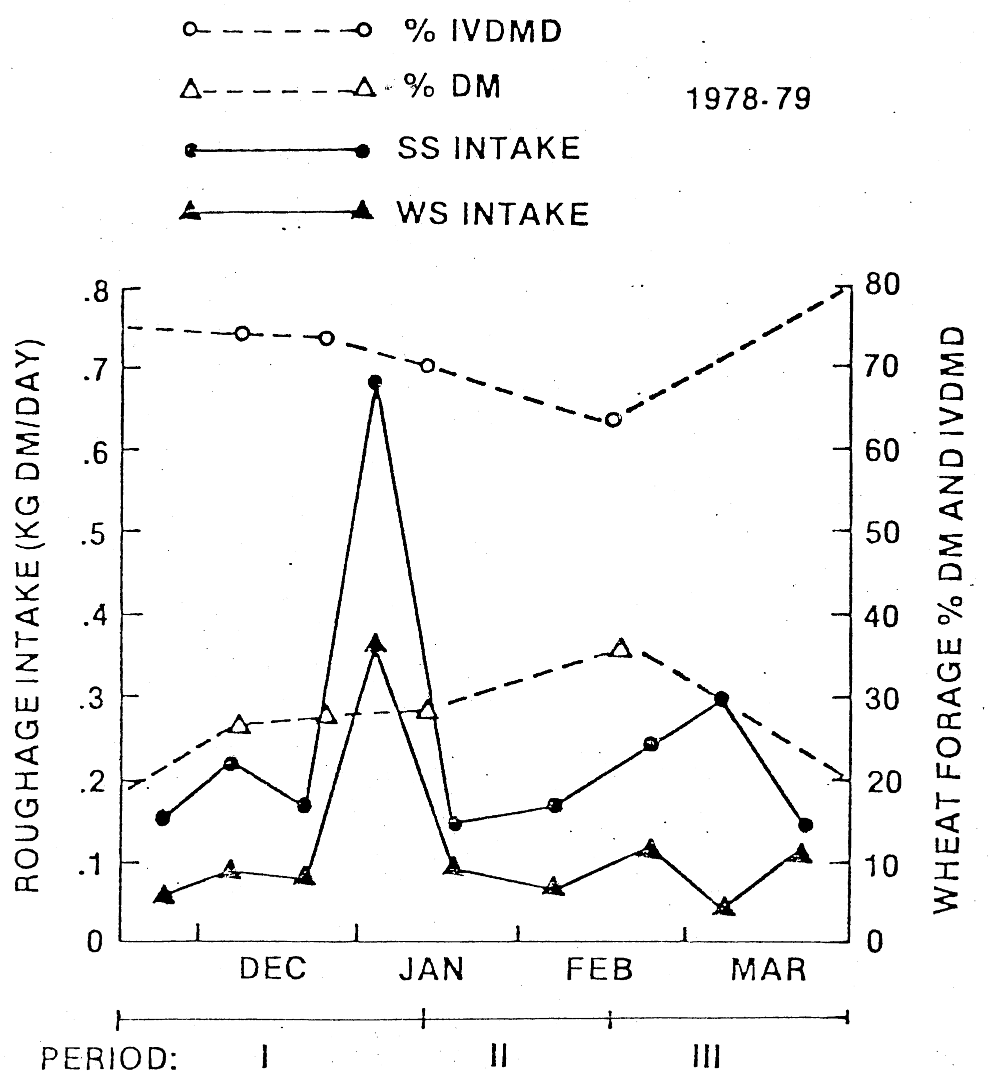

Figure 1. Wheat forage dry matter (DM) and in vitro DM digestibility (IVDMD), and wheat straw (WS) and sorghum sudan hay (SS) intake as measured in the 1978-79 grazing season.

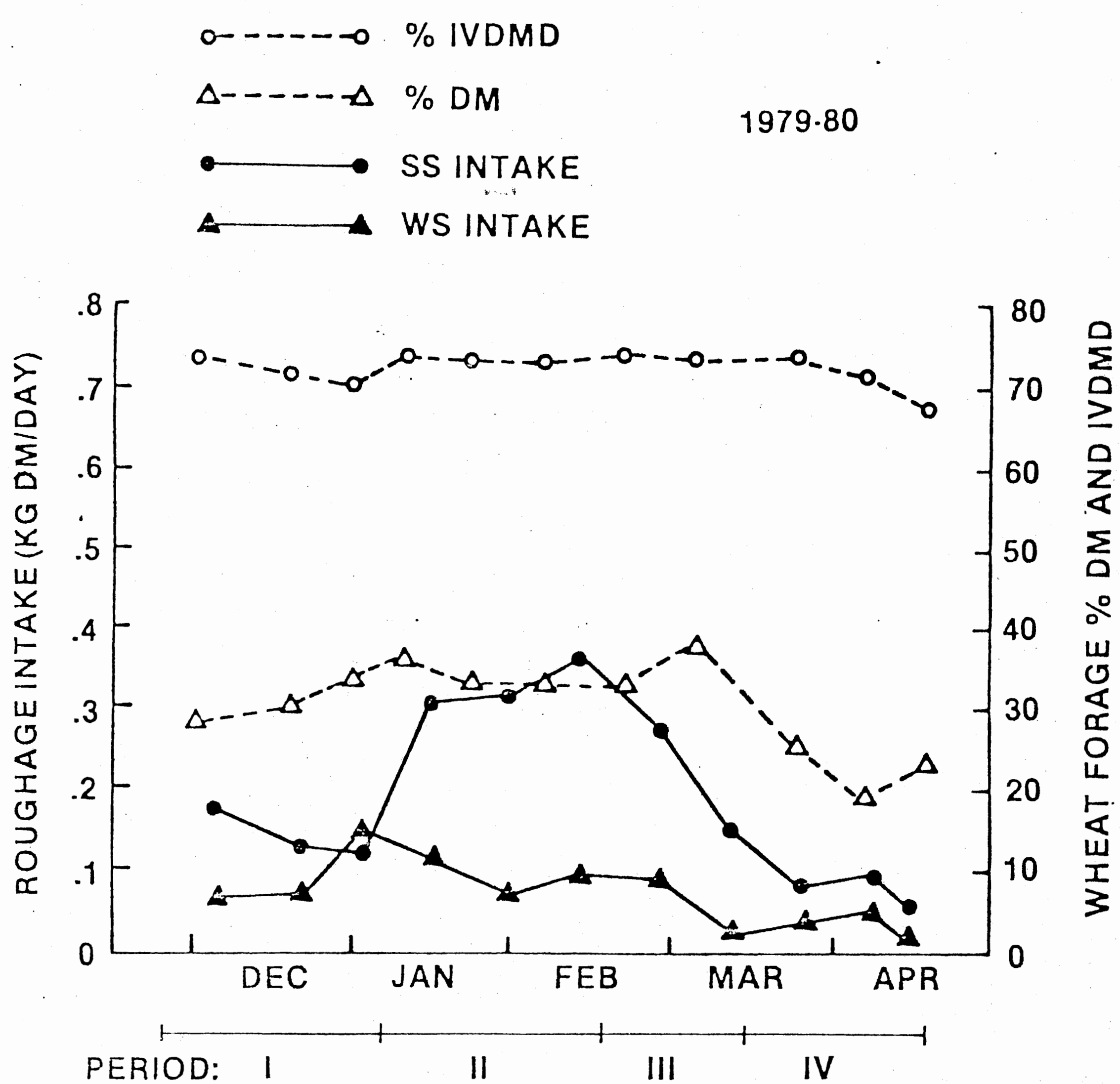

Figure 2. Wheat forage dry matter (DM) and in vitro DM digestibility (IVDMD), and wheat straw (WS) and sorghum sudan hay (SS) intake as measured in the 1979-80 grazing season.

TABLE 4. MEAN DAILY WEIGHT GAINS OF STEERS GRAZING WHEAT PASTURE

	Control	Wheat Straw	Sorghum-Sudan Hay
No. of Steers	65	55	65
Live, kg			
November 23 to January 11(I)[ab]	.70	.65	.68
January 12 to February 20(II)[ab]	.72	.65	.74
February 21 to March 24(III)[ab]	.94	1.04[d]	.97
November 23 to March 24(I-III)[abe]	.79	.77	.79
March 25 to April 27(IV)[ac]	.97	1.13[d]	1.00
Carcass, kg[bf]	.59	.57	.59

[a]Dates are approximate (averaged across years) but deviate only 3 to 7 days from actual dates within individual years.

[b]Based upon data obtained during the 1978-79 and 1979-80 grazing season.

[c]Based upon data obtained during the 1979-80 and 1980-81 grazing season.

[d]Means in the same row with different superscripts differ ($P \leq .10$).

[e]Period of time typically associated with the normal wheat pasture grazing season.

[f]Average gains of steers obtained during the normal grazing season (1978-79) and through a graze-out period (1979-80).

similar among the 3 treatments. The data indicate that LQR consumed at these levels does not effect ADG. These results disagree with results of McMillen and Langham (1942) in which overall ADG (January 29 to May 15) of steers fed sumac cane were greater (.70 vs. .63 kg) than ADG of steers not fed sumac cane. It should be noted, however, that both of the above steer groups received mineral free-choice and that another group of steers which received no mineral or sumac cane had ADG of .67 kg while grazing wheat pasture. If the feeding of LQR "enhances" rumen motility of steers consuming lush forage, as suggested by Colvin (1958 a and b), passage rate of ruminal digesta might be increased which could increase forage intake. Evidence to support a greater passage rate has been shown by Mader (1981d) in which steers fed LQR had lower ($P < .05$) GIT retention times of wheat forage compared to control steers. Decreased retention would allow greater consumption of wheat forage by the animal, resulting in an improvement in ADG. Since overall ADG were very similar, the intake of digestible DM was probably not altered. Also, since LQR intakes were low, the substitution of LQR for wheat forage in the diet was not apparent.

The incidence and severity of bloat are presented in table 5. Except for one chronically bloating steer, bloat was observed only in the last two weeks of period III in the first year of this study, therefore, the number of steer days of bloat was very small. Of the 19 (9.5 x 2 blocks) steers days of bloat observed for control steers, 18 were associated with steers of block 2. Because of this apparent block by treatment interaction, differences in steers days of bloat ($P > .45$) and mean bloat score ($P > .35$) were not significant among the treatments. However, the number of steer days of bloat observed in control

TABLE 5. INCIDENCE AND SEVEREITY OF BLOAT OF WHEAT PASTURE STOCKERS FED LOW-QUALITY ROUGHAGES[a]

	Control	Wheat Straw	Sorghum-Sudan Hay
Steer Days of Bloat[b]	9.5[c]	.5[c]	2.0[c]
Mean Bloat Score[b,d]	1.2[c]	.5[c]	1.0[c]

[a]For period III of the 1978-79 grazing season only; no incidence of bloat was noted in any other period or year, except for one chronic bloater observed during the 1978-79 grazing season.

[b]Mean of the two steer groups receiving the same treatment.

[c]Means with a common lettered superscript are not significantly different ($P > .05$).

[d]0 - no visible sign of bloat
1 - slight distention of left side
2 - marked distention of left side
3 - left and right sides distended

(9.5) was greater than the number of steer days of bloat observed in steers fed WS (.5) and SS (2.0).

Wheat forage composition and IVDMD from the 6 pastures for the period of observed bloat are shown in table 6. In the block 2 control pasture, where bloat was observed for several steers, the crude protein content and IVDMD were higher ($P < .05$) and NDF content was lower ($P < .05$) than in the block 1 control pasture in which only 1 steer bloated. This agrees with data of Horn et al. (1977) in which wheat forage samples from bloat-provocative pastures were higher in crude protein (31.8 vs. 25.4%) and lower in NDF (35.0 vs. 44.6) and dry matter (22.3 vs. 28.5) as compared with forage samples of pastures where bloat was not observed.

Crude protein and IVDMD of wheat forage of the control pasture in which bloat was observed (block 2) were not significantly different from the crude protein level and IVDMD of pastures grazed by steers that were fed WS or SS. Also, the dry matter content of the wheat forage from all these pastures was below the level (22.3 percent) observed by Horn et al. (1977) in bloat-provocative pastures. These data would suggest that a situation conducive to bloat existed in the pastures in which steers were fed LQR. Therefore, LQR consumed at the levels observed in this study may decrease the incidence of bloat of steers grazing wheat pasture. However, more studies need to be conducted before making final conclusions and recommendations to producers.

Reasons why bloat was not observed in other periods and years of this trial are unclear. One explanation is that in other periods wheat forage tended to be lower in crude protein (table 1) and (or) higher in dry matter (figures 1 and 2) than in the period in which bloat was

TABLE 6. WHEAT FORAGE COMPOSITION DURING PERIOD OF OBSERVED BLOAT (1978-79)

	Control	Wheat Straw	Sorghum-Sudan Hay
Roughage Intake, kg DM/head/day			
Block 1	---	.13	.08
Block 2	---	.10	.22
Steer Days of Bloat			
Block 1	1	0	1
Block 2	18	1	3
Dry Matter, %			
Block 1	21.41[b]	19.35[ab]	18.68[a]
Block 2	21.06[b]	21.63[b]	21.60[b]
Crude Protein, %			
Block 1	23.13[a]	29.56[b]	30.06[b]
Block 2	29.06[b]	27.50[b]	29.50[b]
NDF, %[f]			
Block 1	43.7[bc]	49.5[e]	39.6[ab]
Block 2	38.8[a]	48.5[de]	45.3[cd]
ADF, %[f]			
Block 1	18.2[a]	19.6[a]	19.2[a]
Block 2	17.6[a]	19.4[a]	19.1[a]
IVDMD, %[f]			
Block 1	75.6[a]	79.5[b]	77.4[ab]
Block 2	80.9[b]	78.8[b]	78.0[ab]

[abcde]Means with different superscripts within a specific forage component are different ($P < .05$).

[f]NDF = neutral detergent fiber; ADF = acid detergent fiber; IVDMD = in vitro dry matter digestibility.

observed. It should be noted, however, that two consecutive days of cloudy, cooler weather preceeded the 2-week period in which bloat was observed. On the day following the 2 days of cloudy weather, bloat was observed in steers on four of the six pastures. The influence of changing weather patterns on grazing behavior may, therefore, contribute to the incidence of bloat in cattle grazing wheat pasture. Similar findings were reported by Horn et al. (1976).

A final objective of this study was to determine the effect of wheat forage availability, IVDMD and chemical composition on LQR intake. Wheat forage dry matter and IVDMD and LQR intake for the 1978-79 and 1979-80 grazing seasons, respectively, are shown in figures 1 and 2. To determine the relationship between LQR intake and the various characteristics of wheat forage, multiple regression analysis was conducted using LQR intake as the dependent variable and wheat forage availability, dry matter, crude protein, NDF, ADF, and IVDMD as independent variables. Data of periods I, II and III in the normal wheat pasture grazing seasons were used in this analysis.

Preliminary analysis of variance, which included treatments (SS and WS), years and periods with each of the individual wheat forage characteristics as sources of variation, indicated that for LQR intake there were no significant ($P > .05$) year or period effects and no 2- or 3-way interactions of years, periods and wheat forage characteristics with treatments. Interactions of wheat forage ADF with periods and years and IVDMD with periods were significant ($P < .05$), however. The exact nature of these interactions are not clear, since LQR intake was somewhat variable within each period and no consistent pattern was apparent. Multiple regression analysis conducted using the model statement, represented by equation 15 of table 7, indicated that wheat forage availability and IVDMD were factors which had the greatest effect ($P < .05$) on LQR intake and ADF a lesser effect ($P < .20$). Wheat forage dry matter ($P > .30$), NDF ($P > .70$) and crude protein ($P > .85$) did not affect LQR intake. Since the interactions of the individual wheat forage characteristics and treatments were not significant, the regression coefficients (slopes) were assumed to be similar for both treatments.

A number of regression equations which include wheat forage availability and (or) IVDMD as variables which affect LQR intake are shown in table 7. Treatment was included in the model statements, in order to account for the difference in mean intake of WS versus SS. R-squares from .52 to .57 are obtained when only 2 characteristics of wheat forage were included as independent variables. The largest R^2 obtainable was only .62, however. This data would suggest that in general, as wheat forage availability decreases or IVDMD increases, LQR intake increases.

An interesting result of the above analysis was that LQR intake increased as wheat forage ADF ($P < .05$ in three equations) increased. This was opposite to the expected response. Caution should be exercised, however, when considering the effect of wheat forage ADF on LQR intake, since a significant interaction between wheat forage ADF and periods and years was found. The fact that wheat forage dry matter did not affect LQR intake contradicts common belief that LQR intake increases as wheat forage dry matter decreases (i.e., a negative relationship). The regression coefficients of table 7 were positive and suggest an opposite trend exists, however. R-squares of only .13 and

TABLE 7. MULTIPLE REGRESSION EQUATIONS FOR ESTIMATING LOW-QUALITY ROUGHAGE INTAKE (LQRI) FROM WHEAT FORAGE AVAILABILITY (WFA), DIGESTIBILITY (IVDMD)[a] AND CHEMICAL COMPOSITION

Equation No.	Dependent Variable, g/DM/day	Intercept	Treatment[c]	Independent Variable[b] WFA, Kg/ha	IVDMD,%	ADF,%	Dry Matter,%	NDF,%	Crude Protein,%	Coefficient of Determination (R^2)	Residual Standard Deviation, g/day
1	LQRI =	148	+ 130(T)	- 0.08*	- 0.17					.52	74
2	LQRI =	- 764	+ 140(T)		+ 8.10*	+ 11.48*				.53	73
3	LQRI =	7	+ 130(T)	- 0.08*		+ 5.29				.56	71
4	LQRI =	35	+ 121(T)	- 0.09*	+		+ 3.62*			.57	70
5	LQRI =	- 450	+ 126(T)		+ 6.00		+ 5.44*			.51	75
6	LQRI =	- 958	+ 133(T)		+ 10.15*	+ 9.06*	+ 3.76			.56	71
7	LQRI =	- 1	+ 123(T)	- 0.08*		+ 2.42	+ 2.80			.56	70
8	LQRI =	- 518	+ 135(T)	- 0.07*	+ 5.95	+ 9.32*				.58	70
9	LQRI =	- 355	+ 120(T)	- 0.08	+ 4.83		+ 5.21*			.59	69
10	LQRI =	- 617	+ 135(T)	- 0.06*	+ 6.31	+ 7.35		+ 2.22		.60	69
11	LQRI =	- 402	+ 129(T)	- 0.07*	+ 6.33	+ 7.58			- 3.92	.59	70
12	LQRI =	- 714	+ 126(T)	- 0.07*	+ 8.04*	+ 6.63	+ 4.02*			.62	67
13	LQRI =	- 719	+ 127(T)	- 0.07*	+ 7.90*	+ 6.39	+ 3.56	+ 0.61		.62	68
14	LQRI =	- 727	+ 126(T)	- 0.07*	+ 8.04*	+ 6.74	+ 4.08		+ 0.34	.62	68
15	LQRI =	- 689	+ 126(T)	- 0.07*	+ 7.87*	+ 6.08	+ 3.30	+ 0.76	- 0.80	.62	69

[a]IVDMD = in vitro dry matter digestibility.

[b]Regression coefficients are listed under independent variables.

[c]Treatment (T) was included in the model statements as a dummy variable in order to correct for difference in mean intake (g/day) of wheat straw (WS) versus sorghum-sudan hay (SS). The value of T is equal to 0 and 1, respectively, for calculating WS and SS intake.

*Significantly different from zero ($P < .05$)

.08 were obtained with simple regression of WS and SS intake, respectively, on wheat forage dry matter.

Colvin et al. (1958 a and b) and Colvin and Daniels (1965) suggested that scabrous material is needed by the ruminant in order to maintain or reinforce the tonic activity of motor neurons responsible for rumen motility. This physiological need for scabrous material in the diet would suggest that a positive relationship exists between intake of scabrous material and moisture and neutral detergent solubles content in the diet of ruminants consuming succulent forages. A negative relationship would, thus, exist between LQR intake and percent dry matter and NDF (fiber) in wheat forage. These relationships were not observed in this study, however. Since wheat forage crude protein, dry matter and NDF content did not significantly affect LQR intake, the data suggests that wheat forage constituents that are conducive to bloat (Horn et al., 1977) are not necessarily the same as the factors that stimulate LQR intake.

Results further suggest that LQR, although consumed at very low levels, may decrease the incidence and severity of bloat in cattle grazing wheat pasture. Previous research (Meyer et al., 1956; Hull et al., 1957) has shown that 1.3 to 2.3 Kg dry matter of oat hay or sudan hay would effectively control legume-bloat. However, studies have not been conducted to quantify the minimum amounts of scabrous material capable of controlling legume-bloat and it is uncertain if these minimum levels of intake would apply to wheat pasture bloat as well. Factors which stimulate LQR intake and the physiological mechanism by which these roughages aid in the prevention of bloat require further study.

CHAPTER IV

MODELS AND MARKER TECHNIQUES USED FOR QUANTITATING PASSAGE RATE OF DIGESTA AND FECAL OUTPUT IN THE RUMINANT

Summary

The two-compartment time-independent (TI) model and the time dependent time-independent (TD) model were fit to fecal excretion curves derived from steers consuming wheat forage (WF), WF plus wheat straw (WS), or WF plus sorghum-sudan hay (SS) in grazing and metabolism trials. The best fit was obtained with the TD model (R^2=.99 vs. .94). Larger estimates of ruminal turnover rate, (k2) were consistently obtained with the TD model, while larger ($P < .01$) estimates of the time of first appearance of marker in feces (7.3 vs. 5.2 hr) and longer mean retention times of wheat forage (27.7 vs. 22.4 hr) were obtained with the TI model. Fecal output (FO) predicted from the TD model varied with feeding regime, but overall averaged very close to actual FO (98.4 to 99.0 percent of collected). Twice daily administration of Cr_2O_3 in gelatin capsules and fecal sampling was found to be an unsuitable method for determining FO of steers consuming lush high-quality feedstuffs, such as WF. Variation in Cr concentration of fecal grab samples and poor Cr recovery may be attritubed to incomplete mixing of Cr_2O_3 with digesta.

(Key words: Models, Markers, Rate of Passage, Fecal Output.)

Introduction

To quantitate the rate of passage of ingested feedstuffs, several mathematical models have been proposed (Blaxter et al., 1956; Brandt and Thacker, 1958; Hungate, 1966; Matis, 1972; Waldo, 1972; Grovum and Williams, 1973c; Mertens, 1977; Mertens and Ely, 1979; Ellis et al. 1977 and 1979). These models characterize the ruminant digestive process by quantitating the disappearance and (or) passage rate of various cell wall constituents or by analysis of the kinetics associated with administration of a marker or labeled material to the animal. Administration of a single pulse dose of a marker has become a standard procedure for measuring passage rate (often referred to as turnover rate) of digesta through the gastrointestinal tract (GIT) of the ruminant (Faichney, 1975). A two-compartment time-independent exponential flow model was utilized by Grovum and Williams (1973c) for describing the fecal excretion curve (fecal marker concentration plotted against time post dosing). Grovum and Williams (1973 b and c) suggested that the reticulo-rumen and the cecum-proximal colon are the two compartments represented by this model and that the large exponential rate constant, determined from rising portion of the fecal excretion curve and, henceforth, referred to as k_1, is associated with passage rate of digesta from the cecum-proximal colon. The smaller rate constant, determined from the declining portion of the fecal excretion curve and, henceforth, referred to as k_2, represents the passage rate of digesta out of the reticulo-rumen.

Hungate (1966) however, postulated that the rumen is composed of a large particle-rumination pool (compartment) and a small particle-liquid pool. This would suggest that k_1 is the rate which digesta enters the liquid-small particle pool through mixing and/or particle size reduction. Assuming this to be correct, Matis (1972) proposed a time-dependent model in which the passage of digesta from the large particle-rumination pool is dependent upon the decrease in particle size which, in turn, is a function of residence time in the rumen (time dependent). Slow and incomplete mixing of digesta is also assumed to contribute to the time dependency. Ellis et al. (1977 and 1979), subsequently, proposed a time-dependent time-independent model which provided an equal or superior fit to the fecal excretion curve when compared to the two-compartment time-independent model utilized by Grovum and Williams (1973c). The time-dependent time-independent model is also a two compartment model, however, one advantage of this model over the two-compartment time-independent model is that estimates of fecal output, which can be used in estimating feed or forage intake, can be obtained.

The objectives of this study were to: (1) compare these two models (two-compartment time-independent versus time-dependent, time-independent) and determine how accurately they describe the fecal excretion curve, (2) assess the capabilities of the time-dependent time-independent model for predicting fecal output, when using ytterbium (Yb) as a particulate phase marker (3) assess the accuracy of the chromium (Cr) dilution method (daily dosing of Cr_2O_3 and fecal sampling) for predicting fecal output of steers consuming lush high-quality wheat forage, and (4) assess the accuracy of acid insoluble ash (AIA) and indigestible neutral detergent fiber (INDF) for estimating digestibility of high-quality wheat forage.

Experimental Procedures

Metabolism Trial

As a part of on-going trials, in which the effects of feeding low-quality roughage (LQR) to steers consuming wheat forage were studied (Mader, 1981 a and d), ten Hereford steers (283 ± 6 kg) were utilized in a completely randomized design and were fed harvested wheat forage or harvested wheat forage plus sorghum-sudan hay (SS). The SS was coarsely ground (6-12 cm in length) and fed at a level of .64 kg dry matter (DM)/head/day. The trial included a 9-day preliminary period in which wheat forage was available ad libitum, and a 5-day fecal collection period in which an average of 5.6 kg DM wheat forage was fed each steer which was 90 percent of the average daily feed consumed during the preliminary period. Total feces of steers fed SS was adjusted for the amount of hay DM appearing in the feces, which was determined by multiplying the amount of hay fed by the indigestible portion (one minus estimated in vivo digestibility) of SS. Estimated in vivo digestibility was determined from in vitro dry matter digestibility (IVDMD) using the regression equation of OH et al. (1966) for obtaining apparent feedstuff digestibility from IVDMD procedures. This procedure was found to be fairly accurate, since the actual digestibility (58.0 ± 1.2 percent), which was determined from total intake and fecal collection of five steers (Mader, 1981d), of SS fed in this trial was found not to differ ($P > .05$) from the estimated digestibility (58.2 ± .3 percent).

Nine-hundred and fifty (950) g of Yb-labeled wheat forage (25 percent DM) was fed, as a single pulse dose, to each steer at the beginning of the fecal collection period. Each steer received approximately 2.5 g of Yb. Wheat forage was labeled using the immersion technique described by Teeter (1981) in which feedstuffs are labeled by immersion in an aqueous solution of $YbCl_3$ (approximately .5 to 1% w/v Yb), allowed to equilibriate 18 to 24 h after which the supernatant fluid is removed and the feed is rinsed with distilled water 2 to 3 times for 4 to 6 h to remove any unbound and weakly associated Yb. After labeling the wheat forage was then dried to its approximate original DM.

In this trial and the subsequent grazing trial which is described in this study, fecal grab samples were taken at 4 hr intervals during the first 16 h and 24 to 36 h, post-dosage, and then twice daily (approximately 0700 and 1700 h) for the remainder of the fecal collection period. A larger number of samples was required in the early portion of the fecal collection period to adequately estimate the rate constant, k_1, which is associated with the rising portion of the fecal excretion curve. The fecal excretion data (Yb concentration vs. time) was fit to both the two-compartment time-independent (Grovum and Williams, 1973c) and the time-dependent time-independent (Ellis et al. 1977 and 1979) models. The respective models are represented by the following equations:

$$Y = Ae^{-k_2(T-TT)} - Ae^{-k_1(T-TT)} \qquad T > TT \qquad (1)$$

$$Y = 0 \qquad T \leq TT \qquad (2)$$

and

$$Y = K_0 \cdot e^{-k_1(T-\tau)} \left(\frac{k_2{}^2(T-\tau)}{k_2-k_1} - \frac{k_1{}^2}{(k_2-k_1)^2} \right) + K_0 \cdot e^{-k_2(T-\tau)} \left(\frac{k_1}{k_2-k_1} \right)^2 \qquad T > \tau \qquad (3)$$

$$Y = 0 \qquad T \leq \tau \qquad (4)$$

where Y is the concentration of marker in the feces. A and k_0 are analogous terms, however, A is assumed to be biologically undefined (Hartnell and Satter, 1979b), whereas, k_0 represents the initial concentration of marker in the time-independent compartment (small particle-liquid pool). TT and τ (TAU), both represent the time of first appearance of marker in feces and are referred to as the time delay. The rate constants k_1 and k_2 have previously been defined for each model, however, for the two-compartment time-independent model, the rate constants k_1 and k_2 have been interchanged (as written here) compared to the model as proposed by Grovum and Williams (1973c). This change in notation should avert confusion which is often associated with the discussion of these models, by allowing k_1 to represent the larger rate constant while k_2 represents the smaller rate constant in both models.

A computer program (Hartnell, 1977) based upon procedures used by Grovum and Williams (1973c) was used to fit the fecal excretion data to the two-compartment time-independent model. When fitting data to this model, the rate constant, k_2, is first determined from the natural logarithm (Ln) of the fecal marker concentration associated with the declining portion of the curve. This value of k_2 is then placed in the model and the remaining parameters are determined with the computer program. A nonlinear regression program (Barr et al., 1979), which was based upon the format presented by Ellis (1979) was used to fit the fecal excretion data to the time-dependent model. In the latter model, convergence (minimum residual error) was obtained with minimal use of computer time and cost. Attempts were made to fit the fecal excretion data to the two compartment time-independent model using similar nonlinear regression procedures. However, convergence could not be obtained for all steers and for the fecal excretion curves of steers in which convergence was obtained, the greater computer time and cost prohibited further use of this procedure for the two-compartment time-independent model. Similar conclusions were drawn by Ellis et al. (1979). Sums of squares, which were needed for R-square determinations, for both models were obtained with the use of the nonlinear regression program, however. Various parameters and R-square values estimated by the models were compared using paired T-tests.

Estimates of daily fecal output (FO) of DM were determined using the time-dependent time-independent model and the following equations (Ellis et al., 1977):

$$\text{Undigested GIT DM pool size (UDMG), g} = \frac{\text{Yb fed, g}}{k_0\text{, (g Yb/g feces)}}$$

$$\text{FO, g} = \text{UDMG} \times k_2/\text{h} \times 24\text{h}$$

For both models the total mean retention time (TMRT) of ingested feedstuffs was determined from the following equation:

$$\text{TMRT} = 1/k_1 + 1/k_2 + \text{time delay}$$

Estimates of FO also were determined by continuous marker dosing procedures in which 4 g of Cr_2O_3 were administered twice daily in gelatin capsules to each steer. FO was calculated by dividing the g of Cr administered daily by the Cr concentration of composite fecal grab samples which were taken at the time of bolusing (approximately 0700 and 1700 h). The accuracy of using acid insoluble ash (AIA) and indigestible neutral detergent fiber (INDF) also were tested as indices of digestibility for steers consuming high quality forage diets, such as wheat forage. Forage and fecal grab samples were analyzed for AIA by the 2 N HCl procedure of Van Keulen and Young (1977). INDF concentration in forage and fecal samples, were determined after a 96-hr in vitro incubation period in buffered rumen fluid followed by neutral detergent fiber analysis (Goering and Van Soest, 1970).

Grazing Trial

Nine Hereford and HerfordxAngus steer calves (291 ± 7 kg) were used in three 3 x 3 latin square designs with period on wheat pasture and treatment as factors. During each of the three periods steers grazed a common wheat pasture for approximately 10 to 12 h each day. The steers were removed from wheat pasture overnight, placed in individual feeding stalls, and had free access to (1) no LQR, (2) wheat straw (WS), or (3) SS overnight. The WS and SS were coarsely ground (6-12 cm in length). Consumption of WS and SS averaged .22 and .60 kg DM/head/day, respectively. Each period consisted of 11- and 5-day preliminary and collection phases, respectively. At the beginning of each collection phase, all steers were fed approximately 600 g of wheat forage (33 percent DM) labeled with $YbCl_3$ (1.7 g Yb/steer). Hand clipped wheat forage (10-15 cm in length) was labeled and fed in a form similar to the labeled wheat forage fed in the metabolism trial. Steers receiving LQR (WS and SS) were also fed 30 to 55 g of Cr-mordanted WS or SS (2.5 to 2.7 g Cr), respectively. Cr-mordanted WS and SS were prepared using procedures described by Uden et al. (1980).

Total feces were collected using fecal collection bags and compared to FO of undigested wheat forage estimated from the Yb concentration in fecal grab samples and the time-dependent time-independent model. Actual fecal output was corrected for the undigested portion of WS and SS according to procedures previously described for purposes of making comparisons. The rate constant, k_2, estimated from the time-dependent time-independent model was compared with k_2 determined from the natural logarithm of points associated with the declining portion of the fecal excretion curve. Differences were compared using paired T-tests.

Forage and Marker Analysis

Crude protein was determined by Kjeldahl procedures (Horwitz, 1975). NDF and acid detergent fiber (ADF) were determined by methods described by Goering and Van Soest (1970). IVDMD was determined by procedures modified from Tilley and Terry (1963). IVDMD procedural modifications consisted of adding 1.0 g of urea per liter of buffer plus rumen fluid, acidifying with 2.4 N HCL after incubation in buffered rumen fluid and filtering contents of the digestion tubes 24 hours later through Whatman No. 4 qualitative filter paper following 24 hr pepsin digestion.

Yb and Cr were both analyzed by atomic absorption spectrophotometry. Samples for Yb analysis were digested with a 1:1 v/v mixture of 3 N nitric and 3 N hydrochloric acid according to procedures described by Ellis et al. (1981). Standard addition procedures (Schrenk, 1971) were employed to correct for matrix interferences associated with Yb analysis. Cr was determined by procedures described by Williams et al. (1962).

Results and Discussion

The composition and IVDMD of wheat forage, WS and SS consumed by steers in the metabolism and grazing trials are shown in table 1. Parameters estimated from the two-compartment time-independent model (Grovum and Williams, 1973c) and the time-dependent time-independent model (Ellis et al., 1977 and 1979) are presented in table 2. The best fit to the fecal excretion curve was obtained with the time-dependent time-independent model (R^2=.99). This was significantly different ($P < .05$) from the R^2 (.94) obtained with the two compartment time-independent model. The estimates of the rate constant, k_1, were very similar, for both models. However, k_2, when estimated by the time-dependent time-independent model, was higher for steers consuming wheat forage in the metabolism trial and in the grazing trial ($P < .1$). Estimates of k_2 for WS and SS also were higher when estimated by the time-dependent time-independent model, however, these differences were not significant ($P > .1$). These data would suggest that, as the magnitude of k_2 increases, the difference in k_2 estimated by these models, increases. The time delay and TMRT of undigested wheat forage were lower ($P < .01$) when estimated by the time-dependent time-independent model.

The first appearance of marker in feces (time delay) of 5 to 7 h is very low since lower intestinal tract transit time usually assumed to exceed 18 h (F. N. Owens, personal communication). However, other researchers (Castle, 1956; Balch et al., 1957; Lamboune, 1957 a and b; Yadava et al., 1964) have found markers (Cr_2O_3, stained hay and C^{14} labeled hay) to be excreted in feces of sheep and cows as early as 5 h,

TABLE 1. COMPOSITION OF WHEAT FORAGE SORGHUM-SUDAN HAY AND WHEAT STRAW

Trial	Dry matter,%	Crude protein,%	NDF[a],%	ADF[a],%	IVDMD[a],%
Metabolism					
Wheat forage	30.2	27.8	68.6	29.0	71.8
Sorghum-sudan hay	90.5	8.7	74.1	48.4	56.1
Grazing					
Wheat forage	28.3	27.2	60.2	19.0	72.5
Wheat straw	89.5	3.5	83.6	53.5	33.1
Sorghum-sudan hay	89.0	8.0	73.1	46.2	52.3

[a]NDF=neutral detergent fiber; ADF = acid detergent fiber; IVDMD = in vitro dry matter digestibility

TABLE 2. COMPARISON OF MODELS REPRESENTING THE FECAL EXCRETION CURVE AFTER ADMINISTRATION OF LABELED MATERIAL

Trial	Parameter	No. of steers	Model: Grovum[a]	Model: Ellis[b]
Metabolism[c]	R-square	10	.94	.99**
	Time dependent turnover rate (k_1)[d], %/h	10	16.1	16.4
	Time independent turnover rate (k_2)[e], %/h	10	7.7[f]	10.4**
	Time delay[g], h	10	7.3	5.2***
	TMRT[h], h	10	27.7	22.4***
Grazing[i]	Time independent turnover rate (k_2)[d], %/h			
	Wheat forage	27	4.6[f]	5.1*
	Sorghum-sudan hay	9	1.8[f]	2.2
	Wheat straw	9	1.4[f]	1.5

[a]Two compartment time-independent model described by Grovum and Williams (1973 c) and Brandt and Thacker (1958). Parameters estimated by computer program described by Hartnell, 1977.

[b]Time-dependent time-independent model. Model and computer program for estimating parameters are described by Ellis et al. (1977 and 1979) and Ellis (1979).

[c]All parameters were estimated from steers fed ytterbium (Yb)-labeled wheat forage.

[d]Assumed to be turnover rate of contents in the hindgut or cecum and proximal colon (Grovum model) or the turnover rate of particles in the upper strata of the rumen and (or) an artifact due to mixing (Ellis model).

[e]Assumed to be ruminal turnover rate (Grovum and Williams, 1973b; Grovum and Phillips, 1973; Hartnell and Satter, 1979b).

Table 2. (continued)

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[f]Estimated from the declining portion of the curve of the natural logarithm of fecal marker concentration.

[g]Time of first appearance of marker in feces.

[h]Total mean retention time (TMRT) = $1/k_1 + 1/k_2$ + time delay.

[i]Steers were grazed on a single wheat pasture and administered Yb-labeled wheat forage. Eighteen steers were given chromium-mordanted wheat straw or sorghum-sudan hay.

* $P < .1$.

** $P < .05$.

*** $P < .01$.

but tended to average around 10 h. The loose "watery" feces of steers consuming wheat forage may be indicative of a rapid flow of digesta through the lower gastrointestinal tract (GIT) and, therefore, may account for the very early appearance of marker in the feces. The first appearance of marker in feces, which was actually observed by analytical methods, tended to be similar to that estimated by the models.

In regard to the rate constant, k_2, Grovum and Williams (1973c) determined that for Cr-ethylene-diamine-tetra-acetic acid (Cr-EDTA; a liquid phase marker) the value of k_2 as measured from the fecal excretion model was equal to the turnover rate (k_2) of Cr-EDTA as measured from samples of rumen fluid. Hartnell and Satter (1979) assumed that k_2 (k_1-using their notation) when estimated from both solids and liquids markers, respectively, represented the passage rate of solids and liquid out of the rumen. However, data in support of these assumptions is limited. Recently, Teeter (1981) presented data showing no difference ($P > .05$) in k_2 when estimated from ruminal, abomasal or fecal samples. In Teeter's study, the passage rate (k_2) of prairie hay, cottonseed hulls, soybean meal and corn was determined from the slope (Ln marker concentration vs. time) of the declining portion of the curve. Ytterbium and (or) dysprosium were used as particulate phase markers. Similar data was also reported by Teeter (1981) when using cobalt-EDTA as a liquid phase marker. These data would, therefore, support the suggestion that rumen turnover rate is represented, and can be measured by the rate constant, k_2, of the fecal excretion curve.

FO of undigested wheat forage as determined from total collection (actual), the time-dependent time-independent model, and by chromium dilution are presented in table 3. For steers fed only wheat forage (control), the estimated FO, when estimated from the time-dependent time-independent, was 94.0 to 95.3 percent of actual FO. For steers fed SS, the estimated FO exceeded actual FO by 1.5 to 5.5 percent, whereas, for steers fed WS, the estimated FO was lower (97.6 percent of actual). In previous research Ellis et al. (1977) and (1980) found that estimated FO ranged from 101.7 to 102.6 percent of actual FO for cows and sheep fed up to 10 different forages. However, Delaney et al. (1981) reported a range of 70 to 128 percent. A similar range (62 to 122 percent) in estimated as a percent of actual FO was also noted in this study (Delaney et al., 1981) when FO was measured using continuous marker dosing procedures. The large variation in estimated FO in the above study was attributed to problems of accurately quantitating the amount of marker fed (K.R. Pond, personal communition).

The data in this study would suggest that relatively close estimates of FO are obtainable using the time-dependent time-independent model. In the grazing trial, regression analysis was conducted for each treatment group with actual FO as the dependent variable and estimated FO as the independent variable. Regression equations were:

FO (control), g = 263.1 + .895 (estimated FO); $R^2 = .88$

FO (WS), g = −118.2 + 1.119 (estimated FO); $R^2 = .94$

FO (SS), g = 76.3 + .970 (estimated FO); $R^2 = .93$

Ideally, the intercepts should be 0 and slopes 1. The intercepts did not differ from 0 ($P > .25$), whereas, the slopes were highly significant ($P < .0002$).

TABLE 3. COMPARISON OF ESTIMATED VERSUS MEASURED DAILY FECAL OUTPUTS OF UNDIGESTED WHEAT FORAGE (WF) FOR STEERS CONSUMING WF ONLY, WF PLUS SORGHUM SUDAN-HAY (SS) OR WF PLUS WHEAT STRAW (WS)

				Estimated Fecal Output			
Trial	Treatment	No. of steers	Total collection[a], kg DM/day	Pulse dosage of ytterbium labeled WF[b], kg	As % of collected[c]	Bolusing Twice Daily with Cr_2O_3 (Cr Dilution)[a], kg	As % of collected[d]
Metabolism	WF	5	1.37	1.31	95.3±3.9	1.54(1.40)[e]	112.8±3.9
	(WF plus SS)	5	1.40	1.42	101.5±2.5	1.53(1.45)[e]	108.7±2.3
	Over both treatments	10	1.39	1.37	98.4±2.4	1.53(1.43)[e]	110.8±2.6
Grazing	WF	9	1.68	1.58	94.0±2.8		
	WF plus WS	9	1.59	1.53	97.6±3.0	---	---
	WF plus SS	9	1.57	1.64	105.5±3.1	---	---
	Overall treatments	27	1.61	1.58	99.0±1.9	---	---

[a]Corrected for the undigested portion of WS and SS appearing in feces.

[b]Ellis (1979) and Ellis et al. (1977 and 1979).

[c](Fecal output (estimated by pulse dose) ÷ actual Fecal output) x 100; Mean ± SEM.

[d](Fecal output (estimated by daily administration of Cr_2O_3) ÷ actual fecal output) x 100; Mean ± SEM.

[e]Fecal output corrected for Cr recovery (Estimated fecal output based on fecal grab samples x correction factor). Correction factor = estimated fecal output based upon Cr concentration in total feces collected ÷ estimated fecal output based upon Cr concentration in fecal grab samples.

In the metabolism trial, FO was consistently overestimated (average of 10.8 percent) using the Cr dilution method. This was attributed to incomplete recovery (91.3 ± 3.2 percent) of Cr in fecal grab samples, since 97.3 ± 2.3 percent (not significantly difference from 100 percent) of the Cr fed was recovered in the total quantity of feces collected. Correcting for the incomplete Cr recovery in fecal grab samples greatly improved the estimate of the FO over both treatments. Low Cr recoveries (approximately 80 to 95 percent) has been observed in many studies (Barnicoat, 1945; Crampton and Lloyd, 1951; Corbett et al., 1958a; Clanton, 1962; Nelson and Green, 1969; Kiesling et al., 1969; Whittington et al., 1978). These low Cr recoveries could possibly be due to inadequate mixing of Cr_2O_3 with the rumen digesta and a function of sampling procedure. For instance fecal grab samples, which are taken only once or twice daily on the average, would contain Cr concentrations which are lower than the overall average, since peak fecal Cr concentrations would represent a much smaller time interval than the time interval associated with low Cr fecal concentrations. Balch et al. (1957) and Corbett et al. (1958b) have graphically illustrated and presented data that shows a large proportion of Cr fails to be adequately mixed with rumen contents and passes out of the rumen within 30 min to 4 h after administration of Cr_2O_3 in gelatin capsules.

Daily variation (diurnal variation) of fecal marker concentrations appear to be greater with infrequent (once or twice daily) dosing. Lambourne (1957 a and b) effectively illustrated fecal concentrations of marker associated with different dosing and sampling intervals. Brisson et al. (1975) observed minimal diurnal variation when chromic oxide was administered six times per day. Other studies have shown that when marker is completely mixed with the total quantity of fed material, diurnal variation is considerably reduced or non-existant (Elam and Davis, 1961; Luckey et al., 1975a). Also, administration of concentrated doses of marker, such as in gelatin capsules, may cause diurnal variation due to uneven mixing of marker with rumen contents and passage of the marker in advance of material it is intended to mark (Corbett et al., 1958a, 1959 and 1960).

Teeter (1981) discussed the concept of "direct ruminal escape" of markers and estimated that as much as 5.7 percent of a pulse dose of Co-EDTA completely by-passed the rumen to the lower intestinal tract. The quantity of marker which escapes the rumen and associated diurnal variation would, therefore, be a function of dosing interval and the procedure used for administration of marker (gelatin capsule versus mixing in diet). The administration of marker relative to the time of feed consumption also is a factor which influences the magnitude of the diurnal variation (Lambourne, 1957 a; Balch, 1957; Brisson, 1957).

These data would suggest that diurnal variation and the related average estimates of marker concentration in fecal grab samples are a source of considerable error in estimating FO with daily dosing of a concentrated quantity of marker. In these studies (table 3) the coefficient of variation in Cr concentration of fecal grab samples averaged 21 percent. Twice daily administration of Cr_2O_3 and fecal sampling proved to be inadequate for predicting FO.

In table 4 is shown the actual and estimated digestibilities of diets fed in the metabolism trial. INDF overestimated diet digestibility of both feeding regimes, however, treatment differences were only

TABLE 4. COMPARISON OF INDIGESTIBLE NEUTRAL DETERGENT FIBER (INDF) AND ACID INSOLUBLE ASH (AIA) AS INDICES OF DIGESTIBILITY

Feeding regime	No. of steers	Actual diet digestibility,%	INDF,%	AIA,%
Wheat forage only	5	75.2	77.0	78.3*
Wheat forage plus Sorghum-sudan hay	5	73.0	78.3*	72.8

*Significantly different from the actual digestibility ($P < .05$).

significant ($P < .05$) for steers on the wheat forage plus SS feeding regime. Digestibility estimated by AIA was significantly ($P < .05$) greater for the steers fed wheat forage only. Overall, the most accurate digestibility estimates were obtained with AIA. This data agrees with data of Block et al. (1981) who found fecal recovery of AIA to be very close to 100 percent and, therefore, a suitable internal marker. Using the procedures outlined, it is questionable whether INDF fractions in feed is the same as the INDF of feces, since products of microbial origin may add to INDF in feces and therefore overestimate digestibility as shown in this study.

Results of this study indicate that the fecal excretion curves can be adequately described by models currently being utilized (R^2=.94 to .99). The best fit was obtained with the time-dependent time-independent model. The ability to predict FO using this model permits practical application in grazing studies. However, caution should be exercised when comparing predicted FO of steers on different feeding regimes. In this study the estimated FO as a percent of collected was consistently lower for steers consuming only wheat. Thus, when making comparisons of steers on different feeding regimes, verification of the estimates of FO may be required and regression analysis conducted to correct for any discrepancies.

Why the estimated FO (as a percent of actual outputs) was lower for steers fed only wheat forage and higher for steers fed SS is not apparent, since the intake of SS was low relative to the intake of wheat forage and errors in accounting for the undigested portion of SS in FO would be small. The actual digestibility of the SS used in the metabolism trial was determined and found to be very close to the estimated SS digestibility used for correcting FO (Mader, 1981d). Negative associative effects of wheat forage on SS digestibility could partially explain this discrepancy, however, no such associative effects were found (Mader, 1981d). This discrepancy could be attributed to marker migration from wheat forage to the SS or to other previously unlabeled wheat forage components. However, using similar labeling procedures, Teeter (1981) found marker migration to be insignificant, particularly with fibrous feedstuffs. The inability to identify the factor or factors which would account for these differences suggest that the model and associated parameters used to predict FO may differ slightly depending on the type and composition of diet fed.

The use of Cr_2O_3 administered twice daily in gelatin capsules proved to be unsatisfactory as an alternative for predicting FO in these studies. This was due to its poor recovery. However, the high specific gravity (5.2) of Cr_2O_3 and its tendency to flow independently of both solids and liquids (Bull et al., 1979; Faichney, 1975) makes its usefulness as a marker questionable. However, when Cr_2O_3 is thoroughly mixed with the entire ration or the frequency of marker administration is increased, it has been shown to effectively estimate digestibility of feedstuffs.

CHAPTER V

COMPARISON OF FORAGE LABELING PROCEDURES FOR CONDUCTING PASSAGE RATE STUDIES

Summary

Spray immersion and mordanting labeling techniques were compared. In the first study twelve steers grazing a common wheat pasture were utilized in a cross-over design and fed a single pulse dose of wheat forage (WF) which had been labeled with ytterbium (Yb) by either spray or immersion techniques. In a second study, 55 g of Yb-labeled sorghum-sudan hay (SS) and 30 g of chromium (Cr)-mordanted SS were both fed to five steers consuming SS. In these studies estimates of fecal output (FO), total mean retention time (TMRT) and the following fecal excretion curve parameters were compared: k_1 (assumed to be turnover rate of the large particle-rumination pool of the rumen), k_2 (ruminal turnover rate), and time delay (time of first appearance of marker in feces). In a final study the above comparisons were made for WF which had been labeled with Yb by the immersion technique but which had been either hand-clipped or preferentially selected for by two steers and removed from the previously evacuated rumen of the steers. However, removal of salivary and rumen fluid contaminants (capable of forming insoluble Yb complexes) from the selected forage prevented objective comparisons due to physical disruption (shredding and some particle reduction) of the WF fiber.

In the first study data suggests that for the spray technique the loosely bound Yb not only migrated to particles leaving the rumen, but also to particles of WF which entered the rumen following dosing. This resulted in lower ($P < .05$) estimates of time delay and k_2 as compared with estimates obtained by the immersion technique. In the second study, both k_1 and k_2 ($P < .01$) and the estimated FO (77.3% of actual) were lower ($P < .05$) when estimated from the Cr-mordant. The large depression in IVDMD of the Cr-mordanted SS (9.5 vs. 54.8%), would account for lower estimated turnover rates and FO. IVDMD of Yb-labelled SS was also depressed (35.1 vs. 54.8), but a much closer estimate of FO (93.4 percent of actual) was obtained. The studies indicate that the immersion labeling technique allows marker to be more evenly distributed throughout fiber constituents, while having the least effect on digestibility.

(Key words: Labeling Techniques, Spray, Immersion, Mordant, Passage Rate.)

Introduction

Rare-earth elements have been used extensively as particulate phase markers (Ellis and Huston, 1968; Huston and Ellis, 1968; Miller and Byrne, 1970; Miller et al., 1971; Young et al., 1975). Rare-earth elements have a strong affinity for particulate matter (Kyker, 1962), although, information regarding the nature of the binding and migrational characteristics of rare-earth elements has been studied only recently. Hartnell and Satter (1979a), Ellis et al. (1980) and Teeter (1981) have shown that the affinities and capacities for binding rare-earth elements differ among feedstuffs in that up to 7.4% of the rare-earth applied to grain is exchangeable, but when applied to hay a smaller amount (as little as .8%) is exchangeable. In the above studies, the feedstuff had been sprayed with the rare-earth element (Hartnell and Satter, 1979) or the feedstuff had been immersed in a solution containing the rare-earth element (Teeter, 1981). The latter procedure which involves rinsing off the excess marker is more laborious but allows for a greater proportion of the potentially exchangeable rare-earth element to be removed. Since feedstuffs which are labeled differently may display different passage rate characteristics, one objective of this study was to compare these two methods of labeling feedstuffs for estimating parameters from the fecal excretion curve. The immersion method of labeling feedstuffs with rare-earth elements was also compared to a labeling procedure recently described by Uden et al. (1980) in which chromium is mordanted to plant cell walls.

Experimental Procedures

Method of Labeling

Experiment I. Twelve steers were used in a cross-over design. The steers grazed a single wheat pasture and were fed a pulse dose of Yb-labeled wheat forage. In each period six steers received 535 g hand-clipped wheat forage which had previously been partially dried, sprayed with a 10 percent $YbCl_3$ solution, mixed, and then dried to approximately the original dry matter content of 34 percent. Yb was applied to the wheat forage so that each steer received approximately 2.0 to 2.4 g Yb per 100 kg body weight (Ellis, 1979). In each period, six steers also received 535 g of the same wheat forage labeled with Yb using the immersion technique (Teeter, 1981). In this method, feedstuffs are labeled by immersion in a .5 to 1 percent w/v aqueous solution of $YbCl_3$ allowed to equilibrate 18 to 24 after which the supernatant fluid is removed and the feed is rinsed in distilled water two to three times for four to six h to remove the unbound and weakly associated Yb. For both methods of labeling 120 g of hydrated $YbCl_3$ were used in the spray and immersion solutions.

The time-dependent time-independent model (Ellis et al., 1977 and 1979) and a nonlinear regression program (Barr et al., 1979), which was based upon a format presented by Ellis (1979), was used to estimate the fecal excretion curve parameters and fecal output. The parameters that were obtained by this procedure included the following: (1) time-dependent rate constant (k_1), assumed to be the turnover rate of particles in the upper strata of the rumen (large particle-rumination pool) and/or an artifact due to mixing (Ellis et al., 1979); (2) time-independent rate constant (k_2), assumed to be ruminal turnover rate (Grovum and Williams, 1973 b and c; Hartnell and Satter, 1979b; Teeter, 1981); and (3) time delay which is the time of first appearance of marker in feces. Total mean retention time (TMRT) of ingested feedstuffs was also obtained and calculated as $TMRT=1/k_1 + 1/k_2$ + time delay. Each period consisted of nine-day preliminary and five-day fecal collection phases. In this and subsequent trials that were conducted in this study, fecal grab samples were taken at 4 h intervals during the first 16 h and 24 to 36 h, post-dosage, and then twice daily (approximately 0700 and 1700 h) for the remainder of the fecal collection period. A larger number of samples was required in the early portion of the fecal collection period to adequately estimate k_1, which is associated with the rapidly increasing portion of the fecal excretion curve.

Experiment II. Five steers were individually fed ground (6-12 cm in length) SS during a nine-day preliminary and five-day fecal collection phase. At the beginning of the collection phase, all steers were fed both Yb-labeled SS (55 g) and Cr-mordanted SS (30 g) to determine if these labeling methods produce fecal excretion curves that differ in the estimated parameters as assessed by the time-independent time-dependent model. SS was labeled with Yb using the immersion procedure described by Teeter (1981). Cr-mordanted SS was prepared by the procedure described by Uden et al. (1980). Labeled SS was fed at approximately 90 percent DM. Total feces were collected using fecal collection bags. Grab samples were taken at the times specified above. Treatment means were compared using the paired t-test.

Form of Forage Labeled

To determine if passage rate parameters differed between hand-clipped wheat forage and wheat forage preferentially selected for by the animal, twelve steers grazing a single wheat pasture were utilized in a completely randomized design. Six steers were fed hand-clipped wheat forage that had been labeled with Yb using the immersion technique. Six steers were also fed wheat forage, which was removed from the rumen of two ruminal cannulated steers, and labeled with Yb in a similar manner. Prior to the removal of consumed wheat forage, the rumen of the two steers was completely evacuated and the steers were allowed to graze wheat pasture 30 to 60 min. After removal from the rumen, the wheat forage was rinsed free of saliva and then labeled. A five-day fecal collection (grab samples) phase followed a nine-day preliminary phase.

Forage and Marker Analysis

Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined by methods described by Goering and Van Soest (1970). IVDMD was determined by procedures modified from Tilley and Terry (1963). IVDMD procedural modifications consisted of adding 1.0 g of urea per liter of buffer and rumen fluid, acidifying with 2.4 N HCL after the rumen microorganism fermentation period and filtering contents of the digestion tubes through Whatman No. 4 qualitative filter paper following a 24 hr pepsin digestion.

Yb and Cr were analyzed by atomic absorption spectrophotometry. Samples for Yb analysis were digested with a 1:1 v/v mixture of 3 N nitric and 3 N hydrochloric acid according to procedures described by Ellis et al. (1981). Standard addition procedures (Schrenk, 1971) were employed to correct for matrix interferences associated with Yb analysis. Cr was determined by procedures described by Williams et al. (1962).

Results and Discussion

Method of Labeling

Experiment I. Chemical composition and IVDMD of wheat forage unlabeled or labeled with Yb (by spray and immersion techniques) are shown in table 1. Concentration of Yb applied by spray and immersion techniques averaged 48.6 and 15.6 mg/g wheat forage DM, respectively. IVDMD was decreased from 77.4 percent (unlabeled) to 63.5 and 65.7 percent, respectively, for the wheat forage labeled by spray and immersion techniques. This is in partial disagreement with data presented by Teeter (1981), who, also found a depression in IVDMD of feedstuffs labeled with Yb. However Teeter reported that the percent change in IVDMD of Yb labeled prairie hay was highly correlated with final Yb concentration (r=.97). This relationship was not observed in this study with wheat forage, since the higher level of Yb did not reduce IVDMD further.

With the spray application, Yb is absorbed on the exterior surface of the forage and not necessarily allowed to equilibrate with all the fibrous constituents of forage. More complete marker penetration is expected with the immersion technique. Although a larger quantity of Yb was applied to the forage by the spray technique, the amount of

TABLE 1. COMPARISON OF METHODS OF LABELING WHEAT FORAGE (WF) WITH YTTERBIUM (YB)

	Unlabeled WF	Spray[a]	Immersion[b]
Yb fed, g/steer[c]	---	8.7	2.5
Yb, mg/g dry matter WF fed[c]	---	48.6	15.6
Dry matter, %[c]	34.0	33.5	30.2
IVDMD, %[cd]	77.4	63.5	65.7
NDF, %[cd]	56.2	49.8	70.8
ADF, %[cd]	17.7	15.4	22.2
Time dependent turnover rate (k_1), %/h	---	19.6	16.0
Time independent turnover rate (k_2), %/h	---	4.9	5.9*
Time delay, h	---	4.0	5.6*
TMRT, h[e]	---	31.1	29.6
Estimated fecal output, kg	---	1.84	1.97

[a]WF was partially dried, sprayed with a solution of $YbCl_3$, mixed and dried back to approximately the original dry matter.

[b]WF was immersed in a $YbCl_3$ solution for 18 to 24 h, rinsed periodically in distilled water and dried back to approximately the original dry matter.

[c]Statistical analysis of data was not conducted.

[d]IVDMD = in vitro dry matter digestibility; NDF = neutral detergent fiber; ADF = acid detergent fiber.

[e]Total mean retention time of ingested feedstuffs = $1/k_1 + 1/k_2$ + time delay.

*$P < .05$.

by the spray technique, the amount of tightly bound Yb was probably similar, since a similar depression in wheat forage IVDMD was observed with both techniques. The lower NDF and ADF values of forage labeled by the spray technique would largely be accounted for by the quantity of Yb applied and, subsequently, solubilized in the detergent extraction procedures. The greater NDF and ADF values of wheat forage labeled by the immersion technique, compared with unlabeled wheat forage, indicates that a portion of the cell contents are removed in the rinsing procedure.

Method of labeling did not significantly ($P > .05$) alter the estimates of k_1, TMRT and fecal output (table 1). However, k_2 was smaller ($P < .05$) when estimated from wheat forage labeled by the spray technique. The lower time delay suggests that a portion of the Yb that was sprayed on the wheat forage was loosely bound and quickly passed out of the rumen possibly as insoluble hydroxides (Kyker, 1962) or attached to previously unlabeled particles of the solid phase. Ellis et al. (1981) indicated that ruminal migration of unbound marker should shift the distribution of marker to smaller size particles due to their greater surface area per unit weight. This appears to be the case in this trial when Yb was sprayed on the forage, as is evident from the greater k_1 and smaller time delay. However, the lower estimate of ruminal turnover rate, k_2, suggests that migration from smaller to larger particles occurs as well. Any migration of marker to larger forage particles which enter the rumen, after the original time of marker dosing, would underestimate the ruminal turnover rate. A lower k_2 would also lower the estimate of FO. This data would suggest that, particularly for the spray technique, there is a continual migration (attachment reattachment) of Yb among particles of digesta in the rumen.

In studies conducted to quantitate marker migration, Hartnell and Satter (1979 a and b) sprayed very low concentrations (approximately 1.4 mg/g of feed) of rare-earth elements (La, Sm and Ce) on alfalfa hay and corn, and found rate of marker migration from one feedstuff to the other to range from 0.8 to 7.4 percent per 24 h period: However, reattachment of exchangeable marker to feedstuffs to which the marker was originally applied was not considered. The low marker concentration used in their study also should aid in minimizing marker migration assuming marker would attach to high affinity binding sites first. However, detection of marker in feces would be difficult with conventional atomic absorption spectrophotometry methods unless larger than normal fecal grab samples were obtained. In a study conducted by Teeter (1981), five different feedstuffs that had previously been labeled by the immersion technique, were placed in dialysis bags to measure marker migration. The rate of Yb migration from the feedstuffs was found to range from .036 to .57 percent per h. In this study the dialysis bags were submerged in distilled water having a dilution rate of 47 percent per h. This is considerably higher than the dilution rate of water in the rumen; therefore rate of marker migration under physiological conditions was probably overestimated. Although neither the spray or immersion technique appears "ideal" for labeling feedstuffs, the immersion technique allows for greater exposure to binding sites. Therefore, a better distribution of marker is obtained throughout the fibrous constituents.

<u>Experiment II</u>. Chemical composition IVDMD and estimated passage rate parameters of SS labeled with Yb by the immersion technique and

SS labeled with Cr by the mordanting procedure (Uden et al., 1980) are presented in table 2. The high concentrations of bound Yb (20.4 mg/g SS) and Cr (43.8 mg/g SS) indicate that lower marker concentrations could be utilized in these binding procedures. Lower levels probably would help prevent the large depression in IVDMD of SS. However, for the Cr-mordant, the extraction procedure and subsequent harsh treatment of the fiber with the oxidizing agent, dichromate, would most likely always result in a large depression in IVDMD.

The lower ($P < .01$) turnover rates (k_1 and k_2) of the Cr-labeled SS suggest that the mordanting procedure inhibits particle size reduction and passage rate. The time of first appearance of marker in the feces (time delay) was the same for both methods of labeling. This would indicate that the size of particles labeled were similar for both methods and those particles that required little or no reduction in size exited the rumen at the same time regardless of labeling procedure. The greater ($P < .01$) TMRT of the Cr-mordanted SS would be expected due to the lower turnover rates. The estimated FO was greater ($P < .05$) when measured from data obtained with Yb-labeled SS. Regardless of the magnitude of the depression in IVDMD of the Yb-labeled SS, the estimated FO was reasonably close (93.4 percent) to actual feces collected. This data would suggest that, although the immersion technique of labeling results in a depression in IVDMD, feedstuffs labeled by immersion techniques follow a similar pattern as unlabeled feedstuffs in the gastrointestinal tract.

Form of Forage Labeled

Comparisons of hand-clipped and selected wheat forage labeled with

TABLE 2. COMPARISON OF YTTERBIUM (YB)-LABELED VERSUS CHROMIUM (CR)-LABELED SORGHUM-SUDAN HAY (SS)

	Unlabeled SS	Yb-labeled SS[a]	Cr-labeled SS[b]
Marker fed, g/steer[c]	---	1.0	1.2
Marker mg/g dry matter SS fed[c]	---	20.4	43.8
IVDMD, %[cd]	54.8	35.1	9.5
NDF, %[cd]	72.2	82.0	84.9
ADF, %[cd]	42.4	44.8	43.7
Time dependent turnover rate (k_1), %/h	---	13.4	9.7**
Time independent turnover rate (k_2), %/h	---	2.6	1.8**
Time delay, h	---	6.7	6.7
TMRT, h[e]	---	53.5	72.3**
Estimated fecal output, Kg	---	2.6	2.2*
Estimated as % of collected[f]	---	93.4	77.3*

[a]SS labeled using immersion and rinsing procedures (Teeter, 1981).

[b]SS labeled using mordanting procedures (Uden et al., 1980).

[c]Statistical analysis of data was not conducted.

[d]IVDMD = in vitro dry matter digestibility; NDF = neutral detergent fiber; ADF = acid detergent fiber.

[e]Total mean retention time of ingested feedstuffs = $1/k_1 + 1/k_2$ + time delay.

[f](Fecal output (estimated by pulse dose)÷actual fecal output) x 100; Mean ± SEM.

* $P < .05$

** $P < .01$

Yb are presented in table 3. Wheat forage that was removed from the rumen of the two cannulated steers displayed very little evidence of mastication and was similar in appearance to that of hand-clipped wheat forage. The greatest problem associated with this technique was in the removal of the contaminants of saliva and fluids that entered the rumen following evacuation. Even though the rumen had been completely evacuated, the forage that was extracted from the rumen was bathed in these fluids. The wheat forage was rinsed several times and the liquid manually squeezed from the forage.

Removal of these contaminants was considered to be critical to the labeling procedure, since Yb is known to form insoluble complexes with hydroxides (Kyker, 1962) and phosphates (R.G. Teeter, personal communications). Such insoluble complexes would not necessarily be associated with the particulate phase of the rumen and would bias passage rate estimates. A similar problem of saliva contamination also would exist for esophageal samples as well. Removal of these components resulted in shredding of many of the wheat forage leaves and some particle size reduction. Furthermore, some of the wheat forage soluble components were removed as is noted by the decreased percent IVDMD (62.4 vs. 74.5) and increased NDF (64.4 vs. 61.5) and ADF (31.7 vs. 22.1) for wheat forage removed from the rumen compared to the unlabeled hand-clipped wheat forage.

Wheat forage removed from the rumen and labeled with Yb had a lower IVDMD (48.8 vs. 63.0) than Yb-labeled hand-clipped wheat forage. The higher k_1 ($P < .05$) and k_2 ($P > .05$) and the lower ($P < .01$) time delay and TMRT of the wheat forage removed from the rumen would be

TABLE 3. COMPARISON OF HAND-CLIPPED WHEAT FORAGE LABELED WITH YTTERBIUM (YB) VERSUS WHEAT FORAGE REMOVED FROM THE RUMEN AND LABELED WITH YB

	Hand-Clipped[a]	WF from rumen[b]
Yb fed, g/steer[c]	0.6	1.6
Yb, mg/g dry matter fed[c]	18.0	23.6
IVDMD, %[cd]	63.0 (74.5)[e]	48.8 (62.4)[e]
NDF, %[cd]	61.0 (61.5)[e]	60.0 (64.4)[e]
ADF, %[cd]	23.5 (22.1)[e]	30.0 (31.7)[e]
Time dependent turn-over rate (k_1), %/h	13.1	18.8*
Time independent turn-over rate (k_2), %/h	5.7	7.2
Time delay, h	7.2	4.8**
TMRT, h[f]	33.3	25.9**
Estimated fecal output kg	1.31	1.67*

[a]Forage clipped to 10-15 cm in length and labeled by immersion procedures.

[b]Rumen contents were removed from two rumenally cannulated steers. Steers were allowed to graze 30 to 60 min and contents were again' removed rinsed free of saliva, and then labeled by immersion procedures.

[c]Statistical analysis not conducted.

[d]IVDMD = in vitro dry matter digestibility; NDF = neutral detergent fiber; ADF = acid detergent fiber.

[e]Parenthetical numbers represent the mean % IVDMD, ADF and NDF of unlabeled wheat forage prepared in the same manner as the labeled wheat forage.

[f]Total mean retention time of ingested feedstuffs = $1/k_1 + 1/k_2$ + time delay.

* $P < .05$.

**$P < .01$.

expected for labeled particles which are smaller in size, or particles that are shredded and more accessible to rumen microbes.

These data would support the suggestions of Ellis et al. (1979) that the rate constant, k_1, is associated with the turnover rate of large particles in the rumen. Entry of smaller particles into the rumen would result in less time spent in the large particle pool and a faster turnover rate (18.8 vs. 13.1 percent/h; $P < .05$) of this pool. Grovum and Williams (1973b) suggested that k_1 is the turnover rate of particles in the cecum and proximal-colon although they presented no conclusive data to substantiate this suggestion. Results of this study do not support their suggestion, since k_1 values were different between the treatments. Only if there was segregation of labeled particles in the region of the cecum and proximal-colon and differential flow rates for these two particle sizes in that region, would these data support the suggestions of Grovum and Williams (1973 b and c). Also, the size of particles which exit the rumen should be similar, regardless of the size of particles which were originally labeled. Therefore, turnover rate in the cecum and proximal-colon, as estimated by k_1, should be the same for both sizes of labeled particles. This was not found in the present study, however.

Unless a more effective means of removing contaminants of saliva and rumen fluid can be found, the use of ruminal contents and possibly esophageal extrusates may be limited for labeling fragile feedstuffs such as lush wheat forage with rare-earth elements. Longer and more frequent rinsing periods with little or no manual agitation might prevent some of the deterioration if forage. Compared with samples obtained from the rumen, hand-clipped wheat forage samples appeared to be adequate for labeling purposes. However, if attempts are made to label forages which are selected by the animal, further research needs to be conducted relative to the effects of salivary contaminants, etc., on rare-earth binding and passage rate estimates.

Of the three methods of labeling tested (spray, immersion and mordanting), the immersion technique was preferred. This technique prevents localized concentration of the marker which may exceed the binding capacity of the feedstuffs. Although IVDMD of feedstuffs which are labeled by this technique is depressed, Teeter (1981) found that the magnitude of depression in digestibility was less in situ than in vitro. The relatively close estimate of FO when SS was labeled by the immersion technique would suggest that the magnitude of the depression in digestibility which was shown in vitro was probably not as great in vivo, therefore, "relatively" accurate passage rate estimates were obtained. To partially overcome the depression in IVDMD and associated errors smaller quantities of bound marker (less than one percent w/w) are recommended. In these studies,feedstuffs labeled by the immersion technique were placed in solutions of $YbCl_3$ which were assumed to contain enough Yb to saturate all binding sites. Lower concentrations of marker in the immersion solution may allow for a larger proportion of binding only to the high affinity sites. This would facilitate less of marker migration and reduce the effect of marker on digestibility of feedstuffs.

CHAPTER VI

EFFECT OF FEEDING LOW-QUALITY ROUGHAGES ON WHEAT FORAGE INTAKE AND UTILIZATION

Summary

Grazing and metabolism trials were conducted to determine the effect of feeding wheat straw (WS) and sorghum-sudan hay (SS) on wheat forage (WF) intake, digestibility and passage rate. In the metabolism trial, steers were fed WF or WF plus SS. In grazing trials, which were conducted over a three year period, steers grazed a common wheat pasture and were fed no supplemental low-quality roughage (control) or WS or SS were available to steers ad libitum. Intakes of WF were identical (5.6 Kg dry matter), for both treatment groups of the metabolism trial, however, the greater ruminal turnover rate, k_2, ($P < .15$) and time of first appearance of marker in feces, time delay, ($P < .05$) and lower ($P < .20$) total mean retention time (TMRT) of WF for steers fed SS suggest that SS decreases the retention of wheat forage in the rumen. Feeding SS had little effect on WF digestibility (75.2 vs. 74.7 percent). In the grazing trail estimated WF intakes did not differ among treatments. Parameters estimated from the fecal excretion curve (k_1, k_2 and time delay) were not different ($P > .05$), however, TMRT of WF were lower ($P < .05$) and k_2 of WF were consistently greater for steers fed WS and SS. Since a corresponding increase in WF intake did

not accompany the decrease in ruminal retention time of WF (evident from an increase in k_2 and time delay while TMRT was lower), this data suggest that the WS and SS occupies the ruminal space voided by the WF. This is further verified in the grazing trial where passage rates of WS and SS were found to be independent of the WF passage rate and the TMRT of WS (86.1 h) and SS (68.9 h) were significantly greater ($P < .05$) than the TMRT of WF (30.8 to 31.4 h).

Introduction

Low-quality roughages (LQR) such as wheat straw (WS) or sorghum-sudan hay (SS) are frequently fed to steers grazing wheat pasture. It is commonly believed that LQR slows the rate of passage of "washy" wheat forage and, thereby, improves its digestibility and (or) utilization. In early studies with dairy cows, Cole and Kleiber (1945) found that sudan hay did not affect forage intake of dairy cows grazing alfalfa pastures. However, hay was not consumed every day and intake of alfalfa was measured with only three cows for intervals of two or six h only. Ittner, et al. (1954) implied that "scouring" steers, grazing alfalfa pastures, were more prone to bloat and that feeding 1.4 to 1.5 kg of oat hay DM to the steers was required to maintain firm feces and to preclude the danger of bloat. In studies that were conducted to determine blood mineral levels of steers grazing wheat pasture, McMillen and Langham (1942) allowed steers (five per treatment) to have access to sumac cane plus mineral or mineral alone or nothing. The mean daily consumption of sumac cane was .41 Kg (as is basis), while the respective average daily gains were .70, .63 and .67 kg. In this study diarrhea was noted in steers not having access to sumac cane. More recently Mader (1981a) reported that LQR did not significantly ($P > .05$) alter daily weight gains when fed to steers grazing wheat pasture. Although mean daily intakes of WS (.10 kg) and SS (.25 kg) were low, results supported suggestions of Colvin, et al. (1958 a and b) that scabrous material in the diet aids in the prevention of bloat.

The above studies suggest that LQR influences the utilization of lush high-quality forages possibly by altering intake, digestibility, and (or) passage rate of the high-quality forage. The objective of this study was to acquire data relative to the intake of LQR by steers grazing wheat pasture and assess the effect of LQR on wheat forage intake, passage rate and digestibility.

Experimental Procedures

Metabolism Trials

Ten Hereford steers (283 ± 6 kg) were utilized in a completely randomized design and fed harvested wheat forage or harvested wheat forage plus SS. The SS was coarsely ground (6-12 cm in length) through a hammermill (approximately 1500 RPM), with no screen. Wheat forage was harvested every two or three days using a small flail harvester. After harvesting, the forage was placed in large plastic bags (approximately 18 kg/bag), excess air was removed and the bags were tied with string. The bagged forage was stored at 2°C and fed within one to three days after harvesting. Samples of wheat forage fed to steers were taken daily during the fecal collection phase of the trial and frozen for later analysis. The trial included a nine-day preliminary period in which wheat forage intake was fed at maximum intake, and a five-day fecal collection period, in which wheat forage was fed at 90 percent of maximum intake.

Nine hundred and fifty (950) grams of ytterbium (Yb)-labeled wheat forage (25% dry matter) was fed to each steer at the beginning of the fecal collection period. Each steer received approximately 2.5 g of Yb. Wheat forage was labeled using the immersion technique described by Teeter (1981) in which feedstuffs are labeled by immersion in an aqueous solution of $YbCl_3$ (approximately .5 to 1 percent w/v Yb), allowed to equilibrate for 18 to 24 h after which the supernatant is removed and the feed is rinsed with distilled water two to three times for 4 to 6 h to remove any unbound and weakly associated Yb. The labeled material was then dried back to approximately the original dry matter content. Fecal grab samples were taken at 4 h intervals during the first 12 h and 24 to 36 h post-dosage and then twice daily (approximately 0700 and 1700 h) for the remainder of the fecal collection period.

In this trial and the subsequent grazing trial parameters of the fecal excretion curve (Yb concentration versus time, post-dosage) were estimated using the time-dependent time-independent model (Ellis et al., 1979) and a nonlinear regression program (Barr et al., 1979) based upon the format presented by Ellis (1979). The estimated parameters that were obtained included the following: (1) time-dependent rate constant (k_1), assumed to be the turnover rate of particles in the upper strata of the rumen and (or) an artifact due to mixing (Ellis et al., 1979); (2) time-independent rate constant (k_2), assumed to be the ruminal turnover rate (Grovum and Williams, 1973 b and c; Hartnell and Satter, 1979b; Teeter, 1981); and (3) time delay, which is the time of first appearance of marker in feces. Along with the above parameters, the initial marker concentration (k_0) in the time-independent compartment obtained. The gastrointestinal tract fill of undigested dry matter (UDMG) was then determined by dividing the quantity of marker consumed by k_0 (Ellis et al., 1977). Total mean retention time (TMRT) of ingested wheat forage was also obtained and calculated as $TMRT=1/k_1+1/k_2+$ time delay.

Digestibilities of the wheat forage and the wheat forage plus SS diets were determined from total feed intake and fecal collection. In a separate metabolism trial one Hereford and four HerefordxAngus steers (323 ± 11 kg) were fed only SS at 90 percent of maximum intake (based on free-choice intakes during nine-day preliminary period) for a five-day total fecal collection period to determine the digestibility of the SS fed in the previous metabolism trial. Thus the associative effects of feeding SS with wheat forage were determined from the difference in the actual vs. calculated digestibilities of the mixed diet (wheat forage plus SS). For steers fed wheat forage and wheat forage plus SS, five percent and one percent, respectively, of the daily fecal and urine output were retained for dry matter and nitrogen (N) determinations (Horwitz, 1975). Comparisons of N digestibility and retention were made between feeding regimes.

Grazing Trial

In each of three years, nine Hereford and Hereford X Angus steers, which averaged 226 ± 7 kg (1978-79), 343 ± 14 kg (1979-80) and 291 ± 7 kg (1980-81) in weight, were used in three 3X3 latin square designs with steers, period on wheat pasture and treatment as factors. The same steers were used the first two years; a second group of steers was used the third year. Data were collected to correspond with grazing intervals utilized in previous studies (Mader, 1981a) in which the effect of feeding WS and SS to steers grazing wheat pasture on weight gains and incidence of bloat was determined. Grazing intervals and approximate dates were the fall grazing interval prior to winter wheat dormancy (December through mid-January), interval of winter dormancy of wheat (mid-January through February), and interval of lush spring growth (March). During each period all steers grazed a common wheat pasture for 9 to 12 h each day. The steers were removed from wheat pasture, placed in individual feeding stalls and hd ad libitum accesss to (1) no LQR, (2) WS or (3) SS overnight. The WS and SS were coarsely ground (6-12 cm in length) in the same manner, which was described in the metabolism trial. Each period consisted of eleven- and five-day preliminary and collection phases, respectively. At the beginning of each collection phase, all steers were fed a single pulse dose of wheat forage labeled with $YbCl_3$. Fecal grab samples were taken according to procedures previously described in the metabolism trial.

In the first year of this trial, labeled wheat forage was prepared by spraying a 10 percent solution of $YbCl_3$ on hand-clipped forage. Each steer was fed approximately 9.7 g Yb adsorbed onto 250 g wheat forage (50 percent DM). This concentration of Yb was required to achieve a recommended level of 10 g of marker to be fed to each steer (W. C. Ellis, personal communication). This was later found to be in excess of the quantity of Yb needed, however. In the last two years of this study wheat forage was labeled by the immersion technique described by Teeter (1981), and each steer was fed approximately 1.6 g of Yb adsorbed onto 650 g (30 percent DM) of hand-clipped wheat forage. In previous studies (Mader, 1981c), k_2 and the time delay were found to be lower ($P < .05$) when estimated using wheat forage labeled by spray versus immersion techniques. However, since no year by treatment interactions ($P > .05$) were found for any of the parameters estimated in this study, data was pooled across years and analyzed accordingly. The quantity and concentration of marker and IVDMD of labeled and unlabeled feedstuffs that were used in the metabolism and grazing trials are listed by year and period in table 6 of Appendix.

Estimates of daily fecal DM output (FO) of undigested wheat forage were determined from the fecal excretion curve parameters estimated from the time-dependent, time-independent model and are obtained by multiplying the estimate of UDMG by the portion of digesta passing out of the time-independent compartment daily (k_2/h x 24h; Ellis et al., 1977). Wheat forage DM intake was calculated by dividing FO by wheat forage indigestibility (one minus estimated in vivo wheat forage digestibility). Estimated in vivo digestibility of wheat forage was determined from the in vitro dry matter digestibility (IVDMD) using the regression equation of OH et al. (1966) for obtaining apparent digestibility of feedstuffs from IVDMD procedures.

In the third year of this trial, steers were fitted with fecal collection bags to verify the accuracy of procedures (Ellis et al., 1977 and 1979; Ellis 1979) for estimating FO. These results have been reported previously (Mader, 1981b). Since the estimated FO of undigested wheat forage varied, somewhat, with feeding regime, the following regression equations were developed (Mader, 1981b) to adjust estimated FO of steers fed WS, SS or no supplemental LQR:

$$FO\ (control),\ g = 263.1 \pm .895\ (estimated\ FO);\ R^2 = .88;\ SE = 130g$$

$$FO\ (WS),\ g = 118.2 \pm 1.119\ (estimated\ FO);\ R^2 = .94;\ SE = 133g$$

$$FO\ (SS),\ g = 76.3 \pm .970\ (estimated\ FO);\ R^2 = .93;\ SE = 136g$$

Wheat forage intakes were calculated and reported for both unadjusted and adjusted estimates of FO. Also, in the third year of this trial, steers receiving low-quality roughage were fed approximately 55 g of chromium (Cr)-mordanted WS or SS (2.5 to 2.7 g chormium). Cr-mordanted WS and SS were prepared using procedures described by Uden et al. (1980). Passage rate parameters of the LQR were compared to those of wheat forage by paired t-test. Statistical analysis of data, which was pooled across years, was conducted using the General Linear Models procedure of the Statistical Analysis System (Barr et al., 1979). Means were compared using Duncan's multiple range test.

Forage and Marker Analysis

Crude protein was determined by Kjeldahl procedures (Horwitz, 1975). Soluble protein and non-protein N concentrations of wheat forage were determined by procedures described by Wohlt et al. (1973). NDF and acid detergent fiber (ADF) were determined by methods described by Goering and Van Soest (1970). IVDMD was determined by procedures modified from Tilley and Terry (1963). Procedural modifications consisted of adding 1.0 g of urea per liter of buffer and rumen fluid, acidifying with 2.4 N HCL after incubation in buffered rumen fluid and filtering contents of the digestion tubes 24 h later through Whatman No. 4 qualitative filter paper following 24 h pepsin digestion.

Yb and Cr were both analyzed by atomic absorption spectrophotometry. Samples for Yb analysis were digested with a 1:1 v/v mixture of 3 N nitric and 3 N hydrochloric acid according to procedures described by Ellis et al. (1981). Standard addition procedures (Schrenk, 1971) were employed to correct for matrix interferences associated with Yb analysis. Cr was determined by procedures described by Williams et al. (1962).

Results and Discussion

Metabolism Trial

Composition of the wheat forage, SS and WS, that was fed in the metabolism and grazing trials is presented in table 1. The composition of hand-clipped wheat forage obtained in each year of the grazing trial is shown in table 4 of Appendix. Except for the slightly higher IVDMD value of SS fed in the metabolism trial, the composition of these feedstuffs was similar to that of feedstuffs consumed by steers in previously reported grazing trials (Mader, 1981a). Comparisons of dry matter, total N and soluble N fractions of fresh-cut wheat forage versus wheat forage that was stored in the cooler and fed in the metabolism trial are shown in table 2. In general, changes in dry matter (DM) and total N were small, although both soluble protein N and soluble non-protein N were somewhat higher in wheat forage which had been stored. This is opposite to results of MacRae (1970) who reported a marked decrease in soluble N content when grass and clover was stored frozen (-20°C). In the present study, wheat forage was stored at a low temperature to minimize enzymatic degradation of the forage, but not frozen to prevent cellular damage which could occur in the freezing and thawing process if the forage was frozen. Overall, preservation of the cooler-stored wheat forage was very good, and appeared to be very similar in physical characteristics to fresh-cut forage when removed from the cooler.

Comparisons of wheat forage intake, digestibility and turnover rates of steers fed wheat forage or wheat forage plus SS are shown in table 3. Intakes of SS were 2.6-fold (.64 vs. .25 kg) greater than SS intakes of steers grazing wheat pasture in previous studies (Mader, 1981a). However, SS intakes expressed as a percent of metabolic body weight ($wt^{.75}$, kg) were approximately two-fold greater (.93 versus .45). Daily intakes of wheat forage were identical (5.55 kg) for steers fed wheat forage or wheat forage plus SS indicating that SS was not substituted for wheat forage in the diet. Also the associative effects of feeding SS with wheat forage were found to be small or non-existent (.4 ± .4 percent). This is shown in table 4, along with the calculated wheat forage and SS digestibilities for steers fed the mixed diet (wheat forage plus SS). Since associative effects were not apparent, wheat forage digestibilities were determined to be similar for steers fed wheat forage with or without supplemental SS. However, from these calcualtions it is shown that wheat forage tended to have a depressing effect on SS digestibility (54.3 vs. 58.0 percent); although these means were not different ($P > .05$) and for two steers fed wheat forage and SS the SS digestibility was greater than 58.0 percent.

If feeding scabrous material "enhances" rumen motility of steers consuming lush forage as implied by Colvin (1958b) and Colvin and Daniels (1965), then a corresponding increase in ruminal passage rate

TABLE 1. COMPOSITION OF WHEAT FORAGE, SORGHUM-SUDAN HAY AND WHEAT STRAW

Trial	Dry matter, %	Crude protein,%	NDF,%[a]	ADF,%[a]	IVDMD,%[a]
Metabolism					
Wheat forage	30.2	27.8	68.6	29.0	71.8
Sorghum-sudan hay	90.5	8.7	74.1	48.4	56.1
Grazing					
Wheat forage					
I[b]	28.1	27.7	50.4	17.5	76.8
II[b]	23.7	29.7	56.6	20.7	73.9
III[b]	19.1	31.6	55.3	22.9	75.6
Wheat straw	89.5	3.4	84.5	57.0	28.2
Sorghum-sudan hay	89.8	8.3	74.7	44.1	50.4

[a]NDF = neutral detergent fiber; ADF = acid detergent fiber; IVDMD = in vitro dry matter digestibility.

[b]Grazing intervals associated with each period of time a trial was conducted; I = interval prior to winter wheat dormancy, II = interval of winter wheat dormancy, and III = interval of lush spring growth.

TABLE 2. SOLUBLE PROTEIN AND NON-PROTEIN NITROGEN OF HARVESTED WHEAT FORAGE FED IN METABOLISM TRIAL

	Fresh-cut	Stored in cooler[a]
Number of samples	3	5
Dry matter (DM), %	31.53	30.18
Total nitrogen (N), %	4.39	4.45
Soluble N		
% of DM	.77	1.11
% of total N	17.58	24.90
Soluble protein N		
% of DM	.33	.45
% of total N	7.67	10.07
Soluble non-protein N		
% of DM	.44	.65
% of total N	9.91	14.83

[a]Storage time of one to three days at 2°C.

TABLE 3. WHEAT FORAGE INTAKE, DIGESTIBILITY AND TURNOVER RATES OF STEERS IN METABOLISM TRIAL

	Wheat Forage (Control)	Wheat Forage Plus Sorghum-Sudan Hay
Roughage intake Kg DM/day	---	.64
% metabolic BW[a]	---	.93
Wheat forage intake, kg DM/day	5.55	5.55
% of body weight	1.97	1.96
Wheat forage digestibility, %	75.2	74.7
UDMG, kg[b]	.69	.51
Time Dependent Turn- over Rate (k_1), %/h	17.8	15.0
Time Independent Turn- over Rate (k_2), %/h	9.1	11.6
Time Delay, h	4.65	5.84*
TMRT, h[c]	23.4	21.5

[a]Sorghum-sudan hay intake expressed as a percent of metabolic body weight ($wt^{.75}$, kg).

[b]UDMG=gastrointestinal tract fill of undigested dry matter (Ellis et al., 1977).

[c]Total mean retention time of ingested wheat forage = $1/k_1 + 1/k_2$ + time delay.

*Significantly different from control ($P < .05$).

TABLE 4. ESTIMATED ASSOCIATIVE EFFECTS OF WHEAT FORAGE (WF) AND SORGHUM-SUDAN HAY (SS) FED IN METABOLISM TRIAL

	Steer Number					Mean
	2	3	7	8	12	(±SE)
WF Intake, kg	5.20	6.60	5.80	5.14	5.02	5.55(.30)
SS Intake, kg	.63	.77	.60	.54	.67	.64(.04)
Diet (WF + SS) digestibility,%						
Actual	72.2	74.0	74.2	72.9	71.7	73.0(.5)
Calculated[a]	73.3	73.4	73.6	73.6	73.2	73.4(.1)
Deviation[b]	+1.1	-0.6	-0.6	0.7	+1.5	0.4(.4)
WF digestibility, assuming SS digestibility is constant,%[a]	73.9	75.9	75.8	74.4	73.5	74.7(.5)[c]
SS digestibility, assuming WF digestibility is constant,%[a]	47.2	63.6	64.1	50.9	45.5	54.3(4.0)[d]

[a]Based upon WF and SS intakes and mean ±SE WF and SS digestibilities of 75.2(.5) and 58.0(1.2), respectively which were determined from measured intakes and fecal outputs of five steers fed WF and SS in separate trials.
[b]Estimated associative effect.
[c]Not different from actual WF digestibility ($P > .05$).
[d]Not different from actual SS digestibility ($P > .05$.

and decrease in ruminal digestion might be expected. However, in this trial (table 3) neither rate constant (k_1 or k_2) was found to be significantly different ($P > .05$), although, a significantly greater ($P < .05$) time delay was found for steers fed SS. These results suggest that the SS either (1) physically prevented or hindered the initial passage of small particles of wheat forage from the large particle-rumination pool to the pool of small particles, which are capable of passing out of the rumen, or (2) increases retention time (slows the rate of passage) of digesta through the lower gastrointestinal tract (GIT). Since loose diarrhea-like feces tended to be prevalent for steers not fed LQR (in both metabolism and grazing trials) the latter explanation (increased retention time in lower GIT) may be preferred to the first. Overall, however, the TMRT (21.5 vs. 23.4 h; $P < .20$) of ingested wheat forage was decreased. Since feeding SS increased time delay these data suggest that SS apparently decreases retention time of wheat forage in the rumen and, therefore, are in agreement with data of Colvin (1958b) and Colvin and Daniels (1965). The greater ruminal turnover rate k_2, (11.6 vs. 9.1 percent/h; $P < .15$) for steers fed SS substantiate this. However, the magnitude of the change in k_2 is apparently not great enough to affect wheat forage digestibility, (table 4). The lower mean UDMG (.51 vs. .69 kg; $P < .10$) for steers fed SS suggest that SS decreases the gastrointestinal tract volume occupied by the wheat forage. The greater time delay for steers fed SS indicates that this is a ruminal effect, as well.

Nitrogen balance data for steers fed wheat forage and wheat forage plus SS are shown in table 5. Nitrogen retention and digestibility were very similar for steers of both treatments. The percent N digestibility of the wheat forage (82.6) was very close to the N digestibilities of high protein (> 24 percent of DM) fresh-cut perennial ryegrass (84.1 percent digestible) and white clover (82.1 percent digestible) that were reported by MacRae and Ulyatt (1974). Nitrogen retention, expressed as a percent of N digested, was much lower for the perennial ryegrass (14.0) and white clover (8.0) than for the wheat forage (30.3) of this study. Although the data of MacRae and Ulyatt (1974) were obtained with sheep, Lake et al. (1973), reported negative N retention (-1.6g/day) for steers fed fresh forage (mixture of orchardgrass, smooth brome, and alfalfa) and a slight positive N retention (6.6g/day) for steers fed the same forage dried. Apparent N digestibilities were similar (59.3 versus 59.1 percent). They concluded that drying lowered N solubility in the rumen, consequently, ruminal ammonia losses were decreased and N retention increased. However, actual ammonia losses were not reported. Nevertheless, these N retentions were very low and would not support the reported daily weight gains of steers fed the fresh (.93 kg/day) and the dried (.99 kg/day) forage. In the present study, nitrogen retentions are much greater than needed to support daily weight gains that are typically observed for steers grazing wheat pasture. However, gaseous, hair and scurf losses of N are not accounted for and, consequently, would be included in the N fraction retained. These data, although contrary to data reported by Lake, et al. (1973), suggest that ruminal losses of N as ammonia are small and that N per se is not the nutrient which limits gains of cattle grazing lush high-quality forages.

TABLE 5. NITROGEN (N) BALANCE OF STEERS FED WHEAT FORAGE ALONE OR WITH SORGHUM-SUDAN HAY IN METABOLISM TRIAL[a]

Treatment	Daily N intake, g/day	N digestibility, %	N retention		
			g/day	Percent of N intake	Percent of digested N
Wheat forage	245	82.6	61.6	25.1	30.3
Wheat forage plus Sorghum-sudan hay	254	81.9	61.0	24.0	29.3

[a]Treatment means were not different (P > .05).

Grazing Trial

Roughage and wheat forage intakes and estimates of parameters of the fecal excretion curve are shown in table 6. Wheat straw (.30 versus .18) and SS (.85 versus .45) intake, expressed as a percent of metabolic body weight, were somewhat higher than those reported in previous grazing trials (Mader, 1981a). Neither the unadjusted ($P > .15$) or adjusted ($P > .35$) wheat forage intakes were different among treatments. Although the adjusted intakes were lower for steers fed WS and SS, the high probability level would indicate that no such trends exist. These results are in agreement with results of the metabolism trial and suggest that neither WS or SS was substituted for wheat forage in the diet. However, since steers were allowed to graze only 9 to 12 h daily, the possibility exists that their wheat forage intakes were lower than those of steers which had continuous access to wheat pasture, in studies previously reported (Mader, 1981a). During the third year of the study average daily gains (based on 16 h shrunk weights) of the nine steers were .97 kg and 1.01 kg, respectively, during a 28-day and a subsequent 38-day period in which grazing of wheat pasture was limited to 9 to 12 h daily. Therefore, dry matter intakes of steers in this study were assumed to be comparable to intakes of steers of previous studies (Mader, 1981a). These results do not support the contention that high moisture levels in lush high-quality forages limits intake and, consequently, daily gains of cattle grazing such forages. Similar results were reported by Lake et al. (1973), in which DM consumption of steers fed fresh (22 percent DM) or dried (81 percent DM) forage was similar (i.e., 7.85 vs. 7.89 kg).

TABLE 6. WHEAT FORAGE INTAKE, TURNOVER RATE AND TOTAL MEAN RETENTION TIME OF STEERS IN GRAZING TRIAL

	Wheat forage (control)	Wheat forage plus Wheat straw	Wheat forage plus Sorghum-sudan hay
Roughage intake, kg DM/day		.22	.59
% metabolic BW[a]		.30	.85
Wheat forage intake (unadjusted), kg DM/day	4.82	4.79	5.30
% of body weight	1.74	1.72	1.87
Wheat forage intake (adjusted),[b] kg DM/day	5.28	4.92	5.08
% of body weight	1.92	1.77	1.79
UDMG, kg[c]	1.31[e]	1.18[f]	1.29[e]
Time dependent turnover rate (k_1), %/h	22.3	21.9	25.4
Time independent turnover rate (k_2), %/h	4.4	4.7	4.8
Time delay, h	4.7	4.5	4.8
TMRT, h[d]	33.8[e]	31.7[f]	31.4[f]

[a]Low-quality roughage intake expressed as a percent of metabolic body weight ($wt^{.75}$, kg).

[b]Wheat forage intakes adjusted by linear regression equations developed for the respective treatments (Mader, 1981b).

[c]UDMG=gastrointestinal tract fill of undigested dry matter (Ellis et al., 1977).

[d]Total mean retention time of ingested wheat forage = $1/k_1 + 1/k_2$ + time delay.

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

Treatment differences in the rate constants, k_1 and k_2, and in the time delay were not significant ($P > .05$). However, UDMG of wheat forage was significantly ($P < .05$) lower for steers fed WS and TMRT of wheat forage was significantly lower ($P < .05$) for steers fed WS and SS. The greater k_2 (ruminal turnover rate) for steers fed WS and SS would account for the lower TMRT, since it is the only parameter of the three (k_1, k_2 and time delay) that is used to calculate TMRT, which would consistently result in a decreased TMRT for steers fed WS and SS relative to TMRT of control steers. Although treatment differences for k_2 were not significant ($P = .20$), these data would support the data of the metabolism trial which suggest that ruminal retention time is decreased when LQR is fed to steers consuming wheat forage. Lower retention time would be accompanied by a lower UDMG provided intake is constant. This is evident, in particular, for steers fed WS.

Even though time delay was not different among treatments in the grazing trial, steers consuming LQR had more solid, drier appearing feces. In the year (third) that total feces were collected fecal dry matter concentrations were similar among treatments and averaged 20.9, 20.4 and 19.9 percent, respectively, for steers grazing wheat pasture and fed no LQR, WS or SS. The drier appearance of feces for steers fed LQR would most likely be attributed to the increased water holding capacity of the added fiber in the diet. The ability of undigested fibrous residues to bind and hold water is well known and has been discussed in detail by a number of researchers involved in human nutrition (McConnell et al., 1974; Eastwood and Mitchell, 1976; Van Soest, 1978).

It should be noted that the ruminal turnover rates of steers in the metabolism trial were approximately two-fold greater than those of the grazing trial while the UDMG were approximately two-fold greater in the grazing trial. This is probably due to the steers in grazing trial having to consume a large volume of wet wheat forage in a short time period (9 to 12 h), whereas, steers in the metabolism stalls had access to wheat forage at all times. Therefore, steers of the grazing trial maintained a greater gastrointestinal tract capacity and, consequently, the UDMG of wheat forage were greater for steers of the grazing trial. Since intakes were similar in both trials, the greater UDMG resulted in a proportionaly lower ruminal turnover rate for steers in the grazing trial.

Passage rate parameters and TMRT of steers fed Yb-labeled wheat forage and Cr-mordanted LQR are shown in table 7. Previous studies (Mader, 1981c) have shown the Cr-mordanted SS underestimated k_1 by 27.6 percent (9.7 vs. 13.4) and k_2 by 30.8 percent (1.8 vs. 2.6) and overestimated TMRT by 35.1 percent (72.3 vs. 53.5) when compared to Yb-labeled SS (immersion technique). The estimate of time delay was identical (6.7 h) for both methods of labeling. For exact comparisons to be made, the method of labeling LQR and wheat forage should be the same. However, if the present data are adjusted for the method of labeling based on the changes mentioned above the trends among treatments remain unchanged. These data suggests that k_1, time delay and TMRT are higher and k_2 is lower for LQR than wheat forage. This suggests that LQR moves through the GIT at a slower rate than wheat forage. Also, comparisons of these data for SS with data obtained from steers fed only SS (Mader, 1981c) suggests that LQR moves through

TABLE 7. COMPARISON OF TURNOVER RATES, TIME DELAY AND TOTAL MEAN RETENTION TIME OF YTTERBIUM-LABELED WHEAT FORAGE AND CHROMIUM-MORDANTED LOW-QUALITY ROUGHAGES (THIRD YEAR ONLY)[a]

	Wheat forage[b]	Wheat straw[b]	Wheat forage[c]	Sorghum sudan-hay[c]
Time dependent turnover rate (k_1), %/h	15.9	18.0	16.8	18.0
Time independent turnover rate (k_2), %/h	5.3	1.5*	5.4	2.2*
Time Delay, h	4.6	5.5	4.8	5.5
TMRT, h[d]	30.8	86.1*	31.4	68.9*

[a]Differences among low-quality roughages were not statistically significant ($P > .05$).

[bc]Paired comparisons were made between values under headings with like superscripts. Numerical values represent a mean of nine observations.

[d]Total mean retention time of ingested feedstuffs = $1/K_1 + 1/K_2$ + time delay.

*Significantly different from wheat forage ($P < .05$).

the GIT largely independent of the wheat forage since TMRT of the Cr-mordanted SS were similar (68.9 versus 72.3 h) in both studies.

The data of the grazing trial demonstrate that LQR decreases ($P < .05$) the retention time of wheat forage in the GIT. Data of the metabolism trial suggest that passage rate of wheat forage through the lower intestinal tract is less ($P < .05$) for steers fed SS. Therefore, the effect of LQR on decreasing wheat forage retention time appears to be ruminal. Although differences in ruminal turnover rate were not significant ($P > .05$), these values (k_2) were consistently greater for steers consuming LQR plus wheat forage in both the metabolism and grazing trials. If ruminal retention of wheat forage is decreased then a corresponding increase in wheat forage intake would be expected to fill the ruminal space voided by the wheat forage and maintain the same level of UDMG of wheat forage. However, this data has shown that LQR lowered UDMG of wheat forage while wheat forage intakes remained constant. Therefore, the consumed LQR is thought to make up or occupy the ruminal space voided by the wheat forage since LQR has been shown to have a slower passage rate than wheat forage. Feeding LQR would, thus, have no net effect on wheat intake, as shown in both the metabolism and grazing trials and no effect on average daily gain as shown in previous trials conducted by Mader (1981a).

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APPENDIX

TABLE 1. WHEAT PASTURE YIELD AND COMPOSITION OF FORAGE OF EXTENSIVE PHASE GRAZING TRIAL

Year	Period	Date	Available Forage kg DM/ha[a]	Dry Matter, %	Crude Protein, %	NDF, %	ADF, %	IVDMD, %[b]
1978-79	I	11-17	554	18.9	24.5	41.8	23.1	74.9
		12-7	557	26.5	24.9	42.4	20.6	74.1
		12-20	863	27.6	24.8	49.1	21.9	72.9
	II	1-16	330	29.4	27.0	57.1	21.7	69.5
		2-21	443	36.2	22.7	65.5	31.2	62.9
	III	3-27	493	20.6	28.1	45.3	18.9	78.4
1979-80	I	11-30	1144	28.1	22.3	47.4	20.8	73.7
		12-12	888	29.5	23.6	54.0	21.3	71.5
		12-27	1045	32.8	24.5	56.1	22.3	69.0
		1-9	681	36.4	21.2	55.0	24.0	75.0
	II	1-22	423	33.0	23.1	58.9	25.3	72.9
		2-7	297	33.5	21.4	57.1	26.6	72.8
		2-20	312	33.2	23.6	56.3	24.4	74.5
	III	3-5	413	39.1	24.5	58.8	23.8	72.9
		3-19	693	27.2	25.0	59.0	24.4	74.4
	IV	3-24	1085	25.7	22.3	59.2	28.2	70.9
		4-7	1085	19.7	20.6	59.8	28.0	72.9
		4-18	3657	23.9	15.2	60.3	30.6	68.9
1980-81	IV	3-24	1866	29.8	27.5	48.9	20.7	74.4
		3-31	1100	19.5	23.1	51.9	23.9	72.5
		4-7	1218	22.9	22.0	52.8	25.5	69.8
		4-15	1156	23.0	17.4	56.6	26.0	67.7
		4-22	1511	24.6	16.3	64.5	31.3	64.6
		4-28	1459	32.9	14.1	63.3	31.2	64.3

[a]Average quantity of forage per hectare of pasture, based upon 3 one-half square meter clippings.

[b]NDF = neutral detergent fiber; ADF = Acid detergent-fiber; IVDMD = In vitro dry matter digestibility.

TABLE 2. LOW-QUALITY ROUGHAGE INTAKES (KG DM/HD/DAY) OF WHEAT PASTURE STOCKERS OF EXTENSIVE) PHASE GRAZING TRIAL

	Wheat straw	Sorghum-sudan hay
Period I		
1978-79(Nov. 17 to Jan. 12)	.146	.304
1979-80(Nov. 27 to Jan. 9)	.095	.146
Period II		
1978-79(Jan. 13 to Feb. 16)	.079	.159
1979-80(Jan. 10 to Feb. 21)	.102	.336
Period III		
1978-79(Feb. 17 to Mar. 28)	.091	.259
1979-80(Feb. 22 to Mar. 18)	.061	.224
Period IV		
1979-80(Mar. 19 to Apr. 22)	.033	.074
1980-81(Mar. 24 to Apr. 28)	.142	.323
Overall (PD I-III)		
1978-79	.111	.256
1979-80	.089	.237
% MWT[a]		
1978-79	.20	.48
1979-80	.15	.40

[a]Percent of metabolic body weight ($weight^{.75}$, k_g).

TABLE 3. MEAN SLAUGHTER WEIGHTS AND DRESSING PERCENTS, AND DAILY WEIGHT GAINS OF WHEAT PASTURE STOCKERS OF EXTENSIVE PHASE GRAZING TRIAL

	Control	Wheat straw	Sorghum-sudan hay
Live Daily Gains, kg			
Period I			
1978-79	.76	.75	.80
1979-80	.65	.58	.56
Period II	.51	.46	.60
1978-79	.94	.85	.90
1979-80			
Period III	.96	1.01	.91
1978-79	.93	.97	1.01
1979-80			
Period IV	1.02	1.35	1.02
1979-80	.92	1.01	.98
1980-81			
Final Slaughter Group[a]			
Weight, kg			
1978-79	255.5	257.0	250.9
1979-80	298.1	317.3	280.9
Dressing Percent			
1978-79	57.74	56.35	55.91
1979-80	59.23	57.66	61.14
Carcass Daily Gains[b]	.54	.51	.51
1978-79	.64	.63	.69
1979-80			

[a]Initial slaughter group (four steers per year) live weight and dressing percent (DP) for steers of the 1978-79 and 1979-80 grazing seasons were 153.7 kg and 49.62%, and 170.6 kg and 47.95%, respectively. Final slaughter group included three steers per treatment for each year.

[b]Estimated for all steers on trial based on dressing percent of slaughter groups.

TABLE 4. COMPOSITION OF HAND-CLIPPED WHEAT FORAGE SAMPLES OF INTENSIVE PHASE GRAZING TRIAL

Year	Period[a]	Date[b]	Dry Matter,%	Crude Protein,%	NDF,%	ADF,%	IVDMD,%
1978-79	I	12-13	26.8	28.6	37.2	15.8	83.1
	II	3-12	19.9	34.1	50.5	21.1	74.7
	III	4-3	19.3	32.2	41.2	24.8	79.2
1979-80	I	12-18	28.0	27.5	52.4	18.0	75.8
	II	1-28	18.4	30.9	60.7	22.1	73.5
	III	3-31	15.6	32.2	64.3	24.8	75.2
1980-81	I	12-28	29.5	27.0	61.6	18.8	71.6
	II	2-7	32.8	24.1	58.5	19.0	73.4
	III	3-7	22.5	30.4	60.4	19.1	72.5

[a]The three periods were as follows: (1) prior to dormant stage of winter wheat (2) during period of winter wheat dormancy and (3) after winter wheat dormancy period.

[b]Month and day five-day fecal collection began.

TABLE 5. WHEAT FORAGE INTAKE, TURNOVER RATES, AND TOTAL MEAN RETENTION TIME OF STEERS IN INTENSIVE PHASE GRAZING TRIAL

	Control	Wheat Straw	Sorghum-Sudan Hay
Roughage Intake, kg DM/day			
1978-79		.10	.44
1979-80		.33	.74
1980-81		.22	.60
Wheat Forage Intake, kg DM/day			
1978-79	4.11	4.11	4.20
1979-80	5.02	5.08	6.14
1980-81	5.34	5.18	5.57
Wheat Forage Intake (Adjusted)[a] kg DM/Day			
1978-79	4.74	4.12	4.07
1979-80	5.43	5.26	5.86
1980-81	5.67	5.40	5.32
k_1, %/h			
1978-79	31.32	29.99	38.57
1979-80	18.00	19.73	20.85
1980-81	17.52	15.85	16.78
k_2, %/h			
1978-79	4.32	4.55	4.33
1979-80	4.46	4.36	4.75
1980-81	4.43	5.29	5.43
Time Delay, h			
1978-79	4.92	4.36	4.20
1979-80	4.55	4.48	5.40
1980-81	4.50	4.62	4.80
TMRT, h[b]			
1978-79	33.29	31.23	30.85
1979-80	34.16	33.02	31.88
1980-81	34.01	30.78	31.44

[a]Adjusted by linear regression equations developed for the respective treatments.

[b]TMRT = total mean retention time.

TABLE 6. CONCENTRATION AND AMOUNT OF MARKER IN LABELED FEED COMPONENT AND IVDMD[a] OF LABELED VERSUS NON-LABELED FEED COMPONENT.

Trial	Year	Period	Marker	Feedstuff	Marker Concentration, mg/g	Marker fed,g	IVDMD[a] (labeled) %	IVDMD[a] (not labeled) %
Metabolism[b]	1979-80	-	Yb[c]	Wheat Forage (WF)	10.67	2.54	66.6	71.8
Grazing[d]	1978-79	1	Yb[c]	WF	69.13	9.56	70.6	83.1
		2	Yb[c]	WF	73.99	11.27	58.9	74.7
		3	Yb[c]	WF	87.21	8.38	52.5	79.2
					76.78	9.74	60.7	79.0
	1979-80	1	Yb[c]	WF	6.66	1.26	73.7	75.8
		2	Yb[c]	WF	9.60	2.16	67.6	73.5
		3	Yb[c]	WF	5.92	0.97	69.3	75.2
					7.39	1.46	70.2	74.8
	1980-81	1	Yb[c]	WF	5.93	1.23	67.7	71.6
		2	Yb[c]	WF	10.54	1.95	67.9	73.4
		3	Yb[c]	WF	10.48	1.90	61.3	72.5
					8.98	1.69	65.6	72.5
	1980-81	1	Cr[e]	Wheat Straw	36.00	1.30	3.1	26.1
		2	Cr[e]	Wheat Straw	55.29	3.89	0.9	43.2
		3	Cr[e]	Wheat Straw	44.60	2.85	2.1	30.0
					45.30	2.68	2.0	33.1
	1980-81	1	Cr[e]	Sorghum-Sudan	36.24	1.26	0.9	48.7
		2	Cr[e]	Sorghum-Sudan	65.16	3.90	3.3	53.3
		3	Cr[e]	Sorghum-Sudan	49.25	2.33	6.1	55.0
					50.22	2.50	3.4	52.3

[a]IVDMD = in vitro dry matter digestibility.

[b]Trial conducted in metabolism stalls.

[c]Yb = Ytterbium.

[d]Three year study, evaluating the effects of low-quality roughage on WF turnover rates and intake.

[e]Cr = Chromium.

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