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Effect of roughage source on ruminal kinetics of digestion and passage of individual feed components in mixed diets for steers

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EFFECT OF ROUGHAGE SOURCE ON RUMINAL KINETICS OF DIGESTION AND PASSAGE OF INDIVIDUAL FEED COMPONENTS IN MIXED DIETS FOR STEERS

by

Jose Ricardo Bárcena Gama

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As members of the Final Examination Committee, we certify that we have read the dissertation prepared by Jose Ricardo Barcena-Gama

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and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of DOCTOR OF PHILOSOPHY.

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DEDICATION

I want to dedicate this dissertation to Ana Luz, for her love and because she has always been with me in the good and tough times, and to my son Ricardo who has brought a new sparkle of life to my living.

To my mother and brothers who have been my inspiration.

To the memory of my father Amando, to whom I owe more than my existence.

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ABSTRACT

Total tract digestion coefficients for dry matter (DM) and neutral detergent fiber (NDF), passage rates for grain and roughage components of diets and liquid turnover were measured for 65 and 90% concentrate diets in separate 4x4 Latin square experiments using intact growing steers. Kinetics of in situ digestion for DM and NDF in diet ingredients, rumen pH, volume and DM distribution were determined in mature, rumen cannulated steers. Rates of passage and digestion were combined to calculate apparent extent of ruminal digestion (AERD) for diet ingredients.

Diets were based on steam flaked milo. The control roughage was chopped alfalfa hay (AH). In 65% concentrate diets, chopped wheat straw (WS), bermudagrass straw (BS) or cottonseed hulls (CSH) replaced 50% of the AH. In 90% concentrate diets, all of the AH was replaced by WS, BS or CSH.

Total tract starch digestion was not influenced by source of roughage at either concentrate level.

In 65% concentrate diets, total tract digestion of DM and NDF was not adversely affected by substitution of WS for 50% of the AH. Digestion of these fractions was lower

(P<.05) for BS and CSH diets, but the severity of depression was greatest (P<.05) for the CSH diet. Reduced digestibility of the CSH diet was attributed to lower digestibility of CSH in comparison with AH. Although WS and BS were also less digestible than AH, their inclusion in the diet improved (P<.05) AERD of DM and NDF from milo and AH. Improved AERD for NDF appeared to be related to the raft-forming properties of WS and BS, and their ability to maintain rumen pH in a more desirable range for NDF digestion.

In 90% concentrate diets, effects of roughage source on utilization of milo were minimal. Total tract digestion of DM and NDF was lower (P<.05) for WS, BS and CSH diets than for the AH diet, because of dilution of the more digestible AH by these roughages. Wheat straw had a tendency to moderate ruminal pH and consequently might be more useful in high concentrate diets than roughages such as CSH and BS.

CHAPTER 1

INTRODUCTION

The use of more forages and less grain in beef cattle feeding systems may be needed in the future. The main reasons for this are the need for energy conservation, potential world grain shortages and greater world demand to use grain for human consumption (Ledoux et al., 1985).

To date most research concerning effects of roughage level on utilization of grain has primarily been concerned with the site and extent of digestion. However, only limited data are available to show effects of low-quality forages in mixed diets on animal performance, starch utilization and digesta flow.

Inclusion of roughage in high concentrate diets can result in several potential benefits to the ruminant. The roughage stimulates feed intake allowing cattle to maximize consumption of digestible energy and daily gain, reduces incidence of acidosis, liver abscesses and metabolic disorders (Wise et al., 1968).

Addition of forages has also been shown to increase rumen pH, buffering capacity and particulate rate of passage. Evans (1981) has suggested that increased dietary forage level may be associated with increased rumination and saliva flow and may alter rumen microbial population, thus increasing efficiency of feed utilization.

As well as forage level, roughage source has been shown to affect nutrient digestibilities, ruminal characteristics and animal performance. Swingle (1986) reported that when wheat straw replaced alfalfa hay in diets for growing (65 and 80% concentrate) and finishing steers (90% concentrate) feedlot performance was not affected negatively as could be expected. It was speculated that inclusion of wheat straw in these diets could have influenced kinetics of ruminal digestion and passage of other feed components changing the site and extent of their digestion. Moore (1987) showed that wheat straw and cottonseed hulls when used as roughage sources in mixed diets differed in their effect on rate of passage and digestion of steam flaked milo and alfalfa hay. Wheat straw stimulated rumination and digestion of fiber from both milo and alfalfa hay, whereas cottonseed hulls did not. Rust and Owens (1981) also reported site and extent of starch digestion was altered when different roughages were included in diets for steers.

Understanding of factors affecting digestion of roughages and grains in mixed diets will enable them to be combined more efficiently in mixed diets. An important step to increase our understanding is to characterize the effects of fiber source on utilization of nutrients and to determine how fiber sources affect kinetic parameters of digestion.

The objective of this dissertation was to utilize four roughage sources (alfalfa hay, wheat straw, bermudagrass straw and cottonseed hulls) in mixed diets for steers to test the hypothesis that kinetics of ruminal digestion and passage of individual feed components in mixed diets can be altered as well as site and extent of nutrient digestion by changing source of roughage.

CHAPTER 2

LITERATURE REVIEW

Site and extent of starch digestion

Many factors which affect total digestibility of diets fed to ruminants also influence site at which digestion occurs. It is possible that much of the change in digestibility observed as a result of factors such as level of feed intake and feed processing result from changes in extent of ruminal digestion, although available data to comfirm this conclusion are limited.

Fermentation of starch in the rumen is accompanied by inevitable losses in heat and methane, amounting to 12 to 20% of the ingested energy (Hungate,1966). Theoretically therefore, it is desirable to encourage starch to escape ruminal fermentation if there is sufficient capacity to digest starch post-ruminally, thus reducing fermentation losses.

According to Waldo (1973), starch is digested primarily in the rumen, with some digestion occurring in the small intestine and ceacum. The small intestine is considered the preferred location for starch digestion because digestion of starch in the small intestine is more efficient (20 to 25%) than digestion by ruminal microbes. However, capacity of the small intestine to digest starch may be limited (Mayes and Ørskov, 1974; Russell et al., 1981) Therefore, it would be beneficial to have starch escape rumen fermentation when the capacity for digestion or absorption in the small intestine is not exceeded (Owens et al., 1986).

This has led to an interest in understanding the extent to which starch, in fact, is fermented in the rumen rather than digested post-ruminally, and in devising methods and strategies for manipulating the site of starch digestion.

Ørskov (1986) summarized findings of Karr et al., (1966), Ørskov et al., (1969) and Beever et al., (1970) by stating that when oats, barley or wheat are fed to ruminants as whole or crushed grains, at least 90% of the starch is fermented in the rumen. Corn is different from other cereals, due to a slower rate of starch digestion, up to 40% of corn starch can, on occasions, escape fermentation in the rumen. In these experiments, it was interesting to note that a greater proportion of starch escaped degradation in the rumen if fibrous roughages formed part of the diet.

Garret and Johnson (1983) observed that in animals fed mixed forage:grain diets at high levels of intake, as much as 50% of the starch was digested postruminally. Johnson and Bergen (1982) found that as much as 40% of the organic matter in diets based on dry rolled or ground corn was digested postruminally. This resulted from less extensive digestion of corn starch in the rumen in comparision to barley starch.

Stock et al., (1987) worked with combinations of high moisture corn and dry rolled grain sorghum for finishing steers and found that feeding grain mixtures improved feed efficiency approximately 4.2% above expected means. They concluded that high moisture corn was primarily digested in the rumen, whereas only half of the dry rolled grain sorghum was digested in the rumen. When 33% of the high moisture corn was replaced with dry rolled grain sorghum, ruminal starch digestion was similar to that of high moisture grain alone. Thus, digestion of starch from dry rolled grain sorghum in the mixure was increased. When 67% of high moisture corn was replaced by dry rolled sorghum, the digestibility of sorghum grain in the rumen was decreased and the amount of starch digested in the small intestine was increased compared with 100% of high moisture corn.

Stock et al., (1987b) evaluated early harvested and reconstituted sorghum grain in diets for finishing steers and found early harvested ground sorghum, reconstituted sorghum or dry rolled corn had similar total tract starch digestion coefficients which were greater than coefficients for dry rolled grain sorghum. Stock et al., (1987c) evaluated combinations of high moisture corn and dry whole corn for finishing cattle and reported that steers fed mixtures of high moisture corn and dry whole corn gained faster and more efficiently than steers fed either grain form alone.

From these experiments, it is clear that type of grain and grain processing may alter site and extent of starch digestion. According to Kreikemeier et al., (1987), the combination of rapidly degraded grains (like wheat or barley) with slowly digesting grains (like sorghum or corn) would be beneficial because ruminal acidosis would be reduced. Stock et al., (1987b) commented that improved starch utilization may result from combining grain types.

Positive effects have resulted when rapidly digesting grains and slowly digesting grains were combined (Lee et al., 1982; Stock et al., 1987a,b). For example, wheat has a rapid rate of starch digestion and has been used in several acidosis studies (Allison et al., 1964; Muir et al., 1981). In contrast, grain sorghum is digested slowly in the rumen and a greater proportion of grain sorghum may leave the small intestine undigested (McNeil et al., 1971; Spicer et al., 1986; Hibberd et al., 1985). Thus, feeding combinations of rapidly digested and slowly digested grains may optimize cattle performance by partitioning digestion over the entire gastrointestinal tract (Stock et al.,1985).

Axe et al. (1987) fed wheat and high moisture sorghum grain to cattle, singly and in combination and found the ruminal starch digestion (as percent of intake) decrease and digestion in the small intestine increased as the level of sorghum increased in the diet (93.5 and 5.6% for wheat; 71.5 and 20.4% for 40:40 wheat: sorghum; 48 and 32% for sorghum grain). Total tract starch digestion was 8.8 and 6.8% greater for wheat and wheat:sorghum diets respectively, which suggests some limitations on the utilization of sorghum grain starch.

Level of feed intake also may affect site and extent of starch digestion. Wheeler et al., (1975) observed a decrease in total starch digestion by dairy cattle, of approximately 12%, as intake increased from maintenance to 3.2 times maintenance on 70:30 concentrate:roughage diets. In contrast, Kratchner et al., (1973) observed no differences in ruminal or total tract starch digestion with steers fed ad libitum versus 80% ad libitum using diets of either steam flaked or dry rolled sorghum. Galyean et al., (1979) estimated the site and extent of dry matter and starch digestion by feeding cannulated steers with an 84%

corn based diet at 1.00, 1.33, 1.67 and 2.00 times maintenance (M) intake. Total tract dry matter digestion was lower for 2.00 (77.6%) and 1.67M (78.9%) than for 1.33M (84.1%) and 1.00M (85.7%). Dry matter digested intestinally tended to decrease as intake increased from 1.00M to 2.00M. Total tract starch digestion was greater for steers fed 1.00M (99.6%) than those fed 1.67%M (93.8%) and 2.00M (90.4%). Moreover, less starch was digested ruminally as intake increased from 1.00M (94.5%) to 2.00M (89.6%).

In summary, many factors may affect site and extent of starch digestion by ruminants. The factors include: type of grain (slowly and rapidly digested), type of processing (steam flaked, dry rolled, etc.), particle size of feed and level of intake. All these factors should be taken into account when comparing results from one study to another in order to draw valid comparisions, otherwise results may be misinterpreted.

Effect of level and source of roughage

Site of starch digestion is in large part, dictated by rate of passage and possibly rate of digestion. The roughage component of the diet affects ruminal starch digestion (Brink and Steele, 1985; Kim and Owens, 1985), rate of passage (Goetsch et al., 1984) and animal performance (Gill et al., 1981). Decreased rate of passage and increased ruminal starch digestion may be more advantageous with grains having slower rates of digestion than grains with faster rates of digestion.

Cole et al., (1976a) fed four rumen cannulated steers with whole shell corn rations containing 0, 7, 14 or 21% cottonseed hulls. Total, ruminal and intestinal starch digestion coefficients for rations 0, 7, 14 and 21 were 96.4, 80.0, 81.8; 94.7, 67.9, 83.6; 92.2, 71.5, 72.9; and 95.4,72.1, 83.8, respectively. Total digestion coefficients for starch tended to be lowest for ration 14, apparently due to decreased digestion of the concentrate portion of the ration caused by an increased rate of passage through the digestive tract.

Stock et al.,(1987b) fed steers reconstituted grain sorghum (RGS:23.5% or 31.5% moisture) with 0, 5 or 10% ammoniated conrcorbs. Although not significant, there tended to be an interaction between grain and roughage level on feed efficiency. Steers fed RGS containing 31.5% moisture were 4.7% more efficient than steers fed RGS containing 23.5% moisture at 0% roughage. At 5 and 10% roughage, steers fed 31.5% RGS were 11.1 and 12.8% more efficient, respectively, than steers fed 23.5% moisture RGS. As the level of roughage increased, the rate of passage out of the rumen increased which perhaps allowed more starch to escape rumen fermentation and to be digested in the small intestine.

Siciliano-Jones and Murphy (1989) evaluated nutrient digestion in the large intestine of growing steers as influenced by forage to concentrate ratio and forage physical form. Diets fed to steers were: 20% long alfalfa hay and 80% grain; 15% pelleted alfalfa, 5% hay and 80% grain; 80% hay and 20% grain and 60% pellets, 20% hay and 20% grain. Percentage of total tract digestion occurring in the large intestine increased with grain feeding and averaged 1, 1, 3 and 6%, respectively.

Hart (1987) conducted a metabolism trial to quantitate associative effects between sorghum silage and sorghum grain. Steers were fed increasing levels of dry ground grain (0, 15, 30, 45 and 60% of diet dry matter) mixed with sorghum silage. Low levels of ground sorghum grain (15 to 30%) increased digestibility of starch and intake of dry matter. However, higher levels of ground sorghum grain did not result in further increases in diet digestibility. There was no effect on total starch digestion when ground grain sorghum was increased from 15 to 60% in the diets.

Rust and Owens (1981) compared the effect of six roughage sources on digestibility of corn diets by feedlot steers. The roughage sources were, alfalfa hay, prairie hay, cottonseed hulls, sorghum silage and two types of corn silage (a grain and a forage variety). Steers were fed at two levels of intake (1 and 2% of initial body weight) and two levels of roughage (10 and 50%). Starch digestion was greatest (95.6%) with the cottonseed hulls diet and least (82.6%) with the sorghum silage diet. Starch digestion was greater with the 50% inclusion of cottonseed hulls, alfalfa hay, sorghum silage and the grain variety of corn silage than in the diets containing prairie hay or forage variety of corn silage. The results suggest that roughages exert different effects on starch digestion.

Another important factor affecting site and extent of starch digestion is liquid turnover. Liquid turnover may alter efficiency of rumen fermentation (Isaacson et al., 1975). Theoretically, increasing liquid dilution rate increases the amount of starch escaping rumen fermentation and thus available for digestion in the hind gut. Several studies (Estell and Galyean, 1985; Cole et al., 1976b; Goetsch and Galyean, 1982) have shown liquid dilution rate to increase as the level of roughage in the diet is increased.

Saliva production also affects liquid dilution rate (Froetschel et al., 1988). Net salivary flow is related to time spent eating and ruminating (Bauman et al., 1971). Roughage source has shown to affect rumination time (Moore, 1987). Thus roughage type could affect site and extent of starch digestion indirectly by affecting saliva production and, thus, liquid dilution rate.

In a recent study, Froetschel et al., (1988) used slaframine to stimulate saliva secretion in steers fed a 40:60 roughage:concentrate diet. Increasing slaframine from 0 up to 20 ug/kg BW increased dilution rate (8.62 to 10.21%/h). Ruminal digestion coefficients for dry matter, acid detergent fiber and starch were 10 to 16% lower and inversely related to the level of slaframine administered. Postruminal digestion of dry matter, acid detergent fiber and starch increased linearly, as much as 46.7%, 9.5% and 44.0% respectively, in response to slaframine. Total tract digestion of dry matter and acid detergent fiber were not affected. However, total tract starch digestion was increased as much as 5% by slaframine treatment. Slaframine has been reported to stimulate secretion of pancreatic enzymes and buffers and may alter lower tract digestion by this mechanism (Froetschel et al., 1987).

In summary, many factors affect digestion of starch by ruminants. Changes in site of digestion are in large part dictated by changes in rate of passage, liquid dilution rate and possibly rate of digestion. Thus any factor affecting these parameters (as level and type of roughage) may affect the site and extent of starch digestion.

Fiber digestion and passage

Fiber must be regarded as a biological unit and not as a chemical entity. Fiber was originally defined as that "plant material in a feedstuff that resists digestion in the animal" (Van Soest, 1982). However, fiber digestion is extensive in the ruminant animal due to the rumen microbes which live in symbiosis with the host. Van Soest (1982) gave a more precise definition of fiber which is relevant for ruminants as the plant material that cannot be digested by enzymatic secretions produced by the mammalian gut.

Fiber has been separated into two fractions to study its digestion in ruminants; potentially digestible fiber (PDF) and indigestible fiber (IF). The PDF can disappear from the rumen by either digestion or passage (Waldo et al., 1972), whereas IF can only leave the rumen by passage. Digestion and passage are regarded as processes that progress with time according to first order rate constants.

Waldo et al., (1972) proposed a model of cellulose disappearance from the rumen based on the hypothesis that feedstuffs contain two definable components, potentially digestible and indigestible fractions. Others have extended the Waldo model to include a lag phase (Mertens, 1977), rapidly and slowly digesting pools of PDF and rate of particle size reduction as other steps regulating fiber utilization. (Mertens and Ely, 1979, 1982).

Indigestible fiber has been determined as the residue remaining after 72 or 96-h of in vitro or in situ incubation. The IF can also be calculated by extrapolation to infinite time digestion (Mertens and Van Soest, 1972). The IF has a high lignin content and because of this, lignin has been proposed as the compound responsible for limiting the extent of fiber digestion (Smith et al., 1972).

Lag phase has been defined as the time in which passage occurs but digestion does not. The lag time can be calculated as a discrete period (Mertens, 1977), however, its exact nature is not clear. Mertens and Ely (1982) interpreted lag as the time necessary for particle hydration, colonization and attachment to fiber by rumen microorganisms. Recently, Varga (1987) reviewed the concept and factors that influence lag time.

Passage is important because it determines the time available for the process of digestion. Mathematically, the rate constant for passage (Kp) corresponds to the reciprocal of the retention time (Mertens, 1977).

Passage of particles can be determined by tagging them with various indigestible markers and determining marker concentration in feces, or in digesta from the rumen or other sites of the gastrointestinal tract. Determination of Kp by this method implies first-order kinetics.

Fermentation and digesta passage kinetics in ruminants may be influenced by several factors including particle size (Ellis, 1987), level of intake (Owens and Goetsch, 1986), forage type (Varga and Hoover, 1983), forage quality (Smith, 1972), grain processing (Theurer, 1986) and roughage:concentrate interactions (Owens and Goetsch, 1986).

Addition of grain to roughages, generally decreases forage fiber digestion of forage (Horn and McCollum, 1987). Supplementation of roughages with feeds having a high digestion rate often reduces ruminal pH below 6.0 and decreases fiber digestion. Low ruminal pH will reduce attachment of fiber digesting bacteria (Shriver et al., 1986) increasing lag time and reducing rate of digestion. Low ruminal pH decreases fiber digestion (Mould and Ørskov, 1983). Negative associative effects of added starch on rate and extent of fiber digestion are, at least partially, attributable to a low pH (Ørskov and Fraser, 1975).

Certain nutrients have been identified which influence rate of digestion. Branched-chain volatile fatty acids have increased in vitro digestion of alfalfa, low protein forages and corn silage (Gorosito et al., 1985). Specific amino acids (arginine, histidine and methionine) have increased digestion rates of dry matter and neutral detergent fiber of forages (Clark and Petersen, 1985). Several other ruminal factors, such as changes in microbial population due to diet composition, and changes in surface area due to particle size reduction (Mertens and Ely, 1982) may affect kinetics of digestion in the rumen.

Particulate rate of passage

Nutrient supply to the ruminant is a function not only of feed source and voluntary intake, but also of extent and site of digestion within different segments of the gastrointestinal tract (Ellis et al., 1988). Ruminal digestibility of any potentially digestible component is a function of rate of digestion and passage from the rumen (Waldo et al., 1972).

Passage or transit refers to the flow of undigested residues through the digestive tract. Since passage rate may affect the site and extent of digestion of feedstuffs by altering the time for digestive and absorptive processes, the efficiency of feed utilization may also be affected.

Several factors affect rate of passage of feedstuffs in the gastrointestinal tract of the ruminant. Among them are: level of feed intake (Shaver et al., 1986; Staples et al., 1984), particle size (Poppi et al., 1980; Siciliano-Jones and Murphy, 1986; Martz and Belyea, 1986; Welch, 1986; Emanuele and Staples, 1988), changes in specific gravity (Ehle and Stern, 1986; DesBordes and Welch, 1984; Ehle, 1984), level and physical form of forages (Shaver et al., 1986 Ledoux et al., 1985; Collucci et al., 1982). In addition, mastication, rumination and digestibility of the diet influence passage (Conrad et al., 1964; Welch, 1982).

Influence of level and source of roughage.

Turnover rate of particulate digesta in the reticulo rumen is closely associated with voluntary intake of poor-quality roughage by ruminant animals. Therefore a description of ruminal particle turnover is an important aspect of ruminant nutrition.

Roughage affects passage rate of both concentrate and roughage portions of the diet. Poore, (1987) evaluated the influence of 30, 60 or 90% concentrate diets on passage of steam-flaked milo and roughage in diets for cannulated steers. The roughage portion of the diet was a 50:50 mixture of chopped alfalfa hay and chopped wheat straw. Passage rates were determined by marking feeds with rare earth metals. Increasing concentrate level from 60 to 90% decreased rates of passage for wheat straw and alfalfa hay (3.4 vs 2.1%/h and 4.6 vs 4.1%/h respectively) and tended to reduce the rate of passage for steam flaked milo (5.3 vs 4.4%/h). Passage rates (%/h) for milo, alfalfa hay and wheat straw were not different between 30 and 60% concentrate diets (5.34 and 5.08 for milo; 4.63 and 4.22 for alfalfa; 3.37 and 2.97 for wheat straw, respectively).

Snyder et al., (1984) evaluated effects of two rations of corn silage:grain (50:50 or 75:25) in dairy cows. Rate of passage of both grain and corn silage tended to be higher in the 75:25 ration than in 50:50 ration.

Woodford et al., (1986) estimated rates of passage for alfalfa hay and concentrate in diets for lactating cows using feeds marked with rare earths metals. The diets contained 28, 36, 45 or 53% alfalfa hay. Rates of passage for alfalfa hay were 5.0, 6.0, 6.3 and 5.9%/h, and rates of passage for concentrate were 9.7, 10.0, 11.2 and 10.5%/h for the different diets, respectively. The passage rates were not different, and the authors concluded that high quality alfalfa hay does not affect rate of passage when concentrate level is changed. These results do not agree with those of Snyder et al., (1984) who found rates of passage slowed as concentrate level was increased. However, in this case the roughage source was corn silage which might account for the difference between these two experiments.

Ehle et al., (1984) reported no differences in rate of fiber passage in lactating dairy cows fed diets containing different levels (55, 65 or 75%) or sources of forage (alfalfa, smooth bromegrass or mixed haylage). However, the passage estimates were confounded by stage of lactation and level of intake.

Chase and Hibberd (1987), supplemented beef cows being maintained on low-quality native grass with 0, 1, 2 or 3 kg/d of ground corn. Grass was marked with ytterbium by the immersion technique and fecal samples were collected to determine particulate rate of passage. Rate of passage decreased as the amount of grain was increased (3.90, 4.04, 3.72 and 3.68%/h, respectively). However, voluntary intake was lowest when cows received 3.0 kg of corn which could explain the decreased rate of passage.

Merchen et al., (1986) fed Suffolk wethers with diets containing 75 or 25% alfalfa hay, with corn as the concentrate portion, at two levels of intake. Passage rate was faster (4.56%) in wethers fed 75% alfalfa hay than in those fed 25% alfalfa hay (4.17%), and rates of passage were similar at both levels of intake (4.36 vs 4.37%/h for high and low intakes, respectively).

Kinser et al. (1988) evaluated effects of level and source of fiber in the diet on particulate rate of passage. Wethers were fed pelleted diets containing either 39 or 25% NDF with corncobs or cottonseed hulls as roughage sources. Mixed feed was marked with Ytterbium and ruminal samples were analysed to determine passage rates. At 39% NDF, the diet containing cottonseed hulls tended to have a higher rate of passage than the diet with corncobs (4.1 and 3.9%/h, respectively). At 25% NDF, the diet containing corncobs tended to have a faster passage (3.3%/h) than diet with cottonseed hulls (2.9%/h). The increased particulate passage rate with high-fiber diets relative to low fiber-diets is similar to those findings of Merchen et al., (1986).

Ledoux et al., (1985) evaluated the influence of level of chopped tall fescue hay on particulate rate of passage in cannulated steers. Diets contained 4, 8, 16 or 24% tall fescue hay in combination with 86, 82, 74 or 66% whole shelled corn and soybean supplement. Whole shelled corn was marked with ytterbium. Samples to determine rate of passage were collected from both the rumen and feces. Steers fed 4, 8, 16 or 24% tall fescue hay had the following particulate passage rates: 2.3, 2.7, 2.7 and

2.9%/h from fecal analyses, and 2.3, 1.7 2.4 and 2.8%/h from ruminal analyses. Increasing tall fescue hay in the diet resulted in linear and cubic effects on particulate passage rates of corn calculated from rumen analysis. Level of tall fescue hay had no influence on particulate passage rates of corn calculated from fecal samples. Goetsch and Owens (1985) reported that rate of fluid passage calculated from ruminal samples was more rapid than that estimated from samples taken at the duodenum, ileum and rectum and that passage rate for particulates estimated from duodenal, ileal and rectal samples were not correlated. These results show that site of sampling is an important consideration in passage rate determinations.

Miller and Muntifering, (1985) determined the effect of dietary concentrate level on kinetic characteristics of forage fiber digestion in vivo. The forage source was fescue hay and levels of concentrate were 0, 20, 40, 60 or 80% cracked corn. Rates of passage were measured by fecal excretion of chromium-mordanted fescue hay. The rates of passage reported were: 2.1, 2.7, 2.3, 2.4 and 1.9%/h for 0, 20, 40, 60 and 80% dietary corn, respectively. Rate of fiber passage from the rumen was greater for 20% grain than for 80% grain. The extremes of dietary corn addition had lower values compared with intermediates, indicating a lack of a linear relationship between dietary forage:concentrate and ruminal passage of the forage fiber component. However, the use of chromium-mordanted fiber could affect the passage rate estimates since the density of the particles and thus their passage rates could have been changed. (Ehle, 1984).

Owens and Goetsch, (1986) summarized several studies in which the effect of concentrate level on passage rates of grain and roughage was evaluated. In general, these studies showed that rates of passage for both grain and roughage are decreased as concentrate increases and that the passage rate of concentrate is more affected by concentrate level than is the passage rate of roughage.

Moore, (1987) evaluated the influence of roughage source on passage rates cf steam-flaked milo and roughage in diets for steers containing 65% or 90% concentrate. At 65% concentrate, cottonseed hulls or chopped wheat straw replaced half the alfalfa hay in the control diet. At 90% concentrate, roughage sources were chopped alfalfa hay, cottonseed hulls or chopped wheat straw. At 65% concetrate, rates of passage were 6.2, 5.7 and 5.4%/h for milo, 5.6, 5.0 and 4.9%/h for alfalfa hay in diets containing cottonseed hulls, alfalfa hay and wheat straw, respectively. Although not statistically different there was a tendency for milo and alfalfa to pass faster in the cottonseed hulls diet and slower in the wheat straw diet.

At 90% concentrate, passage rate of milo was 4.6, 3.8 and 4.7%/h in the cottonseed hulls, alfalfa hay and wheat straw diets, respectively. Passage rate of milo was slower in the alfalfa hay diet as compared to the cottonseed hull and wheat straw diets.

Varga and Prigge (1982) compared alfalfa hay and orchardgrass hay as roughage sources for rumen-cannulated wethers on all-forage diets. Roughage source did not influence passage rate (6.6%/h).

In a recent study, Glenn et al., (1989) evaluated duodenal nutrient flow and digestibility in Holstein steers fed formaldehyde and formic acid-treated alfalfa or orchardgrass silage at two intakes. Passage rate was not affected by roughage source; however, rate of passage tended to be faster with alfalfa at both levels of intake (4.6 vs 3.6%/h at low intake; 6.5 vs 4.8%/h at high intakes for alfalfa and orchardgrass, respectively).

In summary, the literature reviewed shows that in general particulate passage rate decreases as concentrate level increases. In some studies this effect has not been detected, which could be due to confounding effects such as feed intake, type of marker used and sampling site.

Only a few studies have been examined the influence of roughage source on particulate passage rates, particularly in high concentrate diets. Further research is needed in this area, especially on the effect of roughage source on differential passage rates for roughage and concentrate fractions of the diet.

Rate of digestion

Rate of digestion refers to the quantity of feed that can be digested per unit of time. Composition of the diet, its quality, nutrient deficiencies, excesses and availability affect rate of digestion (Van Soest, 1982).

Within any segment of the digestive tract, digestion rate or fractional rate of digestion is usually calculated as the percentage of the potentially digestible nutrient which is digested per unit of time. The amount of the ingredient and its intrinsic properties determine the magnitude of the rate.

If ruminal bacteria are in equilibrium with the substrate and if enzyme supply is not limiting, the kinetics are first order. This implies that the absolute amount of a feed which is digested decreases over time at a rate proportional to the amount remaining until all the digestible material is exhausted.

Rates of digestion can be measured by in vitro (Goering and Van Soest, 1970) or in situ systems (Mehrez and Ørskov, 1977). Determination of rate constants requires the measurement of digestion or fermentation at different times in order to estimate rate of change.

Influence of level and source of roughage.

Negative associative effects are considered to be responsible for decreased digestion of fiber and starch in mixed diets for ruminants. Depressed fiber digestion has been attributed to low ruminal pH associated with feeding high levels of concentrate. Depressed starch digestion has been attributed to an increased rate of flow through the rumen or small intestine providing less time for digestion and absorption of starch (Zinn and Owens, 1980).

Addition of starch or other readily fermentable carbohydrates to the diet of ruminants reduces dietary fiber digestion (Mertens and Loften, 1980). Reduction of fiber digestion may result from changes in substrate utilization by rumen microorganisms (Van der Linden et al., 1984), reduced numbers of cellulolytic organisms (Stewart, 1977), lowered pH (Mertens and Loften, 1980) and changes in digesta passage rates (Colucci et al., 1984).

Roughage fiber digestibility may be more severely influenced by high concentrate level than grain fiber digestibility. However, grain fiber may account for the majority of fiber digestion depression associated with feeding high concentrate diets due to its high potential digestibility, and its large contribution to total diet fiber (Poore et al., 1987).

Hart (1987) conducted a metabolism trial to quantitate associative effects between sorghum silage and sorghum grain. Diets were formulated by mixing ground sorghum (0, 15, 30, 45 and 60% of diet dry matter) with sorghum silage. Ruminal in situ rate of digestion and lag time were not affected by level of grain (3.8, 3.7, 3.6, 5.3 and 3.3%/h and 0.8, 4.1, 0.7, 3.1 and 0.5 h for 0, 15, 30, 45, and 60% grain, respectively). However, the potentially digestible fraction determined at 48 h was decreased as level of grain increased. Low levels of sorghum grain (15 and 30%) improved fiber digestibility (56.1 and 59.1%, respectively) whereas higher rates of grain supplementation (45 and 60%) tended to decrease fiber digestibility (45.6 and 45.7%, respectively).

Urias (1986) also reported a reduction in fiber digestibility in high concentrate diets. He tested the influence of concentrate level on rate and extent of fiber digestion from steam flaked milo and alfalfa hay. Diets contained 30, 60 and 90% concentrate. Potential extent of digestion of neutral detergent fiber in both milo and forage was depressed in the diet containing 90% concentrate. Potential extents of neutral detergent fiber digestion were: 41.9, 43.2, and 21.4% for alfalfa hay and

78.4, 80.7 and 50.8% for milo in 30, 60 and 90% concentrate diets.

Moore, (1987) conducted two experiments to evaluate the influence of roughage source on rate and extent of dry matter and NDF digestion for individual feed components in mixed diets for steers. In the first experiment, 65% concentrate diets (based on steam flaked milo) were used. The control diet contained 35% chopped alfalfa hay, and chopped wheat straw or cottonseed hulls replaced half of the alfalfa for the experimental diets. Rates of fiber and dry matter digestion for milo (3.0 and 4.8%/h) and alfalfa hay (4.7 and 5.9%/h) appeared to be lower for the cottonseed hulls diet than for the wheat straw diet (5.2 vs 7.9%/h for milo and 6.7 vs 10.0%/h for alfalfa hay, respectively). Extents of digestion for neutral detergent fiber and dry matter from milo and alfalfa hay were higher for the wheat straw diet (83.8 and 94.7%) than the cottonseed hulls diet (59.7 and 94.1%). In the second experiment, 90% concentrate with diets containing either alfalfa hay, wheat straw or cottonseed hulls as roughage sources were evaluated. Rate of digestion for potentially digestible fiber in milo was 2.6, 1.8 and 1.8%/h for diets containing cottonseed hulls, alfalfa hay and wheat straw. Rate of digestion for dry matter in milo was 3.7, 3.7 and 3.4%/h for diets containing cottonseed hulls, alfalfa hay and wheat straw, respectively.

Miller and Muntifering (1985) evaluated the effect of forage:concentrate on kinetics of forage fiber digestion in vivo. They fed five rumen fistulated Holstein steers with 0, 20, 40, 60 and 80% cracked corn with tall fecue hay as the forage source. Rate of forage fiber digestion ranged from 3.9%/h for 20% grain to 6.2%/h for 0% grain but did not differ among treatments, suggesting that concentrate addition to forage does not reduce fiber digestibility by slowing rate of digestion. The potential extent of fiber digestion was lower for 80% grain (28.7%) compared with all other treatments (54.0, 54.8, 48.8 and 47.0% for 0, 20, 40 and 60% concentrate, respectively). Grain fermentation did not detract significantly from potential fiber digestion up to 60% of dietary inclusion. These results agree with those of Mould and Ørskov (1983) who observed that 24 h dry matter disappearance of hay decreased from 51% when only hay was fed to 36% and 24% when the diet was supplemented with 75% whole or ground and pelleted barley, respectively. Urias (1986) also reported that fiber digestibility was depressed in diets containing 90% concentrate; however, no significant differences were observed when the concentrate level was increased from 30 to 60%.

Ledoux et al. (1985) studied the influence of level of chopped tall fescue hay in high concentrate diets on in situ rate and extent of digestion of corn in steers. Rate of in situ ruminal dry matter disappearance of corn was not influenced by fescue hay level, although there was a tendency for the rate to be faster at the 24% (5.9%/h) than at 4% fescue hay (5.2%/h). The decrease in dry matter digestibility as fescue hay level increased from 4 to 24% of the diets had a linear component. However, steers fed 8% forage had higher dry matter digestibility than those fed 4 and 24% fescue hay (81.2, 78.8 and 71.9% respectively). These results agree with reports by Bines and Davey (1970), but are in contrast to those of Cole et al., (1976) who found that dry matter digestibility decreased as cottonseed hulls increased from 0 to 14% in the diet, then increased as cottonseed hulls increased from 14 to 21% of the diet.

Quality of forage may also influence the rate and extent of digestion. Sharma et al., (1988) evaluated neutral detergent fiber digestion from medium and high quality alfalfa and orchardgrass as determined by extended periods of in situ incubation. Estimates of the potentially digestible fiber (50.38% and 41.57%), rates of digestion (10.7%/h and 10.9%/h) and lag times for neutral detergent fiber digestion (3.69 h and 3.24 h) of both high and medium quality alfalfa became stable before 48 h. Stable parameter estimates did not occur until 72 h for the high quality orchardgrass (in vitro dry matter digestibility 87.8%) or

144 h for the medium quality orchardgrass (in vitro dry matter digestibility 64.6%). Parameter estimates of potentially digestible fraction, rate of digestion and lag times at 72 h for high quality orchardgrass were 69.7%, 16.9%/h and 3.9 h; and those for mediun quality orchargrass were 56.0%, 4.2%/h and 10.7 h, respectively. These results suggest that in situ incubation times shorter than 72 h may underestimate indigestible fiber, even in medium quality forages.

Liquid dilution rate

Liquid turnover or dilution rate is an important factor affecting ruminal digestion by altering the efficiency of rumen fermentation (Isaacson et al., 1975). Similar to animals, bacteria require energy for maintenance and are more efficient when growing or multiplying rapidly. As a microbial population grows more rapidly, a smaller percentage of energy is used for maintenance. Theoretically, the highest microbial efficency would be reached when its growth rate was equal to fluid passage rate. If mass is fixed and more feed is provided, production increases while maintenance requirements remain constant, as with animals. This increases efficiency because the amount of energy used for maintenance is constant so the increased efficiency would be due to a "dilution of maintenance."

Isaacson et al., (1985) changed the dilution rate in continuous culture (2, 6 and 12%/h). Increased dilution rate increased microbial efficiency (42, 60 and 84 g of microbial cells/mole of glucose fermented) as well as cell yield per mole of ATP (7.5, 11.6 and 16.7 g, respectively). The fraction of energy used for microbial maintenance was 55% at the low dilution rate, but only 15% at the 12%/h dilution rate.

Liquid turnover may change the site and extent of digestion of feed components. Theroretically, at increased liquid dilution rate more nutrients from feed could escape rumen fermentation and be digested in the lower tract. Liquid turnover can be increased by increasing feed intake (Owens and Isaacson, 1977; Grovum and Williams, 1977), by administration of mineral salts (NaCL, $NaHCO_3$ or mixtures approximating the composition of salivary salts) in the diet (Thompson et al., 1978) or intraruminally (Roger and Davis, 1982), or by increasing saliva flow (Froetschel et al., 1988). Type of forage and particle size affect rumination time. As rumination increases, saliva production increases adding buffer salts and also diluting ruminal contents.

In general, liquid dilution rate can be increased by increasing feed intake and forage content of the diet.

Influence of level and source of roughage

Estell and Galyean (1985) studied relationships between rumen fluid dilution rate, rumen fermentation and dietary characteristics in beef steers. They compiled data from seven beef steer trials. Diets used in these trials varied from 0 to 85% of concentrate and were based on steam flaked milo and corn. Roughage sources used were alfalfa hay, cottonseed hulls, blue grama rangeland and prairie hay. Fluid dilution rate and acetate production were positively related in steers fed with steam flaked milo and alfalfa hay. However, they were negatively related in steers fed cottonseed hulls and milo, blue grama rangeland and prairie hay. Elevated fluid dilution rate was associated with increased propionate in cottonseed meal and milo based supplement and cottonseed hulls, blue grama and prairie hay diets. In general, responses to altered fluid dilution rate were complex and complicated by diet and microbial interactions. The authors concluded that relationships between fluid dilution rate and fermentation often regarded as absolute should be questioned.

Poore et al., (1987) determined the effect of concentrate level (30, 60 or 90%) in the diet on liquid dilution rate. The roughage portion was 50:50 mixture of chopped wheat straw and chopped alfalfa hay. Liquid dilution rates were not different among treatments (8.1, 10.0 and 9.3%/h, respectively). The authors suggested that the inclusion of wheat straw in the diet could have stimulated rumination time, thus increasing saliva production and liquid dilution rates.

Moore (1987) evaluated the influence of roughage source on liquid dilution rate in rumen cannulated steers. Diets were based on steam flaked milo and contained 65 or 90% concentrate. At 65% concentrate, alfalfa hay was the control roughage and cottonseed hulls or chopped wheat straw replaced half of the alfalfa hay in experimental diets. At 90% concentrate the roughage sources were alfalfa hay, cottonseed hulls and wheat straw. At 65% concentrate, liquid dilution rate was not affected by roughage source (9.2, 8.7 and 8.8%/h for cottonseed hulls, alfalfa hay and wheat straw diets, respectively). Although differences observed at the 90% concentrate level were not statistically different, liquid dilution rate tended to be higher in the wheat straw diet. This could have been due to an increased rumination time and hence, increased saliva production.

Kinser et al., (1988) included low-quality roughages in high concentrate pelleted diets for sheep.

Roughage sources were corncobs or cottonseed hulls and diets were formulated to contain either 39 or 25% neutral detergent fiber. Fluid dilution rates were similar among treatments (5.4 and 6.3%/h; 5.6 and 5.2%/h for corncobs and cottonseed hulls at 39 and 25% NDF, respectively). The authors agree that liquid dilution rate is generally increased as roughage increases in the diet; however, they conclude that increasing roughage level to increase NDF from 25 to 39% NDF was not sufficient to increase fluid dilution. This lack of effect may have been related to the particle size of the roughage component of the diets. Roughages were ground to a relatively small particle size (approximately 1.4 mm), which may have reduced rumination time and thus saliva production, and consequently, modified any fiber-level effects on fluid dilution rate in comparison to feeding the same roughage as larger particles.

Merchen et al., (1986) fed four suffolk wethers at two levels of intake with two forage levels in the diet (75 and 25% alfalfa hay). Ruminal fluid dilution rate was not affected by either level of intake or forage (6.48 vs 5.80%/h for high and low intake, and 6.63 vs 5.85%/h for 75 and 25% alfalfa hay), although wethers tended to have faster fluid passage rates when fed 75% forage than when fed 25%.

Glenn et al., (1989) tested the effect of formaldehyde and formic acid treated alfalfa or orchardgrass silage at two levels of intake in growing Holstein steers. Liquid dilution rate did not differ due to silage type or intake. The values were as follows: 5.7 vs 7.9%/h; 5.3 vs 7.6%/h for low and high intake in alfalfa and orchardgrass treated diets, respectively, and 6.8 vs 6.5 %/h for alfalfa and orchardgrass silage, respectively. Although no significant differences were observed between levels of intake, the tendency for a higher liquid dilution rate at the high intake level is clear.

Cole et al. (1976a) found ruminal dilution rates were faster when cottonseed hulls were increased from 0 to 14% of the diet; however, when cottonseed hulls were increased to 21% of the diet, liquid dilution rate was not increased (2.8, 4.4, 5.0 and 4.3%/h for 0, 7, 14 and 21% cottonseed hulls, respectively). Ledoux et al., (1985) found liquid passage rate increased (6.0, 5.3, 6.3 and 8.1%/h) as fescue hay in the diet increased (4, 8, 16, and 24% respectively).

Galyean et al., (1979) studied the effect of feed intake and site and extent of digestion in high concentrate diets with steers. Steers were fed a diet containing 84% corn at 1.00, 1.33, 1.66 and 2.00 times maintenance. Cottonseed hulls were the roughage source. Estimates for liquid dilution rate were 3.0, 3.5, 4.0 and 5.3%/h for different levels of intake, respectively. It is clear from this study that intake level and liquid dilution rate are positively correlated. The authors commented that saliva flow may not be adequate to maintain liquid volume as intake of high concentrate diets increases. Higher roughage levels might stimulate more saliva flow. In line with increased rumen volume, dilution rate (%/h) and outflow (liters/h) increased as intake increased. These results agree with those of Bines and Davey (1970) who also reported that increasing forage level in high concentrate diets promoted faster rumen turnover rates of particulates. Evans (1981) suggested that increased dietary forage might be associated with rumination and salivation or to an alteration in the rumen microbial population.

Owens and Goetsch (1986) summarized several studies in which effects of roughage level and feed intake on ruminal dilution rate were evaluated in cattle. In general, increased feed intake or roughage content in the diet were related to increased ruminal liquid dilution rate.

This review shows feed intake to be an important factor affecting rumen liquid dilution rate. As level of feed intake increases, liquid dilution rate is generally increased. Level of roughage in the diet also affects liquid dilution rate. As roughage is increased, dilution rate is also increased. Minor effects due to roughage source have been shown and it seems that liquid dilution rate is less affected when high quality forages are included in the diet. Inclusion of roughage in high concentrate diets may improve rumen buffering capacity by stimulating rumination, saliva flow, and hence feed utilization. The literature evaluating the influence of roughage source on liquid dilution rate is scarce, suggesting that more research is needed in this area.

CHAPTER 3

EFFECT OF ROUGHAGE SOURCE ON KINETICS OF RUMINAL DIGESTION AND PASSAGE OF INDIVIDUAL FEED COMPONENTS IN 65% CONCENTRATE DIETS FOR STEERS

Summary

Two 4x4 Latin square experiments were conducted to examine the effect of substituting chopped wheat straw (WS), chopped bermudagrass straw (BS) or cottonseed hulls (CSH) for 50% of the chopped alfalfa hay (AH) in 65% concentrate diets on diet utilization and kinetics of ruminal digestion and passage for individual diet ingredients. The concentrate portion of all diets was based on steam-flaked milo. In experiment 1, total tract digestion coefficients for dry matter (DM), neutral detergent fiber (NDF) and starch were determined by total fecal collections using intact, growing steers. Particulate passage rates for grain and roughages in each diet (rare earth metals) and liquid dilution rate (Co-EDTA) were also measured. In experiment 2, mature rumen cannulated steers were used to determine kinetics of in situ ruminal digestion for DM, NDF and starch in milo and roughage components of the diets. The digestion rates were combined with passage rate estimates from experiment 1 to calculate

apparent extent of ruminal digestion (AERD) for each diet ingredient and for total diets. Ruminal pH and DM distribution were also determined in experiment 2.

Substituting WS for AH did not adversely affect total tract digestibilities for DM and NDF, whereas substitution with either BS or CSH depressed (P<.05) digestibility of these fractions. Total tract digestion of starch did not differ among diets and averaged 97%. Potential extents of digestion (72-h in situ) for DM and NDF were higher (P<.05) for AH than for the lower quality roughages and higher (P<.05) for WS and BS than for CSH. Thus, the lower total tract digestion coefficients for the CSH diet can be explained by the diluting effect of CSH when substituted for the more digestible AH. On the other hand, even though WS and BS were less digestible than AH, their inclusion in the diet caused less of a detrimental effect on total tract digestibilities for DM and NDF because they had a stimulatory effect on digestion of these fractions in milo and AH. The improvement in the NDF digestion was due to the tendency for ruminal passage of AH and milo to be slower and digestion rates for DM and NDF in these feedstuffs to be faster when either WS or BS replaced 50% of the AH in the diet. The differential effect of these roughages on ruminal digestion may be related to their effects on rumen environment. A higher proportion ($P<.05$) of rumen DM was in the upper strata (raft) when diets contained WS or BS and pH-hours below 6 tended to be reduced for these diets compared with the CSH or AH diets.

These data show that substitution of low quality forages, such as WS or BS, for a portion of AH in medium concentrate diets for growing beef cattle can improve utilization of the AH and grain. The effect is apparently due to the enhanced digestion of NDF, resulting from slower rates of passage and increased rates of digestion for AH and grain, since in this study forage source did not influence digestion of starch. The failure of CSH to exert an effect similar to that of WS or BS may be related to the less distinct raft formation in the rumen or to rumen pH being less than optimum for ruminal fiber digestion when this roughage was used.

Introduction

Roughage is included in ruminant diets to provide energy, to manipulate energy density of mixed diets or, in the case of high concentrate diets, primarily to stimulate feed intake and reduce the incidence of metabolic disorders such as acidosis and liver abcesses (Wise et al., 1968). Roughages are generally included in ruminant diets based upon tabular values for nutrient and energy concentrations reported in tables of feedstuff composition. Ample evidence exists to show that nutritive value of mixed diets often differs from that predicted from tabular values for the individual ingredients due to associative effects between roughage and concentrates (Mould et al., 1983). The factors responsible for these associative effects on nutrient utilization are not always clear. Moore (1987) demostrated that total tract digestion coefficients for dry matter (DM) and neutral detergent fiber (NDF) in 65% concentrate diets were not adversely affected when WS was substituted for one-half the AH in the diet, but that digestibilities were depressed when CSH replaced AH. It was determined that inclusion of WS improved ruminal utilization of NDF from both AH and milo, whereas inclusion of CSH did not affect these parameters. Digestibility of cell solubles in the diets was not influenced by roughage source. It could not be determined from this study whether the differential effect of CSH and WS on utilization of NDF from AH and milo was specific to these low quality roughages, or whether the effect was characteristic of the low quality roughage classes (forage vs oilseed by-products) that they represented.

Consequently, this study was initiated to obtain additional information on the effects of substituting low quality forages (WS or BS) or an oilseed by-product (CSH) for AH in medium-roughage diets on utilization of nutrients from individual diet ingredients and on ruminal factors (pH and DM stratification) that might be involved in the response.

Materials and Methods

Experiment 1.

Four intact growing steers with an average initial body weight of 267 kg were used in a 4x4 Latin square design to determine the effect of roughage source on apparent total tract digestion of dry matter (DM), neutral detergent fiber (NDF) and starch and to determine rates of passage for milo and roughage sources and liquid dilution rate. Each period of the Latin square consisted of a 21-d adjustment period followed by 7-d for data collection. Steers were housed in individual pens (5.0 x 2.5 m) that were partially shaded and had concrete floors. Steers were fed ad libitum at 12 h intervals (0700 and 1900). Drinking water was provided through automatic waterers.

Diets (table 1) were based on steam-flaked milo. On an as fed basis, the control diet contained 35% chopped alfalfa hay (AH) while chopped wheat straw (WS), chopped bermudagrass straw (BS) or cottonseed hulls (CSH) replaced one half the alfalfa hay in the experimental diets. Alfalfa hay was chopped through a 13.2 x 17.6 cm

TABLE 1. COMPOSITION AND CHEMICAL ANALYSIS OF 65% CONCENTRATE DIETS (DRY MATTER BASIS)[a]

Item	Diet			
	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls
Ingredient, %				
Flaked milo	56.78	55.19	55.19	55.19
Alfalfa hay	35.56	17.74	17.74	17.74
Wheat straw		17.74		
Bermuda straw			17.74	
Cottonseed hulls				17.74
Molasses	3.43	3.43	3.43	3.43
Animal fat	2.18	2.18	2.18	2.18
Urea	0.09	1.05	1.05	1.05
Dicalcium phosphate	0.26	0.48	0.48	0.48
Salt	0.60	0.60	0.60	0.60
Limestone		0.49	0.49	0.49
Rumensin premix	1.10	1.10	1.10	1.10
Analysis, %				
Nitrogen	1.9	2.0	2.0	1.9
NDF	20.52	23.42	25.08	27.64
Starch	32.66	33.13	33.57	36.14
Ca	0.83	0.82	0.88	0.83
P	0.39	0.38	0.43	0.39

[a]All diets were supplemented with 3300 IU of vitamin A and 33 mg monensin/kg.

screen and wheat straw and bermudagrass straw through a 5.5 x 7.7 cm screen in a rotor type mill. Maximum particle length for all chopped forages was approximately 5 to 7 cm.

Apparent total tract digestibilities of DM, NDF and starch were determined by 5-d total feces collection. An aliquot of the daily fecal excretion by each steer was dried at 50 C in a forced air oven. Dry feces were composited by steer and ground through a 2-mm screen in a Wiley mill. Diets were sampled daily for 5-d, composited and ground through a 2-mm screen. Samples of feces and diets were reground through a 1-mm screen in a cyclone grinder prior to analysis for starch.

For particulate passage rate measurements, grain and roughage components of the diet were marked with rare earth metals following the method of Goetsch and Galyean (1983). Milo was marked with ytterbium (Yb), AH with dysprosium (Dy) and WS, BS and CSH with europium (Eu). The quantity of feedstuff added to one liter of distilled water containing 2.5 g of the rare earth chloride was: milo 150 g, alfalfa hay 50 g, wheat straw 75 g, bermudagrass straw 75 g and cottonseed hulls 50 g.

An amount of each ingredient to provide approximately 50 mg rare earth and 2.5 g of Co-EDTA (for determination of liquid dilution rate) were mixed with a small portion of unmarked diet and offered prior to the morning feeding on d-1 of each collection period. Fecal samples were collected at 0, 8, 12, 16, 20, 24, 28, 32, 36, 42, 48, 54, 60, 72, 84, 96, and 120 h post-dosing.

Rates of passage and liquid dilution rate were calculated by regressing the natural log of fecal marker concentration versus time (Grovum and Williams, 1973). Ruminal passage rate was considered to be the absolute value of the slope of the descending portion of the regression line.

Dry matter (DM) in feeds and feces was determined at 100 C under 25 inches of mercury vacuum (AOAC, 1980). Neutral detergent fiber (NDF) in roughages was determined according to Goering and Van Soest (1970). The amylase modification (Robertson and Van Soest, 1977) was used to determine NDF in milo, mixed diets and feces.

Starch was determined on samples of dry diet or feces weighing approximately .4 g. Samples were placed in test tubes containing 2 ml of $CaCl_2$ solution (25% w/v) at pH 2 and allowed to stand for 1-h. Tubes were then autoclaved for 1-h and allowed to cool. Eight mililiters of enzyme solution (31.25 ml Diazyme L-200[1] + 4.65 g acetic acid + 3.046 g sodium acetate diluted to one liter and adjusted to pH 4.2) containing 50 enzyme activity

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[1] Miles Laboratories. Lot No. HBC8EL301

units was added and incubated overnight in a water bath at 60 C.

The hydrolysate was diluted to 100 ml with distilled water and centrifuged at 2000 rpm for 10 min. An industrial analyzer (YSI model 27 from Yellow Springs Instruments, Ohio) was used to determine dextrose concentration in the supernatant. Starch content of samples was calculated as follows:

$$S = (R \times .90)/(P \times .10)$$

where:

S = starch in %

R = analyzer reading in mg/dl

.90 = conversion factor for dextrose to starch

P = sample weight in g

.10 = dilution factor

Feces were prepared for determination of marker concentration by ashing 4 g samples overnight at 500 C and then solubilizing the ash by boiling with 30 ml of 3N solution containing equal molar proportions of nitric and hydrochloric acids. After standing overnight, samples were diluted to 50 ml and filtered through Whatman #4 filter paper. Potassium chloride was added to the filtrate to produce an approximate potassium concentration of 1500 ppm. Samples were diluted 1:2 prior to cobalt determination.

Concentrations of rare earths and Co in feces were determined on a Hitachi 80-70 atomic absorption spectrophotometer using air as the oxidant for cobalt, and nitrous oxide for rare earth metals (Ellis, et al., 1982; Hart and Polan, 1984).

Nitrogen, calcium and phosphorus content in diets were determined using a Technicon autoanalyzer (AOAC,1980).

Experiment 2.

Four mature steers (average body weight of 726 kg) fitted with permanent rumen cannulas were used in a 4x4 Latin square design to determine the effect of roughage source on kinetics of ruminal digestion for DM, NDF and starch, rumen dry matter fill and ruminal pH. Each period of the square consisted of 14-d adjustment and 5-d data collection periods. Steers were fed at maintenance (approximately 1.1% of body weight) at 12 h intervals (0800 and 2000) and drinking water was provided by automatic waterers.

Composition of experimental diets was the same as in experiment 1 (Table 1).

On d-1 of each collection period, rumen pH was determined at 2, 4, 6 and 12 h post-feeding. A sample of rumen digesta obtained from the ventral sac was filtered through four layers of cheescloth and pH of the liquid was measured immediately with a pH-meter. Rumen liquid pH was plotted against time and the area below pH 6.0 was measured by the trapezoidal rule to estimate pH-hours below 6.0 and reported as an index of pH stress (Murphy et al.,1983).

In situ disappearance of DM and NDF was determined by rumen incubation of 6 g of milo or 4 g of roughage in duplicate dacron bags for 6, 12, 24, 36, 48 and 72 h from d-2 to d-4 of each collection period. Bags were 20 x 21 cm with an average pore size of 50 um. Bags were hydrated in warm water for 10 min prior to incubation, and then placed in the rumen in descending order of time (except for the 6 h bags), so that all bags could be removed from the rumen simultaneously. To determine kinetics of ruminal digestion for milo starch, 6 g of milo were incubated in duplicate dacron bags for 2, 4, 6, and 12 h. All bags were tied to clips and attached to a weighted chain to keep them immersed in the ventral sac of the rumen.

Dry matter and NDF remaining in the bags were determined by the method of Moore et al. (1987) with the exception that the dacron bags were rinsed by hand. Bags containing sample residues were dried at 50 C for 48 h in a forced air oven for determination of residual DM. For determination of NDF, one hundred bags were boiled at a time in a 50 l container with NDF solution prepared according to Goering and Van Soest (1970) for roughages or Robertson and Van Soest (1977) for milo. Dacron bags containing 1.5 g of unincubated feed samples were analyzed in the same manner. After boiling 1 h in neutral detergent solution, bags were rinsed by hand and dried as described above. Milo and milo residues were boiled a second time following the amylase treatment. The NDF content determined for diet ingredients was: milo 10.5%, AH 44%, WS 67%, BS 72% and CSH 85%.

Starch remaining in milo residues was quantitated using the procedure described in experiment 1.

Potentially digestible DM (PDDM) and potentially digestible NDF (PDNDF) were defined as 100 - 72 h residue. Digestion rate was calculated by regressing the natural log of the percentage PDDM or PDNDF remaining against time (Smith et al., 1971), where the absolute value of the slope gives the rate of digestion. Rate of starch digestion was determined in the same manner assuming starch to be 100% potentially digestible in the rumen.

On the last day of each collection period, the rumen of each steer was evacuated by hand prior to the morning feeding in order to determine rumen DM fill and total volume. Raft was defined as the relatively dry mass which could be removed by hand, whereas liquid was defined as that portion which could be removed only by using a container (Moore, 1987).

Apparent extents of ruminal digestion (AERD) of DM and NDF were estimated using passage rates for roughages and grain determined in experiment 1 and rates and extent of digestion determined in experiment 2.

The AERD for DM was calculated using the model of Erdman et al., (1987):

$$A = R + (PDDM - R)[Kd/(Kd + Kp)]$$

where:

A = AERD for DM (%)

R = Rapidly degraded fraction (%)

PDDM = Potentially digestible DM at 72 h

Kd = Rate of digestion of PDDM

Kp = Rate of passage

The rapidly degraded fraction (R), was determined as:

$$R = [PDDM - (PDDM \times Y)]$$

where:

PDDM = Potentially digestible DM (%)

Y = Antilog of Y intercept when the natural log of the percentage remaining PDDM was regressed against time.

The AERD for NDF was calculated according to Waldo et al., (1972):

$$B = PDNDF[Kd/(Kd + Kp)]$$

where:

B = Apparent extent of ruminal digestion

PDNDF = Potentially digestible NDF

Kd = Rate of digestion of PDNDF

Kp = Rate of passage

The AERD for milo and roughages were calculated separately, and then used to estimate AERD for the entire diets.

Data from both experiments were analyzed by analysis of variance for a Latin square design (Cochran and Cox, 1950). Following a significant F-test, differences among treatment means were located by the least significant difference method (Snedecor and Cochran, 1967).

Results

Experiment 1.

Mean daily DM intake and total tract apparent digestion coefficients were altered by substitution of low quality roughages for part of the AH in these diets (table 2). Dry matter intake tended to be reduced by substitution of either WS or BS for AH, and tended to be increased when the substitution was by CSH. Mean daily DM intake was

TABLE 2. EFFECT OF ROUGHAGE SOURCE IN 65% CONCENTRATE DIETS ON INTAKE AND TOTAL TRACT DIGESTION COEFFICIENTS

	Diet				
Item	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
DM intake, kg/day	6.6[bc]	6.1[c]	6.2[c]	7.2[b]	.23
Digestion coefficients, %					
Dry matter	79.9[b]	78.8[b]	75.7[c]	72.6[d]	.35
NDF	53.4[b]	52.4[bc]	48.9[c]	43.1[d]	1.36
Starch	97.0	97.3	96.8	96.9	0.39

[a]Standard error of treatment mean based on four observations per treatment.

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

higher (P<.05) for the CSH diet than for diets containing WS or BS. Total tract digestibilities of DM and NDF were not adversely affected when WS was substituted for 50% of the AH in the control diet, but digestion of these fractions was depressed (P<.05) when AH was replaced by BS or CSH. Total tract digestibility of DM differed (P<.05) among diets with low quality roughages, being highest for the WS diet and lowest for the CSH diet. Digestion of NDF followed the same pattern, except that the difference between WS and BS diets was not significant (P>.05). Total tract digestion of starch did not differ among diets.

Rates of passage for milo, AH and liquid did not differ (P>.05) among treatments (table 3). However, AH and milo tended to pass more rapidly in the AH and CSH diets. Among the roughages, passage of each low quality roughage was slower than passage of AH, although the difference between rates of passage for AH and WS (4.6 vs 3.3%/h) was not different (P>.05). Liquid dilution rate was not affected by roughage source.

Experiment 2.

Parameters for kinetics of ruminal DM digestion for ingredients in each diet are presented in table 4. Potential digestibility of DM in milo and AH did not differ among diets (P>.05), although it tended to be higher, especially for AH, for these ingredients in the WS and BS

TABLE 3. EFFECT OF ROUGHAGE SOURCE IN 65% CONCENTRATE DIETS ON RATE OF PASSAGE OF INDIVIDUAL FEED COMPONENTS AND LIQUID DILUTION RATE

	Diet				
	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
Rate of passage, %/h					
Milo	5.7	4.2	4.6	5.3	.62
Alfalfa	4.6[b]	3.6	3.8	4.4	.48
Wheat straw		3.3[bc]			
Bermuda straw			2.3[c]		
Cottonseed hulls				2.4[c]	
					.42
Liquid	11.1	10.3	11.7	12.4	1.05

[a]Standard error of treatment mean based on four observations per treatment.

[b,c]Means among roughage sources with unlike superscripts differ ($P<.05$).

TABLE 4. EFFECT OF ROUGHAGE SOURCE IN 65% CONCENTRATE DIETS ON IN SITU POTENTIALLY DIGESTIBLE DRY MATTER (PDDM), RATE OF DIGESTION AND RAPIDLY DEGRADED DM FRACTION

Item	Diet				
	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
PDDM as % OF DM					
Milo	91.4	94.0	92.6	89.2	1.33
Alfalfa	65.3^{b}	70.4	69.9	62.7	2.52
Wheat straw		51.1^{c}			
Bermuda straw			46.9^{c}		
Cottonseed hulls				25.0^{d}	
					3.45
Rate of PDDM digestion, %/h					
Milo	5.3	5.8	6.1	5.2	.72
Alfalfa	5.1	7.0	7.4	6.4	1.64
Wheat straw		4.5			
Bermuda straw			3.7		
Cottonseed hulls				3.1	
					1.13
Rapidly degraded fraction of DM, %[d]					
Milo	39.0	24.0	31.9	32.5	4.92
Alfalfa	30.1^{b}	24.2	24.9	18.7	4.84
Wheat straw		16.5^{c}			
Bermuda straw			11.9^{c}		
Cottonseed hulls				2.4^{d}	
					1.63

[a]Standard error of treatment mean based on four observations per treatment.

[b,c]Means among roughage sources with unlike superscripts differ ($P<.05$).

[d]Calculated from the natural log transformed plot.

diets (figures 1 and 2). Among the roughages, potentially digestible dry matter (PDDM) was highest ($P<.05$) for AH (65.3%), followed by WS and BS (51.1 and 46.9%, respectively) and CSH (25%). Rates of DM digestion for milo and AH followed the same pattern, tending to be higher for the WS and BS diets than for AH or CSH diets. Rates of DM digestion for the roughages ranged from 5.1%/h for AH to 3.1%/h for CSH ($P>.05$).

The AERD for DM from individual diet ingredients and total diets calculated from passage and digestion kinetic parameters are in table 5. This treatment of the data indicated that inclusion of WS or BS in the diet tended to improve AERD for DM from milo and AH, while inclusion of CSH tended to decrease AERD for these diet ingredients. Among the roughages, AERD indicated that a higher percentage ($P<.05$) of DM from AH was digested in the rumen (47.8%) than was digested from WS or BS (35.4 and 33.5%, respectively) or from CSH (15.0%). Calculated AERD for DM in the entire diet did not differ among AH, WS and BS diets (ranging from 57.4 to 59.1%) and all had higher ($P<.05$) AERD for DM than the CSH diet (48.9%). Ruminal digestion of DM expressed as a percentage of total tract digestion tended to be lower in the CSH diet and higher in the BS diet.

Figure 1. Cummulative in situ milo DM digestion in 65% concentrate diets.

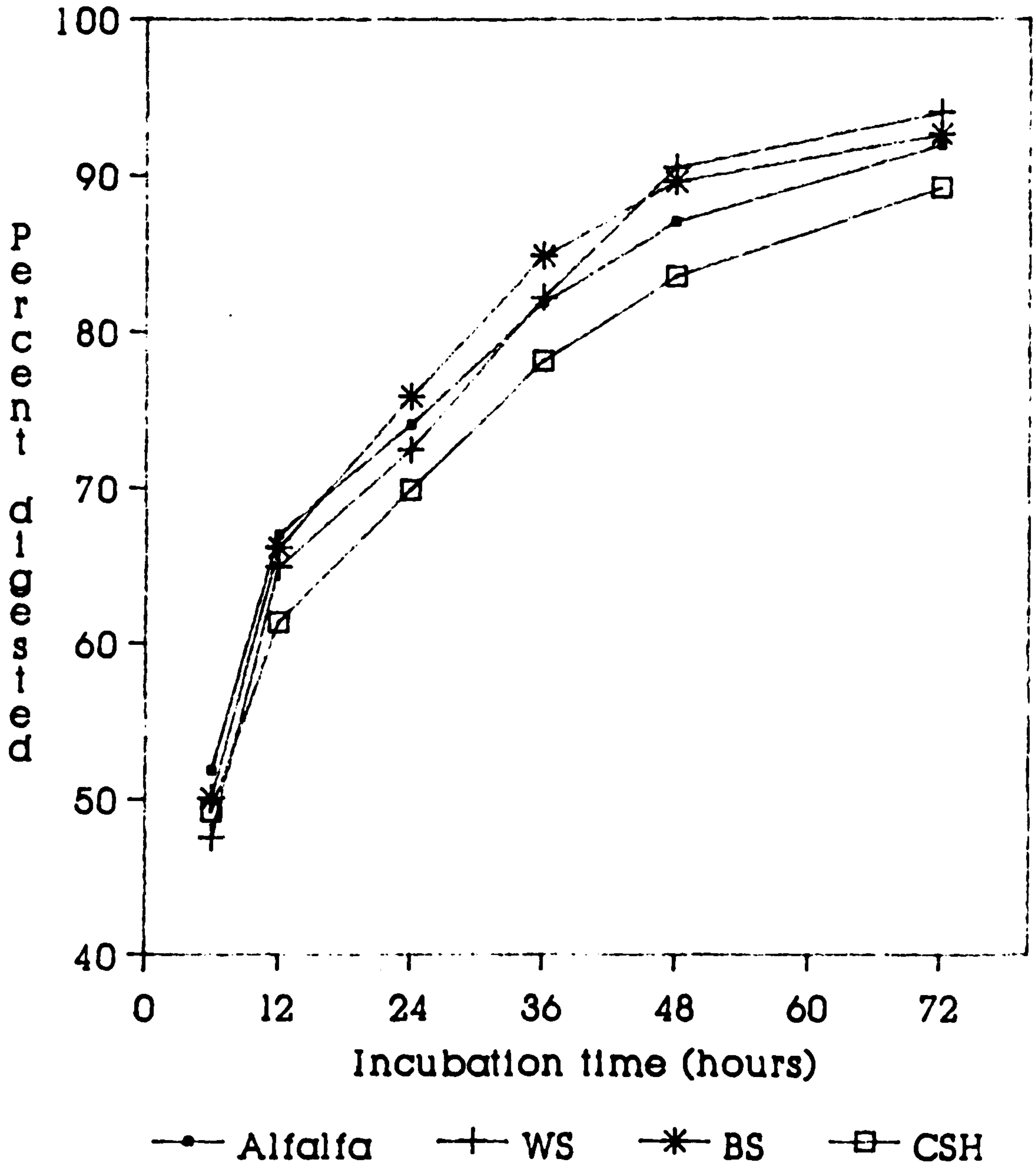


Figure 2. Cummulative in situ alfalfa DM digestion in 65% concentrate diets.

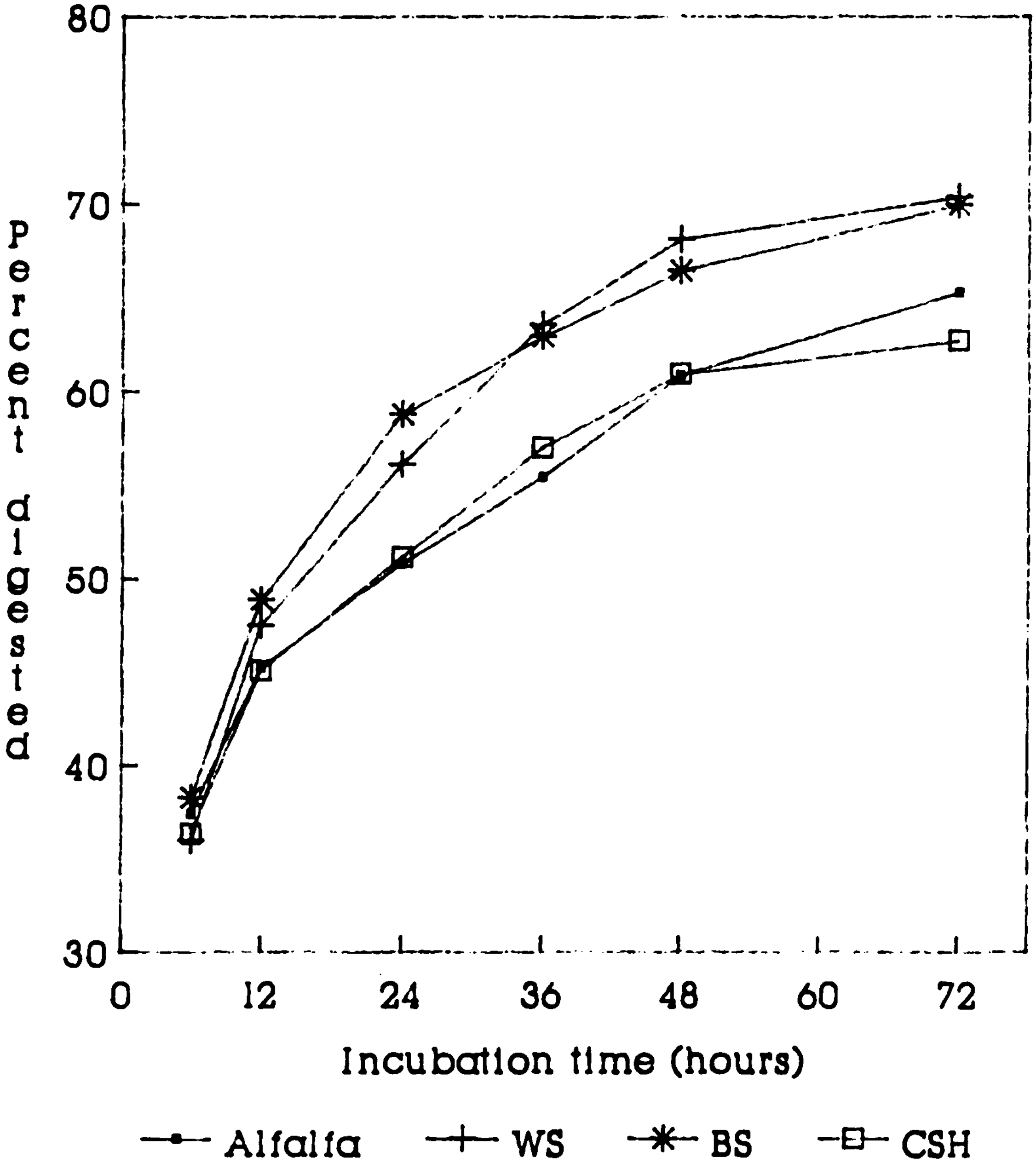


TABLE 5. EFFECT OF ROUGHAGE SOURCE IN 65% CONCENTRATE DIETS ON APPARENT EXTENT OF RUMINAL DIGESTION (AERD) FOR DRY MATTER

	Diet				
Item	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
AERD, % of DM					
Milo	63.9	64.6	67.8	60.2	2.04
Alfalfa	47.8[e]	53.9	53.5	44.9	3.19
Wheat straw		35.4[f]			
Bermuda straw			33.5[f]		
Cottonseed hulls				15.0[g]	
					2.41
Total diet, %	59.1[b]	57.4[b]	58.7[b]	48.9[c]	2.05
Total tract digestion					
coeff. %	79.9[b]	78.8[b]	75.7[c]	72.6[d]	.43
Ruminal digestion, % of					
total tract	73.9	73.5	77.4	67.0	2.81

[a]Standard error of treatment mean based on four observations per treatment.

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

[e,f,g]Means among roughage sources with unlike superscripts differ ($P<.05$).

The effect of roughage source in the diet on the process of starch digestion in the rumen is shown in table 6. While rates of starch digestion and AERD of starch did not differ among treatments, both parameters tended to be higher when the low quality roughages were substituted for part of the AH. Since total tract starch digestion was uniformly high among diets (97%), it appeared that a higher proportion of total tract starch digestion ocurred in the ruminal compartment when diets included low quality roughages (figure 3). However, the differences in ruminal starch digestion as a percentage of total tract starch digestion were less than 10 percentage units in all cases and statistically different (P<.05) only between the AH (65.7%) and BS (73.5%) diets.

Characteristics of digestion for NDF from the different ingredients in each diet are in table 7. Subsitution of any of the low quality roughages for part of the AH in these diets tended to increase PDNDF from milo (figure 4). Extent of digestion for NDF from AH tended to be improved by inclusion of WS and BS in the diet and tended to be reduced when CSH were used (figure 5). The percentage of total NDF that disappeared during 72-h in situ incubations (PDNDF) tended to be higher for AH (46.5%) than for WS (37.4%) or BS (38.5%) and was lowest (P<.05) for CSH (22.0%). Rates of digestion for NDF from

TABLE 6. EFFECT OF ROUGHAGE SOURCE IN 65% CONCENTRATE DIETS ON DIGESTION RATE, RAPIDLY DEGRADED FRACTION AND APPARENT EXTENT OF RUMINAL DIGESTION (AERD) OF STARCH

	Diet				
Item	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
Digestion rate, %/h	4.4	5.5	6.5	6.5	0.88
Rapidly degraded fraction, %[d]	35.7	32.3	30.7	30.1	2.82
AERD as % of starch	63.7	69.4	71.1	68.4	2.00
Digestion coefficient total tract, %	97.0	97.3	96.8	96.9	0.39
Ruminal digestion, % of total tract	65.7[c]	68.9[bc]	73.5[b]	70.6[bc]	1.51

[a]Standard error of treatment mean based on four observations per treatment.

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

[d]Actual 0 h starch digestion.

Figure 3. Cummulative in situ milo starch digestion in 65% concentrate diets.

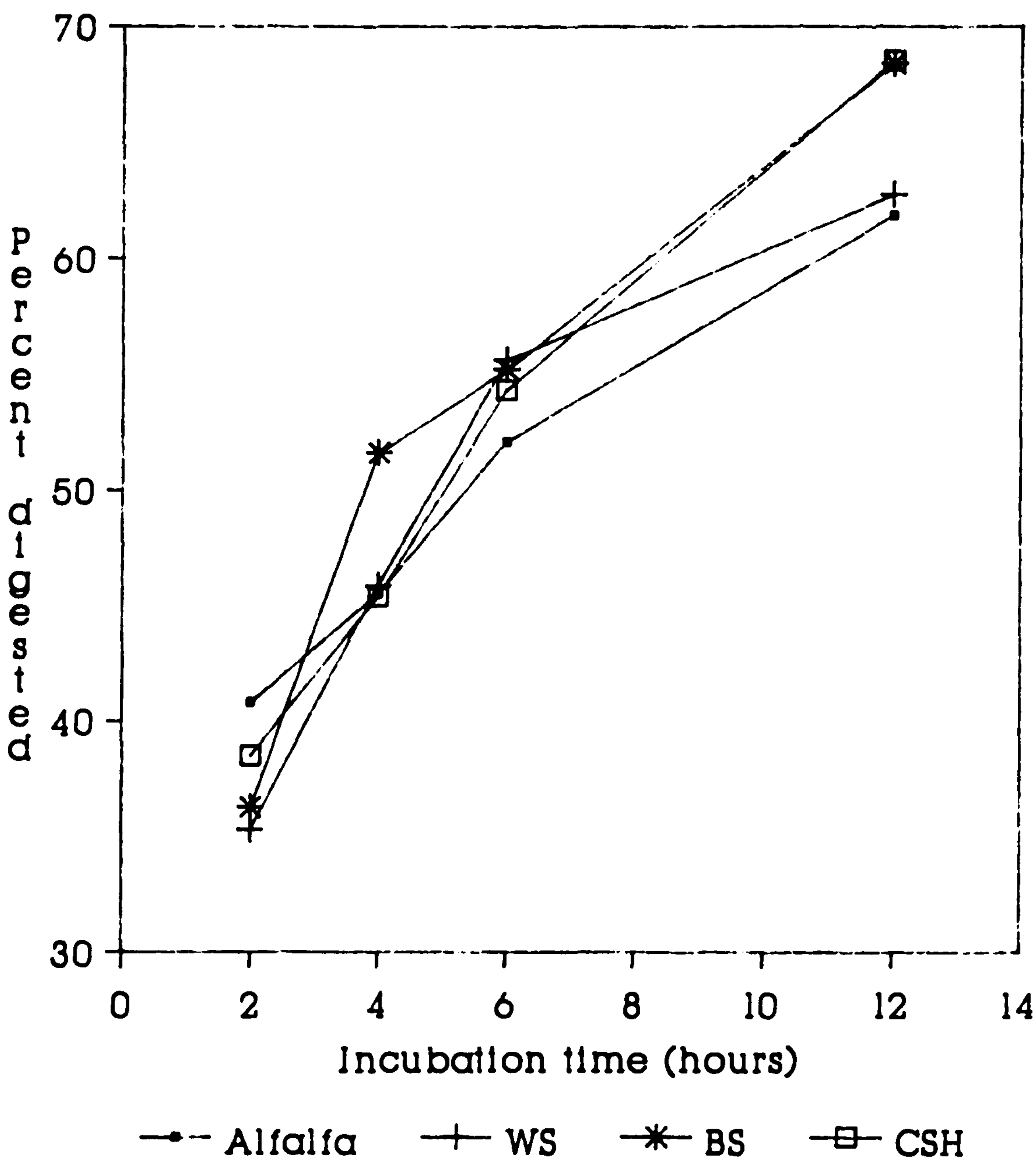


TABLE 7. EFFECT OF ROUGHAGE SOURCE IN 65% CONCENTRATE DIETS ON IN SITU POTENTIALLY DIGESTIBLE NDF (PDNDF), RATE OF DIGESTION AND DIGESTION LAG TIME

	Diet				
Item	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
PDNDF AS % of NDF					
Milo	49.3	67.1	59.7	52.6	5.21
Alfalfa	46.5[bcd]	55.8[b]	49.5[bc]	38.9[c]	3.12
Wheat straw		37.4[d]			
Bermuda straw			38.5[d]		
Cottonseed hulls				22.0[e]	
					2.92
Rate of PDNDF digestion, %/h					
Milo	4.3	5.3	4.7	4.3	.39
Alfalfa	5.4	7.4	7.0	4.9	1.21
Wheat straw		3.2			
Bermuda straw			4.2		
Cottonseed hulls				2.6	
					.95
Digestion lag time, h.[f]					
Milo	3.4[c]	6.1[b]	6.6[b]	6.3[b]	.42
Alfalfa	3.0	3.9	2.6	5.6	2.81
Wheat straw		-1.4			
Bermuda straw			2.2		
Cottonseed hulls				0.8	
					2.93

[a]Standard error of treatment mean based on four observations per treatment.

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

[d,e]Means among roughage sources with unlike superscripts differ, (P<.05).

[f]A negative lag time indicates that a portion of the NDF was calculated to be soluble at zero-hours.

Figure 4. Cummulative in situ milo NDF digestion in 65% concentrate diets.

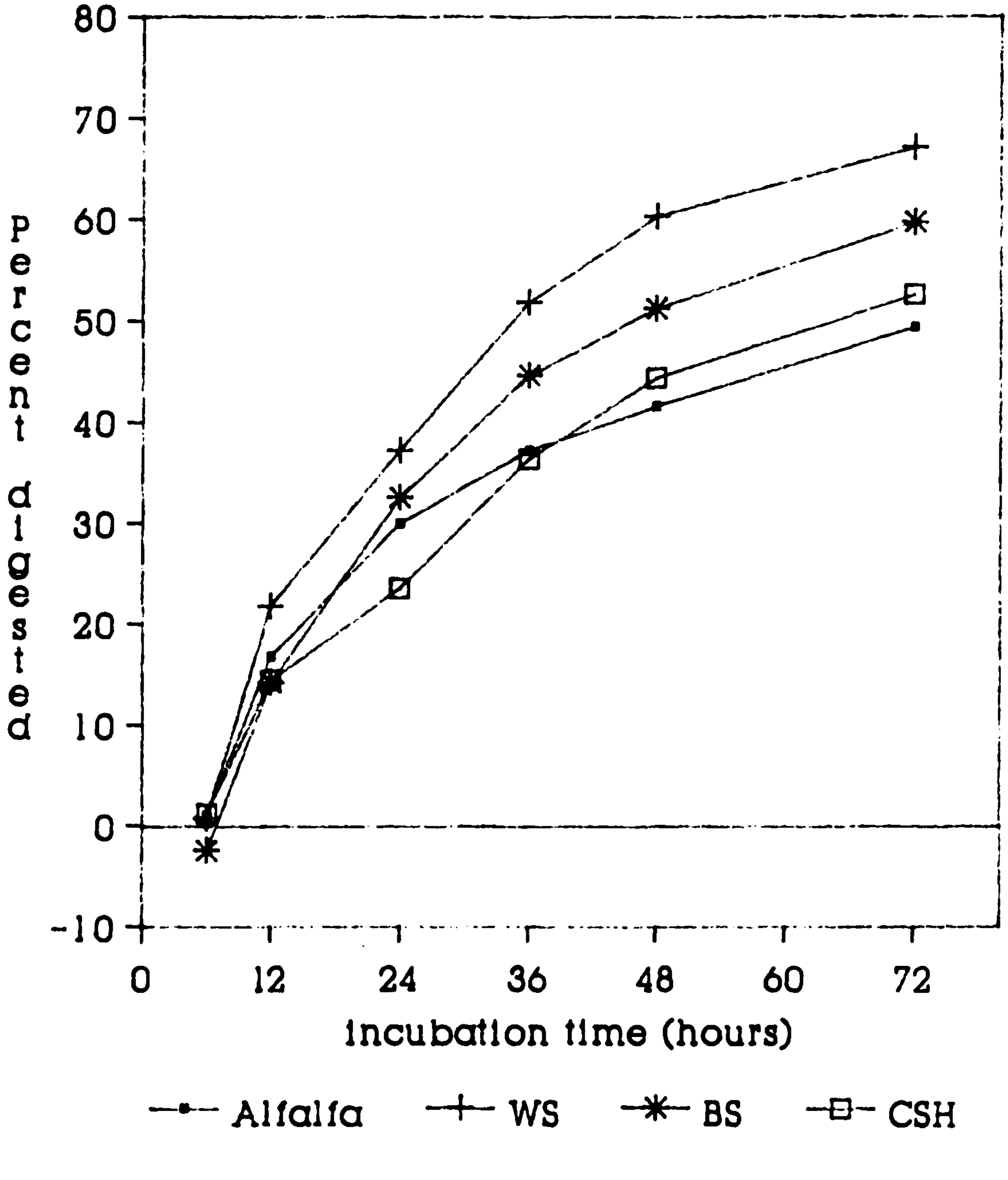
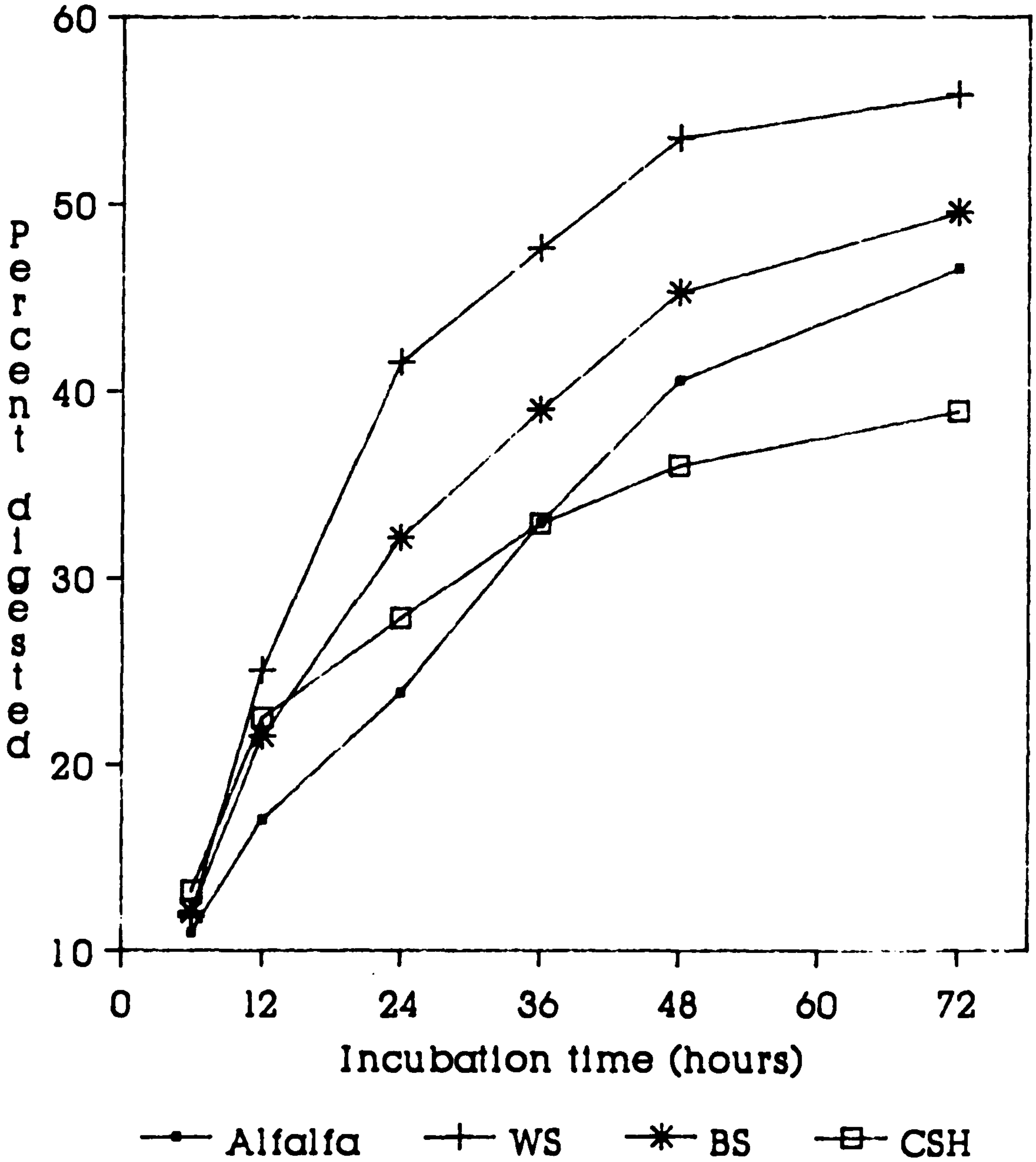


Figure 5. Cummulative in situ alfalfa NDF digestion in 65% concentrate diets



milo and AH tended to be higher for diets containing WS or BS than for the AH or CSH diets. Rate of digestion for PDNDF did not differ among roughages, but tended to be more rapid for AH (5.4%/h) than for the other roughages (4.2, 3.2 and 2.6%/h for BS, WS and CSH, respectively).

As shown in table 8, inclusion of WS or BS in the diet enhanced AERD for NDF from milo (P<.05) compared with AH and CSH diets, although the effect was even greater for WS than for BS (P<.05). The AERD for NDF in AH showed the same general pattern, being higher in the case of the WS diet and tending to be higher for the BS diet, than for AH or CSH diets. The AERD for NDF from CSH was approximately 50% of the AERD for NDF from the other roughages (10.9% vs 23.4, 18.1 and 24.5% for AH, WS and BS, respectively; P<.05). Ruminal digestion of NDF as a percentage of total tract NDF digestion was higher (P<.05) when diets contained WS (58.2%) or BS (55.1%), and tended to be higher for the CSH diet (46.1%) compared with the control AH diet (42.3%).

Digestion of PDNDF for the complete diet was estimated by multiplying the highest PDNDF value for each ingredient by the percentage of each ingredient in the diet. Poore et al., (1987) suggested that fiber digestion should be refered to in terms of PDND for obtaining umbiased comparisons of fiber digestion across

TABLE 8. EFFECT OF ROUGHAGE SOURCE IN 65% CONCENTRATE DIETS ON APPARENT EXTENT OF RUMINAL DIGESTION (AERD) FOR NEUTRAL DETERGENT FIBER

	Diet				
Item	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
AERD, % of NDF					
Milo	25.2[d]	37.3[b]	31.3[c]	25.8[d]	1.31
Alfalfa	23.4[cf]	37.5[b]	30.0[bc]	20.6[c]	3.52
Wheat straw		18.1[ef]			
Bermuda straw			24.5[f]		
Cottonseed hulls				10.9[e]	
					2.89
Total diet	22.6[c]	30.5[b]	29.5[b]	19.8[c]	1.41
Total tract digestion					
coeff. %	53.4[b]	52.4[bc]	48.9[c]	43.1[d]	1.39
Ruminal digestion, % of total					
tract	42.3[c]	58.2[b]	55.1[b]	46.1[c]	2.81

[a]Standard error of treatment means based on four observations per treatment.

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

[f,e]Means among roughage sources with unlike superscripts differ (P<.05).

treatments, since each diet contained a different source of NDF which varied in potential extent of digestion. The PDNDF content of diet DM was similar (13.3 to 14.7%) for all diets.

The calculated total tract digestion for PDNDF for the entire diets is shown in table 9. The PDNDF digestion did not differ (P<.05) among treatments. However, diets containing WS or BS tended to have higher PDNDF digestion (86.2 and 84.8%, respectively), and CSH tended to have lower PDNDF digestion (82.3%) compared to AH diet (82.7%). It is important to point out that milo contributed over 25% of the total PDNDF in all diets. This supports the observations of Van Soest (1982) and Poore (1987) that grain has been overlooked as a substantial source of fiber in mixed diets for ruminants. From this point of view, the importance of evaluating fiber digestion of grain in high concentrate diets is clear.

Rumen pH is an important factor in ruminal environment. The effect of roughage source on rumen pH is shown in table 10. No differences among diets (P<.05) were observed at any of the sampling times. However, WS and BS diets tended to have reduced pH-hours below 6.0 compared with AH and CSH diets. Even more, the tendency to reduce pH-hours below 6.0 was more pronounced in the WS diet.

TABLE 9. EFFECT OF ROUGHAGE SOURCE IN 65% CONCENTRATE DIETS ON CALCULATED CONTENT AND TOTAL TRACT DIGESTIBILITY OF POTENTIALLY DIGESTIBLE NDF (PDNDF)

	Diet				
Item	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
Calculated PDNDF content of the diets					
as % of NDF	64.5	60.8	57.7	52.3	
as % of DM	13.3	14.2	14.5	14.7	
PDNDF digestion coefficient, total					
tract, %	82.7	86.2	84.8	82.3	1.62
Ingredient contribution to total diet PDNDF, %					
Milo	26.2	28.7	25.8	29.5	
Alfalfa	73.8	34.6	32.9	33.5	
Wheat straw		36.7			
Bermuda straw			41.3		
Cottonseed hulls				36.0	

[a]Standard error of treatment means based on four observations per treatment.

TABLE 10. EFFECT OF ROUGHAGE SOURCE IN 65% CONCENTRATE DIETS ON RUMEN pH AND pH-HOURS BELOW 6.0

	Diet				
Item	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
Hour					
0	6.51	6.61	6.58	6.42	.07
2	5.87	6.10	6.11	5.98	.10
4	5.74	5.80	5.71	5.66	.09
6	5.66	5.73	5.80	5.70	.07
12	6.41	6.36	6.44	6.21	.08
pH-hours <6.0	1.89	0.85	1.18	2.61	.77

[a]Standard error of treatment mean based on four observations per treatment.

Total rumen DM, volume and rumen DM distribution are shown in table 11. Total rumen DM did not differ among diets (P>.05), but the quantity of DM tended to be increased for diets containing low quality roughages. Total volume did not differ (P>.05) among treatments, but in contrast to total rumen DM, total volume tended to be higher for the AH diet than for the other treatments. The percentage of rumen DM in the raft was higher (P<.05) when steers were fed WS or BS diets than when AH and CSH diets were fed. Most importantly, the raft found in the AH and CSH diets was extremely low averaging only 8.3% of total rumen DM compared with 43.9 and 57.2% for WS and BS diets, respectively (P<.05).

TABLE 11. EFFECT OF ROUGHAGE SOURCE IN 65% CONCENTRATE DIETS ON RUMEN DRY MATTER FILL AND TOTAL VOLUME

	Diet				
Item	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
Total rumen DM, kg	3.9	4.2	4.8	4.9	.41
Total volume, l	59.3	51.8	56.0	53.8	4.25
Percentage of rumen DM					
In raft	8.3[c]	43.9[b]	57.2[b]	8.3[c]	8.42
In liquid	91.7[b]	56.1[c]	42.8[c]	91.7[b]	8.42

[a]Standard error of treatment mean based on four observations per treatment.

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

Discussion

In an earlier investigation, Moore (1987) reported that substitution of WS for 50% of the AH in 65% concentrate diets did not affect adversely total tract digestion of DM and NDF, while inclusion of CSH at the same proportion depressed digestion of both diet fractions. It was determined that inclusion of WS improved ruminal utilization of NDF from both milo and AH.

However, in the research conducted by Moore (1987), it was not determined if the differential effect of CSH and WS on utilization of NDF from milo and AH was specific to these low quality roughages, or whether the effect was characteristic of the low quality roughage classes (forages vs oilseed by-products) that they represented.

So, the primary objective of this dissertation was to further examine the effect of roughage source on diet utilization. For that effect, another roughage, BS, which was considered to have physical properties intermediate to those of WS and CSH, was included in the experiments. A secondary objective was to determine directly the effect of roughage type on starch utilization.

Substitution of BS or CSH for 50% of AH depressed total tract digestion for DM and NDF in the diets, but inclusion of WS did not. This finding confirms results reported by Moore (1987) regarding the comparative effects of including WS or CSH in medium-concentrate diets on total tract digestion of these fractions by steers. Substitution of BS for part of the AH depressed DM digestion and tended to lower NDF digestion compared to WS diet, however, digestion of both fractions was higher than in the CSH diet.

It was concluded by Moore (1987) that DM digestion of AH and WS diets was similar because inclusion of WS caused ruminal digestion of NDF from milo and AH to be increased. The increased NDF digestion resulted from reduced passage rate and increased rate of digestion for milo and AH in the WS diet. The WS diet promoted a greater raft formation in the dorsal rumen and it was speculated that the raft could entrap AH and grain particles, thus retarding their movement from the rumen. It was considered that the improved ruminal fiber utilization could have also resulted from a more desirable rumen environment when WS was included in the diet; pH-hours below 6 were fewer on this diet than in the AH or CSH diets, possible because of increased rumination. Welch (1982) indicated that stratification of rumen contents is related with rumination. Russell and Dombrowsky (1980) showed that cellulolytic species in the rumen were particularly sensitive to pH below 6. Mertens (1979) indicated that variation in ruminal pH is important in modifying microbial activity and influencing rate and extent of ruminal digestion of dietary fiber.

The increased ruminal digestion of NDF from milo and AH, reduced passage rates, increased rates of digestion for these ingredients, more definitive raft formation and fewer pH-hours below 6 when WS was included in the diet were confirmed in the present study. However, in this study, raft formation was similar for BS and WS diets, but extent of NDF digestion from milo and AH tended to be lower in the BS diet than in the WS diet. Inclusion of BS was not as effective as WS in slowing rates of passage for milo and AH, but passage rates for these ingredients were still slower for the BS diet than for the CSH diet. These tendencies may explain the lower ruminal digestion of NDF from milo and AH when BS, rather than WS, was substituted for part of the AH. They may also explain the higher ruminal digestion of NDF from these two diet ingredients in the BS diet compared with the CSH diet.

Another factor considered by Moore (1987) to be involved in the improved NDF digestion from milo and AH was rumen pH. In that study, and in the present study as well, pH-hours below 6 tended to be reduced for the WS diet followed by AH and CSH diets. The tendency for reduced pH-hours below 6 in the WS diet could have been due to increased rumination resulting from the increased raft on this diet. Moore (1987) indicated that rumination time was increased in the WS diet compared to AH and CSH diets.

In the present study, the proportion of rumen DM located in the raft was similar for BS and WS diets, yet BS was not as effective as WS in stabilizing rumen pH. It is possible that the nature of the rafts was different and that they did not have the same stimulatory effect on rumination. The raft on the BS diet was of a softer consistency than that on the WS diet. On the other hand, the CSH diet did not promote raft formation and rumen pH-hours below 6 tended to be higher compared to the other diets. Even more, raft formation was similar for CSH and AH diets, yet pH-hours below 6 tended to be lower for the AH diet than for the CSH diet. It is possible that the intrinsic buffering capacity of AH contributed to this effect.

All the factors discussed above could have contributed to the differences observed in extent of ruminal NDF digestion among the diets. However, differences in digestibility among the roughages could also have affected the total tract digestion of the diets. Alfalfa hay was more digestible than all the low quality roughages. Among the low quality roughages, CSH was less digestible than WS or BS and WS tended to be more digestible than BS.

As a result of improved ruminal digestion of NDF from milo and AH, AERD for NDF for the entire diet was higher for WS and BS diets than for the AH and CSH diets despite the differences in digestion among the roughages. When ruminal digestion of NDF was expressed as a percentage of total tract digestion, the same pattern was observed, with WS and BS diets having higher ruminal fiber digestion than AH and CSH diets. These findings also agree with those reported by Moore (1987).

Since total tract digestion of NDF was higher for the AH diet than for BS and CSH diets but ruminal fiber digestion was lower, fiber escaping rumen fermentation on the AH diet was apparently digested in the lower tract. Also, it is important to point out that ruminal fiber digestion was higher for BS and WS diets than for AH and CSH diets but total tract digestion of NDF tended to be lower for the WS diet, and was lower for the BS diet, compared to the AH diet.

Ruminal digestion of NDF expressed as a percentage of total tract digestion did not differ between AH and CSH diets. However, NDF content was higher in the CSH diet than in the AH diet due to the high proportion of NDF in CSH. Thus, even though the proportion of fiber digestion occurring in the rumen was similar for both diets, a higher proportion of fiber escaping ruminal digestion was digested in the lower tract on the AH diet than in the CSH diet.

A major difference among the low quality roughages evaluated in this study was in their ability to affect rumen stratification. Both of the forages, WS and BS, were associated with distinct raft phases in the dorsal rumen while CSH was not. Differences in physical properties such as specific gravity, particle size or rate of particle size reduction are most likely responsible for the differential effects observed among roughages in this study.

In summary, inclusion of WS or BS improved digestion of NDF from milo and AH while inclusion of CSH did not. As a result, total tract digestion of DM and NDF were similar for AH and WS diets. Inclusion of BS depressed total tract digestion of DM and NDF compared with AH and tended to depress it in comparison with the WS diet. However, total tract digestion coefficients were higher for diets with BS or WS than for the diet with CSH.

Moore (1987) determined that digestion of cell solubles was not affected when WS or CSH replaced half the AH in 65% concentrate diets, however no direct observations were made on the nutrient fractions contributing to cell solubles.

It is theorized that ruminal digestion of starch would be inversely related to passage rate of milo, and that starch digestion might be enhanced by inclusion of a forage such as WS that slowed milo passage. This relationship was observed for BS and WS diets which had slower rates of milo passage and higher AERD for starch than did than AH diet. The AERD for starch tended to be higher for the CSH diet than for the AH diet despite these two diets having similar passage rates for milo. In this case the differences in AERD for starch can be explained by the tendency for rate of starch digestion to be higher for the CSH diet. It is possible that amylolytic activity of rumen bacteria was enhanced on the CSH diet because of the tendency for rumen pH to be lower. Rate of passage for milo tended to be faster and digestion rate for starch tended also to be faster for the BS diet than for the WS diet. As a result, AERD for starch was similar for BS and WS diets. Ruminal starch digestion expressed as a percentage of total tract starch digestion was higher for the BS diet than for WS and CSH diets and the proportion of starch digestion occurring in the rumen was higher for all low quality roughage diets than for the AH diet. This resulted from the increased rate of digestion for starch and reduced rate of passage for milo in the BS diet. The AH diet had the lowest percentage of starch digestion occurring in the rumen because the rate of digestion for starch tended to be lower and the rate of passage for milo in this diet was faster.

In summary, inclusion of low quality roughages in 65% concentrate diets tended to increase ruminal starch digestion by reducing passage rate for milo (BS and WS diets) or by increasing rate of starch digestion (CSH diet). However, total tract digestion of starch was not different among diets. Theoretically, it is desirable for starch to escape rumen fermentation to avoid losses of energy as heat and methane (Hungate, 1966). The significance, if any, to the shift in site of starch digestion resulting from substitution of lower quality roughages for AH in medium-concentrate diets is not clear.

CHAPTER 4

EFFECT OF ROUGHAGE SOURCE ON KINETICS OF RUMINAL DIGESTION AND PASSAGE OF INDIVIDUAL FEED COMPONENTS IN 90% CONCENTRATE DIETS

Summary

Two 4x4 Latin square experiments were conducted to evaluate the effect of substituting chopped wheat straw (WS), chopped bermudagrass straw (BS) or cottonseed hulls (CSH) for chopped alfalfa hay (AH) in 90% concentrate diets on diet utilization and kinetics of ruminal digestion and passage for the individual fractions in each diet. The concentrate portion of the diets was based on steam-flaked milo. In experiment 1, total tract digestion coefficients for dry matter (DM), neutral detergent fiber (NDF) and starch were determined by total fecal collection using intact steers. Particulate passage rates for grain and roughages in each diet (rare earth metals) and liquid dilution rate (Co-EDTA) were also measured. In experiment 2, mature rumen cannulated steers were used to determine kinetics of in situ ruminal digestion for DM, NDF and starch in milo and roughage portions of the diets. The digestion rates were combined with passage rates estimates from experiment 1 to calculate apparent extent of ruminal

digestion (AERD) for each ingredient and for the total diets. Ruminal pH and DM distribution were also determined in experiment 2.

Replacing AH with the low quality roughages depressed ($P<.05$) total tract digestion of DM and NDF fractions of the diets. Total tract digestion for starch did not differ ($P>.05$) among diets and averaged 97.5%.

Potential extent of digestion (72-h in situ) for DM in milo was lower ($P<.05$) and extent of NDF digestion for milo tended to be lower in the CSH diet than in the other diets. In diets containing either WS or BS, the potential extents of digestion for DM and NDF from milo tended to be higher than in the AH diet.

Among the roughages, the extent of digestion for DM and NDF were higher ($P<.05$) for AH than for the lower quality roughages. No significant differences ($P>.05$) were observed in rate of passage or digestion for milo, although diets containing low quality roughages tended to have faster passage of milo and faster digestion rates for NDF from milo than in the AH diet. Thus, the lower total tract digestion coefficients for diets containing low quality roughages can be explained by the diluting effect of these roughages rather than by their effects on digestibility of the grain portion.

Diets containing WS or BS promoted a higher ($P<.05$)

raft formation than AH or CSH diets and WS diet tended to reduce pH-hours below 6.0 followed by the AH, BS and CSH diets respectively.

The data suggest that substitution of low quality roughages for AH at this level of concentrate depresses digestibility because these roughages are less digestible than AH. The effect of these roughages on kinetics of ruminal digestion and passage for the grain fraction was minimal, but passage tended to be faster for the low quality roughage diets.

However, the data also suggest that inclusion of WS in high concentrate diets may function to maintain rumen pH above critical values, thus improving conditions for NDF digestion and reducing the incidence of metabolic acidosis.

Introduction

Substitution of chopped low quality forages (WS and BS) for part of the chopped AH in 65% concentrate diets fed to steers improved utilization of NDF from AH and grain portions of the diet (Moore, 1987, Chapter 3, this dissertation). The improved NDF utilization was attributed to reduced ruminal passage rates for grain and AH, and to maintenance of a more desirable pH for ruminal digestion of NDF when WS or BS were substituted for part of the hay. If WS and BS were to also slow passage of milo and stabilize ruminal pH when included in higher concentrate diets, ruminal starch digestion might be improved and management problems related to rumen acidosis reduced. However, when Moore (1987) replaced the AH (10%) in 90% concentrate diets for steers with either chopped WS or CSH, total tract digestion of cell solubles (used as an indirect measure of starch digestion) tended to be lower for the WS and CSH diets. There was a tendency for rumen pH to be maintained above 6.0 for a higher proportion of the day when WS was included in the diet, but the effect was small.

This study was conducted to further examine the effect of replacing AH in 90% concentrate diets with low quality roughages on digestibility of diet ingredients, particularly on site and extent of starch digestion and on the ruminal environment.

Materials and Methods

Experiment 1.

Four intact steers with an initial mean bodyweight of 390 kg were used in a 4x4 Latin square design to determine the effect of roughage source on apparent digestion coefficients for dry matter (DM), neutral detergent fiber (NDF) and starch. Particulate rates of passage for grain and roughages and liquid dilution rates were also determined.

Steers were housed in individual pens (5.0 x 2.5 m) that were partially shaded and had concrete floors. Steers were fed ad libitum at 12 h intervals (0700 and 1900). Drinking water was provided through automatic waterers.

Diets were based on steam flaked milo. The control diet contained 10% chopped alfalfa hay (AH) while chopped wheat straw (WS), chopped bermuda grass straw (BS) or cottonseed hulls (CSH) replaced AH in the experimental diets (table 12).

Experiment 2.

To evaluate the effect of roughage source on kinetics of rumen digestion of DM, NDF and starch, four mature steers (average body weight of 726 kg) fitted with permanent rumen cannulae were used in a 4x4 Latin square design. The steers were fed at their calculated maintenance level of 0.9% of body weight at 12 h intervals (0800 and 2000) and fresh water was provided by automatic waterers.

Composition of experimental diets was the same as in experiment 1 (table 12).

Kinetics of in situ DM, NDF and starch disappearance was determined by rumen incubation of dacron bags. The potentially digestible dry matter (PDDM) or potentially digestible neutral detergent fiber (PDNDF)

TABLE 12. COMPOSITION AND CHEMICAL ANALYSIS OF 90% CONCENTRATE DIETS (DRY MATTER BASIS)[a]

	Diet			
Item	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls
Ingredient, %				
Flaked milo	81.72	80.74	80.74	80.74
Alfalfa hay	9.98			
Wheat straw		9.97		
Bermuda straw			9.97	
Cottonseed hulls				9.97
Molasses	2.59	2.59	2.59	2.59
Animal fat	2.19	2.19	2.19	2.19
Urea	0.77	1.32	1.32	1.32
Limestone	0.77	1.05	1.05	1.05
Dicalcium phosphate	0.22	0.38	0.38	0.38
Salt	0.65	0.65	0.65	0.65
Rumensin premix	1.11	1.11	1.11	1.11
Analysis, %				
Nitrogen	2.1	1.9	1.9	2.0
NDF	12.96	14.80	14.61	16.44
Starch	42.71	43.95	43.84	46.13
Ca	0.61	0.50	0.59	0.58
P	0.39	0.40	0.41	0.42

[a]All diets were supplemented with 3300 IU of vitamin A and 33 mg monensin/kg.

were defined by percentages disappearing after 72 h of rumen incubation. Starch was considered to be 100% potentially digestible. Apparent extents of ruminal digestion (AERD) for DM, NDF and starch in diet ingredients were calculated using competing rates passage (experiment 1) and digestion (experiment 2). Rumen pH and rumen DM distribution were also determined.

Details of experimental procedures and analytical and statistical methods were presented in chapter 3.

Results

Experiment 1.

Mean daily DM intake did not differ (P>.05) among diets (table 13). However, DM intake of WS and CSH diets tended to be higher. Among diets containing low quality roughages, DM intake tended to be lower in the BS diet than in the WS or CSH diets.

Total tract digestion coefficients for DM and NDF were depressed (P<.05) in diets containing low quality roughages. Among diets with low quality roughages, digestibilities for DM and NDF were higher (P<.05) in the WS diet than in the CSH diet and tended to be higher than in the BS diet. Total tract digestion

TABLE 13. EFFECT OF ROUGHAGE SOURCE IN 90% CONCENTRATE DIETS ON INTAKE AND TOTAL TRACT DIGESTION COEFFICIENTS

Item	Diet				
	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
DM intake kg/day	6.1	6.8	6.1	6.6	.31
Digestion coefficients, %					
Dry matter	83.9[b]	81.9[c]	80.5[cd]	79.5[d]	0.50
NDF	50.3[b]	42.5[c]	39.5[cd]	37.8[d]	1.16
Starch	97.8	98.0	97.0	97.1	0.28

[a]Standard error of treatment mean based on four observations per treatment.

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

of starch did not differ (P<.05) among treatments and averaged 97.5%.

Passage rate for milo did not differ (P<.05) among treatments (table 14). However, milo passage tended to be slower in the AH diet than in diets containing low quality roughages. Among diets with low quality roughages, passage rates for milo were similar and averaged 3.0%/h. Among the roughages, passage rate was faster (P<.05) for AH than for BS or CSH and tended to be more rapid than WS. The rate of passage for WS was more rapid (P<.05) than for CSH and WS tended to pass faster than BS. Liquid dilution rate did not differ among diets and averaged 3.2%/h.

Experiment 2.

The extent and rates of PDDM digestion for milo and roughages are shown in table 15 and figure 6. The extent of PDDM digestion for milo was lower (P<.05) in the CSH diet than in the other treatments. Among the roughages, AH extent of PDDM digestion was highest (P<.05) for AH (60.0%) and higher (P<.05) for WS and BS (both 37.3%) than for CSH (23.1%). Rates of DM digestion for milo did not differ (P>.05) among treatments. However, the rate of DM digestion for milo tended to be slower in the CSH diet (3.8%/h) and higher in the WS diet (4.6%/h) compared to AH and BS diets (4.1 and 4.0%/h), respectively. Rates of digestion for

TABLE 14. EFFECT OF ROUGHAGE SOURCE IN 90% CONCENTRATE DIETS ON RATE OF PASSAGE OF INDIVIDUAL FEED COMPONENTS AND LIQUID DILUTION RATE

	Diet				
Item	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
Rate of passage, %/h.					
Milo	2.6	3.0	3.1	3.0	.27
Alfalfa	2.9[b]				
Wheat straw		2.7[bc]			
Bermuda straw			1.8[cd]		
Cottonseed hulls				1.6[d]	
					.27
Liquid	3.1	3.3	3.4	3.1	.20

[a]Standard error of treatment mean based on four observations per treatment.

[b,c,d]Means among roughages sources with unlike superscripts differ (P<.05)

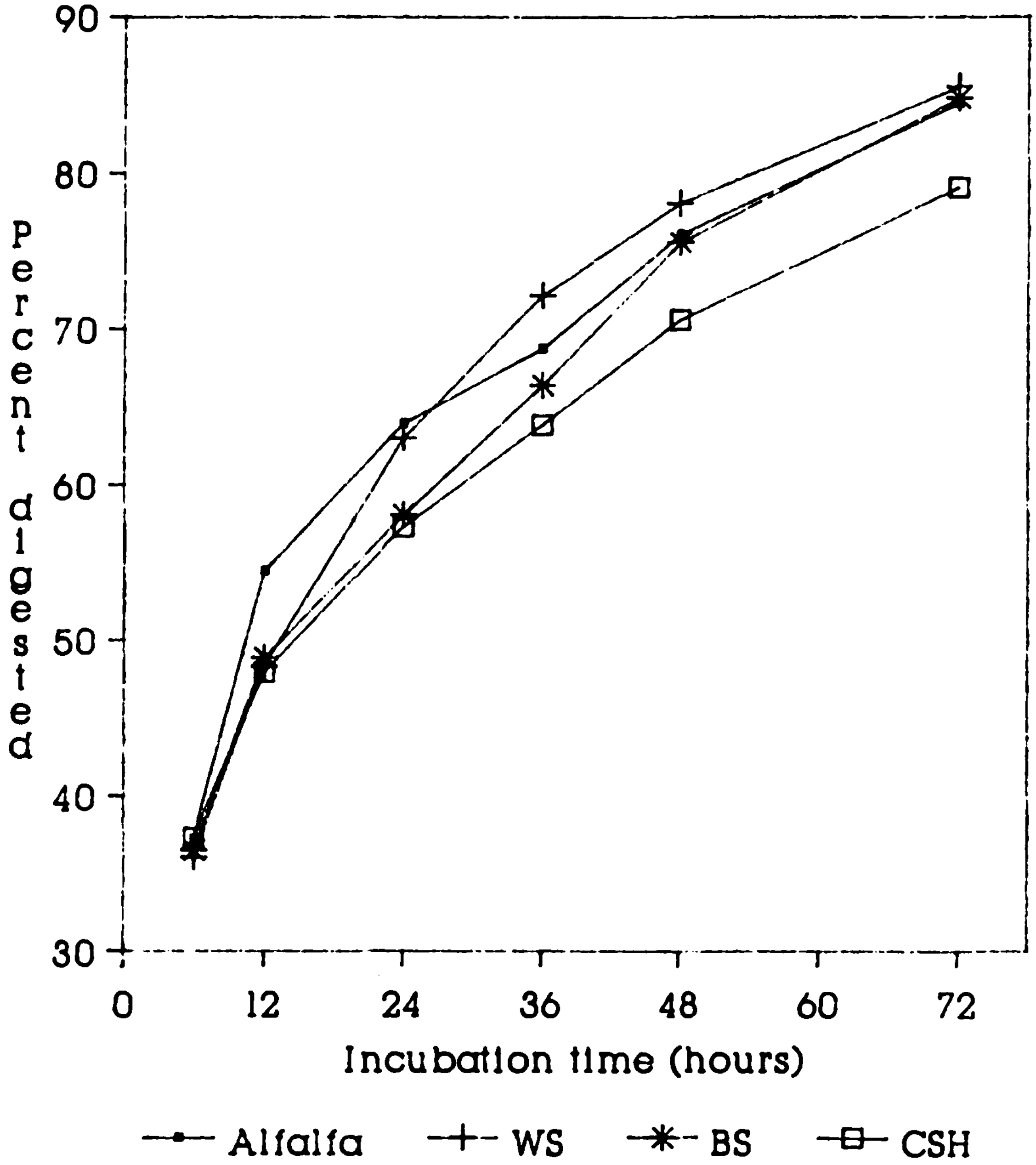
TABLE 15. EFFECT OF ROUGHAGE SOURCE IN 90% CONCENTRATE DIETS ON IN SITU POTENTIALLY DIGESTIBLE DRY MATTER (PDDM), RATE OF (PDDM) DIGESTION AND RAPIDLY DEGRADED DM FRACTION

	Diet				
Item	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
PDDM as % of DM					
Milo	84.5^{b}	85.6^{b}	84.8^{b}	79.1^{c}	1.48
Alfalfa	60.0^{d}				
Wheat straw		37.3^{e}			
Bermuda straw			37.3^{e}		
Cottonseed hulls				23.1^{f}	
					2.01
Rate of PDDM digestion, %/h					
Milo	4.1	4.6	4.0	3.8	.71
Alfalfa	4.7				
Wheat straw		2.5			
Bermuda straw			3.7		
Cottonseed hulls				2.8	
					.92
Rapidly degraded fraction of DM, %					
Milo	30.1	20.2	24.6	28.1	4.69
Alfalfa	26.3^{b}				
Wheat straw		20.6^{bc}			
Bermuda straw			14.4^{cd}		
Cottonseed hulls				9.3^{d}	
					2.51

[a]Standard error of treatment mean based on four observations per treatment.

[c,d,e]Means among roughage sources with unlike superscripts differ, (P<.05)

Figure 6. Cummulative in situ milo DM digestion in 90% concentrate diets.



roughages did not differ (P>.05), although DM digestion tended to be fastest for AH (4.7%/h) followed by BS, CSH and WS (3.7, 2.8 and 2.5%/h, respectively).

The calculated AERD for DM from milo, roughages and for the entire diets are presented in table 16. The AERD for DM from milo did not differ (P>.05) among diets, although it tended to be higher in the AH diet than in the other treatments. Among diets containing low quality roughages, AERD for DM from milo tended to be higher in the WS and BS diets than in the CSH diet. Among the roughages, AERD for DM was highest (P<.05) for AH (46.3%) and higher for WS and BS (28.5 and 29.8%, respectively) than for CSH (19.6%). The calculated AERD for entire diet DM was higher (P<.05) for the AH diet than for diets containing low quality roughages. Although ruminal digestion of DM expressed as a percentage of total tract digestion did not differ (P>.05) among diets, it tended to be higher in the AH diet than in the others (66.5% vs 60.4, 62.5 and 60.5% for WS, BS and CSH diets, respectively).

The effect of roughage source on characteristics of rumen starch digestion is presented in table 17 and figure 7. The in situ rate of digestion and AERD for starch did not differ (P>.05) among diets although rate of starch digestion and AERD for starch tended to be higher in the AH diet than in the others. Ruminal starch digestion expressed

TABLE 16. EFFECT OF ROUGHAGE SOURCE IN 90% CONCENTRATE DIETS ON APPARENT EXTENT OF RUMINAL DIGESTION (AERD) FOR DRY MATTER

	Diet				
Item	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
AERD, % of DM.					
Milo	62.5	57.6	58.1	55.5	2.02
Alfalfa	46.3[e]				
Wheat straw		28.5[f]			
Bermuda straw			29.8[f]		
Cottonseed hulls				19.6[g]	
					1.23
Total diet	55.8[b]	49.5[c]	50.1[c]	48.0[c]	1.39
Total tract digestion coefficient, %					
	83.9[b]	81.9[c]	80.5[cd]	79.5[d]	.50
Ruminal digestion, % of total					
tract	66.5	60.4	62.5	60.5	1.58

[a]Standard error of treatment mean based on four observations per treatment.

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

[e,f,g]Means among roughage sources with unlike superscripts differ, (P<.05).

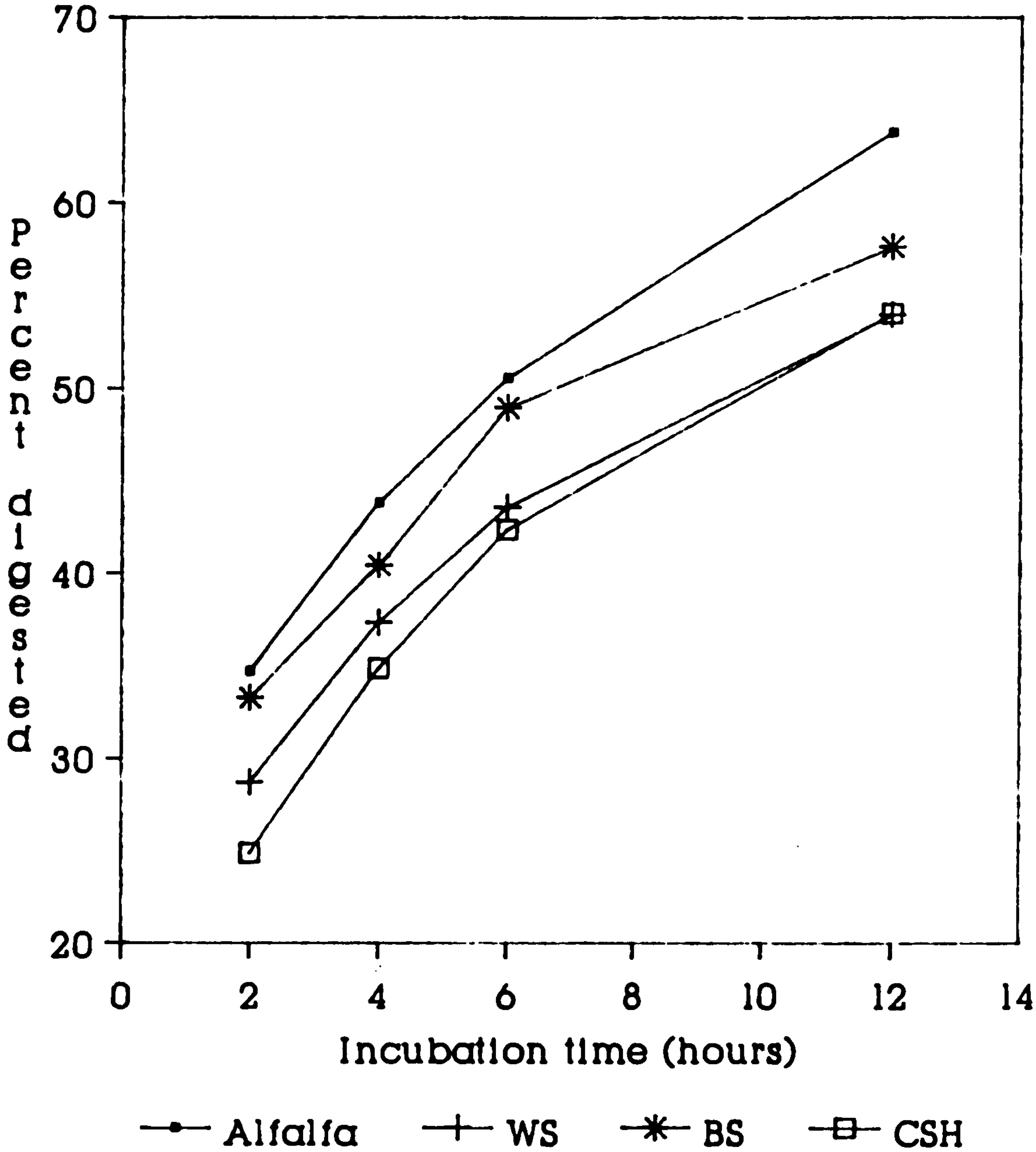
TABLE 17. EFFECT OF ROUGHAGE SOURCE IN 90% CONCENTRATE DIETS ON DIGESTION RATE, RAPIDLY DEGRADED FRACTION AND APPARENT EXTENT OF RUMINAL DIGESTION (AERD) OF STARCH

	Diet				
Item	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
Digestion rate, %	6.0	4.4	4.6	4.8	0.51
Rapidly degraded fraction, %[d]	28.2	24.4	28.6	20.0	3.67
AERD, % of diet starch	77.7	67.8	69.5	68.7	2.75
Digestion coefficient total tract, %	97.8	98.0	97.0	97.1	0.28
Ruminal digestion, % of total tract	79.3	69.2	71.7	70.9	2.83

[a]Standard error of treatment mean based on four observations per treatment.

[b]Actual 0 h starch digestion.

Figure 7. Cummulative in situ milo starch digestion in 90% concentrate diets.



as a percentage of total tract digestion followed the same pattern, tending to be higher for the AH diet (79.3%), followed by BS (71.7%), CSH (70.9%) and WS (69.2%) diets.

Extent of NDF digestion from milo did not differ (P>.05) among treatments (table 18 and figure 8). However, PDNDF tended to be higher in WS and BS diets and lower in the CSH diet compared to the AH diet. Extent of NDF digestion was higher (P<.05) for AH (37.9%) than for WS BS and CSH (19.5, 22.5 and 21.4%, respectively). Rate of digestion for milo NDF did not differ (P>.05) among treatments, but tended to be higher in diets containing low quality roughages. Rate of NDF digestion for roughages did not differ (P>.05) among roughages, but tended to be more rapid for BS (3.4%/h) than for WS, AH and CSH (2.6, 2.3 and 1.9%/h, respectively).

The AERD for NDF from individual diet ingredients and from the entire diets are presented in table 19. The AERD for NDF from milo did not differ (P>.05) among treatments, but tended to be lowest in the CSH diet. Low quality roughages generally had lower AERD for NDF than AH, but the difference was significant (P<.05) only between AH and WS diets (16.9 vs 9.3%, respectively). The AERD for entire diet NDF did not differ (P>.05) among treatments and averaged 21%. However, AERD as a percentage of total tract

TABLE 18. EFFECT OF ROUGAHGE SOURCE IN 90% CONCENTRATE DIETS ON IN SITU POTENTIALLY DIGESTIBLE NDF (PDNDF), RATE OF PDNDF DIGESTION AND DIGESTION LAG TIME

	Diet				
Item	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
PDNDF as % of NDF					
Milo	48.9	51.6	51.9	44.1	2.71
Alfalfa	37.9[b]				
Wheat straw		19.5[c]			
Bermuda straw			22.5[c]		
Cottonseed hulls				21.4[c]	
					2.11
Rate of PDNDF digestion, %/h					
Milo	2.6	3.5	2.9	3.2	.32
Alfalfa	2.3				
Wheat straw		2.6			
Bermuda straw			3.4		
Cottonseed hulls				1.9	
					.42
Digestion lag time, h[d]					
Milo	5.6	6.9	6.7	8.9	2.10
Alfalfa	1.2[b]				
Wheat straw		1.1[b]			
Bermuda straw			5.0[b]		
Cottonseed hulls				-13.3[c]	
					3.37

[a]Standard error of treatment mean based on four observation per treatment.

[b,c]Means among roughage sources with unlike superscripts differ. (P<.05).

[d]A negative lag time indicates that a portion of the NDF was calculated to be soluble at zero-hours.

Figure 8. Cummulative in situ milo NDF digestion in 90% concentrate diets.

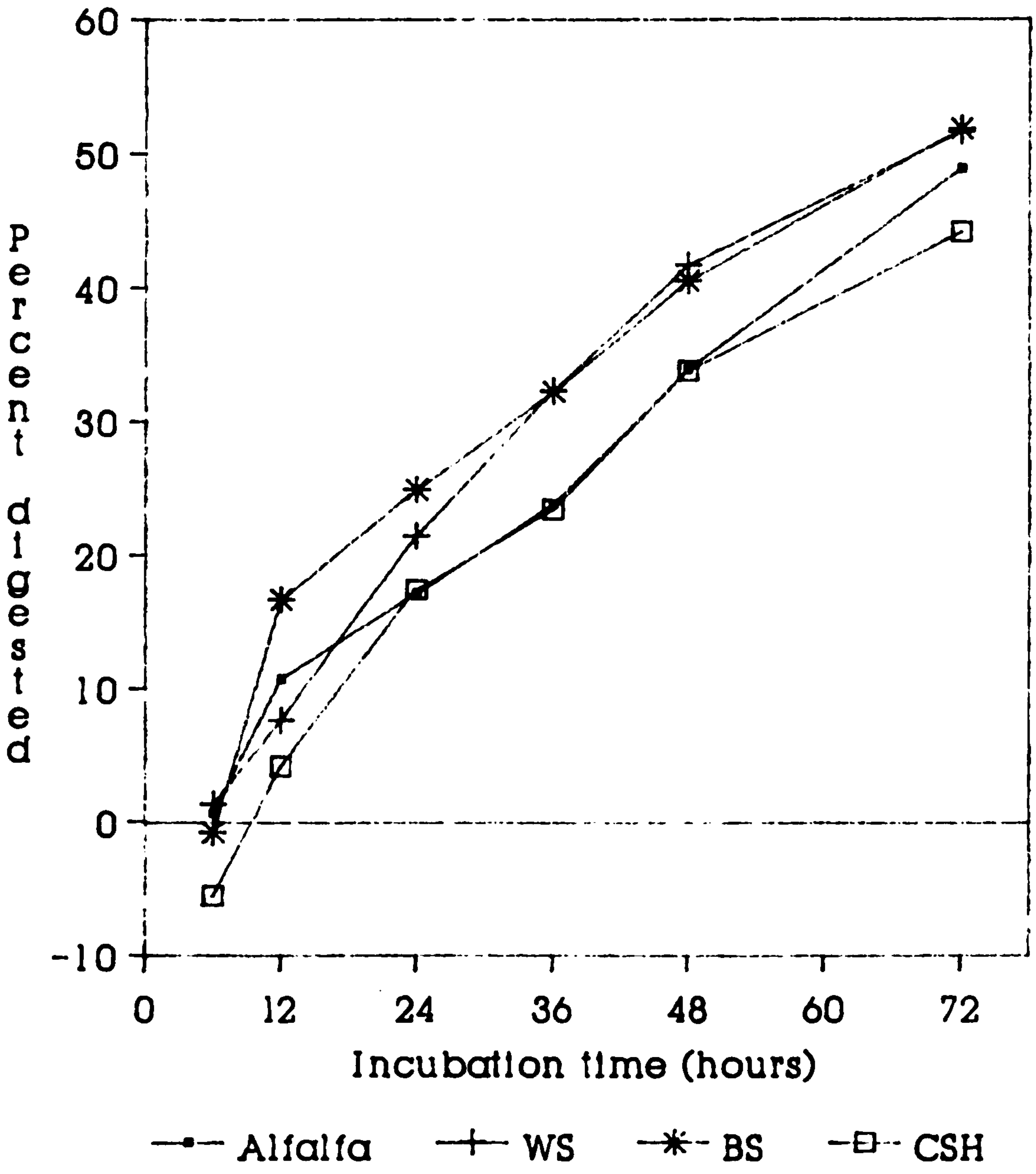


TABLE 19. EFFECT OF ROUGHAGE SOURCE IN 90% CONCENTRATE DIETS ON APPARENT EXTENT OF RUMINAL DIGESTION (AERD) FOR NDF

	Diet				
Item	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
AERD, % of NDF					
Milo	24.3	25.6	24.8	22.5	.91
Alfalfa	16.9[e]				
Wheat straw		9.3[f]			
Bermuda straw			14.2[ef]		
Cottonseed hulls				11.6[ef]	
					1.72
Total diet	21.6	21.7	21.5	19.4	.83
Total tract digestion coefficient, %.					
	50.3[b]	42.5[c]	39.5[cd]	37.8[d]	1.16
Ruminal digestion, % of total					
tract	42.9[c]	51.0[b]	54.5[b]	51.2[b]	1.91

[a]Standard error of treatment mean based on four observations per treatment.

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

[e,f]Means among roughage sources with unlike superscripts differ, ($P<.05$).

digestion was lower (P<.05) for the AH diet than the others.

The digestion coefficient for PDNDF in complete diets was calculated by multiplying the highest PDNDF value for each ingredient by the percentage of each ingredient in the diet. Poore (1987) suggested that expressing fiber digestion in terms of PDNDF for the complete diet is important for obtaining unbiased comparisons of fiber digestion across treatments, since each diet contained a different source of NDF which varied in potential extent of digestion.

Calculated total tract digestion coefficients for PDNDF in the entire diets are presented in table 20. Digestion of PDNDF was lower for all low quality roughage diets (62.5, 55.3 and 60.3% for WS, BS and CSH, respectively) than for AH (66.4%) although the difference between AH and WS was not statistically significant. In this table, it can also be seen that the grain portion of the diets contributed over 65% of the total diet PDNDF.

Rumen pH at each sampling time and pH-hours below 6.0 were not different (P>.05) among treatments (table 21). However pH-hours below 6.0 tended to be reduced when steers were fed AH or WS diets.

Total rumen DM, total rumen volume and DM distribution are shown in table 22. Total rumen DM was

TABLE 20. EFFECT OF ROUGHAGE SOURCE IN 90% CONCENTRATE DIETS ON CALCULATED CONTENT AND TOTAL TRACT DIGESTIBILITY OF POTENTIALLY DIGESTIBLE NDF (PDNDF)

	Diet				
Item	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
Calculated PDNDF content of diets					
as % of NDF	75.8	68.1	71.5	62.7	
as % of DM	9.8	10.1	10.5	10.3	
PDNDF digestion coefficient total tract, %					
	66.4[b]	62.5[bc]	55.3[d]	60.3[cd]	1.61
Ingredient contribution to total diet PDNDF, %.					
Milo	67.8	75.1	71.6	64.6	
Alfalfa	32.2				
Wheat straw		24.9			
Bermuda straw			28.4		
Cottonseed hulls				35.4	

[a]Standard error of treatment mean based on four observations per treatment.

[b,c,d]Means on the same line with unlike superscripts differ, ($P<.05$).

TABLE 21. EFFECT OF ROUGHAGE SOURCE IN 90% CONCENTRATE DIETS ON RUMEN pH AND pH-HOURS BELOW 6.0

	Diet				
Item	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
Hour					
0	6.47	6.48	6.25	6.38	.07
2	5.58	5.52	5.83	5.67	.10
4	5.38	5.46	5.38	5.37	.07
6	5.58	5.60	5.44	5.55	.09
12	6.36	6.37	6.30	6.27	.10
pH-hours <6.0	2.81	2.67	3.22	3.10	.60

[a]Standard error of treatment mean based on four observations per treatment.

TABLE 22. EFFECT OF ROUGHAGE SOURCE IN 90% CONCENTRATE DIETS ON RUMEN DRY MATTER FILL AND TOTAL VOLUME

	Diet				
Item	Alfalfa hay	Wheat straw	Bermuda straw	Cottonseed hulls	SEM[a]
Total rumen DM, kg					
	3.0[c]	3.9[b]	3.9[b]	4.3[b]	.21
Total volume, l					
	59.5	48.3	46.6	46.5	10.93
Percentage of rumen DM					
in raft	1.2[c]	26.6[b]	19.1[b]	0.4[c]	4.02
in liquid	98.8[b]	73.4[c]	80.9[c]	99.6[b]	4.11

[a]Standard error of treatment mean based on four observations per treatment.

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

approximately 1 kg less when steers were fed the AH diet than when low quality roughage diets were fed. Total rumen volume did not differ (P>.05) among diets, but also tended to be higher in the AH diet. Percentage of rumen DM in the raft was higher (P<.05) for diets containing WS (26.6%) or BS (19.1%) than for diets containing either AH or CSH (1.2 and 0.4%, respectively). Raft formation, was negligible on the AH and CSH diets.

Discussion

Total tract digestion coefficients for DM and NDF were depressed in the diets containing low quality roughages. Moore (1987) reported that substitution of WS for AH in 90% concentrate diets tended to reduce DM digestion and depressed NDF digestion, while substitution of CSH for AH depressed both parameters. Inclusion of WS depressed digestion of cell solubles and inclusion of CSH tended to reduce it. It appears that the lower digestion of cell solubles in the WS diet was not due to starch, since in the present study total tract digestion of starch was not different among treatments.

The tendency for DM intake to be higher for WS and CSH diets could account for the increased rate of passage and reduced digestibility on these diets. However, DM intake was possibly not the only factor involved since intake of BS and AH diets were similar but digestibility of the BS diet was lower. Potential extent of digestion (72-h in situ) for DM and NDF were higher for AH than for the low quality roughages. Thus the lower total tract digestion for diets containing low quality roughages can be explained by the diluting effect of these roughages when substituted for the more digestible AH.

Substitution of WS or BS tended to have less detrimental effect on total tract digestion for DM and NDF than CSH. It is possible that this effect reflects the tendency for extent of NDF digestion from milo to be improved in the WS and BS diets. Moore (1987) also reported that inclusion of WS tended to improve extent of NDF digestion from milo.

Rate of passage for milo tended to be faster in diets containing low quality roughages which could have contributed to their lower digestibility compared with AH.

The more distinct stratification of rumen contents when the WS diet was fed probably contributed to reduced pH-hours below 6.0 observed for this diet. Stratification of rumen contents has been related to rumination (Welch, 1982). Increased rumination increases saliva flow to the rumen resulting in increased ruminal buffering capacity. However, results of this study suggest that raft formation is not invariably related to stabilized rumen pH. The diet containg BS produced more raft ($P<.05$) than AH and CSH diets but pH-hours below 6.0 were lower for the AH diet and similar for the BS and CSH diets despite the large difference between these diets in percentage of DM in the raft. Perhaps the raft promoted by BS did not stimulate sufficient rumination to moderate rumen pH, but it is possible that the intrinsic buffering capacity of AH (Van Soest, 1982) could have contributed to the maintenance of rumen pH above 6.

Diets causing a faster passage rate for milo might be expected to have a lower ruminal digestion of starch. Rate of milo passage was slowest on the AH diet but AERD for starch and ruminal digestion of starch expressed as a percentage of total tract digestion tended to be highest on this diet. The tendency for starch digestion to be elevated in the AH diet might be explained by the faster digestion rate for starch in this diet. However, no differences were observed in total tract starch digestion, indicating starch that escaped rumen fermentation was digested in the lower tract. The data suggest that roughage source may affect ruminal digestion of starch by influencing rate of starch digestion and rate of passage for grain, however, more research is needed in this area.

This experiment indicates that substitution of low quality roughages for AH in 90% concentrate diets had relatively little effect on kinetics of rumen digestion and passage of the grain portion of the diet. Inclusion of WS, BS or CSH produced less digestible diets because these roughages were less digestibles than AH. However, the results also indicated that a higher percentage of total tract fiber digestion occured in the rumen when low quality roughages were fed.

The effect of roughage source on kinetics of ruminal digestion and passage for major diet ingredients was more pronounced in 65% than in 90% concentrate diets. In 65% concentrate diets, inclusion of WS or BS increased ruminal fiber digestion for milo and AH. However, this was not observed for the grain in 90% concentrate diets probably because rate of passage for milo tended to be faster when low quality roughages were included in the diets. In contrast, rate of passage for milo and AH tended to be slowest when BS or WS replaced one half of the AH in the 65% concentrate diets.

The impact on feed intake and ruminal pH may be more important than digestibility as characteristics to be considered when selecting roughages for use in high concentrate diets.

CHAPTER 5

Conclusions

In 65% concentrate diets inclusion of WS did not adversely affect total tract digestion coefficients for DM and NDF, whereas inclusion of BS or CSH depressed digestion of these fractions compared to the AH diet. Inclusion of WS or BS in the diet appear to increase ruminal digestion of NDF from both milo and AH, probably by decreasing rates of passage and increasing digestion rates.

Inclusion of WS or BS tended to reduce pH-hours below 6.0 and promoted a higher raft formation in the rumen. The tendency to maintain rumen pH above 6.0 could have improved rumen environment for cellulolytic bacteria activity. Entrapment of AH and milo in the ruminal raft could explain the slower passage of these ingredients in WS and BS diets.

Roughage source did not affect total tract digestion of starch. However, ruminal digestion of starch was greater in diets containing low quality roughages because of increased rate of starch digestion.

In 90% concentrate diets, total tract digestion coefficients for DM and NDF were higher for the AH diet than for diets containing low quality roughages. This effect was due to a dilution of the more digestible AH by the less digestible low quality roughages. No significant differences were observed in total tract digestion of starch. However, inclusion of low quality roughages tended to decrease ruminal starch digestion probably because of the tendency for a starch digestion to be slower and rates of milo passage to be faster on these diets.

Rumen pH was not affected by roughage source, although the WS diet promoted a higher raft formation and tended to reduce pH-hours below 6.0. This could be important in reducing acidosis at this level of concentrate feeding.

In summary, substitution of WS or BS for AH in 65% concentrate diets increased ruminal digestion of fiber, apparently by decreasing particulate passage rate and/or increasing rate of digestion for AH and milo in the diet. A higher raft promoted by WS and BS could have contributed to slower passage of milo and AH and could stimulate rumination thus increasing saliva flow and thereby enhancing rumen environment for cellulolytic bacteria. Ruminal starch digestion was increased when low quality roughages were included in these diets.

The effect of roughage source on kinetics of ruminal digestion and passage for the grain portion in 90% concentrate diets was less evident. Ruminal and total tract starch digestion was not statistically different due to roughage source. Some tendency for faster passage were observed for the grain portion in diets containing low quality roughages.

In general, the effect of roughage source on kinetics of rumen digestion and passage for individual diet ingredients was more pronounced in 65 than in 90% concentrate diets. The differential effects observed among the roughage sources are probably due to differences in physical characteristics, since the chemical composition among them are similar. Probably, rate of particle size reduction and specific gravity are involved.

CHAPTER 6

APPENDIX

INDIVIDUAL STEER DATA

TABLE A1. 65% CONCENTRATE ALFALFA HAY DIET: INTACT STEERS

	Steer #			
	139	7	64	148
Period	3	1	4	2
Intake, kg DM/day	6.10	6.70	6.10	7.68
Digestion coefficients, %				
Dry matter	79.69	78.76	79.83	81.48
NDF	54.58	52.84	55.39	50.65
Starch	97.17	96.62	97.07	97.29
Milo				
Rate of passage	.0534	.0813	.0621	.0618
R squared	.9979	.9850	.9499	.9946
# of points used	11	8	8	10
Alfalfa				
Rate of passage	.0418	.0860	.0288	.0461
R squared	.9943	.9855	.9581	.9709
# of points used	11	8	8	10
Liquid				
Rate of passage	.1104	.0914	.0608	.1830
R squared	.9409	.9493	.9680	.9491
# of points used	11	10	11	7

TABLE A2. 65% CONCENTRATE WHEAT STRAW DIET: INTACT STEERS

	Steer #			
	148	139	64	7
Period	1	2	3	4
Intake, kg DM/day	7.07	5.75	6.20	5.35
Digestion coefficients, %				
Dry matter	80.46	78.69	78.71	77.69
NDF	46.13	54.08	54.73	54.57
Starch	97.54	98.12	97.36	96.09
Milo				
Rate of passage	.0485	.0580	.0340	.0353
R squared	.9640	.9816	.9919	.9861
# of points used	10	7	9	10
Alfalfa				
Rate of passage	.0397	.0396	.0341	.0301
R squared	.9783	.9515	.9900	.9699
# of points used	10	7	9	10
Wheat straw				
Rate of passage	.0363	.0422	.0274	.0275
R squared	.9651	.9560	.9839	.9878
# of points used	10	7	9	10
Liquid				
Rate of passage	.1402	.1277	.0713	.0721
R squared	.9213	.9755	.9484	.9230
# of points used	8	9	10	12

TABLE A3. 65% CONCENTRATE BERMUDA STRAW DIET; INTACT STEERS

	STEER #			
	64	7	148	139
PERIOD	1	2	3	4
Intake, kg DM/day	6.74	5.46	6.95	5.50
Digestion coefficients, %				
Dry matter	76.00	75.47	75.81	75.37
NDF	48.29	50.23	48.79	48.33
Starch	96.46	96.06	97.66	96.96
Milo				
Rate of passage	.0478	.0313	.0645	.0420
R squared	.9814	.9372	.9881	.9879
# of points used	10	9	8	11
Alfalfa				
Rate of passage	.0451	.0276	.0473	.0326
R squared	.9829	.9646	.9725	.9908
# of points used	10	9	8	11
Bermuda straw				
Rate of passage	.0209	.0227	.0289	.0206
R squared	.9910	.9955	.9797	.9920
# of points used	10	7	8	11
Liquid				
Rate of passage	.0837	.1781	.1037	.1017
R squared	.8587	.9930	.8600	.8158
# of points used	12	7	8	9

TABLE A4. 65% CONCENTRATE COTTONSEED HULLS DIET; INTACT STEERS

	STEER #			
	139	64	7	148
PERIOD	1	2	3	4
Intake, kg DM/day	6.94	6.57	6.50	8.80
Digestion coefficients, %				
Dry matter	74.88	72.16	71.93	71.55
NDF	45.95	42.55	40.52	43.22
Starch	97.41	94.94	97.38	97.78
Milo				
Rate of passage	.0670	.0415	.0410	.0621
R squared	.9962	.9601	.9943	.9888
# of points used	8	10	11	9
Alfalfa				
Rate of passage	.0551	.0395	.0340	.0470
R squared	.9907	.9245	.9930	.9865
# of points used	8	10	11	9
Cottonseed hulls				
Rate of passage	.0261	.0200	.0230	.0270
R squared	.9159	.9571	.9886	.9826
# of points used	8	10	11	9
Liquid				
Rate of passage	.1328	.1337	.0872	.1442
R squared	.9493	.9690	.8924	.9465
# of points used	10	9	11	9

TABLE A5. 90% CONCENTRATE ALFALFA DIET; INTACT STEERS

	STEER #			
	7	64	139	148
PERIOD	1	2	3	4
Intake, kg DM/day	5.61	6.38	5.82	6.57
Digestion coefficients, %				
Dry matter	83.06	86.67	83.90	82.23
NDF	46.81	56.29	50.50	47.58
Starch	96.87	98.48	98.38	97.54
Milo				
Rate of passage	.0381	.0198	.0232	.0238
R squared	.9953	.9476	.9826	.9694
# of points used	10	10	9	10
Alfalfa				
Rate of passage	.0376	.0184	.0301	.0266
R squared	.9957	.9754	.9873	.9436
# of points used	8	10	9	10
Liquid				
Rate of passage	.0355	.0259	.0299	.0327
R squared	.9417	.9857	.9661	.9167
# of points used	12	12	12	12

TABLE A6. 90% CONCENTRATE WHEAT STRAW DIET; INTACT STEERS

	STEER #			
	64	139	148	7
PERIOD	1	2	3	4
Intake, kg DN/day	7.42	6.19	6.32	7.40
Digestion coefficients, %				
Dry matter	82.47	80.85	83.43	80.67
NDF	41.63	41.73	42.96	43.90
Starch	97.57	97.84	98.37	98.27
Milo				
Rate of passage	.0307	.0384	.0298	.0232
R squared	.9926	.9858	.9710	.9943
# of points used	11	9	8	12
Wheat straw				
Rate of passage	.0247	.0322	.0305	.0219
R squared	.9859	.9966	.9621	.9949
# of points used	11	9	8	12
Liquid				
Rate of passage	.0354	.0350	.0394	.0212
R squared	.9488	.9887	.9691	.9877
# of points used	13	13	11	13

TABLE A7. 90% CONCENTRATE BERMUDA STRAW DIET INTACT STEERS

	STEER #			
	148	7	64	139
PERIOD	1	2	3	4
Intake, kg DM/day	5.05	5.39	6.44	7.50
Digestion coefficients, %				
Dry matter	77.21	82.46	83.97	78.26
NDF	31.69	45.03	46.69	34.60
Starch	95.75	97.93	97.58	96.77
Milo				
Rate of passage	.0438	.0275	.0127	.0402
R squared	.9910	.9912	.9841	.9920
# of points used	12	10	7	8
Bermuda straw				
Rate of passage	.0219	.0152	.0088	.0265
R squared	.9912	.9662	.9591	.9870
# of points used	12	10	7	8
Liquid				
Rate of passage	.0469	.0362	.0230	.0315
R squared	.9276	.9607	.9871	.9858
# of points used	11	12	7	12

TABLE A8. 90% CONCENTRATE COTTONSEED HULLS DIET; INTACT STEERS

	STEER #			
	139	148	7	64
PERIOD	1	2	3	4
Intake, kg DM/day	5.71	7.19	5.96	7.45
Digestion coefficients, %				
Dry matter	76.74	80.84	82.48	77.72
NDF	35.33	37.69	39.40	38.96
Starch	96.87	97.61	97.83	96.01
Milo				
Rate of passage	.0395	.0363	.0285	.0144
R squared	.9467	.9866	.9717	.9667
# of points used	10	7	12	9
Cottonseed hulls				
Rate of passage	.0163	.0224	.0158	.0077
R squared	.8839	.9871	.9270	.8700
# of points used	10	7	12	6
Liquid				
Rate of passage	.0346	.0370	.0348	.0159
R squared	.9853	.9641	.9722	.9803
# of points used	13	12	12	12

TABLE A9. AVERAGE MARKER CONCENTRATION (mg/g) IN FECES SAMPLES FROM 65% CONCENTRATE DIETS; PERIOD 1

	steer 139			
hour	Yb-milo	Dy-alfal	Eu-CSH	Co-liquid
4	.003	.010	.004	.011
10	.049	.075	.029	.576
14	.095	.176	.069	.575
18	.152	.377	.113	.504
22	.128	.292	.107	.252
26	.091	.230	.106	.042
30	.069	.197	.091	.026
34	.057	.166	.091	.019
39	.043	.132	.084	.010
45	.025	.077	.061	.006
54	.014	.051	.043	.005
66	.012	.041	.040	.005
78	.005	.023	.027	.005
90	.002	.016	.015	.005
102	.001	.011	.012	.005
114	.001	.010	.009	.005

	steer 7			
	Yb-milo	Dy-alfal		Co-liquid
4	.007	.014		.030
10	.109	.209		.290
14	.210	.491		.252
18	.227	.531		.175
22	.208	.514		.098
26	.166	.409		.049
30	.120	.296		.031
34	.086	.231		.022
39	.051	.150		.015
45	.028	.089		.011
54	.015	.054		.008
66	.012	.042		.008
78	.005	.026		.007
90	.001	.015		.005
102		.010		.005
114				.005

TABLE A9. (cont..)

hour	steer 148 Yb-milo	Dy-alfal	Eu-WS	Co-liquid
4	.006	.015	.011	.011
10	.050	.076	.069	.340
14	.096	.167	.141	.420
18	.173	.316	.319	.583
22	.139	.337	.257	.246
26	.113	.243	.227	.082
30	.091	.254	.189	.041
34	.064	.187	.144	.020
39	.047	.158	.123	.010
45	.032	.107	.086	.007
54	.020	.069	.063	.004
66	.014	.052	.050	.004
78	.011	.036	.039	.004
90	.005	.020	.023	.004
102	.002	.016	.018	.004
114	.001	.011	.010	.004

	steer 64 Yb-milo	Dy-alfal	Eu-BS	Co-liquid
4	.005	.009	.003	.018
10	.080	.146	.068	.635
14	.137	.288	.134	.481
18	.158	.400	.182	.354
22	.124	.319	.163	.164
26	.094	.229	.139	.058
30	.074	.186	.129	.031
34	.061	.150	.119	.024
39	.045	.122	.111	.013
45	.028	.082	.092	.007
54	.023	.064	.078	.006
66	.015	.040	.065	.004
78	.009	.026	.050	.004
90	.003	.015	.034	.003
102	.003	.009	.025	.003
114		.006	.019	.003

TABLE A10. AVERAGE MARKER CONCENTRATION (mg/g) IN FECES SAMPLES FROM 65% CONCENTRATE DIETS; PERIOD 2

	steer 139			
hour	Yb-milo	Dy-alfal	Eu-WS	Co-liquid
4		.003	.003	.003
10	.019	.018	.014	.163
14	.094	.099	.079	.914
18	.158	.204	.153	.648
22	.171	.303	.191	.375
26	.144	.290	.172	.150
30	.124	.243	.159	.085
34	.102	.198	.138	.050
39	.085	.161	.117	.030
45	.061	.159	.087	.013
54	.032	.081	.048	.008
66	.037	.077	.056	.009
78	.033	.072	.054	.006
90	.024	.059	.048	.004
102	.010	.030	.031	.003
114	.005	.016	.034	.003

	steer 7			
	Yb-milo	Dy-alfal	Eu-BS	Co-liquid
4		.004		.013
10	.042	.044	.022	.234
14	.136	.156	.085	.444
18	.227	.302	.163	.234
22	.250	.399	.211	.125
26	.214	.367	.200	.057
30	.180	.368	.202	.024
34	.141	.292	.192	.011
39	.112	.246	.183	.006
45	.089	.186	.165	.006
54	.062	.140	.150	.007
66	.056	.118	.139	.007
78	.046	.097	.118	.008
90	.028	.043	.076	.010
102	.007	.026	.053	.011
114	.003	.019	.033	.012

TABLE A10 (cont..)

	steer 148		
hour	Yb-milo	Dy-alfal	Co-liquid
4		.003	.003
10	.027	.045	.028
14	.208	.279	.238
18	.275	.390	.500
22	.250	.371	.315
26	.237	.423	.208
30	.155	.351	.078
34	.115	.263	.016
39	.095	.244	.009
45	.061	.159	.006
54	.034	.099	.004
66	.016	.053	.002
78	.008	.030	.001
90	.002	.017	.001
102		.010	.001
114		.007	.001

	steer 64			
	Yb-milo	Dy-alfal	Eu-CSH	Co-liquid
4		.004	.001	.011
10	.086	.126	.034	.374
14	.168	.295	.077	.245
18	.187	.322	.097	.197
22	.175	.328	.096	.137
26	.131	.247	.089	.049
30	.103	.187	.080	.023
34	.084	.149	.069	.014
39	.062	.107	.067	.007
45	.044	.075	.052	.006
54	.030	.052	.041	.007
66	.025	.046	.037	.007
78	.018	.039	.034	.008
90	.008	.020	.022	.009
102	.005	.017	.017	.010
114	.002	.012	.013	.011

TABLE A11. AVERAGE MARKER CONCENTRATION (mg/g) IN FECES SAMPLES FROM 65% CONCENTRATE DIETS; PERIOD 3

	steer 139			
hour	Yb-milo	Dy-alfal		Co-liquid
4		.004		.004
10	.050	.043		.365
14	.163	.165		1.331
18	.241	.292		1.230
22	.287	.499		.547
26	.286	.598		.236
30	.223	.496		.151
34	.157	.376		.067
39	.122	.314		.034
45	.095	.253		.024
54	.065	.172		.013
66	.033	.096		.007
78	.016	.052		.005
90	.010	.036		.004
102	.004	.022		.004
114	.002	.017		.004

	steer 7			
	Yb-milo	Dy-alfal	Eu-CSH	Co-liquid
4		.004	.002	.008
10	.036	.043	.014	.181
14	.158	.190	.067	1.053
18	.223	.302	.115	1.011
22	.215	.322	.129	.603
26	.213	.320	.139	.335
30	.168	.264	.137	.151
34	.160	.266	.135	.109
39	.119	.202	.113	.041
45	.078	.139	.085	.017
54	.069	.128	.085	.015
66	.045	.083	.067	.010
78	.026	.050	.047	.008
90	.013	.032	.026	.008
102	.009	.023	.026	.007
114	.006	.018	.018	.008

TABLE A11. (cont..)

hour	steer 148			
	Yb-milo	Dy-alfal	Eu-BS	Co-liquid
4		.003		.008
10	.012	.011	.002	.070
14	.083	.083	.038	.677
18	.218	.280	.152	.610
22	.221	.310	.177	.441
26	.205	.338	.208	.167
30	.159	.284	.190	.058
34	.139	.257	.178	.041
39	.067	.139	.125	.013
45	.053	.107	.112	.009
54	.036	.082	.093	.008
66	.014	.044	.060	.007
78	.007	.032	.049	.007
90	.001	.017	.028	.007
102		.009	.017	.007
114		.005	.011	.007

	steer 64			
	Yb-milo	Dy-alfal	Eu-WS	Co-liquid
4		.001		.007
10	.057	.102	.065	.259
14	.141	.261	.167	.481
18	.181	.347	.221	.479
22	.193	.394	.245	.366
26	.188	.361	.257	.208
30	.153	.318	.210	.115
34	.134	.279	.190	.081
39	.113	.262	.169	.068
45	.083	.185	.122	.029
54	.074	.144	.109	.023
66	.043	.083	.075	.010
78	.030	.065	.059	.008
90	.021	.050	.046	.007
102	.010	.025	.029	.007
114	.006	.020	.022	.007

TABLE A12. AVERAGE MARKER CONCENTRATION (mg/g) IN FECES SAMPLES FROM 65% CONCENTRATE DIETS; PERIOD 4

	steer 139			
hour	Yb-milo	Dy-alfal	Eu-BS	Co-liquid
4		.002		.009
10		.003		.009
14	.065	.128	.025	.721
18	.176	.419	.105	.863
22	.218	.599	.158	.675
26	.203	.673	.182	.167
30	.166	.628	.189	.081
34	.133	.577	.175	.037
39	.099	.503	.145	.019
45	.071	.381	.128	.013
54	.049	.275	.100	.010
66	.039	.218	.091	.009
78	.020	.114	.063	.009
90	.016	.104	.054	.009
102	.009	.066	.042	.009
114	.004	.036	.030	.009

	steer 7			
	Yb-milo	Dy-alfal	Eu-WS	Co-liquid
4		.008	.001	.007
10	.012	.029	.012	.256
14	.079	.233	.098	1.039
18	.148	.480	.197	.818
22	.182	.632	.238	.591
26	.194	.698	.250	.322
30	.197	.727	.259	.226
34	.168	.642	.218	.150
39	.171	.739	.223	.116
45	.118	.547	.173	.029
54	.102	.496	.152	.020
66	.077	.389	.122	.012
78	.047	.238	.078	.008
90	.026	.137	.051	.007
102	.016	.091	.035	.007
114	.010	.063	.026	.007

TABLE A12 (cont..)

	steer 148			
hour	Yb-milo	Dy-alfal	Eu-CSH	Co-liquid
4		.006		.005
10	.004	.005	.001	.033
14	.090	.154	.034	1.052
18	.168	.395	.093	.729
22	.191	.523	.115	.414
26	.175	.597	.120	.169
30	.121	.410	.101	.061
34	.104	.406	.097	.038
39	.063	.266	.078	.014
45	.035	.175	.058	.008
54	.022	.118	.047	.007
66	.014	.079	.038	.006
78	.006	.044	.030	.006
90	.003	.029	.020	.005
102	.001	.016	.011	.006
114		.009	.007	.005

	steer 64		
	Yb-milo	Dy-alfal	Co-liquid
4		.004	.010
10	.092	.261	.464
14	.163	.517	.870
18	.244	.848	1.077
22	.250	.935	.540
26	.215	.805	.246
30	.178	.678	.137
34	.130	.524	.078
39	.123	.532	.070
45	.100	.435	.045
54	.070	.307	.024
66	.063	.271	.019
78	.033	.145	.011
90	.018	.085	.010
102	.008	.040	.009
114	.005	.026	.010

TABLE A13. AVERAGE MARKER CONCENTRATION (mg/g) IN FECES SAMPLES FROM 90% CONCENTRATE DIETS; PERIOD 1

	steer 139		
hour	Yb-milo	Eu-CSH	Co-liquid
4		.003	.003
10	.015	.009	.123
14	.059	.029	.194
18	.112	.054	.197
22	.179	.095	.193
26	.180	.095	.139
30	.193	.104	.124
34	.141	.081	.083
39	.184	.115	.101
45	.152	.097	.075
54	.112	.095	.051
66	.073	.071	.031
78	.061	.069	.026
90	.021	.044	.013
102	.013	.037	.010
114	.006	.024	.008

	steer 7		
	Yb-milo	Dy-alfal	Co-liquid
4		.005	.008
10		.004	.008
14	.097	.122	.293
18	.254	.392	.334
22	.329	.604	.363
26	.311	.596	.224
30	.313	.601	.209
34	.273	.537	.152
39	.231	.453	.103
45	.167	.310	.067
54	.129	.221	.053
66	.095	.169	.042
78	.057	.094	.026
90	.031	.056	.018
102	.022	.041	.014
114	.012	.026	.013

TABLE A13. (cont..)

	steer 148		
hour	Yb-milo	Eu-BS	Co-liquid
4		.001	.005
10			
14	.086	.040	.181
18	.198	.108	.273
22	.268	.166	.236
26	.223	.151	.136
30	.195	.140	.088
34	.184	.139	.072
39	.140	.126	.052
45	.110	.116	.035
54	.075	.089	.024
66	.050	.073	.018
78	.030	.052	.012
90	.017	.040	.010
102	.009	.032	.009
114	.004	.021	.008

	steer 64		
	Yb-milo	Eu-WS	Co-liquid
4		.002	.004
10	.030	.039	.124
14	.093	.112	.210
18	.135	.160	.202
22	.154	.180	.182
26	.152	.170	.127
30	.135	.143	.095
34	.106	.110	.064
39	.083	.091	.045
45	.082	.097	.050
54	.057	.072	.035
66	.047	.059	.029
78	.032	.044	.019
90	.021	.032	.015
102	.013	.021	.009
114	.009	.017	.008

TABLE A14. AVERAGE MARKER CONCENTRATION (mg/g) IN FECES SAMPLES FROM 90% CONCENTRATE DIETS; PERIOD 2

	steer 139		
hour	Yb-milo	Eu-WS	Co-liquid
4			.003
10		.001	.013
14	.047	.042	.175
18	.222	.164	.232
22	.271	.196	.205
26	.280	.195	.162
30	.260	.198	.104
34	.280	.223	.122
39	.218	.173	.084
45	.180	.146	.073
54	.139	.110	.055
66	.102	.081	.041
78	.065	.054	.026
90	.039	.036	.016
102	.018	.022	.010
114	.012	.017	.008

	steer 7		
	Yb-milo	Eu-BS	Co-liquid
4		.001	.008
10	.005	.003	.027
14	.072	.031	.190
18	.223	.100	.355
22	.279	.142	.266
26	.311	.173	.240
30	.303	.178	.191
34	.237	.137	.115
39	.251	.162	.110
45	.222	.155	.084
54	.160	.126	.057
66	.114	.096	.037
78	.092	.093	.031
90	.061	.071	.022
102	.040	.059	.017
114	.029	.046	.015

TABLE A14. (cont..)

	steer 148		
hours	Yb-milo	Eu-CSH	Co-liquid
4			
10	.002	.004	.009
14	.086	.031	.150
18			
22	.201	.100	.371
26	.230	.128	.302
30	.242	.142	.235
34	.229	.145	.146
39	.218	.143	.124
45	.205	.145	.095
54	.141	.116	.102
66	.107	.097	.052
78	.057	.068	.024
90	.050	.060	.022
102	.025	.042	.015
114	.016	.029	.013

	steer 64		
	Yb-milo	Dy-alfal	Co-liquid
4		.003	.006
10	.106	.204	.133
14	.171	.344	.178
18	.219	.427	.184
22	.243	.544	.189
26	.250	.564	.163
30	.230	.505	.116
34	.211	.486	.109
39	.245	.444	.090
45	.204	.427	.080
54	.156	.328	.062
66	.150	.309	.052
78	.108	.237	.038
90	.079	.187	.027
102	.050	.122	.019
114	.044	.108	.016

TABLE A15. AVERAGE MARKER CONCENTRATION (mg/g) IN FECES SAMPLES FROM 90% CONCENTRATE DIETS; PERIOD 3

	steer 139		
hour	Yb-milo	Dy-alfal	Co-liquid
4		.003	.005
10	.065	.078	.044
14	.174	.237	.119
18	.383	.668	.209
22	.445	1.061	.268
26	.465	.944	.235
30	.434	.852	.190
34	.389	.725	.150
39	.329	.579	.106
45	.283	.500	.083
54	.212	.347	.052
66	.175	.275	.050
78	.138	.209	.040
90	.075	.117	.029
102	.048	.079	.022
114	.029	.049	.015

	steer 7		
	Yb-milo	Eu-CSH	Co-liquid
4			.004
10	.037	.009	.071
14	.168	.046	.238
18	.231	.067	.262
22	.279	.094	.248
26	.275	.093	.173
30	.241	.078	.120
34	.240	.084	.105
39	.231	.083	.092
45	.190	.074	.063
54	.159	.065	.048
66	.117	.054	.032
78	.082	.052	.020
90	.054	.041	.015
102	.032	.030	.011
114	.019	.017	.009

TABLE A15 (cont..)

	steer 148		
hour	Yb-milo	Eu-WS	Co-liquid
4			.003
10			
14	.108	.058	.218
18			
22	.236	.144	.284
26	.326	.231	.286
30	.314	.219	.194
34	.324	.253	.198
39	.320	.255	.170
45	.251	.180	.106
54	.160	.112	.049
66	.127	.097	.040
78	.128	.096	.035
90	.065	.048	.017
102	.045	.031	.011
114	.030	.022	.010

	steer 64		
	Yb-milo	Eu-BS	Co-liquid
4			.005
10	.035	.009	.035
14	.228	.067	.145
18			
22	.272	.083	.149
26	.308	.118	.183
30			
34	.300	.121	.162
39			
45	.278	.115	.140
54	.251	.112	.124
66	.234	.099	.098
78	.193	.080	.068
90	.169	.078	.049
102	.141	.068	.049
114	.114	.066	.032

TABLE A16. AVERAGE MARKER CONCENTRATION (mg/g) IN FECES SAMPLES FROM 90% CONCENTRATE DIETS; PERIOD 4

	steer 139		
hour	Yb-milo	Eu-BS	Co-liquid
4			.004
10	.008	.002	.030
14	.148	.048	.156
18	.232	.083	.134
22	.305	.129	.157
26	.298	.138	.116
30	.266	.128	.092
34	.248	.124	.083
39	.256	.148	.090
45	.199	.123	.071
54	.117	.080	.039
66	.098	.072	.032
78	.056	.049	.020
90	.033	.036	.014
102	.021	.029	.012
114	.011	.018	.008

	steer 7		
	Yb-milo	Eu-WS	Co-liquid
4			.004
10	.020	.017	.074
14	.107	.079	.208
18	.226	.159	.223
22	.278	.190	.211
26	.260	.158	.147
30	.254	.157	.124
34	.223	.133	.085
39	.221	.137	.087
45	.182	.111	.060
54	.144	.087	.043
66	.119	.075	.035
78	.087	.055	.022
90	.061	.039	.015
102	.046	.032	.012
114	.034	.025	.010

TABLE A16 (cont..)

	steer 148		
hour	Yb-milo	Dy-alfal	Co-liquid
4	.008	.004	.008
10	.017	.017	.034
14	.150	.271	.258
18	.248	.527	.326
22	.310	.741	.347
26	.312	.803	.250
30	.340	.736	.230
34	.286	.615	.167
39	.260	.539	.137
45	.193	.386	.075
54	.138	.238	.052
66	.127	.203	.047
78	.093	.162	.028
90	.058	.097	.021
102	.056	.089	.020
114	.048	.089	.019

	steer 64		
	Yb-milo	Eu-CSH	Co-liquid
4			.005
10	.012	.002	.015
14	.087	.019	.057
18	.134	.036	.087
22	.192	.047	.101
26	.201	.054	.098
30	.177	.049	.078
34	.189	.055	.082
39	.148	.048	.063
45	.142	.051	.064
54	.134	.057	.057
66	.107	.043	.047
78	.093	.040	.037
90	.088	.043	.035
102	.068	.033	.027
114	.050	.035	.022

TABLE A17. 65% CONCENTRATE ALFALFA DIET; CANNULATED STEERS.

	Steer #			
	3	1	2	4
PERIOD	1	2	3	4
Rumen pH at hour:				
0	6.65	6.69	6.15	6.56
2	5.89	6.08	5.58	5.93
4	5.82	6.03	5.36	5.75
6	5.95	5.90	5.35	5.45
12	6.69	6.64	6.01	6.31
Rumen DM fill and volume.				
Dry matter, kg.				
Raft	0.00	1.21	0.00	0.00
Liquid	3.61	2.45	4.08	4.26
Volume, l.				
Raft	0.00	13.00	0.00	0.00
Liquid	72.00	38.00	53.00	61.00
Milo starch digestion (%) at hour:				
0	23.56	20.45	22.34	25.33
2	48.11	41.82	32.72	40.46
4	52.96	45.11	36.08	47.82
6	55.10	50.35	48.23	54.61
12	65.26	66.92	54.73	60.46
Milo DM digestion (%) at hour:				
6	41.28	59.25	51.76	54.96
12	57.62	71.59	69.60	68.87
24	68.82	76.17	79.80	71.38
36	79.72	88.85	80.56	78.29
48	85.32	91.85	82.43	88.42
72	91.84	93.49	85.12	95.17

TABLE A17. (cont.)

Milo NDF digestion (%) at hour:				
6	-0.67	2.97	1.72	-0.17
12	12.76	21.00	19.98	13.12
24	24.93	33.52	32.78	28.55
36	29.09	41.64	44.16	33.70
48	31.57	49.93	47.89	36.64
72	40.39	59.78	54.60	42.57
Alfalfa DM digestion (%) at hour:				
6	32.36	50.52	31.71	34.97
12	42.14	56.97	42.23	39.46
24	53.49	57.24	47.48	44.94
36	57.05	69.29	49.83	45.49
48	66.18	72.32	54.00	50.92
72	67.00	74.40	54.01	65.71
Alfalfa NDF digestion (%) at hour:				
6	7.72	17.67	9.15	9.36
12	15.28	27.84	13.68	11.35
24	28.63	30.90	17.04	18.73
36	40.55	46.15	23.35	21.76
48	42.23	53.15	33.07	33.79
72	43.34	54.29	41.72	46.79

TABLE A18. 65% CONCENTRATE WHEAT STRAW DIET; CANNULATED STEERS

	Steer #			
	1	3	4	2
PERIOD	1	2	3	4
Rumen pH at hour:				
0	6.86	6.74	6.41	6.43
2	6.37	5.86	6.23	5.95
4	6.17	5.70	5.96	5.39
6	6.05	5.72	5.86	5.32
12	6.75	6.31	6.41	5.96
Rumen DM fill and volume:				
Dry matter, kg.				
Raft	2.30	2.68	0.35	2.11
Liquid	1.56	1.48	3.23	2.93
Volume, l.				
Raft	19.00	30.00	2.00	15.00
Liquid	30.00	25.00	52.00	34.00
Milo starch digestion (%) at hour:				
0	23.56	20.45	22.34	25.33
2	34.28	34.96	39.20	32.71
4	45.49	42.88	43.61	51.40
6	49.44	61.72	49.39	61.83
12	55.36	70.55	55.77	69.26
Milo DM digestion (%) at hour:				
6	45.00	42.57	44.98	57.46
12	64.98	53.96	67.22	73.41
24	76.09	67.14	70.71	75.68
36	86.83	75.71	77.80	88.31
48	91.78	90.82	88.11	91.14
72	93.85	94.12	93.35	94.79

TABLE A18. (cont.)

Milo NDF digestion (%) at hour:				
6	-0.22	3.83	-0.05	-0.63
12	22.53	21.96	18.06	24.26
24	46.77	30.39	28.68	42.75
36	57.37	47.24	34.08	68.43
48	67.22	53.88	48.96	70.83
72	74.99	60.33	56.78	76.20
Alfalfa DM digestion (%) at hour:				
6	36.39	35.30	36.81	35.50
12	58.81	46.70	43.03	41.24
24	69.54	56.00	51.07	47.73
36	71.01	64.55	55.48	63.13
48	71.18	70.41	65.56	65.27
72	72.27	73.54	65.97	69.75
Alfalfa NDF digestion (%) at hour:				
6	9.95	15.21	13.41	8.74
12	29.41	25.90	19.34	25.40
24	44.00	44.29	35.51	42.36
36	46.05	53.96	41.18	49.32
48	46.95	56.59	53.74	56.86
72	50.25	59.12	55.69	58.26
Wheat straw DM digestion (%) at hour:				
6	19.99	26.61	26.82	22.45
12	30.12	35.48	29.77	26.10
24	40.86	41.28	36.34	30.97
36	43.99	43.32	39.84	37.65
48	51.22	46.83	49.97	40.59
72	50.03	52.91	56.55	44.85
Wheat straw NDF digestion (%) at hour:				
6	1.44	13.50	6.45	4.09
12	8.86	15.02	9.35	7.06
24	22.33	19.59	16.23	14.57
36	27.81	21.15	23.73	21.80
48	37.37	26.89	31.38	27.83
72	38.86	36.30	40.77	33.66

TABLE A19. 65% CONCENTRATE BERMUDA STRAW DIET; CANNULATED STEERS

	Steer #			
	4	2	3	1
PERIOD	1	2	3	4
Rumen pH at hour:				
0	6.54	6.65	6.62	6.51
2	6.29	5.92	6.01	6.23
4	6.23	5.42	5.69	5.49
6	6.14	5.72	5.70	5.66
12	6.74	6.40	6.40	6.24
Rumen DM fill and volume:				
Dry matter, kg.				
Raft	3.21	2.14	2.81	2.91
Liquid	1.89	2.19	1.61	2.60
Volume, l.				
Raft	29.00	22.00	34.00	20.00
Liquid	34.00	31.00	23.00	31.00
Milo starch digestion (%)at hour:				
0	23.56	20.45	22.34	25.33
2	35.77	34.38	37.15	37.75
4	49.18	53.30	45.59	43.14
6	53.22	56.31	52.97	58.30
12	65.62	66.47	70.41	74.02
Milo DM digestion (%) at hour:				
6	55.06	46.91	49.73	48.38
12	68.82	68.02	61.09	66.60
24	84.12	75.24	69.35	74.61
36	91.27	85.37	77.06	84.91
48	91.96	91.00	83.48	91.79
72	93.78	92.78	91.52	92.39

TABLE A19. (cont.)

Milo NDF digestion (%) at hour:

6	-2.51	-3.47	-2.99	-0.84
12	17.62	15.82	15.42	7.79
24	48.98	33.94	29.86	17.27
36	62.35	43.85	36.68	35.41
48	64.90	50.88	41.68	47.04
72	73.08	59.47	48.04	58.15

Alfalfa DM digestion (%) at hour:

6	36.04	44.04	32.41	40.54
12	56.18	55.93	38.04	45.15
24	70.95	52.87	45.53	55.68
36	70.22	66.37	51.14	63.92
48	71.39	73.54	53.52	67.24
72	71.64	76.59	64.05	67.57

Alfalfa NDF digestion (%) at hour:

6	9.59	16.21	11.88	10.58
12	28.50	27.18	13.32	16.96
24	45.75	40.04	18.21	24.62
36	47.52	44.78	26.17	37.56
48	50.18	54.82	32.05	44.03
72	50.54	58.71	44.50	44.41

Bermuda straw DM digestion (%) at hour:

6	21.40	19.11	18.18	21.60
12	30.97	26.27	20.91	23.99
24	43.75	32.26	24.10	28.25
36	48.47	34.87	25.78	38.54
48	52.47	41.55	28.93	43.02
72	54.37	47.04	36.37	49.97

Bermuda straw NDF digestion (%) at hour:

6	8.46	7.56	9.71	4.46
12	17.33	12.74	11.95	6.67
24	34.57	21.44	14.72	12.34
36	38.45	23.07	20.34	25.10
48	45.03	31.02	25.56	30.68
72	47.25	38.62	30.26	37.95

TABLE A20. 65% CONCENTRATE COTTONSEED HULLS DIET; CANNULATED STEERS

	Steer #			
	2	4	1	3
PERIOD	1	2	3	4
Rumen pH at hour:				
0	6.64	6.45	6.23	6.37
2	6.22	5.65	5.89	6.16
4	5.80	5.68	5.48	5.70
6	5.88	5.67	5.56	5.69
12	6.56	6.01	6.27	5.98
Rumen DM fill and volume:				
Dry matter, kg.				
Raft	1.19	0.00	0.00	0.00
Liquid	2.38	5.61	5.90	4.65
Volume, l.				
Raft	12.00	0.00	0.00	0.00
Liquid	31.00	63.00	64.00	45.00
Milo starch digestion (%) at hour:				
0	23.56	20.45	22.34	25.33
2	37.97	43.90	33.64	38.47
4	49.56	47.30	42.05	42.51
6	57.36	55.69	49.82	54.36
12	68.92	65.92	70.72	68.46
Milo DM digestion (%) at hour:				
6	47.68	41.97	54.64	52.47
12	56.74	54.93	64.64	69.02
24	73.62	65.85	69.72	70.21
36	83.93	70.80	75.98	81.69
48	86.43	75.85	83.38	88.36
72	92.65	87.88	84.16	92.12

TABLE A20. (cont.)

Milo NDF digestion (%) at hour:				
6	-1.85	3.83	-2.08	4.76
12	18.34	12.22	14.02	12.89
24	34.24	17.47	21.04	21.17
36	49.99	29.00	29.58	36.70
48	55.42	36.86	35.27	49.61
72	62.86	41.62	43.38	62.34
Alfalfa DM digestion (%) at hour:				
6	37.38	36.57	35.31	36.08
12	45.59	41.23	41.57	51.93
24	53.50	45.48	46.51	58.99
36	65.98	52.24	47.55	62.22
48	70.36	57.01	52.32	64.02
72	60.09	57.72	59.12	64.97
Alfalfa NDF digestion (%) at hour:				
6	12.85	19.20	12.39	8.38
12	22.88	26.78	17.89	22.32
24	32.40	27.67	20.27	30.93
36	39.16	29.35	27.85	35.30
48	44.85	31.44	29.77	38.02
72	47.62	32.81	33.73	41.65
Cottonseed hulls DM digestion (%) at hour:				
6	7.83	8.81	7.20	7.77
12	8.23	9.71	12.34	8.21
24	14.56	12.06	13.57	10.09
36	18.93	15.96	14.45	14.64
48	24.75	17.50	20.83	18.54
72	32.89	21.81	24.15	21.20
Cottonseed hulls NDF digestion (%) at hour:				
6	2.28	2.00	4.46	4.15
12	6.18	3.10	6.41	5.36
24	9.95	6.48	9.17	7.30
36	12.34	11.01	14.88	9.09
48	17.52	15.81	17.56	13.39
72	24.04	15.91	23.23	24.85

TABLE A21. 90% CONCENTRATE ALFALFA DIET; CANNULATED STEERS

	Steer #			
	4	2	3	1
PERIOD	1	2	3	4
Rumen pH at hour:				
0	6.55	6.39	6.44	6.52
2	6.04	5.80	5.33	5.45
4	5.64	5.52	5.23	5.12
6	5.93	5.53	5.48	5.38
12	6.47	6.27	6.24	6.43
Rumen DM fill and volume:				
Dry matter, kg.				
Raft	0.00	0.13	0.00	0.00
Liquid	2.36	2.64	3.45	3.50
Volume, l.				
Raft	0.00	1.00	0.00	0.00
Liquid	37.00	52.00	28.00	120.00
Milo starch digestion (%) at hour:				
0	21.43	25.83	19.85	22.15
2	31.19	30.99	40.94	35.60
4	38.00	37.55	47.91	51.88
6	45.28	41.52	54.21	54.67
12	61.29	53.82	69.76	70.32
Milo DM digestion (%) at hour:				
6	30.22	31.71	35.53	51.28
12	65.72	49.10	50.61	52.33
24	69.61	55.25	67.86	62.91
36	73.61	61.28	71.14	68.85
48	79.83	70.31	75.40	78.55
72	82.36	84.87	82.32	88.39

TABLE A21. (cont.)

Milo NDF digestion (%) at hour:				
6	-1.71	-1.41	1.89	-1.54
12	8.15	7.58	18.43	8.62
24	14.55	11.01	21.94	20.84
36	20.06	19.91	24.95	30.16
48	28.40	31.54	35.56	39.82
72	39.02	45.84	50.07	60.52
Alfalfa DM digestion (%) at hour:				
6	36.87	34.16	36.65	39.45
12	38.98	37.35	42.42	44.78
24	44.19	40.69	47.14	47.35
36	53.41	46.36	52.37	50.38
48	53.59	48.57	55.36	55.69
Alfalfa NDF digestion (%) at hour:				
6	2.31	5.32	4.96	8.73
12	6.08	9.40	9.95	15.06
24	11.48	14.08	17.34	18.56
36	26.55	21.21	25.52	23.03
48	28.54	24.98	30.18	31.27
72	31.90	35.66	41.98	42.00

TABLE A22. 90% CONCENTRATE WHEAT STRAW DIET; CANNULATED STEERS

	Steer #			
	2	3	1	4
PERIOD	1	2	3	4
Rumen pH at hour:				
0	6.70	6.31	6.36	6.54
2	5.55	5.36	5.33	5.83
4	5.31	5.12	5.58	5.82
6	5.51	5.34	5.58	5.95
12	6.44	6.40	6.25	6.32
Rumen DM fill and volume:				
Dry matter, kg.				
Raft	1.27	1.07	1.06	0.68
Liquid	2.34	2.51	3.23	3.36
Volume, l.				
Raft	13.00	9.00	10.00	6.00
Liquid	36.00	32.00	40.00	47.00
Milo starch digestion (%) at hour:				
0	21.43	25.83	19.85	22.15
2	31.70	40.82	21.71	20.43
4	42.40	49.13	30.00	27.80
6	50.83	54.16	34.48	34.81
12	56.57	65.94	37.54	55.70
Milo DM digestion (%) at hour:				
6	38.07	34.83	32.13	39.07
12	50.44	51.16	44.07	47.41
24	67.39	67.96	56.84	59.76
36	78.51	72.49	69.83	67.67
48	81.65	79.41	76.70	74.87
72	86.80	88.23	85.73	81.46

TABLE A22. (cont.)

Milo NDF digestion (%) at hour:

6	4.83	-3.25	6.01	-2.40
12	10.70	3.51	8.42	7.68
24	25.72	20.41	18.43	21.02
36	35.85	27.39	38.54	27.26
48	49.95	31.91	44.65	40.07
72	53.98	49.12	54.09	49.23

Wheat straw DM digestion (%) at hour:

6	18.46	21.26	22.07	27.61
12	21.91	24.12	27.32	28.49
24	23.97	26.31	29.15	34.53
36	24.89	25.77	33.62	35.81
48	25.35	28.87	40.19	43.46
72	29.73	34.41	41.02	44.16

Wheat straw NDF digestion (%) at hour:

6	0.62	2.69	1.49	2.82
12	3.47	4.93	4.19	7.09
24	6.07	5.26	7.77	12.25
36	7.74	6.98	11.26	16.45
48	10.37	9.71	16.03	25.92
72	12.55	16.21	23.27	26.12

TABLE A23. 90% CONCENTRATE BERMUDA STRAW DIET; CANNULATED STEERS

	Steer #			
	1	4	2	3
PERIOD	1	2	3	4
Rumen pH at hour:				
0	6.13	6.19	6.34	6.34
2	5.78	5.48	5.36	5.99
4	5.11	5.39	5.07	5.55
6	5.51	5.37	5.12	5.75
12	6.31	6.05	6.10	6.28
Rumen DM fill and volume.				
Dry matter, kg.				
Raft	1.36	0.26	1.39	0.00
Liquid	2.21	4.16	2.89	3.48
Volume, l.				
Raft	16.00	2.00	11.00	0.00
Liquid	32.00	55.50	35.00	35.00
Milo starch digestion (%) at hour:				
0	21.43	25.83	19.85	22.15
2	32.99	37.52	35,57	26.88
4	36.93	47.02	40.94	36.86
6	40.98	52.02	45.73	57.05
12	53.74	58.20	49.44	69.03
Milo DM digestion (%) at hour:				
6	31.66	32.45	31.43	50.34
12	48.68	38.21	57.34	51.13
24	60.07	45.13	64.62	62.35
36	74.45	52.21	69.93	68.88
48	84.41	69.23	78.26	70.97
72	88.04	83.83	85.16	82.17

TABLE A23. (cont.)

Milo NDF digestion (%) at hour:				
6	-6.72	1.84	6.73	-5.03
12	13.15	15.17	23.55	15.54
24	24.02	24.73	28.25	22.47
36	35.85	27.85	35.12	29.93
48	55.99	34.43	38.61	32.88
72	60.24	44.91	55.35	46.76
Bermuda straw DM digestion (%) at hour:				
6	18.17	21.30	18.41	22.47
12	26.07	20.43	23.90	24.25
24	32.55	24.31	27.92	25.26
36	33.67	26.99	33.12	28.47
48	38.19	32.45	35.61	31.08
72	39.32	35.84	38.56	37.02
Bermuda straw NDF digestion (%) at hour:				
6	0.65	3.77	0.41	1.52
12	8.00	4.77	3.57	3.71
24	14.89	8.86	6.89	6.70
36	15.78	12.62	14.58	8.59
48	22.54	19.14	18.24	12.71
72	25.04	22.64	22.06	20.36

TABLE A24. 90% CONCENTRATE COTTONSEED HULLS DIET; CANNULATED STEERS

	Steer #			
	3	1	4	2
PERIOD	1	2	3	4
Rumen pH at hour:				
0	6.40	6.49	6.22	6.41
2	5.49	5.83	5.45	5.94
4	5.33	5.20	5.36	5.57
6	5.56	5.41	5.57	5.68
12	6.25	6.42	6.23	6.18
Rumen DM fill and volume:				
Dry matter, kg.				
Raft	0.00	0.06	0.00	0.00
Liquid	4.43	3.82	4.87	4.19
Volume, l.				
Raft	0.00	0.50	0.00	0.00
Liquid	41.00	41.00	53.00	51.00
Milo starch digestion (%) at hour:				
0	21.43	25.83	19.85	22.15
2	27.18	36.45	18.67	17.13
4	34.41	44.26	32.29	28.48
6	42.81	48.00	39.97	38.66
12	52.33	59.79	45.69	58.27
Milo DM digestion (%) at hour:				
6	37.60	37.83	29.18	44.46
12	43.93	45.39	49.12	53.27
24	57.67	54.20	57.02	60.20
36	71.35	57.66	57.89	68.46
48	79.27	73.71	58.79	70.56
72	85.88	83.18	74.55	72.72

TABLE A24. (cont.)

Milo NDF digestion (%) at hour:

6	-9.84	-11.35	-1.97	1.01
12	2.70	-5.89	8.26	11.62
24	10.97	18.22	10.01	21.28
36	23.71	17.08	23.60	29.25
48	42.45	31.41	29.13	32.07
72	50.89	48.05	37.63	39.95

Cottonseed hulls DM digestion (%) at hour:

6	8.06	14.87	12.25	10.81
12	12.47	15.16	16.24	12.87
24	12.91	18.10	19.25	16.51
36	17.86	19.94	20.30	20.32
48	18.16	27.39	20.80	21.01
72	20.56	31.91	27.78	24.62

Cottonseed hulls NDF digestion (%) at hour:

6	1.57	8.55	8.29	6.32
12	4.86	9.61	11.47	7.96
24	5.50	11.22	13.13	9.89
36	7.25	14.56	13.10	12.98
48	11.31	20.54	14.85	15.29
72	15.17	30.50	19.22	20.69

CHAPTER 7

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