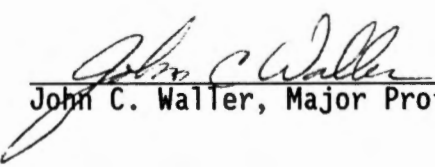
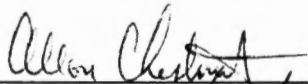


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THE EFFECTS OF ADDING HIGHLY DIGESTIBLE FIBER
TO CONVENTIONAL CORN-CORN SILAGE BASED
GROWING BEEF CATTLE RATIONS

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ABSTRACT

One hundred and ninety-two steer calves (275 kg) were randomly allotted to two groups: 24 pens (six steers/pen) with 6.69 M²/steer, and 24 pens (two steers/pen) with 10.03 M²/steer. A 2 by 3 factorial arrangement of dietary treatments was used. Diets consisted of: 1) 100% corn silage (CS); 2) 85% CS, 15% soyhulls (SH); 3) 70% CS, 30% SH; 4) 80% CS, 20% cracked shelled corn (CSC); 5) 65% CS, 20% CSC, 15% SH, and 6) 50% CS, 20% CSC, 30% SH on a dry matter basis. A ground corn grain:soybean meal (2:1) blend provided supplemental protein and was fed at the rate of .68 kg·steer⁻¹·day⁻¹. A mineral mix containing calcium, phosphorus, and salt was offered free choice. In each group, dietary treatments were arranged in a randomized complete block design with four replications. Block involved pen location within a barn. The trials lasted 56 days with the initial weights taken after the animals had been adjusted to their respective diets.

Average daily gains (kg) and feed:gain ratios of group-fed steers for treatments 1 through 6 were: 0.80, 9.92; 0.90, 9.43; 0.82, 12.21; 0.87, 9.25; 0.90, 9.42; and 1.02, 9.09, respectively. Average daily gain (kg) and feed to gain ratios for steers fed in pens containing two steers for treatments 1 through 6 were: 0.56, 13.12; 0.85, 10.52; 0.78, 11.77; 0.67, 11.24; 0.89, 9.85; and 0.90, 11.40, respectively.

Including SH at 15 and 30% of the dietary dry matter

resulted in cattle performance similar ($P>.05$) to the diets of CS or CS plus CSC.

Two digestion trials were conducted toward the end of the 56-day trial using the steers in pens of two. Lignin and indigestible acid detergent fiber (IADF) served as internal markers. Chromic oxide (Cr_2O_3) was used as an external marker and was mixed with ground corn grain and fed at the rate of 29.768g/day for seven days prior to the collection period. Fecal grab samples were collected at random two-hour intervals representative of a 24-hour period, over a total of 4 (digestion trial I) and 6 days (digestion trial II).

Average dry matter (DM), organic matter (OM), acid detergent fiber (ADF), and neutral detergent fiber (NDF) digestibilities during digestion trial I for treatments 1 through 6 were: 68.16, 69.90, 51.76, 59.46; 71.37, 72.87, 61.30, 65.39; 72.20, 73.72, 65.80, 67.83; 71.08, 72.62, 49.94, 58.74; 74.21, 75.58, 61.81, 66.12; and 72.55, 73.65, 66.60, 67.74, respectively. Average DM, OM, ADF, and NDF digestibilities during digestion trial II for treatments 1 through 6 were: 68.27, 70.12, 52.73, 59.73; 69.67, 71.09, 58.83, 63.08; 70.81, 72.34, 64.17, 66.42; 69.09, 70.54, 48.99, 56.86; 70.34, 71.75, 58.83, 62.03; and 70.31, 71.43, 62.60, 64.41, respectively.

Digestibilities of DM, OM, ADF and NDF increased as SH were included in CS or CS-CSC blend diets in both digestion trials I and II. Digestion trial I resulted in slightly higher digestibility

estimates than digestion trial II in steers fed treatments 2 through 6.

Chromic oxide gave significantly lower estimates of DM, CP, OM, ADF and NDF digestibility than either lignin or IADF in digestion trial I ($P < .05$), while IADF gave higher digestibility estimates than Cr_2O_3 and lignin in digestion trial II ($P < .05$).

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CHAPTER I

INTRODUCTION

Tennessee cattlemen have the opportunity to produce CS as a feed ingredient for growing beef cattle rations. Corn silage typically serves as the major feed ingredient from the time the calf is weaned until a desired weight is reached to start on a high energy finishing ration. In 1987, one hundred-thirty thousand acres of Tennessee farmland was devoted to CS production which led to the harvest of 1,560 thousand tons (Tennessee Agriculture, 1987). However, with the competition for this CS from Tennessee's 203 thousand dairy cows, it is not surprising that CS was not produced in sufficient quantity to feed the calf crop of this state's 1,027,000 beef cows (Tennessee agriculture, 1987). As a result, many of Tennessee's feeder calves are transported out of the state to complete the growing and finishing phases of production.

Extending CS supplies to feed more cattle per farm would add flexibility to Tennessee production systems. This can be accomplished by adding other feeds to the ration thus reducing the quantity of silage fed per animal. Corn grain is the most frequently used silage extender, but the readily available energy provided by the corn alters the efficiency of the entire diet through the reduction of fiber utilization (Burroughs et al., 1949).

To avoid the adverse effects of corn grain additions to CS

based diets, Klopfenstein (1983) suggested that a high energy highly-digestible fiber, such as soybean hulls (SH), can be used to extend existing silage supplies. Boggs (1986) reported improved fiber digestion in wheat silage based diets containing SH as opposed to diets containing grain.

Digestibility estimates of rations are often essential to explain observed animal performance. The marker-ratio technique of determining digestibility eliminates the need for total collection of feces excreted. With this technique, a greater number of animals can be employed thus reducing the effect of animal variation on digestibility. However, the accuracy of digestibility estimates obtained will suffer if diurnal variations in marker excretion are not considered and compensated for by utilizing a proper collection schedule (Hopper et al., 1978; Prigge et al., 1981).

Although research has been conducted on markers, many questions remain as to the nature of marker excretion patterns. In most instances, collecting at random two-hour intervals over a 3- to 7-day period and compositing collected samples has proven sufficient (Pond et al., 1987) in providing accurate estimates of digestibility. However, continued research is needed to determine the most reliable collection schedule.

The objectives of this research were: 1) to evaluate the effects of using SH to extend CS supplies in growing rations for beef cattle, 2) to determine the digestibility of these CS-CSC

blend diets extended with various levels of SH, 3) to compare digestibility estimates obtained from a 4-day collection period to those calculated using a 6-day collection period and 4) to compare digestibility estimates using lignin, indigestible acid detergent fiber (IADF) and chromic oxide as inert markers.

CHAPTER II

REVIEW OF LITERATURE

Use of Corn Silage for Ruminants

Corn is the most common silage crop in the U.S. with the quantity exceeding the second ranked silage (sorghum) by as much as 16 times (Cullison and Lowery, 1987). The corn plant is harvested in late summer and early fall when the grain is in the dough to early dent stage. At this time, the plant contains approximately 65 to 70% moisture and averages 47% grain (Church, 1986). Once chopped, the corn plant is placed in a silo or oxygen limiting environment and packed tightly for the exclusion of air. The silage temperature increases as plant cells use up available oxygen and give off carbon dioxide. Depletion of the oxygen supply creates a favorable environment for anaerobic bacterial fermentation. The lactic acid producing bacteria will become the predominant microorganisms as the pH is continually reduced and soluble carbohydrates are fermented to organic acids. With the production of large quantities of lactic and other organic acids (acetic, succinic, formic, propionic and butyric) the pH is reduced to approximately 4.0, prohibiting additional fermentation. The temperature will equilibrate to that of the surrounding environment and by the 21st day following ensilement, the silage is well preserved and will keep for as long as anaerobic conditions are maintained.

Corn silage production yields more total digestible nutrients (TDN) per acre planted than corn grain. Yields can be expected to range from 15 to 17 tons per acre (Woody and Fox, 1977). If silage is harvested early, silage production may allow the use of double cropping systems, therefore more fully utilizing available land. With proper ensiling, the silage will ensure a year around feed supply.

Several factors affect silage fermentation and quality of the product ensiled. These include dry matter (DM) content, exposure to air and quantity of available carbohydrates. The DM content of CS should range between 25 and 35% (Church, 1986). When silage has less than 25% DM, seepage of soluble nitrogenous compounds, sugars and acids produced by the fermentation process will increase, resulting in a lowering of silage quality. These compounds and products may result in soil and water contamination. In addition, silage low in DM will often lack the quantity of readily available carbohydrates needed to provide adequate fermentation. Butyric acid is produced in large quantities by saccharolytic clostridial bacteria (McDonald et al., 1981). Clostridial bacterial will break down amino acids and amines are formed. The presence of high concentrations of ammonia nitrogen in butyric silage will often cause a reduction in DM intake. The exposure of moist silage to air will promote mold growth, while a dry silage will heat, lowering the digestibility of nitrogen containing compounds (plant proteins). The combination of silage losses associated with seepage, and excessive heat could result in

a reduction of DM of 15 to 25% between field harvest and feeding (Church, 1986).

In addition to variations in fermentation, silage quality can be affected by corn variety used, environmental conditions throughout the growing season and time of harvest. Silage quality is affected by geographic location because length of the growing season and degree days associated with a particular area.

There are several types of silos available (trench, bunker or upright) with a wide range in cost. Silage losses are greater for bunker, trench and concrete compared to sealed oxygen limiting silos. Cost of storing and feeding silage depend on silo type and quantity of silage stored. An animal production system based on extensive use of silage results in a significant investment in storage and feeding facilities. This investment is usually fixed for a given quantity of silage production and the system is rather inflexible to change. In years when animal production proves profitable a producer may wish to feed more livestock. To avoid investing in additional silage storage, producers are either limiting the number of animals fed or extending the existing silage supply by including other feedstuffs in the ration.

Corn Silage Extenders

Corn Grain

Corn grain is often added to silage based diets to extend existing silage supplies. However, this traditional practice is not without problems. Young cattle fed corn grain as a major component

of the dietary ration become overconditioned at too light-of-weight and interactions or associative effects among corn grain-corn silage blended rations often result in animal performance below those predicted by the net energy system.

Cattle on a 50:50 corn grain-corn silage ration from 200 to 250 kg become too fleshy at too light-of-weight. For example, if calves are put on this type of diet at 200 to 250 kg they are carrying a considerable amount of fat by the time they reach 350 kg. In order to have a marketable product, steers should reach 450 to 500 kg and still be lean enough to meet today's consumer demand (yield grade 2-3). Adding 100 to 150 kg to cattle which are already fleshy increases the cost of gain substantially, as the animal's energy requirement for maintenance is increased.

In an attempt to overcome these problems, Fox and Black (1975) suggested a two-phase growing-finishing system. In this system steers are fed a high roughage, low energy ration during the growth phase to keep fat deposition to a minimum while the animal accumulates more total protein (muscle). At 300 to 350 kg the conversion to a high concentrate ration is made until a desired slaughter weight and condition is reached.

Fox and Black (1975) noted three advantages of a two-phase system: 1) the fastest rate of gain is obtained in the finishing phase when steers are at heavier weights, therefore total maintenance requirements are reduced, 2) the feeding of a high roughage diet during the growth phase followed by a high

concentrate diet during the finishing phase in comparison to feeding steers a constant amount of added grain throughout the entire feeding period would eliminate interactions or associative effects among these feedstuffs, and 3) cattle show compensatory performance when switched from a high roughage to a high concentrate diet.

Woody et al. (1983) compared rate of gain and feed efficiency of steers on a two-phase system to those on a one-phase system. On the one phase system grain was distributed throughout the entire experiment, however steers on the two phase system consumed a similar total amount of grain. Feed efficiency was improved 6.5% by the two-phase system while gains were similar to steers on the one-phase system. These results were confirmed by Boggs and Okotie-Eboh (1985b) who reported equal gains, but an 8% reduction in required feed and 15% decrease in supplemental energy (per unit gain) for steers on a two-phase system utilizing wheat silage rations supplemented with 30% SH or various levels of corn grain-soybean meal.

Meiske et al. (1978) evaluated feedlot performance of steers fed all combinations of two growing rations (all CS or CS + 1.36 kg high moisture corn (HMC)) and two finishing rations (all corn grain or corn + 3.63 kg CS). These researchers reported the greatest returns per head were from steers fed corn grain-CS blended rations in both the growth and finishing phase.

When calculating rations including two or more feedstuffs, interactions among these feeds must be considered. This is

especially true of corn grain additions to forage diets such as CS. Grain is high in available energy and should elicit a positive linear response in animal performance as the percentage of corn grain in the ration DM is increased. However, a curvilinear response (Vance et al., 1972) in net energy for gain (NE_g) values (Kromann, 1967) and digestibility may occur due to changes in metabolism of nutrients as dietary feeds interact (Forbes et al. 1933; Kromann, 1967; Kromann and Ray, 1967). In the case of corn grain additions to silage based rations, the rumen environment is altered in such a manner that neither amylolytic nor cellulolytic microorganisms perform at optimum. Therefore, neither the silage nor grain is digested efficiently.

A reduction in fiber digestion by adding starch or any soluble carbohydrate to a forage base ration has been well documented (Burroughs et al., 1949; Mertens and Loften, 1980). The soluble carbohydrate in grains are subject to a quicker rate of degradation by rumen microorganisms than the cellulolytic material found in plant cell walls. The rapid rate of fermentation of these soluble carbohydrates, coupled with a decrease in saliva production (most grains require less mastication and rumination than roughages) result in rumen pH levels below those favorable to cellulolytic bacteria.

The effect of pH on the growth of rumen bacteria in continuous cultures was studied by Russell and Dombrowski (1980). Cell yields of cellulolytic bacteria (*Butyrivibrio fibrisolvens*,

Bacteriodes succinogenes, *Ruminococcus albus* and *Ruminococcus flavefaciens*) were reported to have decreased abruptly and they were eventually washed out as pH values reached 5.7 to 6.15. Severe reductions of in vitro fiber disappearance (Erfle et al., 1982) and cellulolytic activity (Hoover et al., 1984) were reported when pH was reduced from 6.5 to 5.5.

Mould et al. (1983) reported a decrease in fiber digestion as rumen pH levels were reduced to 6.0 by the addition of barley to ground hay rations. Continuous culture fermentations were used by Shriver et al. (1986) to determine the effect of rumen pH levels on fermentation of 35% hay-65% grain diets. Digestibility of neutral detergent fiber (NDF) decreased from 33.1 to 8.1% between pH 6.2 and 5.8 with a marked decrease in microbial attachment to effluent NDF over the same pH range. These researchers concluded that low rumen pH levels decreased digestion by a combination of decreased microbial attachment and increased wash out of cellulolytic bacteria.

Byers et al. (1975) reported a decrease in expected NE_g values of 10.4 and 12.2% when whole shelled corn was added to CS based diets at the rate of 34 and 67%, respectively. These researchers concluded that when a silage ration contained over 40% grain (including grain in the silage), performance would fall short of values predicted by the net energy system. Joanning et al. (1981) reported similar results when 60% CSC was added to either immature or mature corn silage. Dry matter digestion coefficients of the grain-silage mixture were 11 to 12% below predicted values,

with starch and NDF digestibilities accounting for most of this decrease.

By-Product Feeds

Increasing interest has been placed on the use of high-fiber by-product feeds in growing beef cattle rations as a means of extending existing silage supplies and avoiding the negative associative effects often observed with the addition of corn grain.

By-product feeds are typically residual materials resulting from the processing of various agricultural products for human or animal use. By using such by-products, the producer may lower feed cost while adding flexibility to the feeding program.

There are many by-product feeds which have been used in beef cattle rations. Sugar beet pulp, wheat middlings, citrus pulp, apple pomace, corn gluten feed and SH are a few of the more common by-product feeds.

By-product feeds are variable in nutrient value, therefore dietary recommendations for by-product use is difficult. Availability is another factor affecting by-product use. These products are often seasonal thus delivery can be sporadic.

Sugar Beet Pulp (IFN 4-00-669)

Sugar beet pulp is a by-product of the production of sugar for human use. The sugar is extracted by soaking the sugar beet in water so that only a residue remains. This residue is frequently

shredded and dried or pelleted to avoid difficulties in shipping and handling.

Due to the extraction process, all water soluble nutrients are removed, therefore the crude fiber content (16%) is higher than would be expected of a concentrate. Although beet pulp is fibrous in nature the digestibility of this fiber is high, presumably due to a low lignin content. Beet pulp is low in crude protein (9 to 10%) and ranges from 75 to 85% in TDN.

Nutrient digestibility and energy utilization of rations containing four levels of beet pulp (0, 30, 45, and 60%) as a replacement for ground shelled corn was evaluated by Bhattacharya and Sleiman (1971). No difference in the digestibility of DM, energy or crude protein was noted among these rations indicating that beet pulp, when properly supplemented, is of equal value to corn as an energy source. Crude fiber digestibility of dairy rations was increased from 46% to 72% as beet pulp levels were increased from 0 to 73%, respectively (Bhattacharya and Lubbadah, 1971).

McCullough (1968) compared beet pulp-forage (silage or bermudagrass hay) diets to steam flaked corn-forage diets on in vitro cellulose disappearance. Regardless of forage type, beet pulp was superior to corn in cellulose disappearance.

Citrus Pulp (IFN 4-01-237)

- Citrus pulp is the portion of fruit remaining after the citrus juices have been removed for human consumption. Citrus pulp

therefore consists of ground peel, residue of the inside portions and occasionally cull fruits of the citrus family.

The residue is shredded or ground and pressed to remove juices. It can be fed in wet form, but is often dried to facilitate transfer and storage during the off-season. The resulting product is course and flaky with crude fiber ranging from 11 to 13%. Although high in fiber, citrus pulp is highly digestible and is used primarily as an energy source with a TDN value of approximately 82%. The protein content is low (6.5 to 7.0%) while the calcium content may be high (1.7 to 1.9%), due to the addition of calcium oxide or calcium hydroxide which aid in processing.

Although not very palatable to non-ruminant species, dried citrus pulp has been fed to dairy cows and can be used successfully in complete ruminant rations at levels approaching 50 to 60% (Church, 1986). When citrus pulp was fed at 40% of a CS based diet, it was equal to alfalfa pellets in DM intake and increased fat corrected milk yield, and it produced a slightly higher fat percent than alfalfa pellets-CS blended diets (Drude et al., 1971).

Wheat Middlings (IFN 4-05-205)

Historically, the first by-products generated in significant quantity were those coming from the wheat milling industry. The production of wheat flour for human use yields several grades of by-products such as bran, middlings or thirds, shorts, red dog, germ oil and germ meal.

In the dry roller milling process used today, the wheat is cleaned, scoured and blended into a grist. This grist is then passed through a series of rollers. The first set of rollers have a tearing action which removes the coarse outer covering from the wheat kernel thus producing wheat bran. The remaining kernel is gradually broken apart by each set of rollers, where the flour is removed by sieving. About 28% of the original grain can be classified as by-product material. This can be sold as straight run wheat feed or as the separate products previously mentioned.

Wheat middlings or common thirds consist of small particles of bran with some adhering endosperm, germ, and a few coarse flour particles. Wheat middlings are a finely ground material and brownish in color. Middlings are lower in crude fiber and have a higher TDN value than wheat bran. To standardize product quality the Association of American Feed Control Officials stated that wheat middlings are to contain no greater than 9.5% crude fiber with a minimum of 10 to 14% crude protein.

Caution must be taken when using wheat millfeeds. In addition to variations in product quality, exceedingly high levels of these by-products tend to restrict animal intake (Church, 1986).

Varga and Hoover (1983) determined the rate and extent of NDF degradation of various feedstuffs in situ. Cattle were maintained on a mixed hay diet supplemented with a corn-oat mixture. Following 24 hr in situ digestion, 52.1% of the total NDF in wheat midds had disappeared as compared to 42.3% of the total NDF in corn grain. The rate of degradation for both wheat bran and

wheat middlings exceeded those of corn and the corn by-products evaluated (hominy, corn gluten feed and corn gluten meal).

Corn Gluten Feed (IFN 5-28-243)

Corn gluten feed (CGF) is the part of corn grain that remains after the extraction of the larger portion of starch, gluten and germ by the processes employed in the wet milling industry for the production of corn starch or fructose syrup.

Cleaned shelled corn is soaked in water and sulfur dioxide. Soaking causes the kernel to swell and the germ to float to the surface where it is removed and further processed to extract the oil. The residue which contains the bran, gluten and starch is ground and the bran is removed by sieving. The bran or fiber is then mixed with the remaining liquid fraction and sold as either wet corn gluten feed (WCGF) or dry corn gluten feed (DCGF).

The feeding value of CGF is dependent on several factors including the form in which it is fed (wet or dry), dietary levels and interactions with the basal diet. However, CGF has been used successfully as both a protein and energy source in ruminant rations. Corn gluten feed has a protein and crude fiber content of approximately 21 and 8.4%, respectively. Both of these fractions are highly digestible giving CGF a TDN value of 80 to 89%. Corn gluten feed is high in phosphorus (0.8 to 1.0%) and low in calcium (0.3 to 0.4%), therefore calcium supplementation is required in order to maintain a Ca:P ratio.

Firkins et al., (1985) compared WCGF to DCGF as protein

supplements to silage based rations in steer growing, steer finishing and lamb metabolism trials. The inclusion of CGF in silage based rations resulted in increased intake (7.8%), increased gain and an improvement in feed efficiency of 7.6%. Wet CGF resulted in better feed to gain ratios than DCGF in both the growing (6.42 vs 6.86) and finishing (5.37 vs 7.01) trials. Lambs fed WCGF had greater NDF and ADF digestibilities than those receiving DCGF.

Although research indicates that WCGF is preferred over DCGF, problems arise with the shipping and handling of this product. Wet CGF will not ferment due to a low pH (4.3). However, extensive mold growth will occur if not stored in an anaerobic environment. Therefore, as with CS, the commitment for silos or anaerobic storage facilities becomes a problem when using this product in wet form.

Soybean Hulls (IFN 1-04-560)

Soybean Hulls consists of the outer covering of the soybean. It is a by-product of the manufacturing of 49% soybean meal and soybean flour. Soybean hulls may contain varying amounts of other by-products resulting from normal milling operations and be marketed as soybean millfeed, or be steam rolled to produce soybran flakes.

Soybean hulls have a protein value of 11 to 12%, are high in ADF (35 to 40%), yet have a TDN value of 60 to 70%. When compared to corn grain, hulls have a slower rate of energy release, presumably due to their fibrous nature (Klopfenstein, 1983). Their high fiber content limits their use in non-ruminant rations; however, they are

used in dairy and beef rations where they serve primarily as a source of bulk.

Soyhull additions to growing beef cattle rations have been studied at Nebraska (McDonnell et al., 1982; McDonnell et al., 1983; Merrill and Klopfenstein, 1984). The use of this high energy, highly digestible fiber source was proposed by Klopfenstein (1983) as a means of avoiding the adverse effects often observed with the addition of grain to high roughage rations. The fibrous nature of SH would presumably aid in maintaining rumen pH levels favorable to cellulolytic bacteria, while still providing the supplemental energy required for economic gain.

Merrill and Klopfenstein (1985) compared corn grain to whole SH as a supplemental source of energy to a ground corn stalk base diet. A negative associative effect on NDF digestion of 22.7% was reported for the ration containing 50% corn, whereas a positive associative effect of 3.8% was observed with the hull-corn stalk ration. Boggs and Okotie-Eboh (1985a) reported similar results when 30% SH replaced corn grain in wheat silage-corn grain diets fed to crossbred lambs. Neutral detergent fiber and ADF digestion were improved by the addition of SH.

In vitro digestibility of SH are reported to be approximately 94% (Van Soest, 1982), however this value may overestimate actual in vivo digestion (Boggs, 1986). Because of the small particle size of SH, they are subject to a fast transit through the rumen. Therefore maximum digestion may not be obtained when feeding high levels. Hintz

et al. (1964) reported an improvement in digestibility of ground SH (TDN 53.8 to 72.9%) when mixed grass hay was added to steer and wether rations. These researchers assumed that the hay increased rumen retention time of the SH allowing more digestion to occur.

Soyhulls may prove beneficial as a CS extender. This high energy-highly digestible fiber source may eliminate the negative effects of corn grain on depression of rumen pH and the resulting fiber degradation. However, the optimum level at which SH can be used to extend CS in beef cattle rations is unknown.

Evaluating the Nutritive Value of Blended Feeds

The nutritive value of a feed is classified into three general components: digestibility, feed consumption and energetic efficiency (Raymond, 1969). Of these components, digestibility is the least affected by inter-animal variation and is therefore the most common measure of nutritive value (Van Soest, 1982).

Physical and chemical characteristics of a feed, such as particle size (Van Soest, 1982), amount and quality of fiber (McDonald et al., 1981), solubility and buffering capacity (Van Soest, 1982), will influence digestibility and are likely to be altered by food processing. Other factors affecting digestibility include associative effects of blend rations, level of intake and frequency of feeding (McDonald et al., 1981).

With in vivo studies, both feed and animal factors affecting digestibility are involved in estimates obtained through the monitoring of animal performance on a given ration. In vitro

digestibility estimates, however, only simulate the digestive processes occurring in the rumen and do not consider entire gastrointestinal tract digestion. As a result, the effects of rate of passage (Ellis, 1978), level of intake (Van Soest, 1982) and associative effects (Mehrez et al., 1983) may be ignored causing digestibility estimates obtained from in vitro studies to differ significantly from actual in vivo performance.

Various methods of determining digestibility in vivo have been proposed. The collection and analysis of total feces is the most reliable method, however, it too has disadvantages. Digestion trials require a great deal of labor and expense. This limits the number of animals which can be employed, thus increasing the effect of animal variation on mean digestibility. An alternative is the use of the marker-ratio technique. This technique requires the use of indigestible substances which do not interfere with the digestibility of dietary components. Such an inert marker is added to the ration in a ratio to either the total feed supplied or to a given nutrient within the feed. Fecal output is then monitored and quantity of indicator in the feed and feces determined. The quantity digested can be calculated using the following formula.

Apparent Digestibility

$$= \frac{\text{g indicator / kg feces} - \text{g indicator / kg food}}{\text{g indicator / kg feces}}$$

(McDonald et al., 1981)

The advantage of the ratio technique is that total collection of feces becomes unnecessary since digestibility can be computed from selected subsamples of total fecal output.

The accuracy of digestibility values obtained by this method depends on several assumptions. The inert material must be evenly distributed within the ingesta and must remain associated with the ingested nutrients as they pass through the gastrointestinal tract. If these assumptions are valid and the rate of passage of the marker and ingesta are equal, then one fecal sample would be sufficient. A problem often encountered when calculating digestibility estimates by this procedure is that rate of excretion of the marker and(or) nutrients in the ration are irregular and diurnal. This diurnal pattern leads to sampling errors when using a limited portion of total daily fecal production.

Researchers (Kane et al., 1953; Bradley et al., 1958) have shown that digestion coefficients obtained by the ratio technique, when using chromic oxide as an inert marker, did not differ significantly from those calculated from total collection methods. Other investigators (Hardison and Reid, 1953; Davis et al., 1958) considered it to be unacceptable due to the low recovery of this inert material. In these instances, large diurnal variations in the excretion of markers were observed. Inaccuracies in calculated digestive coefficients will result if improper selections of indigestible markers, collection periods or collection schedules are made.

Marker Classification and Criteria

Indigestible markers may be classified as being either internal or external. Internal markers are substances occurring naturally in feedstuffs such as lignin, silica, acid insoluble ash, indigestible acid detergent fiber and indigestible neutral detergent fiber.

External markers are normally not natural constituents of feedstuffs and are added to the diet or administered to the animal. Examples of external markers include metal oxides (ferric oxide and chromic oxide), inert metals (ytterbium and lanthanum) and water soluble markers (polyethylene glycol and Cr-EDTA).

Markers may be classified also according to the fraction of the feedstuff with which they are associated. Chromic oxide is used for the detection of the particulate fraction, whereas polyethylene glycol equilibrates with the liquid phase. A list of several markers used in ruminant nutrition studies is provided in Table 1.

The criteria for effective nutritional markers were presented by Kotb and Luckey (1972). These requirements have been modified to a more current summarization, provided by Faichney (1975).

The criteria for marker-ratio digestibility studies require that markers:

- 1) be strictly nonabsorbable.
- 2) must not affect or be affected by the gastrointestinal tract or its microbial population.
- 3) must be physically similar to or intimately associated with the material they are to mark.
- 4) must be estimable in digesta samples by a method which is specific and sensitive and does not interfere with other analysis.

TABLE 1. DIGESTIBILITY MARKERS

MARKER	REFERENCE
CHROMIC OXIDE	Clanton, 1962 Johnson et al., 1964 Prigge et al., 1981
LIGNIN	Thonney et al., 1979 Fahey and Jung, 1983 Hunt et al., 1984
INDIGESTIBLE ACID DETERGENT FIBER (IADF)	Berger et al., 1979 Waller et al., 1980 Krysl et al., 1986
INDIGESTIBLE NEUTRAL DETERGENT FIBER (INDF)	Van Soest et al., 1966 Hunt et al., 1984 Cochran et al., 1986
ACID INSOLUBLE ASH (AIA)	Van Keulen and Young, 1977 Thonney et al., 1979
RU-103 PHENANTHROLINE	Evans et al., 1977
SAMARIUM	Hartnell and Satter, 1979
YTTERBIUM	Teeter et al., 1979 Prigge et al., 1981 Ellis et al., 1983
CERIUM	Ellis and Huston, 1968 Hartnell and Satter, 1979 Uden et al., 1980

Errors can arise if these criteria are not considered, yet few, if any, markers meet all of these requirements. A close evaluation of available markers for the successful use of marker-ratio technique is necessary prior to making a selection.

Internal Markers

Lignin

As a plant constituent, lignin would presumably be a convenient and accurate marker. However, problems exist in both the fecal recovery and quantitative analysis of this material (Fahey and Jung, 1983).

Lignin is a protective substance which gives structural support and rigidity to plant cell walls. "Core lignin" is a noncarbohydrate phenylpropanoid polymer of high molecular weight, which occurs in matrix form (Van Soest, 1982). It is regarded as being indigestible because there are no known anaerobic microorganisms or mammalian enzymes capable of polymerized phenol degradation (Van Soest, 1982). However, the intrinsic characteristics of lignin have been shown to vary (Reeves, 1985a,b) and are affected by plant species and probably plant maturity (Van Soest, 1982). The phenolic monomers, ferulic acid and para-coumaric acids have been identified in grasses as part of the lignin-carbohydrate complex and are present in various proportions (Van Soest, 1982). These "noncore" fractions may serve as a link to structural carbohydrates (Jung and Fahey, 1983).

Reports on the use of lignin as an inert marker in digestion studies have shown considerable variation. Kane et al. (1950)

reported no significant difference between digestibility coefficients obtained by the use of lignin and those calculated by the total collection method when feeding dairy cows second crop alfalfa conserved as silage, field cured hay or barn cured hay. These results agree with Hunt et al. (1984) who reported no significant difference between these two methods when calculating digestion coefficients for chopped orchardgrass hay fed to steer calves. However, Thonney et al. (1979) reported the permanganate lignin method to have underestimated digestibility determined by total collection by an average of 23.9% when steers were fed early and late cut mixed grass hay with various levels (0, 20, 40, 60 and 80%) of concentrate. Average permanganate lignin recoveries were 52.5 and 59.3% for the early and late cut hays, respectively. These researchers concluded that part of the permanganate lignin was digested and lignin is therefore unreliable as a marker.

Several researchers (Allison and Osbourn, 1970; Neilson and Richards, 1978; Galyean et al., 1979; Muntifering, 1982) have reported digestion or changes in the molecular structure of lignin to occur with passage through the digestive tract of ruminants. The site and extent of lignin digestion or structural alteration has yet to be determined. Fahey et al. (1979) speculated that part of the apparent digestion of lignin may be due to the formation of soluble lignin-carbohydrate complexes in the rumen which pass through the digestive tract as polymers in solution. These

polymers are not recovered in the fibrous residue of feces and are therefore not measured by conventional gravimetric methods.

According to Van Soest (1982) the problem with using lignin as an indigestible marker results from fecal recovery and the inability of current analytical procedures to isolate and identify true lignin, rather than lignin digestion. Lignin artifacts or contamination of crude lignin by digestible dietary constituents may occur when using the 72% sulfuric acid (Klason) method. This method of lignin isolation includes insoluble residues, such as protein, cutin and Maillard-type browning products as lignin, while some true lignin may be destroyed (Goering and Van Soest, 1970).

Streeter (1969) provides an excellent review of techniques used to estimate digestibility. He concluded that many of the negative and positive digestion coefficients reported for lignin may be attributed to differences in the lignin content of feed and fecal samples resulting from drying at excessively high temperatures. High temperatures during drying will cause condensation of carbohydrate end products with proteins and amino acids in a non-enzymatic Maillard reaction. Artifacts formed through Maillard reactions can be avoided however, by keeping drying temperatures below 50C (Streeter, 1969).

Several alternative methods of determining lignin have been introduced (permanganate lignin, acid detergent lignin (ADL) and acetyl bromide soluble lignin (ABSL)). Despite vast amounts of research, both negative and positive digestion coefficients continue to be reported. Data indicating lignin digestion in the gastrointestinal tract and difficulties in fecal recovery and

quantitative analysis would warrant cautious use of this material as an inert marker.

Indigestible Acid Detergent Fiber (IADF)

Van Soest et al. (1966) reported that undigested forage residues in sheep and cattle feces are composed of plant cell wall material (lignin, cellulose and hemicellulose) and that non cell wall material has a true digestibility of 98% or greater. Undigested cell wall material was therefore assumed to meet the criteria of an ideal marker (Van Soest et al., 1966).

In vitro digestibility estimates of twenty hays (12 grasses and 8 legumes) were compared to reported in vivo digestions by Van Soest et al. (1966). In vitro procedures consisted of: 1) a 48-hour rumen fermentation followed by a 48-hour acid pepsin digestion (Tilley and Terry, 1963) or 2) replacing the acid pepsin digestion step with a NDF extraction. The modified in vitro method which uses undigested cell walls (NDF) as the basis for determining digestibility was more precise than the unmodified Tilley and Terry procedure. These results initiated the use of indigestible neutral detergent fiber (INDF) as an indicator of digestibility.

The differences in in vitro and in vivo digestion of fiber with increasing levels of sodium hydroxide (NaOH) treatment were studied by Berger et al. (1979). Abomasally cannulated lambs were fed diets consisting of 80% ground corn cob and 20% supplement with various levels of NaOH treatment (0, 2.5, 5.0, 7.5 and 10%). Indigestible NDF and indigestible acid detergent fiber (IADF) served as markers and

were isolated by procedures similar to those of Van Soest et al. (1966) with the exception of extending fermentation to 96 hours and including a 48 hour acid pepsin digestion. These researchers reported IADF and INDF do meet the criteria of an ideal marker and were excellent markers for studying site and extent of digestion.

Waller et al. (1980), in a study evaluating the site and extent of digestion in steers fed corncob based diets supplemented with soybean, used IADF and INDF as internal markers for the particulate fraction. Procedures used to isolate cell wall materials were similar to those of Van Soest et al. (1966); however, feed samples were incubated in an acid pepsin solution for 16 hours prior to in vitro fermentation. The fermentation period was extended to 96 hours. These researchers reported IADF to meet the criteria of an ideal marker. However, difficulties in filtering NDF were reported along with lower dry matter digestion (DMD) and organic matter digestion (OMD) coefficients. These researchers warn that for diets low in ADF, IADF may be of limited use as a marker due to the insensitivity of laboratory techniques. Hunt et al. (1984) re-emphasized the potential use of IADF when reported digestion coefficients for chopped orchardgrass hay did not differ significantly from total collection when IADF served as an internal marker.

Cochran et al. (1986) evaluated IADF and INDF as potential markers for determining digestibility of four forage-based diets when fed to steers. In vitro fermentation was extended to 6 days and

followed by detergent extraction. In vivo apparent DMD of cubed alfalfa hay and mature tall wheatgrass hay (supplemented with soybean meal) were similar to DMD estimated by feed:feces ratios of IADF and INDF. However, IADF and INDF were unreliable as indicators for immature tall fescue and mature prairie hay where fecal recoveries averaged less than 52 and 90.6%, respectively. These results agree with those of Krysl et al. (1986) who reported INDF and IADF (96-h in vitro fermentation, 48-h acid pepsin digestion and detergent extraction) DMD significantly below those obtained in vivo for sheep rations of prairie hay, alfalfa hay or 50:50 hay-sorghum grain.

Review of research conducted on the use of IADF and INDF as internal markers reveals considerable variation in the accuracy in which they predict digestibility. Lippke et al. (1986) suggest that laboratory techniques receive more attention and attribute variations in IADF and INDF recovery to differences in particle size of feed samples, although they were ground through the same Wiley mill. Cochran et al. (1987) speculated that different chemical entities may exist among fiber-based diets evaluated thus far, resulting in the observed variations or possibly these "indigestible" substances are not really indigestible at all. Given the limited information in this relatively new area of ruminant nutrition, further research is needed for a true understanding of reported data.

External Markers

Chromic Sesquioxide (Cr_2O_3)

Chromic oxide is a fine, heavy, insoluble powder which has

been widely accepted as an inert marker for the particulate fraction of ingesta. However, this marker often fails to meet criterion 3 (p 20) in that it does not remain intimately associated with the feed material it is to mark.

Cyclic fluctuations in Cr_2O_3 excretion have been attributed to the incomplete mixing with digesta in the gastrointestinal tract (Langlands et al., 1963) and the lack of adhesion between Cr_2O_3 and the particulate phase (MacRae, 1974). These irregularities in marker excretion make Cr_2O_3 a more suitable digestibility marker than passage marker; however, gross sampling errors can result when using a limited portion of total daily fecal production.

Elam et al. (1962) evaluated Cr_2O_3 as an inert marker for determining the digestibility of sheep rations containing 60% ground alfalfa hay and 40% ground barley. Fecal samples were collected at 8am and 4pm where the mean recoveries of Cr_2O_3 were 94 and 100%, respectively. These researchers concluded that Cr_2O_3 was a reliable marker for estimating digestibility as Cr_2O_3 feed:feces ratio estimates did not differ significantly from total collection (65.6 vs 65.4%). Similar results were obtained by Hopper et al. (1978) when studying Cr_2O_3 excretion patterns of lactating cows grazing low quality (tall fescue) and high quality (70% tall fescue and 30% red clover) pastures. Although diurnal variations in Cr_2O_3 excretion were reported, unbiased estimates of fecal output could be obtained by combining fecal samples collected at 8am and 5pm. Despite these results, several researchers (Hardison and Reid, 1953; Davis et

al., 1958; Hunt et al., 1984) have reported chromic oxide to be unreliable as an inert marker.

The effectiveness of Cr_2O_3 as a digestibility marker depends on the form of Cr_2O_3 administration (Bradley et al., 1958; Langlands et al., 1963; Johnson et al., 1964), dosing technique (Prigge et al., 1981) and collection schedule used (Kane et al., 1952; Bloom et al., 1957) and interactions with the diet to which it is added (Clanton, 1962).

Chromic oxide can be administered as a powder, as an oil suspension in gelatin capsules, in pellet form or impregnated onto paper. When administered in a powder or gelatin capsule form to animals receiving primarily roughage rations, large errors often result. Johnson et al. (1964) in a study to compare Cr_2O_3 paper to the powder form, observed that the rate of passage of Cr_2O_3 paper was slower than the powder, yet still faster than the bulk of the ingested diet. Crampton and Lloyd (1951) and Kane et al. (1953) were able to avoid this problem by mixing Cr_2O_3 with a flour to form a bread. This bread was incorporated into the grain portion of the ration and adhesion to ingesta was greatly improved.

Several combinations of dosing and collection schedules have been used to reduce the diurnal variations in Cr_2O_3 excretion. Prigge et al. (1981) reported twice-daily dosing of Cr_2O_3 tended to reduce excretion variation, however, Davis et al., (1958) reported considerable variation in Cr_2O_3 excretion regardless if administered once or twice daily.

Multiple sampling times are required; however, the duration

and sampling interval necessary to obtain optimal mean marker concentration is an arbitrary figure. Kane et al. (1952) reported Cr_2O_3 concentration to be above average in morning samples and below average in fecal samples collected in the evening. Bloom et al. (1957) reported maximum excretions of Cr_2O_3 (flour mix) to occur between 5am and 9am. These results agree with Hopper et al. (1978) who reported maximum and minimum excretions at 9am and 8pm, respectively.

A procedure of feeding chromic oxide and sampling feces at 7 to 9am and 3 to 5pm has been widely adopted, mainly due to convenience. However, such a schedule requires the assumption that the diurnal excretion pattern is compensated for by combining samples taken from equal distance points above and below the point of inflection on a symmetrical excretion curve. Lambourne (1957) speculated that the excretion patterns of Cr_2O_3 would depend upon the rate of passage, digestibility and intake level of the diet. Different fecal excretion patterns were reported for sheep fed various qualities and quantities of dried grass (Blaxter et al., 1956).

Rare Earths

Rare earth elements including cerium (Ce), dysprosium (Dy), erbium (Er), europium (Eu), lanthanum (La), samarium (Sm), terbium (Tb) and Ytterbium (Yb) have been used as indigestible particulate markers in digestibility and rate of passage studies (Pond et al., 1987).

Rare earth elements are reported as indigestible metals

which become tightly bound to plant material (Ellis, 1968 and Ellis and Huston, 1968). The strong binding capacity of these elements to fiber would presumably minimize the diurnal variation in marker excretion and therefore, simplify dosing and sampling procedures (Prigge et al., 1981). However, critics have suggested that rare earths do not bind with sufficient tenacity and are free to migrate among particles of digesta.

Ellis and Huston (1968) administered Ce^{144} by sprinkling a Ce^{144} solution onto alfalfa hay to study digesta flow in sheep. The average recovery of Ce^{144} was 103%. These researchers concluded that the high Ce^{144} recovery was due to marker migration and adsorption onto indigestible particles. These results agree with Uden et al. (1980) who reported Ce to be an unsuitable digesta marker, as it would not form strong complexes with plant cell walls capable of withstanding the digestive process.

In vitro and in vivo studies were conducted by Hartnell and Satter (1979) to determine marker movement of Sm, Ce and La from treated to untreated ground grain or alfalfa hay. Following 24-hr in vitro fermentation, 92.6 and 99.2% of the elements remained associated with the grain and hay, respectively. These researchers concluded that rare earth elements were tenaciously bound to the particulate phase. Rare earths are best suited to mark fiber-based diets, because they bind to forage fractions which undergo little digestion in the gastrointestinal tract of ruminants. The starch particles of grain are eventually fermented leaving markers free to migrate (Hartnell

and Satter, 1979). Teeter et al. (1979) indicated that the procedure used to mark the material has a significant effect on the portion of marker bound, and that bound Yb was not liberated, nor did it migrate to other feedstuffs upon digestion. Diurnal variations in Yb excretions were noted by Prigge et al. (1981), but Yb was as effective as Cr_2O_3 as a fecal indicator. These results are supported by Hunt et al. (1984) who reported that fecal outputs and digestion coefficients estimated from Yb did not differ from values obtained by total collection.

Teeter et al. (1981) reported that feeds had several binding sites for Yb and that these binding sites had varying degrees of affinity for this rare earth element. Ellis et al. (1983) marked coarsely ground corn, alfalfa hay and bermudagrass hay by soaking them overnight at pH 6.0 with Yb-acetate. Samples were incubated for 12 hr at various pH levels (3.0, 2.5, 2.0 and 1.5) to determine acid-resistant binding of Yb. The percentage of initial Yb retained decreased with each successive reduction in pH and was 8, 5 and 12% for the corn, alfalfa hay and bermudagrass hay, respectively at pH 1.5.

Toxic effects of rare earth elements on rumen microbes have been reported. Johnson and Kyker (1966) evaluated Ce uptake by yeast cells (*Saccharomyces cerevisiae*). Living cells had a maximum uptake of 86.3% of the available Ce tracer during a 24-hr period. Cerium uptake by the yeast was reported to involve absorption of the element by some solid phase on or in the yeast cell rather than through active transport. Ruthenium phenathroline concentrations of 10^{-3}M were

reported to completely inhibit the production of acetic and propionic acids (Evans et al., 1977). Beever et al. (1978) reported a reduction in organic matter digestibility at Ru concentrations of $2.2 \times 10^{-5}M$ and above. However, Coleman (1979) reported that Yb had no effect on in vitro digestibility of DM or cell walls. These results agree with those of Teeter et al. (1979) who reported that digestibility was not effected by Yb when measured by disappearance from dacron bags.

Activation analysis for the quantification of rare earth elements are more sensitive than gravimetric procedures. However this method is expensive and can place restrictions on experimental procedures. Nonradioactive Yb has successfully been detected by X-ray fluorescent spectrometry (Beever et al., 1978) and through atomic absorption spectrophotometry (Prigge et al., 1981).

Marker Administration and Fecal Collection Schedules

Several combinations of marker administration and fecal collection schedules have been used. Pond et al. (1987) suggested that markers be administered at least five days prior to sampling and that samples should be collected over a 3- to 7-day period. The diurnal variations reported for several markers require multiple sampling times. Excretion patterns vary with the marker selected (Kane et al., 1952), dosing techniques (Prigge et al., 1981)- and dietary interactions (Crampton and Lloyd, 1951).

Factors Affecting Digestibility Estimates

Digestibility of dietary feed ingredients is a dynamic process and is effected by several related factors. Management practices such as individual verses group feeding and frequency of feeding (McQuire et al., 1966) can affect digestibility. Apparent digestibility of crude protein was reported to be significantly reduced when steers were fed six times daily compared with feeding once daily (McQuire et al., 1966). However, digestibility of other nutrients were unchanged by frequency of feeding.

The extent of degradation of a feed is influenced by the retention time of that feed in the rumen. Ruminal retention time has been reported to vary among animals (Balch and Campling, 1965) and among dietary ingredients (Hartnell and Satter, 1979), which is affected by both the particle size (Balch and Campling, 1965) and the quantity of feed consumed (Lindberg, 1982). Increasing levels of intake are associated with a depression of digestibility (Schneider and Flatt, 1975). Tamminga et al. (1979) reported that the amount of undegraded intake protein in lactating cows consuming 8.2 and 12.9 kg of DM daily was 29 and 45%, respectively. A common criticism of digestion studies is that feed intake is often restricted to maintenance levels. In addition, animals housed in digestion crates or wearing fecal collection bags are subjected to stress which often results in abnormally low and erratic intake (Schneider and Flatt, 1975). Under such conditions, digestibility estimates of a feed would be greater than those expected in a typical production system.

Ruminal retention time is affected by environmental temperatures. An increased rate of digesta passage was reported by Kennedy et al. (1976) for sheep subjected to cold stress.

Environmental temperatures can have a significant effect on voluntary food intake. Intake may be increased as much as 30% when animals are subjected to cold stress, whereas high temperatures and high humidity may result in a maximum of a 30% depression in voluntary food intake depending on the severity of these environmental conditions (NRC).

Digestibility estimates obtained from either total fecal collection or marker-ratio technique studies leave several factors affecting digestibility and the extent of their involvement to speculation. Researchers should be aware that animal response to a given diet will vary with animal type, environmental conditions and management practices, and that digestibility estimates apply only to the conditions in which the experiment was conducted.

CHAPTER III

MATERIALS AND METHODS

Trial 1 (6 Steers/Pen)

One hundred forty-four steer calves (72 Angus and 72 Angus x Hereford) ranging in weight from 273 to 295 kg were randomly allotted to twenty-four feedlot pens (6 steers/pen) in a randomized complete block design. Block assignments were used to remove the possible effect of pen location within a barn on steer performance. All cattle were weighed upon arrival at Blount Farm and at 28-day intervals for the remaining fifty-six day trial.

Each pen was randomly allotted to one of six dietary treatments with four pens per treatment. Mixed grass hay was full fed on day one with a gradual decrease in amount of hay fed each day through day 14. The respective rations were fed on day two and gradually increased as hay was removed from the ration. On day 14, cattle were on full feed of their respective dietary treatments.

Experimental rations consisted of urea treated CS base diets with three levels of SH and two levels of CSC (Table 2) in a 2 by 3 factorial arrangement. A soybean meal (SBM) blend (2 parts ground corn and 1 part SBM) was fed at the rate of $.68 \text{ kg} \cdot \text{steer}^{-1} \cdot \text{day}^{-1}$ to provide an additional source of protein. A mineral mix containing calcium, phosphorus and salt was offered free choice. Feed was provided ad libitum. Feed records were maintained daily for each pen

TABLE 2. EXPERIMENTAL RATIONS FOR TRIALS 1 AND 2

TREATMENT NUMBER	CORN SILAGE	CRACKED SHELLED CORN	SOYBEAN HULL
----- % OF DM -----			
1	100	0	0
2	85	0	15
3	70	0	30
4	80	20	0
5	65	20	15
6	50	20	30

and feed refusal monitored. Samples of each feed ingredient were collected weekly.

Trial 2 (2 Steers/Pen)

Forty-eight steer calves (24 Angus and 24 Angus x Hereford) were purchased in October, 1986 and ranged in weight from 273 to 295 kg.

Calves were paired on the bases of biological type. Each pair contained one Angus and one Angus x Hereford calf. The paired calves were randomly allotted to twenty-four pens in a randomized complete block design. Treatments were blocked according to location within barn. Each pen was considered as one experimental unit.

Each unit was randomly allotted to one of six dietary treatments. The growth phase followed a two-week adjustment period during which calves were converted from mixed grass hay to their respective diets.

Experimental rations consisted of urea treated CS supplemented with various levels of SH and CSC (Table 2) in a 2 x 3 factorial arrangement. All calves received a ground corn-SBM (2:1) mix as a supplemental protein source at the rate of $.68 \text{ kg} \cdot \text{steer}^{-1} \cdot \text{day}^{-1}$ and cattle were provided with a free choice mineral mix containing calcium, phosphorus and salt. Feed was provided ad libitum throughout the trial with the exception of a restriction to 90% ad libitum during the digestion trial. Feed offered and feed refusal were recorded for the 56-day trial.

Initial weights were taken on day one of the feeding trial and on every 28 days following.

Digestion Trials I and II

Digestion trials were conducted toward the end of the 56-day period, utilizing the steers in trial 2. Lignin and IADF served as internal markers. Chromic oxide was used as an external marker of the particulate fraction of ingesta.

A chromic oxide mix was made to minimize Cr_2O_3 losses during handling and to improve adhesion to ingesta. Each batch of marker was made by mixing 4,400 g of Cr_2O_3 with 17.59 kg of ground corn and water. The mix was dried in a 60C oven for approximately four days.

The Cr_2O_3 mix was added to the diet seven days prior to fecal collections. Feed offered was reduced to 90% ad libitum based on DM intake levels of the previous ten days. A 300-g sample of Cr_2O_3 mix was added to rations fed to each of the 24 pens on day one. On the following 23 consecutive days, a 200-g sample of Cr_2O_3 mix was added to the daily feed of each pen.

In digestion trial I, fecal samples were collected from steers in pens 1 through 12 for a total of four days followed by a seven-day period in which no collections were made, yet Cr_2O_3 administration was continued. The four-day collection schedule was then repeated using animals in pens 13 to 24. Digestion trial II was conducted during the same time frame, however scheduled collections continued for a total of six days. Chromic oxide was administered for the following three days. On day ten, the second

replication of digestion trial II began. Fecal grab samples were collected from pens 1 through 12 for the following six days. Fecal grab samples were collected from each steer in a minimum of 12 of the 24 pens at each scheduled collection. Samples were collected at randomly allotted two-hour intervals representative of a 24-hour period. Fecal samples collected from steers in a pen were combined. The two digestion schedules were employed and conducted simultaneously.

Collection schedules are illustrated in Tables 3 and 4. Ration feedstuffs and refused feeds (containing Cr_2O_3 mix) were collected daily during the collection period and stored for later analysis.

Analysis of Feed, Refused Feed and Fecal Samples

Feed, refused feed and fecal samples were dried in a 60C forced air oven, and ground through a 1 mm screen. Dry matter, ash and CP were determined on all samples (A.O.A.C., 1984). Chromic sesquioxide content of refused feed and fecal samples was determined by chromium analysis with the atomic absorption method of Williams et al. (1962). All samples were analyzed for ADF, lignin and NDF (Goering and Van Soest, 1970). Indigestible acid detergent fiber was determined on all samples. Inoculum preparation and incubation procedures were similar to those described by Waller et al. (1980) with the exception of increasing subsamples to 0.5 g and eliminating incubation of feed samples in acid-pepsin solution. Analysis of ADF in digested samples

TABLE 3. DIGESTION TRIAL I (4-DAY COLLECTION)

SAMPLING SCHEDULE		
DATE		SAMPLING TIME
PEN		

(1 TO 12)	(13 TO 24)	
1/26	2/5	8:00 AM
1/26	2/5	2:00 PM
1/26	2/5	10:00 PM
1/27	2/7	12:00 AM
1/27	2/7	4:00 PM
1/27	2/7	8:00 PM
1/28	2/8	12:00 PM
1/28	2/8	4:00 AM
1/28	2/8	10:00 AM
1/29	2/6	2:00 AM
1/29	2/6	6:00 AM
1/29	2/6	6:00 PM

TABLE 4. DIGESTION TRIAL II (6-DAY COLLECTION)

SAMPLING SCHEDULE		
DATE		SAMPLING TIME
PEN		

(13 TO 24)	(1 TO 12)	
1/27	2/4	8:00 AM
1/27	2/4	12:00 AM
1/27	2/4	4:00 PM
1/27	2/4	8:00 PM
1/29	2/6	2:00 AM
1/29	2/6	6:00 AM
1/29	2/6	6:00 PM
1/29	2/6	10:00 PM
1/31	2/8	12:00 PM
1/31	2/8	4:00 AM
1/31	2/8	10:00 AM
1/31	2/8	2:00 PM

was conducted using the method described by Goering and Van Soest (1970).

Variability Among Dietary Feed Ingredients

The average nutrient value and standard error for each feed ingredient collected during the 56-day trial is presented in Table 5. Table 6 illustrates the average nutrient value and standard error of feeds collected daily during digestion trials I and II. The variation in nutrient value is less than those for samples collected throughout the entire 56-day trial. Calculations of dietary digestibility estimates for both digestion trials were made using the values presented in Table 6. Average nutrient values for CS, CSC and SH are similar in Tables 5 and 6, therefore digestibility estimates should reflect overall animal performance throughout the growth trial.

Tables 7 and 8 contain the nutrient values of dietary treatments based on each feed ingredients contribution to the total ration on a DM bases. Tables 7 and 8 were calculated using values from Tables 5 and 6, respectively.

Calculating Digestibility Estimates

Digestibility estimates for the DM, OM, CP, ADF and NDF fractions of dietary treatments were calculated using the following equations.

A. $\text{kg marker offered} = \% \text{ marker in feed} \times \text{kg DM offered}$

TABLE 5. FEEDSTUFF VARIABILITY - AVERAGE NUTRIENT VALUE AND STANDARD ERROR OF EACH DIETARY FEED INGREDIENT

NUTRIENT ^a	CORN SILAGE		CRACKED SHELLED CORN		SOYHULLS		CORN + SBM	
	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE
----- % DM -----								
DM	31.92	0.29	89.34	0.29	89.99	0.81	89.27	0.28
CP	12.44	0.69	9.15	0.55	12.87	0.68	25.98	0.42
ADF	30.03	1.09	2.85	0.19	51.24	0.60	5.66	0.28
NDF	50.67	0.73	17.31	1.20	67.13	0.82	8.98	0.35
LIGNIN	3.64	0.34	0.43	0.06	1.62	0.07	0.42	0.06

^aDM = dry matter, CP = crude protein, ADF = acid detergent fiber, NDF = neutral detergent fiber.

TABLE 6. AVERAGE NUTRIENT VALUE OF EACH FEED INGREDIENT DURING THE DIGESTION TRIAL

NUTRIENT ^a	CORN SILAGE		CRACKED SHELLED CORN		SOYHULLS		CORN + SBM	
	MEAN	SE	MEAN	SE	MEAN	SE	MEAN	SE
----- % DM -----								
DM	32.94	0.14	89.96	0.17	92.31	0.10	89.96	0.13
CP	11.97	0.22	9.31	0.09	10.84	0.04	23.62	0.86
ASH	5.00	0.05	1.41	0.02	4.58	0.04	3.42	0.12
ADF	28.95	0.34	3.10	0.09	50.59	0.05	4.65	0.07
NDF	51.88	0.59	17.64	0.50	67.61	0.26	14.96	0.12
LIGNIN	3.55	0.09	0.54	0.02	1.65	0.05	0.63	0.03
IADF	10.70	0.35	0.90	0.17	3.09	0.19	0.84	0.13

^aDM = dry matter, CP = crude protein, ADF = acid detergent fiber, NDF = neutral detergent fiber, IADF = indigestible acid detergent fiber.

TABLE 7. RATION COMPOSITION^a DURING THE 56-DAY GROWTH TRIAL

ITEM ^c	CSC ^b :			20		
	SH ^b : 0	15	30	0	15	30
	----- % DM -----					
DM	31.92	40.63	49.34	43.40	52.11	60.83
CP	12.44	12.51	12.57	11.78	11.85	11.91
ADF	30.03	33.21	36.39	24.59	27.78	30.96
NDF	50.67	53.14	55.61	44.00	46.47	48.94
LIGNIN	3.64	3.34	3.03	3.00	2.70	2.39

^aA ground corn-SBM blend (2:1) was fed at the rate of .68 kg/steer/day.

^bCSC = cracked shelled corn, SH = soybean hulls.

^cDM = dry matter, CP = crude protein, ADF = acid detergent fiber, NDF = neutral detergent fiber.

TABLE 8. RATION COMPOSITION^a DURING DIGESTION TRIALS I AND II

ITEM ^c	CSC ^b :	0			20		
	SH ^b :	0	15	30	0	15	30
----- % DM -----							
DM		32.94	41.85	50.75	44.34	53.25	62.16
CP		11.96	11.80	11.63	11.44	11.27	11.10
ASH		5.00	4.94	4.87	4.28	4.22	4.16
ADF		28.95	32.20	35.44	23.78	27.03	30.27
NDF		51.88	54.22	56.57	45.03	47.38	49.72
LIGNIN		3.55	3.27	2.98	2.95	2.66	2.38
IADF		10.70	9.56	8.42	8.74	7.60	6.46

^aA ground corn-SBM blend (2:1) was fed at the rate of .68 kg/steer/day.

^bCSC = cracked shelled corn, SH = soybean hulls.

^cDM= dry matter, CP = crude protein, ADF = acid detergent fiber, NDF = neutral detergent fiber.

B. $\text{kg marker consumed} = \text{kg marker offered} - (\text{kg refused feed} \times \% \text{ marker})$

C. $\text{kg DM excreted} = \text{kg marker consumed} / \% \text{ marker in feces}$

D. $\text{kg DM disappeared} = \text{kg DMI} - \text{kg DM excreted}$

E. $\% \text{ digested} = (\text{kg DM disappeared} / \text{kg DMI}) \times 100$

An average value of each component (DM, CP, ash, ADF, NDF, lignin, IADF) was determined for feedstuffs collected daily during the digestion trial. Dietary treatments were mathematically reconstituted using the average value for each component of feed ingredients and their contribution to the dietary treatment as a percentage of total DM. Refused feeds and fecal samples were evaluated for each pen to determine Cr_2O_3 content and values of each component in which digestibility was to be estimated.

Statistical Analysis

An analysis of variance was performed on data collected from trial 1 and trial 2 using General Linear Model procedure (SAS Institute, Inc., 1985). Animal performance data was analyzed to evaluate the effects of the independent variables (SH, CSC, block and barn) on the dependent variables (average daily gain, DM intake and feed:gain ratios (F/G)). The statistical model for trial 1 is as follows: $\text{ADG, DMI and F/G} = \text{SH CSC block barn SH} \times \text{CSC SH} \times \text{block SH} \times \text{barn CSC} \times \text{block CSC} \times \text{barn block} \times \text{barn}$ and initial weight, where initial weight served as a covariant. The statistical model for trial 2 was similar, except the effect of barn on animal performance was removed. Contrasts were used to detect differences among levels of

main effects when significance was indicated by the "F" test.

Contrasts were as follows: 1) SH 0 vs 15 and 30%, 2) SH 15 vs 30%, 3) CSC 0 vs 20%.

In vitro fermentation data on feed, refused feed and fecal samples were analyzed using General Linear Model procedure (SAS Institute, Inc., 1985). The effects of independent variables (treatment, batch and tube number) on the dependent variable (IADF) were evaluated. When a variable had a significant effect as indicated by the "F" test, Student-Newman-keuls was used to illustrate the magnitude of these differences.

Digestibility differences due to main effects were analyzed using analysis of variance. The statistical model was as follows: the digestibility of DM, CP, OM, ADF, NDF = SH CSC block marker SH x CSC SH x block SH x marker CSC x block CSC x marker and block x marker. Model sum of squares for each main effect was separated into single-degree-of-freedom comparisons of SH and CSC levels. Linear contrasts were as follows: 1) SH 0 vs 15 and 30%, 2) SH 15 vs 30%, 3) CSC 0 vs 20%, 4) Cr vs lignin and IADF, 5) lignin vs IADF.

CHAPTER IV

RESULTS AND DISCUSSION

Trial 1 - Steer Performance

Average daily gain (ADG), dry matter intake (DMI) and feed to gain (F/G) ratios for steers in trial 1 are shown in Table 9.

Including SH (15 or 30% of total DM) and (or) CSC in CS based growing diets resulted in no difference ($P>.05$) in animal performance.

Trial 2 - Steer Performance

Table 10 shows ADG, DMI and F/G ratios of steers in trial 2. Adding 20% CSC to CS based diets resulted in no significant difference ($P>.05$) in ADG, DMI or F/G. Average daily gain and DMI increased ($P<.05$) when SH were included in CS based diets with or without added CSC. Dry matter intake increased linearly ($P<.05$) with increased levels of SH, whereas F/G was not affected.

Steer Performance (Trial 1 vs Trial 2)

Average daily gain, DMI, F/G and standard errors of these means for steers in trial 1 and trial 2 are presented in Table 11.

Animal response in ADG and DMI of both groups showed similar trends to increased levels of SH, however only animal performance for steers in trial 2 was significantly affected ($P<.05$).

Both trials 1 and 2 indicate that at least 30% SH can be

TABLE 9. TRIAL 1 CATTLE PERFORMANCE ON CORN SILAGE-CORN-SOYBEAN HULL DIETS

----- % DRY MATTER -----											
CSC ^a :		0		20		Statistical Analysis					
ITEM	SH ^a :	0	15	30	0	15	30	SE ^b	0 vs 20% CSC	0 vs 15 and 30% SH	15 vs 30% CSC x SH
AVG. DAILY GAIN, KG		.80	.90	.82	.87	.90	1.02	.06			
DRY MATTER INTAKE, KG/D		7.84	8.31	9.16	7.94	8.28	9.21	.39			
FEED/GAIN		9.92	9.43	12.21	9.25	9.42	9.09	.26			

^a CSC = cracked shelled corn, SH = soybean hulls.

^b SE = standard error of the mean.

TABLE 10. TRIAL 2 CATTLE PERFORMANCE ON CORN SILAGE-CORN-SOYBEAN HULL DIETS

ITEM	----- % DRY MATTER -----									
	CSC ^a :					SH:				
	0	15	30	0	15	30	0	15	30	SE ^b
Statistical analysis										
P<										
0 vs 20% 0 vs 15 and 30% 15 vs 30%										
CSC SH SH CSC x SH										
AVG. DAILY GAIN, KG	.56	.85	.78	.67	.89	.90	.10	.05		
DRY MATTER INTAKE, KG/D	7.11	8.95	9.15	7.30	8.80	9.97	.39	.05		
FEED/GAIN	13.12	10.52	11.77	11.24	9.85	11.40	.55			

^a CSC = cracked shelled corn, SH = soybean hulls.

^b SE = standard error of the mean.

TABLE 11. CATTLE PERFORMANCE ON CORN SILAGE-CORN-SOYBEANHULL DIETS

CSC ^a :		----- % DRY MATTER -----						Statistical Analysis				
		0		20				P<				
ITEM	SH ^a :	0	15	30	0	15	30	SE ^b	0 vs 20% CSC	0 vs 15 and 30% SH	0 and 15% SH	CSC x SH
----- AVG. DAILY GAIN, KG -----												
TRIAL 1		.80	.90	.82	.87	.90	1.02	.06				
TRIAL 2		.56	.85	.78	.67	.89	.90	.10		.05		
---- DRY MATTER INTAKE, KG/D ----												
TRIAL 1		7.84	8.31	9.16	7.94	8.28	9.21	.39				
TRIAL 2		7.11	8.95	9.15	7.30	8.80	9.97	.39		.05		
----- FEED/GAIN -----												
TRIAL 1		9.92	9.43	12.21	9.25	9.42	9.09	.26				
TRIAL 2		13.12	10.52	11.77	11.24	9.85	11.40	.55				

^a CSC = cracked shelled corn, SH = soybean hulls.^b SE = standard error of the mean.

used to extend existing CS supplies without reducing animal performance.

Data For Calculating Apparent Digestibility

The average nutrient value of refused feeds in digestion trials I and II are presented in Appendix Tables 1 and 2, respectively. The selective nature of animals in their eating habits can be noted by comparing refused feed values to the nutrient values of feed offered (Table 8). Refused feeds contained a higher average portion of lignin, NDF, IADF and CP. The increase in CP content of refused feed may be due to the adhering of the ground corn-SBM blend to the fibrous fraction of feed or sifting to the bottom of the feed bunk where it remained unconsumed.

Appendix Tables 3 and 4 contain the average values for fecal samples collected in digestion trials I and II, respectively. Fecal samples contained a higher percentage of the less digestible fractions (ash, ADF, NDF, lignin and IADF) than feed offered. Table 6 and Appendix Tables 1 to 4 were used to calculate apparent digestibilities of DM, CP, OM, ADF and NDF for each experimental unit during digestion trials I and II.

Calculated digestibility estimates for trials I and II for each unit using internal markers (lignin, IADF) and the external marker, Cr_2O_3 , are presented in Appendix Tables 5 and 6, respectively. These values were used to calculate the average digestibilities of each dietary treatment as estimated by each marker (Tables 12 and 13).

TABLE 12. APPARENT DIGESTIBILITY (DIGESTION TRIAL 1)

CSC ^a :		0						20					
NUTRIENT ^b	SH ^a :	0		15		30		0		15		30	
		MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
LIGNIN													
DM		68.55	4.20	71.64	2.08	72.53	1.25	70.72	3.45	74.87	0.81	73.62	3.43
CP		62.75	5.05	65.57	2.51	66.09	2.37	61.46	3.59	66.33	1.69	62.80	6.02
OM		70.27	4.00	73.13	1.80	74.03	1.12	72.28	3.35	76.21	0.90	74.77	3.49
ADF		52.40	5.44	61.67	1.99	66.20	1.83	49.35	4.66	62.79	2.20	67.00	2.76
NDF		59.94	6.30	65.74	3.02	68.19	2.05	58.20	4.97	66.99	1.58	68.29	2.48
IADF													
DM		68.94	2.16	71.77	1.45	73.86	1.44	72.74	1.44	75.52	1.05	76.17	3.63
CP		63.22	2.40	65.72	1.96	67.68	3.27	64.05	1.39	67.15	2.69	66.39	6.15
OM		70.64	2.03	73.24	1.31	75.27	1.50	74.19	1.54	76.83	0.80	77.20	3.66
ADF		52.93	2.74	61.80	1.84	67.84	1.72	52.77	1.38	63.73	2.63	70.23	2.95
NDF		60.44	4.03	65.90	2.21	69.75	1.60	61.09	1.78	67.83	1.89	71.39	2.78
CP													
DM		66.99	2.98	70.70	6.20	70.23	2.01	69.79	3.49	72.23	2.39	71.33	5.47
CP		60.83	4.52	64.44	7.56	63.34	1.40	60.20	4.12	62.80	3.10	59.45	9.35
OM		68.78	3.03	72.25	5.80	71.86	1.77	71.39	3.46	73.69	2.49	72.56	5.47
ADF		49.95	4.53	60.43	8.04	63.37	2.50	47.71	4.96	58.92	3.24	64.26	4.79
NDF		57.99	4.51	64.54	8.06	65.54	2.50	56.94	4.34	63.53	2.96	65.65	4.57

^aCSC = cracked shelled corn, SH = soybean hulls.^bDM = dry matter, CP = crude protein, OM = organic matter, ADF = acid detergent fiber, NDF = neutral detergent fiber.

TABLE 13. APPARENT DIGESTIBILITY (DIGESTION TRIAL 11)

CSC ^a :		0			20								
NUTRIENT ^b	SH ^a :	0		15		30							
		MEAN	SD	MEAN	SD	MEAN	SD						
LIGNIN													
DM		67.77	3.56	69.72	1.91	69.78	0.81	68.19	1.70	70.20	2.05	69.67	1.35
CP		61.31	5.67	62.35	4.64	60.68	3.50	58.21	0.88	58.09	3.26	57.61	2.65
OM		69.65	3.54	71.15	1.97	71.37	0.97	69.68	1.67	71.62	2.14	70.75	1.46
ADF		52.02	3.67	58.89	1.28	62.91	2.45	47.53	1.59	58.65	1.68	61.61	1.87
NDF		59.10	4.27	63.12	1.89	65.24	1.64	55.60	1.93	61.85	1.77	63.33	2.07
IADF													
DM		69.18	2.50	70.18	1.38	71.52	2.46	70.10	0.51	71.83	1.30	73.77	1.35
CP		63.02	4.29	62.94	4.06	62.98	3.97	60.65	1.98	60.33	3.39	63.35	2.14
OM		70.98	2.49	71.58	1.46	73.01	2.52	71.50	0.58	73.18	1.39	74.70	1.46
ADF		54.07	2.29	59.48	0.58	65.02	3.97	50.64	1.18	60.90	0.99	66.81	1.47
NDF		60.87	2.89	63.67	1.33	67.22	3.37	58.25	0.53	63.93	0.61	68.31	1.61
Cr													
DM		67.87	2.36	69.12	4.73	71.13	0.48	68.99	2.29	69.00	3.52	65.33	5.06
CP		61.49	3.84	61.62	6.87	62.42	3.50	59.22	3.19	56.36	5.72	51.68	6.29
OM		69.74	2.60	70.56	4.68	72.65	0.31	70.45	2.17	70.46	3.61	66.57	5.00
ADF		52.11	2.52	58.12	5.41	64.58	1.97	48.80	4.12	56.96	4.84	56.17	6.06
NDF		59.21	2.82	62.44	5.08	66.80	0.98	56.69	3.39	60.31	4.21	58.14	5.87

^aCSC = cracked shelled corn, SH = soybean hulls.^bDM = dry matter, CP = crude protein, OM = organic matter, ADF = acid detergent fiber, NDF = neutral detergent fiber.

Digestion Trial I (4-Day Collection)

Interactions between marker and the level of SH in dietary treatments and marker with CSC were not significant for the apparent digestibilities of DM, CP, OM, ADF and NDF. Since no marker by diet interaction was detected, the apparent digestibilities of each dietary treatment were averaged across markers and are presented in Table 14.

Including SH in CS based diets resulted in an increase ($P<.05$) in the apparent digestibility of all dietary components evaluated. These results are consistent with trends in animal performance (Table 10). Average daily gain increased ($P<.05$) as SH were added to CS based diets. Increasing SH levels from 15 to 30% resulted in an increase ($P<.05$) in ADF and NDF digestibility. Soyhulls are high in fiber and the fibrous fractions of SH are highly digestible when compared to CS, therefore ADF and NDF digestibility would be expected to increase with increasing levels of SH.

Average DM and OM digestibility increased ($P<.05$) and CP digestibility decreased ($P<.05$) when CSC was added to CS and CS-SH blended diets. The increase in DM and OM digestibility when CSC was included in the diet may be due to differences in the structural arrangement and complexity of carbohydrates in CSC and CS. The carbohydrates in corn grain are more readily available than those in CS. Crude protein digestibility decreased as CSC was included in dietary treatments. Zein is the principle protein in corn grain and accounts for about half of the total protein in the kernal (Church,

TABLE 14. AVERAGE DIGESTIBILITIES OF EACH TREATMENT (DIGESTION TRIAL I)

NUTRIENT ^b	CSC ^a		0				20				Statistical Analysis			
	SH	0	15		30		0		15		P<		SH	CSC x SH
			0	30	0	30	0	30	0	30	0 vs 20% CSC	0 vs 15 and 30% SH	15 vs 30% SH	
DM		68.16	71.37	72.20	71.08	74.21	72.55				.05	.05		
CP		62.26	65.24	65.70	61.90	65.42	61.04				.05	.05		.05
OM		69.90	72.87	73.72	72.62	75.58	73.65				.05	.05		
ADF		51.76	61.30	65.80	49.94	61.81	66.60				.05	.05	.05	
NDF		59.46	65.39	67.83	58.74	66.12	67.74				.05	.05	.05	

^aCSC = cracked shelled corn, SH = soybean hulls.^bDM = dry matter, CP = crude protein, OM = organic matter, ADF = acid detergent fiber, NDF = neutral detergent fiber.

1986). This protein is less degradable than the protein in the corn plant, therefore CP digestibility would be expected to decrease with increasing levels of CSC.

Digestion Trial II (6-Day Collection)

Although each marker resulted in a different estimate of DM, CP, OM, ADF and NDF digestibility (Table 13), a significant marker by treatment interaction was not detected by the "F" test. The apparent digestibilities of each dietary treatment were averaged across marker and are presented in Table 15.

Including SH in CS and CS-CSC blended diets resulted in increased ($P<.05$) DM, OM, ADF and NDF digestibility. Acid detergent fiber and NDF digestibility increased ($P<.05$) as SH were increased from 15 to 30%.

Adding 20% CSC to CS or CS-SH blended diets resulted in a decrease ($P<.05$) in CP, ADF and NDF digestibility. The observed decrease in ADF and NDF digestibility with CSC additions may have been due to a slight shift in the rumen microbial population in preference toward amylolytic microorganisms. These associative effects may have caused SH and CS to be less efficiently utilized as cellulolytic microbes decrease in number.

Soyhull levels and CSC interactions had no significant affect on apparent digestibilities ($P>.05$).

TABLE 15. AVERAGE DIGESTIBILITIES OF EACH TREATMENT (DIGESTION TRIAL II)

NUTRIENT ^b	CSC ^a				20				Statistical Analysis P<			
	0											
	SH ^a	0	15	30	0	15	30	0 vs 20% CSC	0 vs 15 and 30% SH	15 vs 30% SH	CSC x SH	
DM	68.27	69.67	70.81	70.31	69.09	70.34	70.31		.05			
CP	61.94	62.30	62.03	58.79	59.36	58.26	58.79	.05				
OM	70.12	71.09	72.34	71.43	70.54	71.75	71.43		.05			
ADF	52.73	58.83	64.17	62.60	48.99	58.83	62.60	.05	.05	.05		
NDF	59.73	63.08	66.42	64.41	56.86	62.03	64.41	.05	.05	.05		

^a CSC = cracked shelled corn, SH = soybean hulls.^b DM = dry matter, CP = crude protein, OM = organic matter, ADF = acid detergent fiber, NDF = neutral detergent fiber.

Digestion Trial I vs Digestion Trial II

Digestibility estimates can be affected by collection schedule (Pond et al., 1987) and marker selection (Kane et al., 1952).

Apparent digestibility estimates obtained from digestion trials I and II are presented in Tables 14 and 15, respectively.

Apparent DM digestibility estimates of CS diets (68.16% for trial I and 68.27% for trial II) are similar to those reported by Joanning et al. (1981) where DM digestibility of immature and mature CS were 68.4 and 67.2%, respectively.

Dry matter, OM, ADF and NDF digestibilities showed a similar response to SH additions in both digestion trials I and II. Acid detergent fiber and NDF digestibilities increased as SH were increased from 15 to 30% ($P < .05$). Dry matter and NDF digestibilities reported for both digestion trials exceeded those values reported by Boggs and Okotie-Eboh (1985b) where DM and NDF digestibility of a 70% wheat silage-30% SH blend diet were 65.3 and 65.0%, respectively. The higher estimates of digestibility in this trial may be due to incomplete marker recovery, differences among experimental animals or procedures used, or differences between digestibility of CS and wheat silage based diets.

Dry matter intake increased when SH were added to CS based diets, presumably due to an increased rate of passage. Hintz et al. (1964) reported that the small particle size of SH reduced ruminal retention time when SH served as the sole feed ingredient in steer and lamb diets. An increased rate of passage has been reported to

result in a decrease in DM digestibility (Hintz et al., 1964; Balch and Campling, 1965). In this experiment, DMI and DM digestibility were increased ($P<.05$) as SH was added to CS based diets. The CS and CSC in these diets may have increased the ruminal retention time of SH to the extent that DM digestibility was not reduced, or the rate of fiber digestion in the rumen may have been greater for SH than CS.

Adding 20% CSC to CS and CS-SH blend diets resulted in a significant decrease ($P<.05$) in average CP digestibility in both trials. In digestion trial I, CSC additions resulted in an increase in average DM and OM digestibility, while in trial II, NDF and ADF digestibilities were reduced ($P<.05$).

Factors Affecting Marker Excretion

Several factors affected marker excretion. The diurnal variations in marker excretion are shown in Table 16. Lignin and IADF had similar trends in excretion with maximum (10.37 and 30.58% of DM) excretions at 12pm and minimum excretions (7.90 and 23.74% of DM) at 6pm. Chromic oxide excretion was significantly affected ($P<.05$) by the time of fecal collection, with a maximum excretion of 6.84 mg/g of DM at 8am and a minimum excretion of 5.73 mg/g of DM at 4pm. These results agree with Bloom et al. (1957) who reported maximum excretion of Cr_2O_3 to occur between 5am and 9am. However, Kane et al., (1952) reported Cr_2O_3 concentrations to be above average in morning samples and below average in fecal samples collected in the evening which disagrees with observed results. Diurnal variations in marker excretion may have been reduced if the animals had been fed more than

TABLE 16. THE EFFECTS OF FECAL COLLECTION TIME ON MARKER EXCRETION

TIME	MEAN
LIGNIN	
	(% DM)
12 AM	9.27 c
2 AM	9.45 bc
4 AM	9.04 c
6 AM	8.15 d
8 AM	8.24 d
10 AM	7.91 d
12 PM	10.37 a
2 PM	9.38 bc
4 PM	9.07 c
8 PM	9.87 b
10 PM	9.18 c
IADF	
	(% DM)
12 AM	26.96 d
2 AM	28.44 bc
4 AM	28.29 bc
6 AM	23.74 f
8 AM	25.66 e
10 AM	25.60 e
12 PM	30.58 a
2 PM	27.81 cd
4 PM	26.60 de
6 PM	27.08 d
8 PM	29.22 b
10 PM	28.38 bc
Cr	
	(MG/G DM)
12 AM	6.31 abc
2 AM	6.55 abc
4 AM	6.55 abc
6 AM	6.69 ab
8 AM	6.84 a
10 AM	6.76 a
12 PM	6.71 ab
2 PM	6.57 abc
4 PM	5.73 d
6 PM	5.80 d
8 PM	6.18 bcd
10 PM	6.06 cd

a,b,c,d,e,f Means within marker without a common superscript differ ($P < .05$).

once daily. Lignin and IADF are substances occurring naturally in feedstuffs, therefore diurnal variations in marker excretion may be a reflection of the passage rate of dietary feed ingredients. Chromic oxide may have remained associated with the ground corn grain to which it was added and followed a digesta flow pattern similar to CSC or it may have traveled through the gastrointestinal track as part of the liquid phase.

Appendix Table 7 contains average marker excretions as affected by collection date. Collection date did have a significant effect ($P < .05$) on excretion of lignin, IADF and Cr_2O_3 , however no identifiable pattern is apparent.

Variations in marker excretions for each pen are presented in Appendix Table 8. Excretion of lignin and IADF by pen are a reflection of treatment assignment. Appendix Table 10 contains the effects of treatment on marker excretion. Comparing these values to Table 8 demonstrates the positive correlation between intake and excretion of these internal markers. Chromic oxide excretion as affected by pen (Appendix Table 8), treatment (Appendix Table 9) and block (Appendix Table 10) is a reflection of Cr_2O_3 intake.

Indigestible acid detergent fiber concentrations of feed, refused feed and fecal samples were affected significantly by laboratory procedures. The effects of in vitro run are presented in Appendix Table 11. Tube placement in the incubator had a significant affect on IADF concentrations.

A Comparison of Lignin, IADF and Cr as Markers

In digestion trial I (4-day collection), Cr_2O_3 provided the lowest ($P < .05$) estimates of digestibility of all dietary components evaluated. No significant difference was noted between digestibility estimates calculated using lignin and IADF as markers (Table 17).

Indigestible acid detergent fiber provided the highest ($P < .05$) estimates of digestibility in digestion trial II, while no difference was detected between lignin and Cr_2O_3 estimates (Table 18).

Hunt et al. (1984) reported digestion coefficients for lignin and IADF to be similar to total collection for steers fed chopped orchardgrass hay, while Cr_2O_3 underestimated digestibility. Chromic oxide may have underestimated DM digestibility in this experiment, however total collections were not made.

The higher digestibility estimates reported for IADF as compared to Cr_2O_3 and lignin may be due to the experimental design. Feed samples were collected, incubated and subjected to ADF extraction separately. The IADF content of feed offered was determined by mathematically reconstituting dietary treatments using the average IADF value for each feed ingredient and their contribution to the diet as a percentage of total DM. Therefore, any possible interactions between the IADF content in dietary feed ingredients were not evaluated.

TABLE 17. AVERAGE DIGESTIBILITIES AS ESTIMATED BY EACH MARKER
(DIGESTION TRIAL I)

NUTRIENT ^a	MARKER		
	LIGNIN	IADF	Cr
DM ^b	71.79	72.88	69.99
CP ^b	64.02	65.43	61.67
OM ^b	73.26	74.29	71.54
ADF ^b	59.55	61.08	57.06
NDF ^b	64.34	65.73	62.11

^aDM = dry matter, CP = crude protein, OM = organic matter, ADF = acid detergent fiber, NDF = neutral detergent fiber.

^bContrast of Cr vs lignin and IADF was significant ($P < .05$).

TABLE 18. AVERAGE DIGESTIBILITIES AS ESTIMATED BY EACH MARKER
(DIGESTION TRIAL II)

NUTRIENT ^a	MARKER		
	LIGNIN	IADF	Cr
DM ^b	69.26	71.03	68.88
CP ^b	59.91	62.26	59.38
OM ^b	70.77	72.45	70.39
ADF ^b	56.83	59.25	56.35
NDF ^b	61.40	63.61	60.95

^aDM = dry matter, CP = crude protein, OM = organic matter, ADF = acid detergent fiber, NDF = neutral detergent fiber.

^bContrast of IADF vs Cr and lignin was significant ($P < .05$).

CHAPTER V

SUMMARY

Soyhulls can be used to extend CS supplies in growing rations for beef cattle without causing adverse effects on animal performance. In trial 2 (2 steers/pen), adding 15 or 30% SH to CS based diets resulted in increased ADG and DMI ($P<.05$). Average daily gain, DMI and F/G ratios were not affected by SH additions in trial 1 ($P<.05$).

The digestibility of DM, OM, ADF and NDF increased ($P<.05$) as SH were used to extend corn silage in CS or CS-CSC blend diets for beef cattle. As SH levels were increased from 15 to 30%, ADF and NDF digestibility increased ($P<.05$). The addition of 20% CSC to CS or CS-SH blend diets resulted in a decrease in CP digestibility ($P<.05$).

Dry matter, OM, ADF and NDF showed similar trends of increased apparent digestibility with increasing levels of SH in both digestion trials. Digestibility estimates of all dietary components evaluated tended to be slightly higher in trial I, except for treatment 1, in which only CP digestibility was higher. Digestion trial II was more sensitive to differences among fiber digestion (ADF and NDF) as affected by the addition of 20% CSC. Crude protein digestibility decreased ($P<.05$) when CSC was added to CS based diets in both trials.

Chromic oxide provided the lowest digestibility estimates of all dietary components evaluated in digestion trial I, and reported values were significantly lower than those when IADF and lignin served as markers ($P<.05$). Indigestible acid detergent fiber provided significantly higher estimates of digestibility than either Cr_2O_3 and

lignin in digestion trial II. The excretion of Cr_2O_3 was minimally effected by fecal collection time, while IADF showed considerable variations in excretion.

BIBLIOGRAPHY

BIBLIOGRAPHY

- Allison, D. W. and D. F. Osbourn. 1970. The cellulose-lignin complex in forages and its relationship to forage nutritive value. *J. Agric. Sci. (Camb.)* 74:23.
- AOAC. 1984. Official Methods of Analysis (14th Ed.) Association of Official Analytical Chemists. Washington, DC.
- Balch, C. C. and R. C. Campling. 1965. Rate of passage of digesta through the ruminant digestive tract. In: R. W. Dougherty, (Ed.). *Physiology of Digestion in the Ruminant*. pp. 108. Butterworths Washington, D. C.
- Beever, D. E., R. C. Kelloway, D. J. Thomson, J. C. MacRae, C. C. Evans, and A. S. Wallace. 1978. A comparison of two radioactive digesta marker systems for the measurement of nutrient flow at the proximal duodenum of calves. *J. Agric. Sci.* 90:157.
- Berger, L., T. Klopfenstein, and R. Britton. 1979. Effect of sodium hydroxide on efficiency of rumen digestion. *J. Anim. Sci.* 49:1317.
- Bhattacharya, A. N. and W. F. Lubbadah. 1971. Feeding high levels of beet pulp in high concentrate dairy rations. *J. Dairy Sci.* 54:95.
- Bhattacharya, A. N. and F. T. Sleiman. 1971. Beet pulp as a grain replacement for dairy cows and sheep. *J. Dairy Sci.* 54:89.
- Blaxter, K. L., N. Graham, and F. W. Wainman. 1956. Some observations on the digestibility of food by sheep, and on related problems. *Brit. J. Nutr.* 10:69.
- Bloom, S., N. L. Jacobson, R. S. Allen, L. D. McGilliard, and P. G. Homeyer. 1957. Effects of various hay:concentrate ratios on nutrient utilization and production responses of dairy cows. II. Observations on ration digestibility and on the excretion pattern of chromic oxide. *J. Dairy Sci.* 40:240.
- Boggs, D. L. 1986. Overcoming negative associative effects in steer growing-finishing diets. *Proc. Georgia Nutr. Conf.*, p. 67.
- Boggs, D. L. and G. O. Okotie-Eboh. 1985a. Effects of soyhulls and level of grain on digestibility of wheat silage diets. *J. Anim. Sci.* 61(Suppl. 1):481.
- Boggs, D. L. and G. O. Okotie-Eboh. 1985b. Soyhull supplementation and one versus two phase finishing systems for steers fed wheat silage based diets. *J. Anim. Sci.* 61(Suppl. 1):481.

- Bradley, N. W., R. M. Forbes, W. W. Albert, G. E. Mitchell, Jr., and A. L. Neumann. 1958. Use of the chromic oxide method for determining digestible energy and protein in complete pelleted steer rations. *J. Anim. Sci.* 17:1199 (Abstr).
- Burroughs, W., W. P. Gerlaugh, B. H. Edgington, and R. M. Bethke. 1949. The influence of corn starch upon roughage digestion in cattle. *J. Anim. Sci.* 8:271.
- Byers, F. M., J. K. Matoushima, and D. E. Johnson. 1975. The significance of associative effects of feeds on corn silage and corn grain energy values. *Colorado State Univ., Exp. Sta. Bull.* 949, p. 18-21.
- Church, D. C. 1986. *Livestock Feeds and Feeding*. 2nd Ed. Prentice-Hall. Englewood Cliffs. New Jersey.
- Clanton, D. C. 1962. Variations in chromic oxide methods of determining digestibility of hand fed beef cattle rations. *J. Anim. Sci.* 21:214.
- Crampton, E. W. and L. E. Lloyd. 1951. Studies with sheep on the use of chromic oxide as an index of digestibility of ruminant rations. *J. Nutr.* 45:319.
- Cochran, R. C., D. C. Adams, J. D. Wallace, and M. L. Galyean. 1986. Predicting digestibility of different diets with internal markers: Evaluation of four potential markers. *J. Anim. Sci.* 63:1476.
- Cochran, R.C., E. S. Vanzant, K. A. Jacques, M. L. Galyean, D. C. Adams, and J. D. Wallace. 1987. Internal markers. *Proc. Grazing Livestock Nutr. Conf.* p. 39-49.
- Coleman, S. W. 1979. The use of Ytterbium as a rumen kinetic marker. *J. Anim. Sci.* 49 (Suppl. 1):38 (Abstr.)
- Cullison, A. E. and R. S. Lowrey. 1987. *Feeds and Feeding*. 4th Ed. p. 239. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.
- Davis, C. L., J. H. Byers, and L. E. Luber. 1958. An evaluation of the chromic oxide method for determining digestibility. *J. Dairy Sci.* 41:152.
- Drude, R. E., J. R. Eacano, and L. L. Rusoff. 1971. Value of complete feeds containing combinations of corn silage, alfalfa pellets, citrus pulp and cottonseed hulls for lactating cows. *J. Dairy Sci.* 54:773(Abstr.).
- Elam, C. J., P. J. Reynolds, R. E. Davis, and D. O. Everson. 1962. Digestibility studies by means of chromic oxide, lignin and total collection techniques with sheep. *J. Anim. Sci.* 21:189.

- Ellis, W. C. 1968. Dysprosium as an indigestible marker and its determination by radioactivation analysis. *J. Agric. Food Chem.* 16:220.
- Ellis, W. C. 1978. Determinants of grazed forage intake and digestibility. *J. Dairy Sci.* 61:1828.
- Ellis, W. C. and J. E. Huston. 1968. Ce-141 Pr-144 as a particulate digesta flow marker in ruminants. *J. Nutr.* 95:67.
- Ellis, W. C., G. T. Schelling, and L. W. Green. 1983. The acid resistant binding of ytterbium with feedstuffs. *J. Anim. Sci.* 57(Suppl. 1):429 (Abstr.).
- Erfle, J. D., R. J. Boila, R. M. Teather, S. Mahadevan, and F. D. Saver. 1982. Effect of pH on fermentation characteristics and protein degradation by rumen microorganisms in vitro. *J. Dairy Sci.* 65:1457.
- Evans, C. C., J. C. MacRae, and S. Wilson. 1977. Determination of ruthenium and chromium by X-ray fluorescence spectrometry and the use of inert ruthenium (II) phenanthroline as a solid phase marker in sheep digestion studies. *J. Agric. Sci. (Camb.)* 89:17.
- Fahey, G. C. Jr., G. A. McLaren, and J.E. Williams. 1979. Lignin digestibility by lambs fed both low quality and high quality roughages. *J. Anim. Sci.* 48:941.
- Fahey, G. C., Jr. and H. G. Jung. 1983. Lignin as a marker in digestion studies. A review. *J. Anim. Sci.* 57:220.
- Faichney, G. J. 1975. The use of markers to partition digestion within the gastrointestinal tract of ruminants. In: I. W. MacDonald and A. C. I. Warner (Ed.). *Digestion and Metabolism in the Ruminant*. pp. 277-291. Univ. of New England Publishing Unit, Armidale, NSW, Australia.
- Firkins, J. L., L. L. Berger, and G. C. Fahey, Jr., 1985. Evaluation of wet and dry distillers grains and wet and dry corn gluten feeds for ruminants. *J. Anim. Sci.* 60:847.
- Forbes, E. B., W. W. Bramen, M. Kriss, R. Swift, A. Black, D. E. Frear, O. J. Kahlenberg, F. J. McClure, and A. Boris. 1933. The associative effects of feed in relation to the utilization of feed energy. *J. Agric. Res.* 46:753.
- Fox, D. G. and J. R. Black. 1975. The influence of cow size, crossbreeding, slaughter weight, feeding system and environment on edible beef production. *Proc. of 1975 Reciprocal Meats Conf.* p. 90.

- Galyean, M. L., D. G. Wagner, and F. N. Owens. 1979. Level of feed intake and site and extent of digestion of high concentrate diets by steers. *J. Anim. Sci.* 49:199.
- Goering, H. K. and P. J. Van Soest. 1970. Forage fiber analyses (apparatus, reagents, procedures and some application). *Agric. Handbook No. 379.* ARS, USDA.
- Hardison, W. A. and J. T. Reid. 1953. Use of indicators in the measurement of the dry matter intake of grazing animals. *J. Nutr.* 51:35.
- Hartnell, G. F. and L. D. Satter. 1979. Extent of particulate marker (samarium, lanthanum and cerium) movement from one digesta particle to another. *J. Anim. Sci.* 48:375.
- Hintz, H. F., M. M. Mathias, H. F. Ley, Jr., and J. K. Loosli. 1964. Effects of processing and feeding hay on the digestibility of soybean hulls. *J. Anim. Sci.* 23:43.
- Hoover, W. H., C. R. Kincaid, G. A. Varga, W. H. Thayne, and L. L. Junkins, Jr., 1984. Effects of solids and liquid flows on fermentation in continuous culture. IV. pH and dilution rate. *J. Anim. Sci.* 58:692.
- Hopper, J. T., J. W. Holloway, and W. T. Butts, Jr. 1978. Animal variation in chromium sesquioxide excretion patterns of grazing cows. *J. Anim. Sci.* 46:1096.
- Hunt, C. W., J. A. Paterson, S. J. Miller, and J. E. Williams. 1984. Comparison of several internal and external markers for estimating dry matter digestibility and fecal output of steers. *J. Anim. Sci.* 59:(Suppl. 1):427.
- Joanning, S. W., D. E. Johnson, and B. P. Barry. 1981. Nutrient digestibility depressions in corn silage-corn grain mixtures fed to steers. *J. Anim. Sci.* 53:1095.
- Johnson, D. E., W. E. Dinusson, and D. W. Bolin. 1964. Rate of passage of chromic oxide and composition of digesta along the alimentary tract of wethers. *J. Anim. Sci.* 23:499.
- Johnson, G. T. and G. C. Kyker. 1966. The mechanism of cerium uptake by *Saccharomyces cerevisiae*. *Mycologia* 58:91.
- Jung, H. G. and G. C. Fahey, Jr. 1983. Nutritional implications of phenolic monomers and lignin: A review. *J. Anim. Sci.* 57:206.

- Kane, E. A., W. C. Jacobson, and L. A. Moore. 1950. A comparison of techniques used in digestibility studies with dairy cattle. *J. Nutr.* 41:583.
- Kane, E. A., W. C. Jacobson, and L. A. Moore. 1952. Diurnal variation in the excretion of chromium oxide and lignin. *J. Nutr.* 47:263.
- Kane, E. A., R. E. Ely, W. C. Jacobson, and L. A. Moore. 1953. A comparison of various digestion trial techniques with dairy cattle. *J. Dairy Sci.* 36:325.
- Kennedy, P. M., R. J. Christopherson, and L. P. Milligan. 1976. The effect of cold exposure of sheep on digestion, rumen turnover time and efficiency of microbial synthesis. *Br. J. Nutr.* 36:231.
- Klopfenstein, T. 1983. By-products for ruminants. *Proc. Georgia Nutr. Conf.*, p. 120.
- Kotb, A. R. and T. D. Luckey. 1972. Markers in nutrition. *Nutr. Abstr. and Reviews.* 42:813.
- Kromann, R. P. 1967. A mathematical determination of energy values of ration ingredients. *J. Anim. Sci.* 26:1131.
- Kromann, R. P. and E. E. Ray. 1967. Energy metabolism in sheep as influenced by interactions among nutritional and genetic factors. *J. Anim. Sci.* 26:1379.
- Krysl, L. J., M. L. Galyean, R. E. Estell, and B. F. Sowell. 1986. Comparison of internal markers used to evaluate diet digestibility. *J. Anim. Sci.* 63(Suppl. 1):473.
- Lambourne, L. J. 1957. Measurement of feed intake of grazing sheep. II. The estimation of faeces output using markers. *J. Agric. Sci. (Camb.)* 48:415.
- Langlands, J. P., J. L. Corbett, I. McDonald, and G. W. Reid. 1963. Estimation of the faeces output of grazing animals from the concentration of chromium sesquioxide in a sample of faeces. II. Comparison of estimates from samples taken at fixed times of day with estimates from samples collected from the sward. *Brit. J. Nutr.* 17:219.
- Langlands, J. P. 1975. Techniques for estimating nutrient intake and its utilization by the grazing ruminant. In: I. W. McDonald and A. C. I. Warner (Ed.). *Digestion and Metabolism in the Ruminant*. University of New England Publishing Unit. Armidale, NSW, Australia.

- Lindberg, J. E. 1982. Ruminant flow rate of soya-bean meal, rapeseed meal and cottonseed meal in cows fed at maintenance and at three times maintenance. *J. Agric. Sci., Camb.* 98:689.
- Lippke, H., W. C. Ellis, and B. F. Jacobs. 1986. Recovery of indigestible fiber from feces of sheep and cattle on forage diets. *J. Dairy Sci.* 69:403.
- MacRae, J. C. 1974. The use of intestinal markers to measure digestive function in ruminants. *Proc. Nutr. Soc.* 33:147.
- McCullough, M. E. 1968. Influence of hay or silage and ratio of flaked corn or beet pulp to forage on cellulose disappearance in vitro. *J. Anim. Sci.* 27:780.
- McDonald, P., R. A. Edwards, and J. F. D. Greenhalgh. 1981. *Animal Nutrition*. 3rd Ed. Longman, Inc., New York.
- McDonnell, M. L., T. J. Klopfenstein, and J. K. Merrill. 1982. Soybean hulls as energy source for ruminants. *Nebraska Beef Cattle Report MP-43:54*.
- McDonnell, M.L., T. J. Klopfenstein, and J. K. Merrill. 1983. Soybean hulls can replace corn in growing rations. *Nebraska Beef Cattle Report MP-44:17*.
- McQuire, R. L., N. W. Bradley, and C. O. Little. 1966. Effects of frequency of feeding on excretion of chromic oxide, crude protein and gross energy and on nutrient digestibility by steers. *J. Anim. Sci.* 25:185.
- Mehrez, A. Z., M. M. El-Shinnawy, M. A. El-Ashry, and H. M. E. Ead. 1983. Assessment of the associative effect of roughages and concentrates. *J. Anim. Sci.* 57(Suppl. 1):452.
- Meiske, J. C., R. D. Goodrich, and D. W. Crawford. 1978. Corn grain-corn silage feeding systems for steer calves. *Minn. Cattle Feeders Report* p. 9.
- Merrill, J., and T. Klopfenstein. 1984. Soybean hulls for grazing beef cattle. *Nebraska Beef Cattle Report.*, p. 40.
- Merrill, J., and T. Klopfenstein. 1985. Soyhulls utilization in forage diets. *Nebraska Beef Cattle Report.*, p. 48.
- Mertens, D. R. and J. R. Loften. 1980. The effects of starch on forage fiber digestion kinetics in vitro. *J. Dairy Sci.* 63:1437.

- Mould, F. L., E. R. Orskov, and S. A. Gauld. 1983. Associative effects of mixed feeds. II. The effect of dietary addition of bicarbonate salts on the voluntary intake and digestibility of diets containing various proportions of hay and barley. *Anim. Feed Sci. and Technol.* 10:31.
- Muntifering, R. B. 1982. Evaluation of various lignin assays for determining ruminal digestion of roughages by lambs. *J. Anim. Sci.* 55:432.
- NRC. 1984. Nutrient Requirements of Domestic Animals, Nutrient Requirements of Beef Cattle. Sixth Rev. Ed. pp. 38. National Academy of Sciences-National Research Council. Washington, D. C.
- Neilson, M. J. and G. N. Richards. 1978. The fate of the soluble lignin-carbohydrate complex produced in the bovine rumen. *J. Sci. Food Agric.* 29:513.
- Prigge, E. C., G. A. Varga, J. L. Vicini, and R. L. Reid. 1981. Comparison of ytterbium chloride and chromium sesquioxide as fecal indicators. *J. Anim. Sci.* 53:1629.
- Pond, K. R., J. C. Burns, and D. S. Fisher. 1987. External markers-use and methodology in grazing studies. *Proc. Grazing Livestock Nutr. Conf.* pp. 49.
- Raymond, W. F. 1969. The nutritive value of forage crops. *Advan. Agron.* 21:1.
- Reeves, J. B. 1985a. Lignin composition and in vitro digestibility of feeds. *J. Anim. Sci.* 60:316.
- Reeves, J. B. 1985b. Lignin composition of chemically treated feeds as determined by nitrobenzene oxidation and its relationship to digestibility. *J. Dairy Sci.* 68:1976.
- Russell, J. B. and D. B. Dombrowski. 1980. Effect of pH on the efficiency of growth by pure cultures of rumen bacteria in continous culture. *Appl. Environ. Microbiol.* 39:604.
- SAS Institute, Inc. 1985. SAS user's guide: Statistics. SAS Institute Inc., Cary, NC.
- Schneider, B.H. and W. P. Flatt. 1975. The evaluation of feeds through digestibility experiments. p. 27-29. The Univ. of Georgia Press, Athens.
- Shriver, B. J., W. H. Hoover, J. P. Sargent, R. J. Crawford, Jr., and W. V. Thayne. 1986. Fermentation of high concentrate diet as affected by ruminal pH and digesta flow. *J. Dairy Sci.* 69:413.

- Streeter, C. L.. 1969. A review of techniques used to estimate the in vivo digestibility of grazed forage. J. Anim. Sci. 29:757.
- Tamminga, S., C. J. VanDer Koelen, and A. M. VanVuuren. 1979. Effect of level of feed intake on nitrogen entering the small intestine of dairy cows. Livestock Prod. Sci. 6:255.
- Teeter, R. G., F. N. Owens, and G. W. Horn. 1979. Ytterbium as a ruminal marker. J. Anim. Sci. 49:412 (Abstr.)
- Teeter, R. G., F. N. Owens, and T. L. Mader. 1981. Ytterbium chloride as a particulate phase marker for ruminants. J. Anim. Sci. 52:436 (Abstr.).
- Tennessee Agriculture. 1987. Tennessee Agricultural Statistics Service. Nashville, Tennessee.
- Thonney, M. L., D. J. Duhaime, P. W. Moe, and J. T. Reid. 1979. Acid insoluble ash and permanganate lignin as indicators to determine digestibility of cattle rations. J. Anim. Sci. 49:1112.
- Tilley, J. M. A. and R. A. Terry. 1963. A two-stage technique for the in vitro digestion of forage crops. J. Br. Grassl. Soc. 18:104.
- Uden, P., P. E. Colucci, and P. J. Van Soest. 1980. Investigation of chromium, cerium and cobalt as markers in digesta rate of passage. J. Sci. Food Agric. 31:632.
- Van Keulen, J. and B. A. Young. 1977. Evaluation of acid insoluble ash as a natural marker in ruminant digestibility studies. J. Anim. Sci. 44:282
- Van Soest, P. J., R. H. Wine, and L. A. Moore. 1966. Estimation of the true digestibility of forages by the in vitro digestion of cell walls. Proc. 10th Int. Grassl. Congr. Helsinki, Finland.
- Van Soest, P. J., 1982. Nutritional Ecology of the Ruminant. O & B Books, Inc. Corvallis, Oregon.
- Vance, R. D., R. L. Preston, V. R. Cahill, and E. W. Klosterman. 1972. Net energy evaluation of cattle-finishing rations containing varying proportions of corn grain and corn silage. J. Anim. Sci. 34:851.
- Varga, G. A. and W. H. Hoover. 1983. Rate and extent of neutral detergent fiber degradation of feedstuffs in situ. J. Dairy Sci. 66:2109.

- Waller, J. C., N. Merchen, T. Hanson, and T. Klopfenstein. 1980. Effect of sampling intervals and digesta markers on abomasal flow determinations. J. Anim. Sci. 50:1122.
- Williams, C. H., D. J. David, and O. Iismaa. 1962. The determination of chromic oxide in feces samples by atomic absorption spectrophotometry. J. Agric. Res. 59:381.
- Woody, H. D. and D. G. Fox. 1977. The effect of corn silage grain content on feedlot performance. Mich. State Univ. Research Report. no. 328. pp. 72-81.
- Woody, H. D., D. G. Fox, and J. R. Black. 1983. Effect of diet grain content on performance of growing and finishing cattle. J. Anim. Sci. 57:717.

APPENDIX

TABLE A1. AVERAGE NUTRIENT VALUE OF REFUSED FEEDS (DIGESTION TRIAL I)

PEN	DM	CP	ASH	ADF	NDF	LIGNIN	Cr	IADF
----- % DM -----								
1	35.17	12.45	5.87	28.95	52.57	3.14	0.70	11.83
2	36.09	12.49	5.13	33.03	58.17	3.45	0.20	11.60
3	33.10	12.34	5.21	39.52	68.99	5.85	0.45	12.25
4	32.80	12.19	5.22	28.37	49.20	4.29	1.45	10.62
5	34.26	13.38	5.43	34.39	61.54	4.93	0.53	12.37
6	38.36	12.60	5.33	26.41	50.80	3.09	0.67	11.28
7	37.37	12.87	4.51	26.40	52.02	3.42	0.48	11.27
8	32.89	12.64	4.59	31.53	55.88	4.74	0.70	11.30
9	39.57	12.70	4.57	31.76	55.36	3.95	0.49	11.64
10	.	.	.	.	.	.	.	.
11	42.74	12.50	4.79	31.81	55.34	4.21	0.71	11.57
12	38.51	13.57	5.55	31.01	56.29	3.46	0.64	12.55
13	38.57	11.96	4.90	31.80	57.58	3.62	0.90	13.24
14	32.02	11.39	5.05	36.97	68.17	4.43	0.49	16.49
15	36.49	12.13	5.09	34.73	63.46	4.10	0.44	12.90
16	46.42	12.08	4.06	30.61	54.85	3.14	0.64	9.14
17	34.80	12.82	5.35	32.28	61.08	3.83	0.81	13.12
18	39.46	12.43	4.63	33.25	59.45	3.91	0.54	13.08
19	44.01	12.24	4.59	28.84	50.38	3.06	0.54	8.98
20	38.58	11.68	4.29	34.82	62.19	4.51	0.70	13.84
21	.	.	.	.	.	.	.	.
22	.	.	.	.	.	.	.	.
23	.	.	.	.	.	.	.	.
24	.	.	.	.	.	.	.	.

TABLE A2. AVERAGE NUTRIENT VALUE OF REFUSED FEEDS (DIGESTION TRIAL II)

PEN	DM	CP	ASH	ADF	NDF	LIGNIN	Cr	IADF
----- % DM -----								
1	35.12	12.58	5.91	28.72	51.24	3.07	0.45	12.67
2	36.08	12.65	5.41	33.25	58.79	3.56	0.75	11.54
3	32.83	12.06	5.30	37.74	65.22	4.90	0.57	13.29
4	32.88	12.62	5.45	27.82	48.85	4.19	2.04	10.25
5	34.07	12.64	5.48	33.04	57.51	4.90	0.50	12.22
6	38.20	12.85	5.38	27.48	50.40	2.86	0.94	10.78
7	37.55	12.28	4.44	26.89	52.64	3.41	0.48	11.07
8	33.15	12.58	4.28	34.45	57.34	5.60	0.70	11.79
9	39.52	13.00	4.57	31.98	55.87	3.64	0.54	13.83
10	.	.	.	.	.	.	.	.
11	42.62	12.40	4.80	35.29	61.05	4.81	0.78	12.59
12	38.59	13.24	5.43	30.76	55.65	3.61	0.66	12.25
13	38.28	12.15	4.97	31.31	56.40	3.55	0.93	12.60
14	31.99	11.87	5.18	33.07	59.74	4.13	0.58	13.46
15	36.41	11.90	5.32	35.28	63.51	4.36	0.39	13.30
16	46.61	12.39	4.08	29.88	53.78	3.05	0.65	8.97
17	34.58	12.47	4.53	31.50	59.01	3.96	0.71	12.91
18	39.58	12.35	4.71	31.34	55.19	3.67	0.99	12.45
19	44.31	12.23	4.42	29.52	49.96	2.91	0.78	8.33
20	38.65	11.79	4.45	34.49	61.47	4.16	0.60	13.32
21	.	.	.	.	.	.	.	.
22	.	.	.	.	.	.	.	.
23	46.03	12.23	3.07	25.50	47.09	2.96	0.88	9.05
24	31.41	10.85	3.75	39.13	70.08	5.94	0.41	8.76

TABLE A3. AVERAGE VALUES FOR FECAL SAMPLES COLLECTED DURING DIGESTION TRIAL I

PEN	DM	CP	ASH	ADF	NDF	LIGNIN	Cr	IADF
----- % DM -----								
1	12.21	14.32	10.46	43.25	64.98	8.79	5.19	29.40
2	12.77	16.24	9.56	36.00	58.59	8.19	6.10	27.10
3	12.40	15.01	10.37	40.11	62.77	10.32	6.44	29.89
4	13.65	16.88	9.97	36.53	58.56	9.19	6.93	26.97
5	11.82	15.38	10.14	39.88	62.78	9.45	5.46	28.72
6	15.35	16.13	8.98	39.20	60.53	8.90	6.21	26.27
7	13.54	15.51	8.82	36.80	58.90	8.89	6.19	25.61
8	13.15	15.52	9.78	39.05	59.73	9.32	7.01	27.09
9	12.10	15.70	10.28	41.69	62.57	9.38	5.99	28.10
10	13.07	15.18	10.64	39.27	61.02	10.42	7.02	31.22
11	13.01	16.87	10.90	37.04	60.37	9.28	8.48	29.58
12	12.92	15.23	9.76	38.80	61.96	8.76	6.71	28.45
13	13.97	15.57	7.73	35.87	56.53	9.19	5.64	27.71
14	13.23	15.00	9.79	41.00	60.24	10.40	5.20	28.74
15	12.55	15.42	9.15	41.68	60.92	11.33	5.93	32.22
16	14.69	17.32	7.62	33.60	53.55	8.04	5.03	22.94
17	14.24	16.04	9.22	40.57	58.95	11.59	6.56	32.89
18	14.79	15.26	7.64	35.31	57.23	8.30	6.18	26.30
19	14.87	16.87	7.45	34.54	53.66	8.23	5.01	22.67
20	13.23	15.63	9.18	41.94	60.25	11.44	6.38	31.53
21	14.98	17.24	8.92	38.02	57.79	10.73	8.42	29.37
22	12.15	16.24	9.12	40.86	61.54	10.10	6.87	27.82
23	11.77	16.80	9.28	36.17	57.28	10.12	6.04	27.70
24	13.65	15.06	10.81	40.61	59.42	11.00	7.67	33.22

TABLE A4. AVERAGE VALUES FOR FECAL SAMPLES COLLECTED DURING DIGESTION TRIAL II

PEN	DM	CP	ASH	ADF	NDF	LIGNIN	Cr	IADF
----- % DM -----								
1	12.22	17.07	10.67	41.78	62.00	9.49	5.51	27.98
2	12.95	16.29	9.00	35.74	58.84	8.17	6.22	26.90
3	12.48	15.63	10.07	38.88	60.30	10.06	6.37	31.06
4	13.66	17.65	7.92	31.19	52.01	7.34	6.03	22.62
5	11.84	17.07	9.01	39.54	61.95	9.03	6.18	27.33
6	15.26	16.50	6.79	36.57	57.81	6.75	3.98	19.48
7	13.57	16.87	7.65	36.31	57.02	7.02	5.21	21.66
8	13.17	17.16	8.21	34.67	56.64	7.93	5.19	23.28
9	12.06	17.49	9.06	39.00	60.31	9.03	6.20	25.32
10	13.09	15.81	8.67	39.83	60.75	9.65	5.53	28.60
11	12.96	17.71	9.00	36.00	58.18	8.78	7.57	25.76
12	12.83	16.09	9.71	37.54	60.17	8.82	6.92	27.84
13	14.03	15.72	8.39	35.85	58.42	7.74	5.84	23.94
14	13.31	14.20	10.03	43.65	63.21	9.07	5.57	26.58
15	12.62	15.14	9.87	42.17	62.38	10.08	6.85	29.44
16	14.77	16.44	8.24	37.05	58.17	7.46	4.79	22.85
17	14.33	15.17	9.62	40.20	61.08	11.01	7.06	33.74
18	14.84	15.33	8.43	32.92	55.78	7.77	6.50	24.19
19	14.97	15.59	7.08	34.90	53.92	6.99	4.47	20.40
20	13.29	14.99	9.64	42.20	62.79	10.47	7.21	29.93
21	15.05	16.09	8.06	34.94	56.59	8.33	7.83	25.68
22	12.18	15.76	9.27	42.21	63.01	8.88	6.55	24.63
23	11.76	17.32	10.26	36.78	59.50	8.69	6.11	24.96
24	13.63	15.25	12.31	40.98	61.53	10.78	7.88	32.98

TABLE A5. DIGESTIBILITY ESTIMATES (DIGESTION TRIAL I)

NUTRIENT	LIGNIN	IADF	Cr	LIGNIN	IADF	Cr
--- PEN 1 ---						
DM	71.74	75.18	68.99	67.37	70.94	65.41
CP	67.05	71.07	63.85	57.43	62.08	54.88
OM	73.47	76.70	70.89	69.21	72.58	67.37
ADF	64.73	69.03	61.30	45.59	51.54	42.33
NDF	66.37	70.47	63.10	54.16	59.17	51.41
--- PEN 2 ---						
DM	69.46	67.20	67.38	74.23	74.87	71.52
CP	64.62	62.00	62.20	64.26	65.15	60.50
OM	71.24	69.11	69.28	75.83	76.43	73.29
ADF	53.48	50.03	50.31	61.43	62.40	57.38
NDF	59.93	56.95	57.19	65.50	66.37	61.88
--- PEN 3 ---						
DM	69.29	70.12	65.33	76.47	79.78	75.33
CP	62.38	63.40	57.53	67.41	71.99	65.82
OM	71.01	71.80	67.28	77.72	80.85	76.64
ADF	59.13	60.24	53.87	67.87	72.39	66.30
NDF	61.85	62.89	56.94	69.59	73.87	68.11
--- PEN 4 ---						
DM	75.66	77.85	76.70	75.48	75.58	74.27
CP	67.69	70.59	69.07	68.36	68.49	66.79
OM	76.88	78.95	77.86	76.94	77.03	75.79
ADF	68.64	71.45	69.97	60.88	61.04	58.94
NDF	69.51	72.25	70.81	66.41	66.55	64.74
--- PEN 5 ---						
DM	71.60	73.45	70.35	70.70	71.99	70.34
CP	63.96	66.32	62.38	65.16	66.70	64.74
OM	73.23	74.98	72.06	72.50	73.71	72.17
ADF	65.10	67.38	63.56	61.70	63.40	61.24
NDF	67.05	69.20	65.60	64.94	66.49	64.52
--- PEN 6 ---						
DM	71.37	74.05	73.89	62.43	66.94	64.96
CP	61.28	64.90	64.69	55.20	60.59	58.23
OM	73.39	75.88	75.73	64.39	68.67	66.79
ADF	49.93	54.62	54.34	44.47	51.15	48.22
NDF	58.03	61.96	61.73	51.06	56.95	54.36
--- PEN 7 ---						
--- PEN 8 ---						
--- PEN 9 ---						
--- PEN 10 ---						
--- PEN 11 ---						
--- PEN 12 ---						

TABLE A5. (CONTINUED)

NUTRIENT	LIGNIN	IADF	Cr	LIGNIN	IADF	Cr
--- PEN 13 ---						
DM	74.12	76.97	69.15	74.32	74.78	68.56
CP	66.60	70.28	60.18	69.00	69.55	62.04
OM	75.11	77.85	70.33	75.68	76.12	70.23
ADF	63.04	67.11	55.94	68.79	69.35	61.79
NDF	66.82	70.47	60.44	71.01	71.52	64.50
--- PEN 15 ---						
DM	74.04	73.61	67.65	73.52	75.73	67.44
CP	68.38	67.85	60.60	61.10	64.35	52.18
OM	75.23	74.81	69.13	74.51	76.63	68.66
ADF	64.00	63.39	55.14	68.60	71.21	61.39
NDF	68.69	68.17	60.99	69.48	72.02	62.47
--- PEN 17 ---						
DM	71.91	71.01	64.55	68.87	72.21	69.41
CP	65.40	64.29	56.34	60.94	65.13	61.62
OM	73.21	72.35	66.19	70.02	73.23	70.54
ADF	56.63	55.24	45.27	46.17	51.93	47.10
NDF	65.04	63.92	55.88	55.34	60.12	56.11
--- PEN 19 ---						
DM	68.83	71.33	65.86	72.52	71.34	79.47
CP	55.00	58.62	50.72	66.37	64.92	74.87
OM	69.95	72.36	67.09	73.77	72.64	80.41
ADF	62.90	65.88	59.37	61.83	60.18	71.48
NDF	64.56	67.41	61.19	67.46	66.06	75.69
--- PEN 21 ---						
DM	75.27	73.74	70.46	72.46	72.01	73.01
CP	66.17	64.09	59.59	64.36	63.77	65.07
OM	76.50	75.05	71.93	73.72	73.29	74.25
ADF	55.71	52.97	47.08	66.16	65.60	66.83
NDF	65.25	63.11	58.49	68.34	67.82	68.97
--- PEN 23 ---						
DM	75.66	74.65	73.97	70.39	70.59	71.05
CP	66.08	64.66	63.72	65.77	66.00	66.53
OM	76.96	76.01	75.36	72.24	72.42	72.85
ADF	65.79	64.36	63.41	55.00	55.30	56.00
NDF	69.21	67.93	67.07	63.71	63.95	64.52
--- PEN 14 ---						
--- PEN 16 ---						
--- PEN 18 ---						
--- PEN 20 ---						
--- PEN 22 ---						
--- PEN 24 ---						

TABLE A6. DIGESTIBILITY ESTIMATES (DIGESTION TRIAL II)

NUTRIENT	LIGNIN	IADF	Cr	LIGNIN	IADF	Cr
--- PEN 1 ---						
DM	70.62	74.32	70.81	67.29	70.72	66.08
CP	59.16	64.30	59.41	57.19	61.68	55.61
OM	72.49	75.95	72.66	68.95	72.20	67.80
ADF	64.62	69.07	64.84	45.85	51.53	43.85
NDF	66.76	70.95	66.97	53.85	58.69	52.14
--- PEN 3 ---						
DM	68.00	68.68	67.04	67.73	70.04	67.27
CP	61.37	62.19	60.21	53.21	56.56	52.53
OM	69.76	70.41	68.86	69.05	71.26	68.60
ADF	52.97	53.97	51.56	58.77	61.72	58.17
NDF	59.81	60.66	58.60	61.64	64.39	61.09
--- PEN 5 ---						
DM	67.88	68.62	69.39	68.24	72.49	61.52
CP	56.52	57.53	58.57	54.97	60.99	45.45
OM	69.30	70.01	70.75	69.20	73.32	62.69
ADF	57.86	58.84	59.84	59.37	64.80	50.78
NDF	60.94	61.85	62.78	60.82	66.06	52.53
--- PEN 7 ---						
DM	69.18	73.81	72.32	71.93	71.83	65.22
CP	55.68	62.33	60.19	59.97	59.83	50.40
OM	70.34	74.79	73.36	73.13	73.04	66.71
ADF	60.82	66.70	64.80	59.86	59.72	50.27
NDF	62.59	68.21	66.39	63.40	63.27	54.65
--- PEN 9 ---						
DM	69.84	71.24	71.35	68.36	69.43	62.35
CP	57.37	59.35	59.51	60.82	62.15	53.39
OM	71.19	72.53	72.63	69.65	70.67	63.89
ADF	65.33	66.94	67.07	58.06	59.47	50.10
NDF	66.28	67.84	67.97	62.31	63.59	55.16
--- PEN 11 ---						
DM	70.58	70.20	70.75	62.68	65.94	66.02
CP	58.23	57.69	58.47	53.28	57.36	57.47
OM	72.07	71.72	72.24	64.61	67.70	67.78
ADF	49.65	49.00	49.94	46.64	51.30	51.42
NDF	58.14	57.60	58.38	52.87	56.99	57.10
--- PEN 12 ---						
DM	70.58	70.20	70.75	62.68	65.94	66.02
CP	58.23	57.69	58.47	53.28	57.36	57.47
OM	72.07	71.72	72.24	64.61	67.70	67.78
ADF	49.65	49.00	49.94	46.64	51.30	51.42
NDF	58.14	57.60	58.38	52.87	56.99	57.10

TABLE A6. (CONTINUED)

NUTRIENT	LIGNIN	IADF	Cr	LIGNIN	IADF	Cr
--- PEN 13 ---						
DM	69.29	73.12	70.22	69.96	72.12	70.65
CP	59.77	64.79	60.99	65.52	67.99	66.31
OM	70.68	74.33	71.56	71.63	73.66	72.28
ADF	56.24	61.70	57.57	61.44	64.21	62.32
NDF	59.44	64.50	60.67	64.77	67.30	65.58
--- PEN 15 ---						
DM	70.82	71.11	72.00	71.45	75.62	65.79
CP	65.28	65.63	66.68	60.02	65.87	52.11
OM	72.38	72.65	73.49	72.70	76.69	67.29
ADF	58.97	59.38	60.62	62.75	68.19	55.38
NDF	63.97	64.33	65.42	64.35	69.56	57.29
--- PEN 17 ---						
DM	70.45	71.76	67.09	66.73	69.50	70.90
CP	65.55	67.08	61.63	58.09	61.58	63.34
OM	71.92	73.17	68.73	68.23	70.88	72.21
ADF	54.90	56.90	49.76	47.04	51.46	53.68
NDF	62.11	63.79	57.80	54.22	58.04	59.96
--- PEN 19 ---						
DM	69.79	73.14	61.69	71.83	71.54	72.73
CP	59.75	64.21	48.96	66.79	66.44	67.85
OM	70.76	74.00	62.92	73.25	72.97	74.11
ADF	63.49	67.54	53.71	60.66	60.24	61.91
NDF	65.57	69.39	56.35	65.27	64.90	66.38
--- PEN 21 ---						
DM	68.15	69.97	68.23	68.68	68.38	71.69
CP	59.34	61.66	59.44	60.66	60.28	64.44
OM	69.45	71.20	69.53	70.16	69.88	73.03
ADF	47.57	50.57	47.71	60.24	59.86	64.07
NDF	56.17	58.68	56.29	63.13	62.78	66.67
--- PEN 23 ---						
DM	71.83	72.32	73.29	69.96	70.32	71.33
CP	59.42	60.12	61.52	65.04	65.45	66.63
OM	73.61	74.07	74.98	72.31	72.63	73.57
ADF	59.73	60.44	61.82	53.56	54.11	55.68
NDF	62.92	63.57	64.84	61.59	62.04	63.34
--- PEN 14 ---						
--- PEN 16 ---						
--- PEN 18 ---						
--- PEN 20 ---						
--- PEN 22 ---						
--- PEN 24 ---						

TABLE A7. THE EFFECT OF FECAL COLLECTION DATE ON MARKER EXCRETION

DATE	MEAN
LIGNIN	
	(% DM)
JAN 26	9.44 bc
JAN 27	9.27 bc
JAN 28	8.74 d
JAN 29	8.02 e
JAN 31	9.04 cd
FEB 04	7.71 e
FEB 05	9.98 a
FEB 06	8.79 d
FEB 07	9.75 ab
FEB 08	9.35 bc
IADF	
	(% DM)
JAN 26	28.73 a
JAN 27	28.32 ab
JAN 28	27.17 bc
JAN 29	25.58 c
JAN 31	26.21 cd
FEB 04	23.14 e
FEB 05	28.88 a
FEB 06	27.17 bc
FEB 07	27.59 b
FEB 08	28.89 a
Cr	
	(MG/G DM)
JAN 26	6.33 b
JAN 27	6.67 ab
JAN 28	6.57 ab
JAN 29	6.29 b
JAN 31	6.56 ab
FEB 04	5.62 c
FEB 05	6.93 a
FEB 06	6.18 b
FEB 07	5.52 c
FEB 08	6.60 ab

a,b,c,d,e Means within marker without a common superscript differ (P<.05).

TABLE A8. THE EFFECTS OF PEN ON MARKER EXCRETION

PEN	MEAN
LIGNIN	
	(% DM)
1	9.68 def
2	8.20 jklmn
3	9.90 cde
4	8.39 ijklm
5	9.25 efgh
6	7.29 o
7	7.73 mno
8	8.45 hijklm
9	8.99 fghij
10	9.94 cde
11	8.57 ghijk
12	8.75 ghijk
13	8.10 klmn
14	9.30 efg
15	10.14 bcd
16	7.52 no
17	10.87 a
18	7.87 lmno
19	7.49 no
20	10.51 abc
21	9.00 fghij
22	9.17 efghi
23	8.30 iklm
24	10.65 ab
IADF	
	(% DM)
1	29.01 cd
2	27.22 efg
3	30.10 bc
4	25.61 gh
5	28.06 def
6	22.24 ij
7	23.50 i
8	25.15 h
9	26.65 efgh
10	30.02 bc
11	27.23 efg
12	28.39 de
13	25.19 h
14	27.08 efg
15	31.09 b

TABLE A8. (CONTINUED)

PEN	MEAN
16	23.16 i
17	33.05 a
18	25.76 gh
19	21.58 j
20	30.38 bc
21	27.36 efg
22	26.36 fgh
23	24.88 h
24	33.11 a
Cr	
	(MG/G DM)
1	5.58 ijk ^l
2	6.24 efghi
3	6.47 defgh
4	7.01 cd
5	5.94 hijk
6	5.23 k ^l
7	5.67 ijk ^l
8	6.69 defg
9	5.97 ghijk
10	6.59 defgh
11	7.55 bc
12	6.45 defgh
13	5.88 ijk ^l
14	5.50 ijk ^l
15	6.55 defgh
16	5.42 jk ^l
17	6.98 cde
18	5.90 ijk ^l
19	5.01 l
20	6.95 cde
21	8.63 a
22	6.82 def
23	6.10 fghij
24	7.75 b

Means within marker within a common superscript differ ($P < .05$).

TABLE A9. THE EFFECTS OF TREATMENT ON MARKER EXCRETION

TREATMENT	MEAN
LIGNIN	
	(% DM)
1	10.03 a
2	9.96 a
3	9.28 b
4	8.41 c
5	8.31 c
6	7.51 d
IADF	
	(% DM)
1	31.13 a
2	29.89 b
3	27.28 c
4	26.88 c
5	25.21 d
6	22.62 e
Cr	
	(MG/G DM)
1	6.90 a
2	6.51 b
3	5.96 c
4	7.07 a
5	6.42 b
6	5.33 d

a,b,c,d,e Means within marker without a common superscript differ (P<.05).

TABLE A10. THE EFFECTS OF BLOCK ON MARKER EXCRETION

BLOCK	MEAN
LIGNIN	
	(% DM)
1	8.77 b
2	8.74 b
3	8.97 ab
4	9.18 a
IADF	
	(% DM)
1	27.02 ab
2	26.83 b
3	27.57 a
4	27.24 ab
Cr	
	(MG/G DM)
1	6.07 c
2	6.49 b
3	6.04 c
4	6.87 a

a,b,c Means within a common superscript differ ($P < .05$).

TABLE A11. THE EFFECTS OF IN VITRO RUN ON IADF CONTENT IN FECES

IN VITRO RUN	MEAN (% DM)
1	27.21 bcde
2	26.52 cde
3	25.97 de
4	29.69 a
5	26.46 cde
6	27.06 cde
7	27.41 bcd
8	27.54 bc
9	27.22 bcde
10	27.96 bc
11	27.23 bcde
12	25.88 de
13	25.75 e
14	28.22 b

a,b,c,d,e Means within a common superscript differ ($P < .05$).

VITA

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