THE INFLUENCE OF ROUGHAGE LEVEL AND CORN PROCESSING METHOD ON THE SITE AND EXTENT OF DIGESTION BY BEEF STEERS

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CHAPTER I

INTRODUCTION

The efficiency of utilization of corn and grain sorghum in high concentrate finishing rations has been greatly improved through the use of grain processing techniques. Although many feedlots still process corn grain in some manner, recent studies have indicated that whole shelled corn can be used satisfactorily without the added expense of processing. The utilization of whole shelled corn, however, may be dependent upon the level of roughage in the ration (Vance et al., 1971).

Roughage is often defined as a feed with a total digestible nutrient (TDN) value of less than 60% or a crude fiber content of more than 15%. Arbitrary roughage values for different feeds that will be used in this report are; cottonseed hulls and hay, 100% and corn silage due to the presence of corn grain, 50% of the feed dry matter.

Most feedlots have fed relatively constant low levels (5 to 15%) of roughage in cattle finishing rations without regard to the type of grain or method of grain processing used. Low levels of roughage served, in some cases, to reduce the incidence of liver abscesses (Wise et al., 1968; Harvey et al., 1968) and acidosis (Dunlap, 1970) and increased feed intake and average daily gain (Wise et al., 1967) in some cases.

There has been a limited amount of research on the apparent interaction between roughage level and method of processing noted with corn grain by Vance et al., (1971). Processing whole shelled corn decreased

efficiency when roughage levels were below approximately 17% but increased efficiency when roughage levels were above approximately 35% of the ration dry matter.

This study was designed to investigate the influence of the level of roughage and corn processing method on the extent of digestion of the concentrate (starch) and roughage (cellulose) portions of the ration in the rumen and intestine of beef steers.

CHAPTER II

REVIEW OF LITERATURE

Importance and Structure of Starch

Cereal grains commonly comprise 80 to 90% of cattle finishing rations and account for the major expense of such rations. Methods to improve the efficiency of utilization of these grains are, therefore, of considerable economic importance. Because most cereal grains contain 70 to 80% starch (Rooney and Clark, 1968; Greenwood, 1970), the efficiency of utilization of the starch portion of the ration is of major importance in the utilization of the whole ration.

Most of the starch of cereal grains is located in the endosperm as small granules embedded in a protein framework (Graeza, 1965; Greenwood, 1970). These starch granules generally consist of approximately equal parts of crystalline and amorphous regions (Hellman et al., 1952). The storage of starch in the granular form serves to make it less soluble in water (Greenwood, 1970; Badenhuizen, 1969) and to decrease its susceptibility to amylase attack (Lathe and Ruthven, 1956).

All natural starches show a layered or shell structure (Badenhuizen, 1969). These layers are composed of two forms of starch molecules, amylose and amylopectin, which are intricately arranged through hydrogen bonding (Pazur, 1965). Amylose is a linear polymer of glucose units joined by alpha-(1-4) linkages to yield chains of several hundred glucose units. Amylopectin is a branched chain glucose polymer with

alpha-(1-4) and alpha-(1-6) linkages. Branch points are located at the alpha-(1-6) bonds and each branch normally contains 20 to 30 glucose units (Pazur, 1965).

The ratio of amylose to amylopectin can vary greatly, but most cereal grain starches contain about 25% amylose. High amylose starches are resistant to amylolytic attack (Sandstedt et al., 1962) while high amylopectin starches are quite susceptible to amylase attack (Leach and Schoch, 1961).

Enzymatic Degradation of Starch

When starches are heated to a temperature of 60 to 80 C, the starch granules irreversibly swell and lose their crystallinity and spherical structure. This process is termed gelatinization.

Gelatinized starch is more readily and rapidly digested by amylase than the native starch granule whose spherical structure forces amylase to work only on the outer surface of the granule (Lathe and Ruthven, 1956).

The complete degradation of starch to glucose in vivo is accomplished by the enzymes alpha-amylase, maltase and isomaltase. Pancreatic alpha-amylase randomly cleaves alpha-(1-4) linkages on the interior of the starch molecule yielding dextrins, oligosaccharides and maltose, which is subsequently cleaved by maltase to glucose (Walker and Hope, 1963). Isomaltase from the intestinal mucose cleaves the alpha-(1-6) linkages of amylopectin.

Importance and Structure of Cellulose

Cellulose comprises from 20 to 50% of the total dry matter of most

plants (Van Soest, 1973) and is therefore quantitatively important as an energy source for ruminants on high roughage rations. For ruminants fed high concentrate rations cellulose is much less important since it comprises only 5 to 20% of the diet.

Cellulose is a straight chain polymer of glucose units joined by beta-(1-4) linkages. It is found mainly in microfibrils in the plant cell walls and is present in two forms--crystalline or amorphous, the proportions varying with plant species. The availability of cellulose to cellulolytic organisms can vary from 0 to 100% depending upon its crystallinity and its association with lignin, cutin and silica (Van Soest, 1973).

The initial enzymatic hydrolysis of cellulose by the enzyme cellulase appears to require two proteins--a hydrolytic factor and an affinity factor which holds the hydrolytic factor to the cellulose molecule (Leatherwood, 1973). Cellobiose, formed by the action of cellulase, is subsequently cleaved by the enzyme cellobiase to two glucose units.

Ruminant Carbohydrate Digestion and Absorption

The first stage of digestion in the ruminant involves an anaerobic fermentation in the rumen. Here carbohydrates yield primarily volatile fatty acids (VFA), carbon dioxide and methane. The products formed during fermentation are the result of complex interactions between the substrates, the microbial population and pH (Sutton and Johnson, 1969). Although end products are produced in widely differing proportions, all carbohydrates are fermented by the standard glycolytic pathway to pyruvate. Subsequently, different products arise from further metabolism of pyruvate (Baldwin, 1965).

VanDerWath (1948) and Nasr (1950) observed that production of alpha-amylase by rumen bacteria was stimulated by the presence of starch in the rumen. Starch digesting microorganisms are present in the rumen under most feeding conditions and increase in number in response to feeding of starch.

VFAs are readily absorbed from the rumen into the portal systen (Annison et al., 1957). VFAs are absorbed by simple diffusion, primarily in the undissociated form (Tsuda, 1956). The relative rates of VFA absorption under acidic rumen conditions are butyric first, propionic second and acetic last. Butyrate is metabolized during passage through the rumen wall (Pennington, 1952, 1954) and most reaches the portal blood as beta-hydroxybutyrate (Hird and Weidemann, 1964). Some propionate reaches the blood as succinate (Pennington and Sutherland, 1956). VFA absorption appears to be enhanced by lowering of the pH of the rumen (Tsuda, 1956; Masson and Phillipson, 1951).

Intestinal starch digestion may be limited in the ruminant. The pancreas produces amylases and maltase and the intestinal mucosa produces amylase, maltase and isomaltase for digestion of starch (Armstrong and Beever, 1969). Siddons (1968) demonstrated a high amylase and low maltase activity in the pancreatic juice of mature cattle. Pancreatic amylase activity appears to increase in response to an increase in starch (corn) in the ration (Clary et al., 1967). Mucosal maltase activity appears to be as high in the mature ruminant as in the young while amylase activity is lower in the mature animal (Siddons, 1968) suggesting that maltase is not a limiting factor in starch digestion. The ability to absorb glucose; however, may be limited in the mature ruminant (White et al., 1971) although the quantity of glucose precur-

sors appears to alter the intestinal absorptive capacity.

Fermentation in the large intestine and cecum appears to be similar to that in the rumen since similar concentrations of VFAs are present in both organs. Cecal capacity to ferment starch appears to be limited (less than 150 gms per day in mature sheep) (Ørskov et al., 1970). Absorption of VFAs from the cecum and colon has been demonstrated by Myers et al., (1967).

Cellulose digestion is primarily confined to the rumen (80 to 100%) (Hale et al., 1940, 1947; Ridges and Singleton, 1962; Hogan and Weston, 1967) although some digestion may occur in the terminal ileum and large intestine.

Feeding Value of Processed Corn

A number of reviews are available on the subject of processing of cereal grains in general (Hale, 1973; Hale and Theurer, 1972). Therefore this review will emphasize processed corn grain. It has been the general consensus that all cereal grains, with the exception of corn grain, should be processed (pressure, heat, moisture, chemical, etc.) in some manner prior to being fed to cattle.

Performance

Whole corn generally produces animal gains and efficiencies superior to rolled corn grain. For example, in one 82-day trial, steers fed an all concentrate (89% corn) ration containing whole shelled corn (WSC) had six percent higher ($P < .05$) average daily gains (3.99 vs 3.44 lbs) and tended to have superior feed efficiencies (4.84 vs 5.29 lbs per lb gain) compared to steers fed the same ration containing cracked corn

(Hixon et al., 1969). Weichental and Webb (1969) reported a 5% increase ($P < .10$) in average daily gain (ADG) and a 7% improvement in feed efficiency with steers fed an all concentrate ration containing WSC when compared to those fed ground corn. At a 10% roughage level, gains were similar for both types of corn but WSC still had a 7% advantage in feed efficiency. Steers on WSC also had fewer abscessed livers at both roughage levels. On high concentrate diets, then, whole corn is well utilized by steers.

In studies at the Ohio Agriculture Experiment station (Vance et al., 1971a) steers were fed rations consisting of free choice corn (WSC or crimped), 2.5 lbs. of supplement and a predetermined level of corn silage (0, 5, 10, 15, 20, or 25 lbs/head/day). When corn silage levels were less than 15 lbs per day, steers fed WSC tended to have higher ADGs and better feed efficiencies. Above a silage level of 15 lbs per day, the steers fed crimped corn had a slight advantage in gain and feed efficiency. Processing method had no effect on carcass characteristics. The net energy for maintenance (NE_m) and net energy for gain (NE_g) values of the WSC rations were higher than crimped corn at silage levels less than 15 lbs of silage per day but were lower at silage levels greater than 15 lbs per day (Vance et al., 1972). Assuming the corn silage fed was 50% grain and 30% dry matter this corresponds to a roughage level of about 17%.

In a similar study (Preston et al., 1972) WSC, crimped corn and rolled high moisture corn (RHMC) were fed at silage levels of 0, 5, 15, and 25 lbs/head/day. WSC and RHMC fed groups had similar ADGs and feed efficiencies at all roughage levels. Crimped corn fed steers tended to have lower ADGs and poorer feed efficiencies at corn silage levels of 15

lbs or less but had higher ADGs at 25 lbs. At the 25 lb per day silage level, feed efficiencies for all groups were similar although WSC tended to have a slight disadvantage. Overall, processing of dry corn would appear to be beneficial at roughage levels above about 17%.

Steers fed flaked corn in a 13% roughage ration had a 6 to 10% higher energy retention than steers fed cracked corn (Johnson et al., 1968). The gross energy of the flaked corn ration was utilized more efficiently for energy retention. Matsushima and Montgomery (1967) reported that thin flaking of corn (1/32 inch) resulted in 4% faster gains and an 8% improvement in feed efficiency over thick flaking (1/12 inch) in 20% roughage rations. Thick flaking had only a slight advantage over grinding.

In general, feed efficiency and gain is superior for whole above processed corn at any moisture level at low ration fiber levels. Intake, total digestibility or site of digestion differences could explain this superiority.

Digestibility of Corn Grain

High moisture corn fed ground is of lower digestibility than rolled high moisture corn. In one study, lactating dairy cows were fed high moisture corn (24 to 26% water) treated with propionic acid or dry ground corn (Clark et al., 1973). Although digestibility was lower for high moisture corn, reductions were significant only for the crude protein ($P < .05$) and ether extract ($P < .01$) fraction of the rations.

Comparing whole to ground dry corn, cows fed a 55% ground corn, 40% alfalfa ration had higher ($P < .01$) digestibilities of dry matter (DM), organic matter (OM), cell solubles and ether extract and higher digesti-

bility of crude protein ($P < .05$) than those fed whole corn (Moe et al., 1973). Digestible energy (DE), metabolizable energy (ME), net energy for maintenance (NE_m) and TDN were all significantly higher for ground corn.

Comparing ground to cracked corn, Moe et al. (1973) found ground corn had higher ($P < .05$) digestibilities for dry matter, organic matter and cell solubles ($P < .01$) but lower digestibilities of acid detergent fiber (ADF) and ether extract ($P < .05$) than cracked corn. Ground corn had higher DE and ME values ($P < .05$) than cracked corn, but there were no significant differences in net energy (NE) and TDN values between rations. Energy values for ground corn, cracked corn and WSC respectively were DE, 3.40, 3.21, and 2.70; ME, 2.92, 2.67 and 2.13 and for NE were 1.87, 1.81 and 1.48 mcal/kg DM, indicating that more extensive processing increased the energy value.

In contrast, Vance et al. (1972) found similar NE_m and net energy for gain (NE_g) values for WSC and crimped corn over the range of 40 to 100% concentrate rations. When corn silage intakes were 0 to 20 lbs/head/day, Vance and Preston (1971) reported slightly higher digestibilities of DM, OM, protein and starch with crimped corn than with WSC, but the differences were not statistically significant.

Steam flaking will generally improve digestibility of dry corn grain above cracking. Johnson et al. (1968) reported that steam flaking increased digestion coefficients for DM, protein and ether extract over unheated cracked corn. The DM and protein digestibilities of steam flaked corn and steam flaked-cracked corn, however, were greater ($P < .01$) than for steam cracked corn. Steam flaked corn also tended to have higher values for DE (78 vs 74.4% and ME 70.9 vs 65.9%) than un-

heated cracked corn.

In contrast to improved digestibility with processing, Mudd and Perry (1969) reported significant linear decreases in the digestibility of DM, protein, crude fiber and nitrogen free extract (NFE) and in TDN as raw cracked corn was replaced with expanded gelatinized corn. The source of the roughage (cobs vs oyster shells) appeared to have an effect on the magnitude of the differences in digestibility. In another experiment, however, no significant differences in digestibility were noted between rations in which the corn was either cracked or gelatinized.

Wilson et al. (1973) studied the digestibilities by sheep and dairy cows of whole shelled corn, coarsely ground corn (CGC), finely ground corn (FGC), whole high moisture corn (WHMC), coarsely rolled HMC and finely rolled HMC at several levels. In general, sheep were able to digest the OM of all forms of corn equally well (91% digestibility). With cows, however, possibly due to less complete mastication of larger particles of grain, the highest OM digestibilities were obtained with FGC and finely rolled HMC (79 vs 80% OMD, respectively). The moisture content of the corn (15 to 35%) had no consistent effect on the digestibility of corn fed in the same form. The particle size, however, had an important influence on digestibility. The optimum modulus of fineness for maximum digestibility was 4.74 to 2.99 for dry corn and 5.42 to 5.10 for HMC (whole shelled corn equal to 6.0).

The digestibility of whole corn appeared to be dependent upon the ability of the dairy cow to crush the grain during eating and ruminating. The roughage level, however, had no marked effect on the digestibility of whole corn suggesting that rumination time was not affected by rough-

age level. Other reports have noted that grinding of corn does not improve its digestibility by beef cattle fed low roughage rations suggesting that rumination is adequate on low roughage, whole corn rations (Hixon et al., 1969; White et al., 1972).

Processing method and protein source (urea vs soybean meal) had no significant effect on digestibility of energy, DM, NFE or protein in all concentrate rations. When rice straw was added to supply 20% of the ration, total digestibility was decreased ($P < .05$) but no differences were attributable to corn processing (White et al., 1972).

Rumen Parameters

Reduced particle size or gelatinization appears to enhance the rate but not the extent of ruminal digestion (Tonroy and Perry, 1974). The 24 hour in vitro dry matter disappearance (IVDMD) of rolled, roasted corn was lower ($P < .05$) than for that of raw rolled, acid treated (ATC), high moisture (HMC) or reconstituted corn (White et al., 1973). The source of the in vitro inoculum (high concentrate or alfalfa hay fed donor steers) appeared to influence the IVDMD of the ATC, HMC, reconstituted and raw corn. Roasting lowered ($P < .05$) the 24 hour IVDMD of all forms of corn tested. In vivo, the processing method had no significant effect on the digestibility of energy, DM, protein or starch although raw corn tended to have a lower starch digestibility. This suggests that the site of digestion may be altered by some processing methods.

Corn processing may increase total ruminal VFA and propionate levels. Raw and gelatinized corn produced similar rumen VFA patterns in steers (Mudd and Perry, 1969). White et al. (1972) reported similar rumen VFA patterns with ground corn and WSC in 20% roughage rations

although ground corn produced higher ($P < .05$) levels of total VFAs. In all concentrate rations, ground corn tended to produce higher total VFA concentrations, lower acetate/propionate ratios and lower rumen pH.

Effects of Concentrate and Roughage Levels on Ration Utilization

Purpose of Roughage

The major problems associated with feeding finishing cattle all concentrate rations are rumen parakeratosis, liver abscesses, lowered feed intake, founder and bloat (Wise et al., 1968). The incidence of rumen parakeratosis and liver abscesses may be reduced substantially by the addition of low levels of course roughage or of antibiotics to the ration (Harvey et al., 1968; Haskins et al., 1969). The "roughage effect" or the reduced rate of ruminal digestion of whole as compared to ground corn may reduce incidence of the above disorders.

Performance

Including low levels of roughage in finishing rations usually does not depress cattle performance. Cattle compensate for the lower energy density of the ration by increasing feed intake (Harvey et al., 1968; Haskins et al., 1969; Tillman et al., 1969; Utley and McCormick, 1972). Hence, total feed efficiency may be reduced as feed intake increases to produce similar daily gains between roughage levels of 0 to 20%. The decreased incidence of disorders; however, may be reflected as increased ADG and improved feed efficiency.

For example, hay addition increased ADG and improved feed efficiency when added to all concentrate rations of WSC or ground corn at a level

of 10% (Weichental and Webb, 1969). The addition of hay to the ration improved ADG and feed efficiency of steers fed ground corn more than for steers fed whole shelled corn. This interaction was noted by Vance et al. (1971). Additions of 0, 5, or 10 lbs/head/day of corn silage to WSC rations produced similar gains, but at 15 lbs/day (approximately 17% roughage), daily gains declined sharply. With crimped corn, gains and feed efficiencies were similar at all silage intakes of 0 to 25 lbs/day, but gains were highest and feed efficiencies were poorest at 10 to 15 pounds of silage.

Digestion of Roughage

As digestibility of roughages is lower than concentrates, higher roughage levels reduce total ration digestibility, and since ruminal passage rate may also be affected with roughage, site and extent of digestion may also be altered.

Vidal et al. (1969) noted that as the ratio of concentrate to hay in the ration increased from 0/100 to 75/25, the digestibility of DM, protein, neutral detergent fiber, crude fiber and TDN increased in a linear fashion. Starch digestion was essentially complete with all rations, but greater proportions of the dietary starch passed through the abomasum as the concentrate (barley) level increased. Raven (1972) reported a linear ($P < .001$) increase in DE, ME, DM and OM digestion as the concentrate portion of the ration increased.

Bines and Davey (1970) fed rations containing 60, 40, 20 and 0% chopped straw and studied the effects on the site and extent of digestion. Total digestibility of DM, OM and protein increased ($P < .01$) as the concentrate portion of the ration increased. Total cellulose digest-

ibility decreased ($P < .05$) as roughage level decreased from 60 to 20% of the ration (49.9 vs 42.9%) then increased ($P < .05$) between 20 and 0% roughage (42.9 vs 58.5%). Source of cellulose had, of course, changed in this final step. Ruminal digestion of DM and OM increased ($P < .01$) as the concentrate level increased. Ruminal cellulose digestion was similar at 60 and 40% roughage (28.6 vs 26.8%) but was lower ($P < .01$) at 20% roughage (12.2%) and higher ($P < .01$) at 0% roughage (50.4%). To check the cellulose digestion of a standard cellulose source, cotton thread was placed in the rumen of cows fed these rations containing 60, 40, 20, and 0% wheat straw. The time required for 25% weight loss of the cotton thread was 30, 30, over 60 and over 120 hours, respectively. Others (Cowsert and Montgomery, 1969; Stone and Fontenot, 1965) have observed similar trends in digestibility with alfalfa hay to concentrate ratios of 100 to 0, 67 to 33, and 33 to 67 or with rations balanced to contain 62, 67, and 72% TDN.

Rumen and Blood Parameters

As the level of roughage in the ration increases, the rumen acetate to propionate ratio increases, total VFA concentrations decrease and rumen pH increases in most cases (Utley and McCormick, 1972; White and Reynolds, 1969; White et al., 1969; Vidal et al., 1969).

Blood parameters are less consistent. Judson et al. (1968) fed sheep rations containing 30, 50 and 100% crushed corn with alfalfa comprising the rest of the first two rations. Plasma glucose concentrations tended to be lower in the sheep fed the lowest concentrate level, but no significant ration effects on glucose entry rates were observed. As the level of starch in the ration increased, the total rumen VFA concentra-

tions decreased but the proportion of propionate increased. The mean production rate of propionate on all rations was similar. The proportion of the glucose entering the body pool from propionate, the net conversion of propionate to glucose and the percentage of the propionate produced in the rumen that was converted to glucose decreased, as the proportion of corn in the ration increased. The reduction in glucose synthesis from propionate on the higher concentrate rations may have been due to a greater amount of starch escaping rumen fermentation and being digested and absorbed in the small intestine.

In summary, much evidence indicates that marked changes in the dietary roughage level alters the rumen fermentation pattern. This change in rumen fermentation leads to changes in the metabolism of the animal, especially gluconeogenesis.

Factors Affecting the Site of Digestion

Much of the data on site of digestion has been reviewed by Armstrong and Beever (1969), Sutton (1971) and Waldo (1973). Numerous factors appear to affect the site of carbohydrate digestion in the ruminant.

The mature ruminant has three major sites of digestion, the rumen, the small intestine and the large intestine. Under normal feeding conditions the major portion (50 to 60%) of the digested dry matter disappears from the rumen through microbial anaerobic fermentation (Annison, 1956). Fermentation of carbohydrates in the rumen and large intestine yield variable proportions of carbon dioxide, methane and the volatile fatty acids (VFA)-acetate, propionate and butyrate-as major end products (Wolin, 1960) whereas digestion in the small intestine yields primarily glucose. Absorbed glucose may be utilized more efficiently

than the VFAs as an energy source (Blaxter, 1962) and for promoting protein deposition (Eskeland et al., 1973). Theoretically, then, greater amounts of dietary carbohydrate (i.e., starch) bypassing the rumen for digestion in the small intestine can improve the efficiency of energy use (Black, 1971). The amount of starch that can bypass the rumen and be used, however, is limited, as the capacity of the small intestine to handle starch (either digest starch or absorb glucose) is limited (Armstrong and Beever, 1969; White et al., 1971). Conversely, bypass of ruminal digestion will reduce the amount of energy available for bacterial growth and microbial protein synthesis. This is important when part of the dietary protein equivalent is supplied by nonprotein nitrogen and when metabolizable protein supply limits performance.

Level of Intake and Site of Digestion

Increasing the total intake of a pelleted concentrate (85%) ration in young steers by .8 to 1 kg per day had no apparent effect on the percent ruminal digestion of the ration dry matter or starch (Topps et al., 1968b). Barley starch, in contrast to corn or sorghum starch, is very readily attacked by rumen microbes. Increasing the intake of a pelleted grass hay had no apparent affect on percent ruminal digestion of dry matter, cellulose or starch. MacRae and Armstrong (1969b) obtained no marked differences in ruminal starch digestion of sheep fed a 100% rolled barley ration at levels of 25.5 and 16.6 g starch per $kg^{.75}$.

When rolled barley comprised only 48% of the ration, increasing the starch intake from 19 to 27 g per $kg^{.75}$ reduced ruminal starch digestion ($P < .001$) from 92.3 to 87.2 (Ørskov et al., 1969). When the diet contained 80% barley, increasing intake decreased ruminal starch

digestion ($P < .05$) from 95.6 to 93.2%.

Sheep fed flaked corn at levels of 67% (MacRae and Armstrong, 1969b) and 80% (Nicholson and Sutton, 1969) of the ration had similar ruminal starch digestibilities regardless of the total daily starch intake.

Kartchner et al. (1973) reported no effect of level of starch intake on ruminal or total starch digestibility with either steam flaked or dry rolled sorghum grain. This suggests that time for breaking physical barriers (the starch granule) rather than bacterial digestive capacity controls the extent of starch digestion in the rumen.

The amount of starch bypassing the rumen and reaching the small intestine could possibly alter the extent of starch digestion in the small intestine. Little et al. (1968) reported that total intestinal starch digestion decreased from 93 to 70% as the intestinal starch infusions increased from 200 to 600 gms. per day in steers. Although the percentage starch digestion in the small intestine did not follow a definite pattern, even a low starch infusion level (200 gm in one infusion) was poorly digested (under 60%) in this segment of the gut. In previous studies as much as 600 gms of starch had been calculated to be digested in the small intestine of steers (Karr et al., 1966). This suggests that under normal conditions, in which starch passes from the rumen at a slow rate, the small intestine can handle more starch than when starch is infused in large quantities.

Overall, with slowly digested cereal grains and large particle sizes, high intakes may flush starch through to the abomasum. Calculations made by regression analysis of rations containing 20 to 80% corn suggest that ruminal corn starch digestion is lowest when the ration contains about 52% corn (Waldo, 1973).

Source and Level of Protein

The level of dietary nitrogen (urea) had no significant effect on total or ruminal cellulose digestion in sheep fed purified diets (Hume et al., 1970). Ørskov et al. (1971) reported N level had no effect on ruminal starch digestion (93%) when all supplementary N was supplied by soybean meal. In contrast, Ørskov et al. (1972), reported an increase in ruminal organic matter and starch digestion as the crude protein content of the ration was increased from 10 to 16.4% with supplemental urea, probably meeting a nitrogen deficit in the rumen. The sheep in this final study were young (seven weeks), whereas previous studies (Hume et al., 1970; Ørskov et al., 1971) had used mature sheep (35 to 40 kg). Recycling of nitrogen in older sheep had probably met ammonia needs in the rumen. When the dietary nitrogen was supplied by urea (U), U + casein, U + gelatin or U + zein in semipurified isonitrogenous diets, treatment had no significant effect on total or ruminal digestibility of OM (Hume, 1970). Ørskov et al. (1974) also reported no effect of N source (fish meal vs urea) or level (9.5 to 15.6%) on site or extent of OM digestibility. Hypothetically; however, ammonia nitrogen deficiency could limit starch digestion in the rumen.

Grain Source and Site of Digestion

It is difficult to compare different grains as to the digestibility since the processing method has such a large influence. Several studies have been conducted in an attempt to evaluate different grains with regard to starch digestibility and processing with different grains.

Kay et al. (1972) compared pelleted diets containing wheat (W), corn (C), barley (B), and oats (O) when fed to steers. All grains were

fed whole. The dry matter digestibility coefficients for the rations were: W, 81.3%; C, 79.5%; B, 77.3% and 0, 70.4%. The proportion of the dietary starch digested in the rumen were: W, 83%; C, 60%; B, 81% and 0, 74%.

Thivend and Vermorel (1971) compared wheat, corn, sorghum (S) and barley (all ground) in ruminal digestibility. They also reported that wheat and barley were degraded in the rumen to a greater extent than corn or sorghum.

Ørskov et al. (1969) studied the digestibility of rations containing 80% rolled barley (RB), flaked corn (FC), ground corn (GC) and cracked corn (CC). The total and ruminal DM digestibilities of the rations were; RB, 73 and 47%; FC, 79 and 57%; GC 78 and 59% and CC, 77 and 50%, respectively. The ruminal starch digestibilities for the four rations were 94, 95, 88, and 85% for the RB, FC, GC and CC diets, respectively. Total starch digestibility was greater than 99% for all rations. In a latter study, Ørskov et al. (1971) reported ruminal starch digestibilities of 91.5 and 80% respectively for pelleted diets containing 93% rolled barley or crimped corn.

Roughage Level and Site of Digestion

In sheep fed rolled barley, the addition of 40% grass hay to an 80% barley ration had no apparent effect on total starch digestion but decreased ruminal starch digestion (Ørskov et al., 1969). This effect appeared to be greater at ad libitum intake than at a restricted feed intake. When daily starch intakes were approximately equal, the added roughage reduced ruminal starch digestibility from 95.6 to 87.3% of intake. MacRae and Armstrong (1969), however, noted no apparent effect

of roughage level (0, 33 and 67%) on ruminal starch digestion (92, 93 and 91%, respectively) with rolled barley. As the roughage level increased, however, the amount of starch presented to the small intestine tended to increase.

Thivend and Journet (1968) noted a trend toward decreased ruminal starch digestion as the roughage level in the ration increased. Ruminal starch digestibilities for rations containing 19, 39, 58 and 78% ground barley were 97, 92, 93 and 98%, respectively. The increase in ruminal digestion between the barley levels of 39 and 19% could be due to the low starch level in the 19% barley ration.

No significant difference was noted in ruminal starch digestibility of rations containing 20, 40, 60 or 80% ground corn when fed to sheep (Tucker et al., 1968). The amount of starch passing the abomasum was similar on rations containing 40, 60 and 80% corn but was less ($P < .05$) on the 20% corn ration. With steers fed similar rations, ruminal starch digestibility tended to decrease with increasing corn levels (Karr et al., 1966).

Ruminal starch digestibilities for rations containing 19, 39, 58 and 78% ground corn were 85, 71, 66 and 81%, respectively, for steers (Thivend and Journet, 1970). These results are difficult to interpret, however, because starch intakes on the 78% corn ration were about 700 gms less than on the 58% corn ration.

The results of two trials in which rations contained 20, 40, 60 or 80% ground corn were inconclusive as to ruminal starch digestibilities (Waldo et al., 1971). Ruminal digestibilities for the 20, 40, 60 and 80% corn rations were: trial 1; 90, 85, 76 and 84% and for trial 2; 59, 59, 50 and 74%, respectively. The amount of starch entering the

intestine tended to increase between 20 and 60% corn and decreased between 60 and 80% corn.

The data on the effects of roughage level on ruminal starch digestion are still inconclusive. With barley or ground corn, a decrease in roughage level appears to increase both the ruminal starch digestibility coefficient and the amount of starch passing the abomasum. Maximal starch bypass appears to occur at about 50% concentrate in the diet (Waldo, 1973).

The effects of roughage level on the site and extent of cellulose digestion are more conclusive. MacRae and Armstrong (1969) reported a decrease in ruminal cellulose digestion and an increase in large intestinal cellulose fermentation as the roughage level of the ration decreased from 100 to 67 to 33% (91, 84 and 56% rumen digestibility, respectively). Total cellulose digestion decreased markedly between roughage levels of 67 and 33%. Mitchell et al. (1967) reported a marked decrease in ruminal cellulose digestibility between concentrate levels of 60 and 80% (ground corn). Although total cellulose digestibility tended to decrease with increasing concentrate levels, cellulose digestion was essentially confined to the rumen at concentrate levels of 20, 40 and 60%.

Processing Method and Site of Digestion

Much of the work on site of digestion has been done to evaluate concentrate and roughage processing methods.

Barley. Ruminal starch digestion coefficients were similar whether sheep were fed barley whole (95%) or rolled (97%) (MacRae and Armstrong, 1969). Pavlicevic et al. (1972) reported that rolling barley substan-

tially reduced the amount of starch passing the abomasum. Pelleting rolled barley decreased ruminal starch digestion whereas pelleting whole barley (WB) increased it. The ruminal starch digestion coefficients for RB loose, RB pelleted, WB loose and WB pelleted were 94, 88, 63 and 74%, respectively.

Ørskov et al. (1969) reported no significant differences in total or ruminal starch digestion of rations containing 80% rolled (93% ruminal digestion) or ground (95%) barley.

Milo. Milo, unless processed, has a very low starch availability. Milo steamed at 3.5 kg per cm^2 pressure for 1.5 minutes and rolled had a higher ($P < .01$) ruminal starch digestibility than milo steamed at atmospheric pressure for 8 minutes and rolled (Holmes et al., 1970; Drennan et al., 1970).

McNeill et al. (1971) reported an increased ($P < .05$) total and ruminal milo starch digestion over dry ground milo (DGM) when the grain was steam flaked (SFM) or reconstituted (RM) but not when it was micronized (MM). Ruminal starch digestion coefficients were; DG, 42; RM, 67; SF, 83 and MM, 43%. This suggests that gelatinization is not the only factor affecting starch digestion since both SFM and MM were almost completely gelatinized (McNeill et al., 1975).

Hinman and Johnson (1974a) reported ruminal starch digestibilities of 68, 97, 95 and 90% for dry rolled, MM, SFM and DG milo, respectively. These values were much higher than those of McNeill et al. (1971) and suggested that micronized milo was as readily fermentable as SFM. In a second study, Hinman and Johnson (1974b) reported no significant differences in ruminal starch digestibility between dry rolled milo and milo micronized at three levels. Ruminal starch digestibilities, how-

ever, tended to increase with increasing degree of micronization. Total and intestinal starch digestion was greater ($P < .05$) for all levels of micronization than for DRM.

Corn. Ørskov et al. (1969) compared steam flaked (SF), ground (G) and cracked (C) corn in 80% corn rations fed to sheep. More than twice as much starch reached the abomasum of sheep fed C (14% of intake) and G (12%) than sheep fed SF (5%) indicating that the raw corn starch was less available to the rumen microbes. Total starch digestion was not affected by processing. Beever et al. (1970) reported that on a ground corn diet, 22% of the starch consumed passed through the abomasum whereas only 4% of the starch intake passed the abomasum when the corn was SF.

Roughage Processing. Thompson and Lamming (1972) reported that the particle size of the roughage component of the ration had an effect ($P < .01$) upon the amount of starch escaping rumen fermentation in a diet containing 55% ground corn and 30% barley straw. Ruminal starch digestion for rations containing long straw, chopped straw and ground straw were 82, 81 and 92%, respectively. Total starch digestion was not affected. This difference could be due to a faster rate of passage of grain particles when long or chopped forage was provided. Thomson et al. (1972) reported that increasing the proportion of fine particles in an alfalfa ration by cobbing or by grinding led to a decrease in ruminal digestion of cellulose and an increase in cecal fermentation ($P < .01$). Beever et al. (1972) also reported that grinding and pelleting of a dried grass resulted in a decrease ($P < .001$) in ruminal cellulose digestion and an increase ($P < .001$) in cellulose digestion in the large intestine.

CHAPTER III

INFLUENCE OF ROUGHAGE LEVEL ON THE SITE AND EXTENT OF DIGESTION OF RATIONS CONTAINING WHOLE SHELLED CORN[1,2,3]

Summary

Whole shelled corn rations containing 0, 7, 14 and 21% roughage in the form of cottonseed hulls (rations 0, 7, 14 and 21, respectively) were fed to four steers fitted with permanent rumen and abomasal cannulae in a 4 x 4 Latin square design. Animals were fed hourly using automatic feeders to obtain steady state conditions in the digestive tract. Ration 14 tended to have lower total starch digestibility, primarily due to lowered ($P < .10$) intestinal digestion, but there were no significant differences in ruminal starch digestion. Ruminal and intestinal digestibilities of starch for rations 0, 7, 14 and 21 were: 80.0, 81.8; 67.9, 83.6; 71.5, 72.9; and 72.1, 83.8, respectively. Total DM digestibilities for rations 0, 7, 14 and 21 were 84.3, 78.4, 71.8 and 74.9%, respectively. Rations 7, 14 and 21 had similar ruminal DM digestibilities

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although ration 0 was higher ($P < .05$) than 14 and 21. There were no significant differences in intestinal digestion of DM. Cellulose digestion was almost totally confined to the rumen in rations 0, 7 and 14, but almost 15% of the digestible cellulose was digested in the intestine on ration 21. The level of roughage appeared to affect the rate of passage through the lower gut and this affected the intestinal digestion of DM, starch and cellulose. The digestibility of the concentrate fraction was decreased at roughage levels of 7 and 14% apparently due to increased rate of passage but was not apparently influenced at 21% CSH.

Introduction

The efficiency of utilization of cereal grains in high concentrate finishing rations has been greatly improved through the use of processing techniques. Although many feedlots still process corn grain in some manner, recent studies have indicated that whole shelled corn can be used satisfactorily when roughage levels are low (Weichental and Webb, 1969; Vance et al., 1971) but is used less efficiently than processed corn at roughage levels above approximately 17% (Vance et al., 1971).

It has been common practice in most feedlots to feed relatively constant low levels of roughage in cattle finishing rations without regard to the type of grain or method of grain processing. Low levels of roughage serve to reduce the incidence of liver abscesses (Wise et al., 1968), reduce acidosis (Dunlap, 1970) and to increase feed intakes and daily gains (Wise et al., 1968).

This study was designed to investigate the influence of dietary roughage level on the site and extent of dry matter, starch and cellulose digestion when the grain portion of the ration was supplied by

whole shelled corn.

Experimental Procedures

Animals and Rations

Four Hereford steers averaging 390 kg (range 378 to 404 kg) and fitted with permanent rumen and abomasal cannulae were used in a 4 x 4 Latin square design. Steers were housed in metabolism stalls and were fed at hourly intervals with the use of automatic feeders (Hinman and Johnson, 1974a). Steers were fed isonitrogenous rations containing 0, 7, 14 and 21% cottonseed hulls (CSH) (Table I). The corn portion of the ration was fed in the whole shelled form (WSC) and the supplement was pelleted through a .64 cm die. A dried acid hydrolyzed wood residue (AHWR)[4] (Butterbaugh and Johnson, 1974) was added to the supplement to supply lignin. The AHWR, due to its chemical treatment, had little or no apparent roughage value. The AHWR (chemical analysis: 55% DM, 15% CP, 60% ADL) was dried in a forced air oven at 50 C and ground through a 3 mm screen prior to being added to the pelleted supplement.

Sampling Procedure

Each period of the Latin square consisted of two weeks with the first nine days being used as an adjustment period to the new ration. Total fecal output was collected on days 10 through 13. Feces was weighed daily and a ten percent aliquot was taken and stored at 4 C in a polyethylene bag. The daily aliquots were then composited, ground through a one mm screen in a Wiley mill and stored in polyethylene bags

[4] Dierks Division, Weyerhaeuser Co., Hot Springs, Arkansas.

TABLE I

COMPOSITION OF RATIONS : TRIAL 1

Ingredient	IRN[a]	Ration (% DM Basis)[b] 0	7	14	21
Corn, dent yellow grain (4)	4-02-935	90.0	82.0	74.0	66.0
Cotton, seed hulls (1)	1-01-599	--	7.0	14.0	21.0
Cotton, seeds w some hulls, solv-extd grnd, mn 41% protein mx 14% fiber mn 0.5% fat (5)	5-01-621	--	1.0	2.0	3.0
Premix[c]		10.0	10.0	10.0	10.0

[a]International reference number.

[b]Rations identified by level of cottonseed hulls.

[c]To provide as a % of diet: corn, yellow, grain, grd 4-02-992, 1.1; cottonseed meal, 5-01-621, 3.2; calcium phosphate dibasic, commercial, 6-01-080, .45; calcium carbonate, commercial mn 38% Ca, 6-01-069, .63; trace mineralized salt, .45; urea, mn 45% N, 5-05-070, .63; acid hydrolyzed wood residue, 3.6; per kg ration: aurofac-50, 22 mg chlortetracycline; vitamin A palmitate, commercial, 7-05-143, 4950 IU; vitamin D_3, commercial, 440 IU.

at room temperature.

Samples of rumen and abomasal contents were obtained twice daily on days 12 and 14 of each period. Rumen samples were taken by suction pump at 55 minutes postfeeding and the two daily samples were composited on an equal volume basis. The pH of the whole rumen contents was taken immediately on collection, and the samples were then filtered through two layers of cheesecloth and stored at 4 C following addition of one ml of 7.2 N sulfuric acid per 50 ml strained rumen fluid to stop bacterial action.

Abomasal samples were taken by removing the cannula plug and tying a polyethylene bag over the cannula opening using elastic bands. Contents were then collected until one to two liters of contents had accumulated. This procedure normally required one to two hours per sampling. The samples were then dried in aluminum pans at 40 C in a forced air oven, ground, composited and stored in polyethylene bags.

Feed samples were collected on days 8 through 14 of each period, ground and stored in polyethylene bags.

Laboratory Analysis and Calculations

Feed, abomasal and fecal samples were analyzed for dry matter (A.O.A.C., 1965), lignin and cellulose (Van Soest, 1963) and starch as alpha linked glucose polymers (MacRae and Armstrong, 1968).

Rumen samples were analyzed for volatile fatty acids (Erwin *et al.*, 1961) using a Bendix 2500 gas chromatograph.

Total digestibility of dry matter, starch and cellulose was determined by total feed and fecal collection. Ruminal digestion was determined using lignin as a marker by the equation:

$$\% \text{ Digestibility} = 100 - 100 \left[\frac{\% \text{ FL}}{\% \text{ AL}} \times \frac{\% \text{ NA}}{\% \text{ NF}}\right]$$

where FL is feed lignin, NA is nutrient in the abomasum, AL is abomasal lignin and NF is nutrient in the feed. Intestinal digestibility was calculated as the digestibility of material passing the abomasum.

Statistical Analysis

The data were analyzed by analysis of variance as a 4 x 4 Latin square design. Treatment effects were tested by least significant difference (Snedecor and Cochran, 1967) when a significant treatment effect was noted in the analysis of variance.

Results and Discussion

The mean chemical composition of the rations, digesta and fecal samples is shown in Table II. The acid detergent fiber (ADF), acid detergent lignin (ADL) and cellulose contents of the rations, digesta and feces increased with increasing roughage level as expected. Starch content of the rations and digesta decreased with increasing roughage levels. The fecal starch content showed little change, except at CSH levels of 21 percent where it decreased markedly.

Ruminal, intestinal and total digestion of starch is shown in Table III. Starch intakes were relatively similar for the 0, 7 and 14% CSH rations due to higher DM intakes at the higher roughage levels but were lower ($P < .05$) for the 21% CSH ration. Total starch digestibility for ration 14 was lower ($P < .05$) than ration 0, apparently due to a lower ($P < .10$) intestinal digestion. The reason for the apparent increase in total starch digestion between ration 14 and 21 may be due to the lower

TABLE II

COMPOSITION OF RATIONS, ABOMASAL DIGESTA AND FECES[a] : TRIAL 1

Item	Ration Roughage Level			
	0	7	14	21
Rations				
DM %[b]	89.17	89.02	89.24	89.52
ADF %[c]	6.03	11.17	16.04	23.43
ADL %[d]	2.51	4.53	6.28	8.79
Cellulose %	3.50	6.61	9.75	14.73
Starch	72.82	60.04	56.07	47.58
CP %[e]	12.37	12.26	12.31	12.37
Abomasal Digesta				
DM	5.41	5.27	5.34	6.52
ADF	9.58	15.78	18.66	29.60
ADL	6.95	10.19	11.29	16.72
Cellulose	2.36	5.52	7.41	12.53
Starch	36.12	35.24	28.11	23.45
Feces				
DM	29.37	27.99	29.26	25.15
ADF	20.70	29.64	38.17	49.26
ADL	15.39	18.96	21.76	28.33
Cellulose	5.09	10.32	15.97	20.24
Starch	15.43	13.74	14.95	7.92

[a] On a dry matter basis

[b] Dry matter

[c] Acid detergent fiber

[d] Acid detergent lignin

[e] Crude protein

TABLE III

STARCH DIGESTION

Item	Ration Roughage Level 0	7	14	21	SE[c]
Intake (g/day)	3246[a]	3140[a]	3189[a]	2822[b]	111.6
Ruminal Digestion (g/day)	2598	2110	2277	2034	147.1
Intestinal Digestion (g/day)	530	849	662	660	105.6
Total Digestion (g/day)	3128[a]	2959[ab]	2939[ab]	2694[b]	110.4
Entering Intestine (g/day	648	1016	908	788	109.2
Ruminal Digestion (% Intake	80.04	67.86	71.54	72.06	3.86
Intestinal Digestion (% entering intestine)	81.79	83.56	72.91	83.76	3.31
Total Digestion (% Intake)	96.40[a]	94.67[ab]	92.25[b]	95.45[ab]	1.14
Ruminal Digestion (% of total)	83.02	71.68	77.55	75.50	3.89
Intestinal Digestion (% of total)	16.98	28.32	22.45	24.50	3.89

[a,b]Values on same row with different superscripts are significantly different ($P < .05$).

[c]Standard error of the mean.

starch intakes on ration 21 since the total amount of starch digested was lower ($P < .10$) on ration 21. Total starch digestibilities were similar to those obtained by Vance and Preston (1971) with whole shelled corn in all-concentrate (94.8%) and 50% corn silage (about 22% roughage; 92.8%) rations. McCullough and Matsushima (1973) reported mean starch digestibilities of 97.6% for whole shelled corn rations containing 0 or 12% corn silage (DM basis). In contrast, several studies have reported essentially complete digestion of ground (Karr et al., 1966; Tucker et al., 1968; Waldo et al., 1971) and steam flaked (MacRae and Armstrong, 1969; Nicholson and Sutton, 1969) corn. The incomplete starch digestion noted in this study could be due to large particle size (Abeed et al., 1971) and/or the poor accessibility of raw corn starch to microbial and enzymatic attack due to its horny endosperm (Kerr, 1950; Ørskov et al., 1969).

Ration 0 tended ($P < .10$) to have higher ruminal percentage starch digestibilities than 7, 14 and 21. All ration values were similar to reported ruminal digestibilities obtained with high (60 to 80%) ground corn rations (Karr et al., 1966; Tucker et al., 1968; Beever et al., 1970; Waldo et al., 1971). In these previous studies, ruminal starch digestibilities ranged from 50 to 84% with a mean value of 71.3%. This suggests that on high concentrate rations, steers are able to ruminate sufficiently with WSC to grind the grain to a size small enough for fermentation. McCullough and Matsushima (1973) reported ruminal starch digestibilities of 61.1% with WSC and 91.1% with SF corn suggesting that raw corn starch is less available to the rumen microbes than steam treated starch.

More starch tended to reach the abomasum on rations 7 and 14 than

on ration 0. Of the starch entering the intestine, markedly less ($P < .10$) was digested on ration 14 than on the other rations. The data of Karr et al. (1966) suggest that the digestibility coefficient of raw corn starch in the intestine is highly dependent upon the amount of starch entering the intestine. Little et al. (1968) also suggested that the capacity of the small intestine to digest starch was limited. The lower intestinal starch digestibility of ration 14 should not be due to an overloading of the lower gut, however, since ration 7 had a higher ($P < .10$) intestinal digestibility in spite of having a greater amount of starch entering the intestine. Since the starch of all rations should have been equally available for digestion in the intestine, the lowered intestinal digestibility of ration 14 suggests that the rate of passage through the lower gut may have been increased. The intestinal digestibilities of all rations in this experiment appear low when compared with studies using ground or steam flaked corn (MacRae and Armstrong, 1969; Ørskov et al., 1969; Waldo et al., 1971) in which essentially all starch entering the intestine was digested. The difference may be due to the presence of whole corn kernels in the intestine which are not readily available for enzymatic attack and the poor accessibility of the raw starch in the intestine.

Cellulose digestibilities are shown in Table IV. Cellulose intake increased with roughage level ($P < .05$). Total digestion of cellulose was highest ($P < .05$) for ration 0 and lowest ($P < .05$) for ration 14. The high digestibility noted with ration 0 is probably due to the small amount of cellulose present in the diet and the fact that the cellulose was from sources other than cottonseed hulls. The low value noted with ration 14 may again be due to a more rapid rate of passage of digesta

TABLE IV

CELLULOSE DIGESTION

Item	Ration Roughage Level 0	7	14	21	SE[e]
Intake (g/day)	156[a]	343[b]	554[c]	877[d]	38.5
Ruminal Digestion (g/day)	113[a]	208[b]	318[c]	485[d]	19.0
Intestinal Digestion (g/day)	9[a]	16[a]	-17[a]	92[b]	20.3
Total Digestion (g/day)	122[a]	224[b]	301[b]	577[c]	31.40
Entering Intestine (g/day)	42[a]	135[ab]	236[b]	392[c]	39.60
Ruminal Digestion (% of intake)	72.92[a]	60.77[b]	57.30[b]	56.26[b]	3.20
Intestinal Digestion (% entering intestine)	21.43	11.85	-7.20	23.47	8.97
Total Digestion (% of intake)	78.15[a]	65.72[b]	54.08[c]	65.96[c]	3.00
Ruminal Digestion (% of total)	93.40[ab]	92.47[ab]	105.95[b]	85.28[a]	5.54
Intestinal Digestion (% of total)	6.60[ab]	7.53[ab]	5.95[b]	14.72[a]	5.53

[a,b,c,d]Values on same row with differing superscripts are significantly different ($P < .05$).

[e]Standard error of the mean.

from the rumen. Although ruminal cellulose digestibility as a percent of total digestibility for cellulose gave impossible results with ration 14 (greater than 100%) the data suggest that cellulose digestion on rations 0, 7 and 14 was almost completely confined to the rumen. Other studies have also reported that 80 to 100 percent of the digestible cellulose was digested in the rumen (Hale et al., 1940, 1947; Ridges and Singleton, 1962; Hogan and Weston, 1967). The post-ruminal digestibility coefficients for cellulose obtained in this study are less than the values of 32.8 and 29% reported by Warner et al. (1972) and Putnam and Davis (1965), respectively, for purified cellulose (Solka Floc) infused into the abomasum. The cellulose in this study, however, was probably less available for microbial attack due to its higher lignin content (Van Soest, 1964).

Dry matter digestion (DMD) is presented in Table V. DM intakes increased as the roughage level increased ($P < .05$). Total apparent DM digestibility decreased ($P < .05$) between 0 and 14% CSH but appeared to increase at 21% CSH. The low total DMD of ration 14 again appeared to be due to a lowered intestinal DMD, thus suggesting an increase in the rate of passage. The DMD coefficients observed are similar to those reported by Vance and Preston (1971) for similar roughage levels.

Ruminal DMD was highest for ration 0, being significantly higher than for rations 14 and 21 and tending ($P < .10$) to be higher than ration 7. Many other studies have reported similar ruminal digestibilities for DM (Ridges and Singleton, 1962; Topps et al., 1968) and for organic matter (Hogan and Weston, 1967). Drennan et al. (1970) reported ruminal DM digestibilities of 58 to 68% with steam rolled grain sorghum rations. The starch in the grain sorghum rations, however, was probably

TABLE V

DRY MATTER DIGESTION

Item	Ration Roughage Level				
	0	7	14	21	SE[e]
Intake (g/day)	4458[a]	5230[b]	5688[c]	5932[d]	67.4
Ruminal Digestion (g/day)	2624	2442	2497	2576	260.7
Intestinal Digestion (g/day)	1135	1644	1588	1851	251.8
Total Digestion (g/day)	3759[a]	4086[ab]	4085[ab]	4427[b]	182.0
Ruminal Digestion (% of intake)	58.86[a]	47.50[ab]	43.83[b]	44.17[b]	3.67
Intestinal Digestion (% entering intestine)	61.89	58.99	49.76	55.15	5.38
Total Digestion (% of intake)	84.31[a]	78.41[b]	71.85[c]	74.88[bc]	1.38
Ruminal Digestion (% of total)	69.72[a]	59.98[ab]	61.00[ab]	58.12[b]	3.99
Intestinal Digestion (% of total)	30.28	40.02	39.0	41.88	3.99

[a,b,c,d]Values on same line with differing superscripts are significantly different ($P < .05$).

[e]Standard error of the mean.

more available to the rumen microbes thus accounting for the higher ruminal DMD coefficients. In contrast, the intestinal DMDs obtained in this study were slightly higher than those reported by Drennan et al. (1970).

The low digestibilities of DM, starch and cellulose on ration 14 may be due to a lowered intestinal digestion and not a reduction in rumen fermentation. The possibility of a marked change in the intestinal microflora or in the secretion of digestive enzymes in the small intestine with only a 7% change in the dietary roughage level appears small and the adaptation period should have been adequate for the small ration changes in this study (Potter and Dehority, 1973). It is interesting to note that this roughage level is the approximate level above which Vance et al. (1971) reported a marked decrease in beef cattle average daily gain and net energy for gain (NE_g) with whole shelled corn.

The DM, cellulose and acid detergent fiber (ADF) digestibilities of the cottonseed hull, cottonseed meal mixture (CSH-CSM) which was added to rations 7, 14 and 21 were calculated by difference (Table VI). Very little starch was present in the CSH-CSM mixture so its digestibility was not calculated. When calculated by difference, the digestion of the CSH-CSM DM was very low on rations 7 and 14 but on ration 21 was similar to reported values for cottonseed hulls (Hale et al., 1969). This suggests some associative digestibility effect of roughage and whole corn levels. Cellulose and ADF digestibilities for all rations were similar to those reported by Hale et al. (1969) for CSH. If only the fiber fraction of the CSH-CSM mixture was digested, digestibility of dry matter would be a minimum of 26, 20 and 32% for rations 7, 14 and 21, respectively. These DM digestibilities for rations 7 and 14 are markedly higher than those calculated by difference. This suggests that the

TABLE VI

DIGESTIBILITY OF COTTONSEED HULLS PLUS COTTONSEED MEAL CALCULATED BY DIFFERENCE : TRIAL 1

Item	Ration[a]		
	7	14	21
Dry matter	10.6	7.1	51.6
Cellulose	53.8	43.7	63.3
Acid detergent fiber	37.8	26.8	46.7
Dry matter[b]	25.5	19.5	31.5

[a]Level of cotton seed hulls.

[b]Minimal CSH-CSM dry matter digestibility calculated from CSH-CSM fiber digestibility alone. ADF and cellulose comprised 65 and 45% of the CSH-CSM mixture, respectively.

digestible DM of the corn plus supplement portion of the ration must have been reduced by CSH-CSM addition at these roughage levels. However, the digestibilities of CSH-CSM in ration 21 suggest that the digestion of corn plus supplement at this roughage level is similar to the value for ration 0. Total starch digestibilities suggest a similar pattern (Table III) with depressed digestibility with 14 percent added fiber.

Rumen pH, total concentrations of volatile fatty acids (VFA) and molar concentrations of VFA's are presented in Table VII. No significant differences were noted in total concentration of VFA or in molar concentrations of acetic acid. Propionic acid concentrations were higher ($P < .05$) for ration 0 than for rations 7 and 14. Butyrate concentrations were highest with ration 14 ($P < .05$) and lowest with ration 0 ($P < .05$). Total molar concentrations of valeric, isovaleric and isobutyric acids tended to decline with increasing roughage level. Acetate to propionate ratio increased ($P < .05$) between rations 0 and 7 but then declined between ration 7 and 14.

The reason for the high levels of acetate in rumen fluid is not clear but may be due to the method of feeding employed. Similar values have been obtained previously (Sharp, unpublished results) with continuous feeding.

TABLE VII

RUMEN pH, TOTAL AND MOLAR CONCENTRATIONS OF VOLATILE FATTY ACIDS : TRIAL 1

		Volatile Fatty Acids					
			Molar %				
Ration	Rumen pH	Total Conc. Micromoles/ml	Acetic	Propionic	Butyric	Other	Acetic: Prop
0	6.15	97.31	59.96	25.34[a]	7.05[a]	7.64	2.94[a]
7	6.29	101.32	65.87	14.18[b]	12.80[c]	7.15	5.07[b]
14	6.37	95.12	66.27	17.82[b]	9.20[ab]	6.72	3.85[ab]
21	6.23	107.15	64.76	19.85[ab]	9.76[b]	5.61	3.81[ab]
SE[d]	0.07	3.52	1.95	2.25	0.85	0.60	0.53

[a,b,c]Values in same column with differing superscripts are significantly different ($P < .05$).

[d]Standard error of the mean.

CHAPTER IV

INFLUENCE OF ROUGHAGE LEVEL AND PROCESSING METHOD ON THE SITE AND EXTENT OF DIGESTION OF HIGH CORN RATIONS[1,2,3]

Summary

The influence of roughage level and corn processing method on the site and extent of dry matter (DM), organic matter (OM), cellulose and starch digestion was studied using four Hereford steers fitted with abomasal cannulae in a 4 x 4 Latin square design. Corn was fed steam flaked (SF) or dry rolled (DR) at roughage levels (cottonseed hulls) of 0 and 21% (rations SF-0, SF-21, DR-0 and DR-21, respectively). Lignin was used as a marker for calculation of ruminal digestibilities. Ruminal DM digestibilities were about 13 percentage units higher ($P < .01$) for rations containing SF than DR corn and approximately 10 percentage units higher ($P < .05$) for rations 0 than 21. Total DM digestibilities were 7% higher ($P < .01$) for SF corn and were 9% higher ($P < .01$) for the 0

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roughage rations. Some 93 to 97% of the total digested cellulose was fermented in the rumen. Ruminal and total digestibilities of OM and DM were similar in pattern but OM digestibilities tended to be higher in magnitude. Mean ruminal and total digestibilities of starch for rations SF and DR were 91.6 and 99.0 and 71.7 and 93.6%, respectively. The higher roughage level reduced ($P < .01$) starch digestibility in the intestine (6%) and in the entire tract (0.7%; $P < .05$).

Introduction

Previous studies (Vance and Preston, 1971; Vance et al., 1971; Cole et al., 1975) have indicated that the level of roughage in the ration influences the utilization and digestion of corn fed in the whole form. Little data is available on roughage level effects on the utilization of corn which has been processed. Cole et al. (1975) noted that small changes in roughage level can influence the site and extent of digestion with whole shelled corn (WSC) rations. Since the site of digestion, especially of starch, can alter the efficiency of energy utilization (Black, 1971), factors which affect the site of digestion may influence energy utilization. This study was conducted to investigate the influence of roughage level on the site and extent of digestion of rations containing steam flaked and dry rolled corn.

Experimental Procedures

Four Hereford steers averaging 460 kg (437 to 494 kg) and fitted with permanent rumen and abomasal cannulae were used in a 4 x 4 Latin square design. Steers were housed in metabolism stalls and were fed hourly by means of automatic feeders.

Steers were fed rations containing steam flaked (SFC) or dry rolled corn (DRC) with cottonseed hulls (CSH) added at 0 and 21% of the ration (Table VIII). The steam flaked corn was prepared by steaming corn for 20 to 30 minutes at 100 C at atmospheric pressure and then rolling to produce flakes with a density of 437 gms/liter. Dry rolled corn was prepared by passing the corn through rollers adjusted to crack 95% of the kernels. The density of the dry rolled corn was 684 gms/liter. A dried acid hydrolyzed wood residue (AHWR)[4] (Butterbaugh and Johnson, 1974) was included in the pelleted supplement to supply lignin.

Sampling and laboratory procedures have been described previously (Cole et al., 1975).

The data were analyzed by analysis of variance as a 2 x 2 factorial arrangement of treatments and a 4 x 4 Latin square design. Treatment effects were tested by protected least significant difference (Snedecor and Cochran, 1967).

Results and Discussion

The mean chemical composition of the rations, digesta and fecal samples are shown in Table IX. Roughage additions increased the levels of acid detergent fiber (ADF), lignin (ADL) and cellulose and decreased the starch content of the rations. Dry matter (DM) and organic matter (OM) contents were similar for all rations.

Because OM and DM digestibilities followed similar trends, they will be discussed together. OM and DM digestibilities are shown in Tables X and XI, respectively. OM and DM intakes were increased

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[4]Dierks Division, Weyerhauser Co., Hot Springs, Arkansas.

TABLE VIII

COMPOSITION OF RATIONS : TRIAL 2[a]

Ingredient	IRN[b]	Ration 0[c]	Ration 21[c]
Corn, dent yellow[d] grain (4)	4-02-935	90.0	66.0
Cotton, seed hulls (1)	1-01-599	--	21.0
Cotton, seeds w some hulls, solv-extd grnd, mn 41% protein mx 14% fiber mn 0.5% fat (5)	5-01-621	--	3.0
Premix[e]		10.0	10.0

[a]Percent, dry matter basis.

[b]International reference number.

[c]Level of cottonseed hulls.

[d]Steam flaked or dry rolled as described in text.

[e]To provide as a % of diet: corn, yellow, grain, grd 4-02-992, 1.1; cottonseed meal, 5-01-621, 3.2; calcium phosphate dibasic, commercial, 6-01-080, .45; calcium carbonate, commercial mn 38% Ca, 6-01-069, .63; trace mineralized salt, .45; urea, mn 45% N, 5-05-070, .63; acid hydrolyzied wood residue, 3.6; per kg ration: aurofac-50, 22 mg chlortetracycline; vitamin A palmitate, commercial, 7-05-143, 4950 IU; vitamin D_3, commercial, 440 IU.

TABLE IX

CHEMICAL COMPOSITION OF RATIONS, DIGESTA AND FECES : TRIAL 2[a]

Item[b]	Ration[c]			
	SF-O	SF-21	DR-O	DR-21
Rations				
DM	88.1	88.8	88.8	89.2
ADF	7.0	20.0	6.2	21.2
ADL	3.3	7.3	2.4	7.9
Cellulose	3.7	12.6	3.7	13.1
Starch	62.0	48.1	60.8	44.6
OM	96.3	96.0	96.4	95.9
Digesta				
DM	5.5	5.4	6.0	6.3
ADF	35.6	34.7	11.9	29.7
ADL	10.6	17.5	5.5	14.1
Cellulose	3.6	13.9	2.4	11.4
Starch	14.8	11.2	36.9	21.8
OM	69.3	84.3	85.0	85.0
Feces				
DM	28.6	26.2	30.9	28.9
ADF	32.4	55.3	22.9	46.5
ADL	21.9	29.6	13.5	25.0
Cellulose	7.9	24.3	6.1	19.2
Starch	2.3	3.2	18.2	10.1
OM	84.3	89.1	87.0	90.5

[a]All values are on a dry matter basis (%).

[b]DM - dry matter, ADF - acid detergent fiber, ADL - acid detergent lignin, OM - organic matter.

[c]SF - steam flaked, DR - dry rolled, 0 and 21 - % cottonseed hulls.

TABLE X

ORGANIC MATTER DIGESTION : TRIAL 2

Item	Ration				
	SF	DR	0	21	SE
Intake, g	4657	4662	4198^{A}	5121^{B}	31.0
Ruminal digest., g	3217^{a}	2518^{b}	2850	2885	57.7
Intestinal digest., g	682^{a}	1062^{b}	733	1010	90.1
Total digest., g	3899^{A}	3591^{B}	3584^{A}	3906^{B}	44.7
Entering intestine, g	1440^{A}	2144^{B}	1348^{A}	2236^{B}	65.4
Ruminal digest., % of intake	69.8^{A}	54.5^{B}	68.0^{A}	56.4^{B}	1.5
Intestinal digest., % of entering	46.4	48.8	51.0	44.2	3.3
Total digest., %	84.2^{A}	77.6^{B}	85.4^{A}	76.3^{B}	.8
Ruminal digest., % of total	82.2^{a}	70.6^{b}	79.0	73.8	2.6
Intestinal digest., % of total	17.9^{a}	29.4^{b}	21.0	26.2	2.6

^{a,b}Means on same row with differing superscripts are significantly different ($P < .05$).

^{A,B}Means on same row with differing superscripts are significantly different ($P < .01$).

TABLE XI

DRY MATTER DIGESTION : TRIAL 2

Item	Ration				
	SF	DR	0	21	SE
Intake, g	4844	4853	4358^{A}	5340^{B}	32.1
Ruminal digest., g	2980^{A}	2344^{B}	2624	2700	100.7
Intestinal digest., g	999	1308	1022	1285	144.4
Total digest., g	3980^{A}	3652^{B}	3646^{A}	3985^{B}	46.8
Entering intestine, g	1864^{A}	2506^{B}	1734^{A}	2636^{B}	114.1
Ruminal digest., % of intake	62.0^{A}	48.9^{B}	60.3^{a}	50.6^{b}	2.4
Intestinal digest., % of entering	51.8	51.3	55.2	47.8	4.7
Total digest., %	82.6^{A}	75.8^{B}	83.7^{A}	74.7^{B}	0.8
Ruminal digest., % of total	75.2^{a}	64.2^{b}	72.0	67.4	3.2
Intestinal digest., % of total	24.8^{a}	35.8^{b}	28.0	32.6	3.2

^{a,b}Means on same row with differing superscripts are significantly different ($P < .05$).

^{A,B}Means on same row with differing superscripts are significantly different ($P < .01$).

($P < .01$) when roughage level increased thus equalizing starch intakes. Approximately 15.3% more OM ($P < .01$) and 13.1% more DM ($P < .05$) was digested in the rumen with SFC than with DRC. This lowered ruminal digestion of DRC was partially compensated for by a greater ($P < .05$) amount of intestinal digestion. The total amount of OM and DM digested was greater ($P < .01$) for rations containing roughage due to the higher total intakes. About 6% more ($P < .01$) total OM and DM was digested with SFC than with DRC.

Ruminal OM and DM digestibility coefficients were higher ($P < .01$) by over 10% for the all concentrate rations and by over 13% for SF corn ($P < .01$). Digestibilities of OM and DM entering the intestine were not significantly different among rations but tended to be higher for the all concentrate diets than for the 21% CSH rations.

Ruminal DM digestion coefficients were 5 to 10 percentage units lower than those for OM and total DM digestion coefficients tended to be slightly lower than total OM digestion. This reflects the secretion of minerals, probably mainly in saliva, anterior to the abomasum and mineral absorption by the intestine.

Starch intakes were higher ($P < .05$) on the all concentrate rations despite the higher DM intakes on the higher roughage rations (Table XII). About 600 g more ($P < .01$) starch was digested daily in the rumen of steers fed SFC than steers fed DRC. About 350 g more ($P < .01$) starch was digested in the intestine with DRC resulting in about 250 g more ($P < .05$) total starch digestion with SFC. Amounts of ruminal and intestinal starch digestion were similar but more ($P < .05$) total starch was digested on the all concentrate diets due to the higher starch intakes.

TABLE XII

STARCH DIGESTION : TRIAL 2

Item	Ration				
	SF	DR	0	21	SE[c]
Intake (g)	2632	2516	2675[a]	2473[b]	54.2
Ruminal digest., (g)	2410[A]	1806[B]	2192	2024	67.5
Intestinal digest., (g)	196[A]	547[B]	396	347	38.5
Total digest. (g)	2606[a]	2354[b]	2588[a]	2371[b]	50.1
Entering intestine (g)	222[A]	709[B]	484	448	35.2
Ruminal digest, % intake	91.6[A]	71.7[B]	81.7	81.6	1.4
Intestinal digest, % enter. intest.	88.4[A]	76.2[B]	85.5[A]	79.1[B]	1.4
Total digest., %	99.0[A]	93.6[B]	96.7[a]	96.0[b]	0.2
Ruminal digest., % of total	92.4[A]	77.0[B]	84.2	85.2	2.1
Intestinal digest., % of total	7.6[A]	23.0[B]	15.8	14.8	2.1

[a,b]Means on same row within same treatment comparison with differing superscripts are significantly different ($P < .05$).

[A,B]Means on same row within same treatment comparison with differing superscripts are significantly different ($P < .01$).

[c]Standard error of the mean.

Ruminal starch digestion coefficients were not significantly effected by roughage level but intestinal ($P < .01$) and total ($P < .05$) starch digestibilities were higher for the all concentrate diets. Ruminal, intestinal and total starch digestion coefficients were higher ($P < .01$) for the SFC than DRC rations. Some 12% more ($P < .05$) of the starch entering the intestine was digested in rations containing SFC than DRC suggesting that the capacity of the intestine to digest starch or absorb glucose may have been reached with the DRC ration. Roughage additions lowered ($P < .01$) intestinal digestion of starch, suggesting that roughage in the lower gut stimulated the rate of passage and thus decreased the time for intestinal digestion. This effect of roughage on intestinal digestion was greatest with SF corn. Intestinal starch digestibilities for rations SF-0, SF-21, DR-0 and DR-21 were 93, 84, 78 and 74%, respectively. The rumen was a more important site of starch digestion with SFC than DR corn with 92 and 77% ($P < .01$) of total starch being digested at this site, respectively.

Cellulose digestibility is shown in Table XIII. Corn processing had no apparent influence on cellulose digestion. Cellulose intakes were higher ($P < .01$) on the rations containing cottonseed hulls resulting in more ($P < .01$) ruminal and total cellulose digestion. The higher roughage level reduced ruminal ($P < .01$) and total ($P < .01$) cellulose digestion coefficients by 14 to 16%. Over 93% of cellulose digestion occurred in the rumen on all rations, although intestinal cellulose digestion appeared to be slightly increased when greater amounts of cellulose entered the intestine.

The digestibility of the cottonseed hull-cottonseed meal (CSH-CSM) supplement of rations SF-21 and DR-21 was calculated by difference (Table

TABLE XIII

CELLULOSE DIGESTION : TRIAL 2

Item	Ration				
	SF	DR	O	21	SE
Intake, g	416	435	160[A]	691[B]	15.9
Ruminal digest., g	235	239	111[A]	364[B]	15.1
Intestinal digest., g	17	26	5	38	13.4
Total digest., g	252	266	116[A]	402[B]	21.3
Entering intestine, g	181	195	49[A]	327[B]	9.3
Ruminal digest., % of intake	61.2	60.8	69.4[A]	52.7[B]	1.3
Intestinal digest., % of entering	4.3	4.0	1.6	6.6	6.8
Total digest., %	64.8	65.2	72.2[A]	57.8[B]	1.9
Ruminal digest., % of total	95.4	94.4	96.4	93.4	5.0
Intestinal digest., % of total	4.6	5.6	3.6	6.6	5.0

[a,b]Means on same row with differing superscripts are significantly different ($P < .05$).

[A,B]Means on same row with differing superscripts are significantly different ($P < .01$).

XIV). Dry matter digestibilities agree with reported values for cottonseed hulls (Hale et al., 1969). Cellulose and ADF digestibilities were slightly higher than the values of Hale et al. (1969). If only the fiber fraction of the CSH-CSM mixture was digested, the DM digestibility of CSH-CSM would be a minimum of 22 and 24% for rations SF-21 and DR-21, respectively. Since observed values match these estimates, this indicates that the roughage fraction of the ration with SF and DR corn had no marked detrimental complementary effect on the digestion of the concentrate fraction of the ration, which had been observed previously with 14% roughage addition to whole shelled corn (Cole et al., 1975). Total starch digestibilities were not markedly depressed by fiber addition in this study (0.7%) (Table XII) also indicating no apparent effect of roughage on the digestion of the concentrate portion of the ration.

Rumen pH and volatile fatty acids (VFA) concentrations are given in Table XV. Rations had no significant effect on rumen pH, total VFA concentration or molar concentration of acetic, propionic and butyric acid. Total VFA and molar concentrations of acetate were about 18% higher for rations containing added roughage. Higher acetate concentrations and higher acetate/propionate ratios with added roughage are typical of many studies (Wise et al., 1968). The higher total VFA concentration with roughage may be a result of the higher feed intakes on these rations or a decrease in the rumen liquid turnover rate. The added roughage may also produce a more favorable environment in the rumen for fermentation. A significant processing method by roughage level interaction was obtained for molar concentration of C-4 and iso-VFAs (valeric, isobutyric and isovaleric). Corn processing method had no apparent effect on molar concentration of C-4 and iso-VFAs at 21% roughage but did with rations

TABLE XIV

DIGESTIBILITY OF COTTONSEED HULLS PLUS COTTONSEED MEAL CALCULATED BY DIFFERENCE

Item	Ration[a]	
	SF-21	DR-21
Dry matter	50.5	42.0
Organic matter	62.4	51.7
Cellulose	48.5	47.0
Acid detergent fiber	40.5	39.6
Dry matter[b] minimum	22.5	23.9

[a]SF - steam flaked, DR - dry rolled, 21 - % roughage.

[b]Calculated from fiber digestion alone. Cellulose and acid detergent fiber comprised 43 and 66% of the dry matter of this mixture, respectively.

TABLE XV

RUMEN pH, TOTAL AND MOLAR CONCENTRATIONS OF VOLATILE FATTY ACIDS : TRIAL 2

Ration	Rumen pH	Volatile Fatty Acids					
		Total Conc. Micromoles/ml	Molar %				
			Acetic	Propionic	Butyric	Other*	Acetic / Propionic
SF	6.0	142.9	66.7	17.3	8.8	7.2	4.0
DR	6.0	151.7	66.6	18.6	8.8	5.9	4.0
0	6.0	135.2	64.5	18.9	9.0	7.6[a]	3.7
21	6.0	159.4	68.8	17.0	8.7	5.5[b]	4.3
SE[c]	0.7	8.6	1.5	1.8	0.4	0.4	0.4

[a,b]Means in the same column with differing superscripts are significantly different ($P < .05$).

[c]Standard error of the mean.

*Significant processing method by roughage level interaction ($P < .05$).

SF-O and DR-O (9.1 and 5.3 molar %, respectively; $P < .05$). Mudd and Perry (1969) noted no consistent effect of level of raw and gelantinized corn in the diet on ruminal VFA levels.

Discussion

Studies of site of digestion are complicated by the difficulty of obtaining accurate estimates of digesta passage from the rumen. Most studies have used lignin or chromic oxide as markers with spot sampling from the abomasum. Previous studies at this institution (Cole and Johnson, 1974, unpublished results) which employed chromic oxide or chromium-EDTA as a passage marker have resulted in negative ruminal dry matter digestibilities. Drennan et al. (1970) also obtained impossible results for ruminal DM digestion with chromic oxide. The similarity between values for ruminal digestion obtained in this study and those using total digesta collection suggest that lignin will work satisfactorily as a marker with spot sampling from the abomasum under continuous feeding conditions.

To test the length of the adaptation period used in this study, fecal collections were made on two steers during a third week on their respective rations. Total digestibility was not changed from the initial fecal collection indicating that the adaptation period was adequate. Potter and Dehority (1973) have reported that five days was an adequate adaptation period following even more drastic ration changes than those in the present study.

In the present studies, ruminal and total starch digestibilities were similar to those reported by other workers for flaked corn (MacRae and Armstrong, 1969b; McCullough and Matsushima, 1973) and steam flaked

sorghum grain (Drennan et al., 1970). McCullough and Matsushima (1973) reported that roughage level (12% corn silage) had little effect on the site or extent of starch digestion with steam flaked corn. Although significant differences were noted between roughage levels in total starch digestion in this study, the differences were small. Total and ruminal DM and OM digestibilities of SF corn were similar to those reported by Drennan et al. (1970) with steam flaked milo.

Ruminal starch digestibilities of DR corn agree with several studies using steers (Waldo, 1973) but are lower than values reported for sheep (Ørskov et al., 1969). Total starch digestibilities for DR corn are slightly lower than previous reports with ground corn fed to cattle (Karr et al., 1966; Waldo et al., 1971) or to sheep (Tucker et al., 1968; Beever et al., 1970). The lower total digestibilities, however, may have been attributable to the particle size of the corn (Wilson et al., 1973) since physical separation of rolled corn indicated that about 5% of the corn was still in the whole form. Ruminal DM digestibilities were similar to previous reports with ground and cracked corn (Ørskov et al., 1969) and with whole shelled corn (Cole et al., 1975).

The higher ($P < .01$) ruminal and total starch digestibilities noted with SF corn over DR corn indicate that gelatinized starch is more available to enzymatic attack in the rumen and intestine. This has been noted in previous experiments (McCullough and Matsushima, 1973; Ørskov et al., 1969; Beever et al., 1970; Galyean et al., 1975).

Increasing roughage level tended to decrease total starch digestion for both SF ($P < .10$) and DR corn ($P < .20$). This was attributable to lowered ($P < .01$) intestinal digestion rather than a decrease in ruminal fermentation, suggesting that roughage in the lower gut may increase the

rate of passage of digesta and decrease intestinal digestion. A similar trend was noted previously with whole shelled corn at a roughage level of 14% (Cole et al., 1975).

As with previous studies (Hale et al., 1940, 1947; Hogan and Weston, 1967; Cole et al., 1975) cellulose digestion was almost totally confined to the rumen on all rations. The lowered cellulose digestion with added roughage may have been due to the change in the level and change in the source of cellulose in the rations.

Dry matter and starch intakes were relatively low in this study compared with normal feedlot conditions. In several studies using barley (Topps et al., 1968), corn (Tucker, et al., 1968; Nicholson and Sutton, 1969) and milo (Kartchner et al., 1973), however, level of starch intake had little or no effect on the extent of ruminal or total starch digestion. Data suggest that numerous factors such as roughage level, starch intake and N intake may influence the site and extent of starch digestion. In most studies, however, these factors have been confounded and thus limited the interpretation of the results.

CHAPTER V

INFLUENCE OF ROUGHAGE LEVEL AND CORN PROCESSING METHOD ON MICROBIAL PROTEIN SYNTHESIS IN BEEF STEERS[1,2,3]

Summary

Two trials were conducted to determine the efficiency of nitrogen (N) utilization in high concentrate rations and to determine the influence of roughage level and corn processing method on N utilization. In trial 1, abomasally cannulated steers were fed rations containing whole shelled corn (WS) at cottonseed hull (CSH) levels of 0, 7, 14 and 21% and in trial 2, rations contained steam flaked (SF) and dry rolled (DR) corn at roughage levels of 0 and 21%. Lignin was used as a marker for determination of digesta passage through the abomasum. In trial 1, g microbial protein synthesis per 100 g dry matter fermented (MP/DDM) in the rumen were 7.5, 8.0, 11.8 and 12.7, respectively. More of the N intake bypassed the rumen undegraded (BPN) on rations 14 and 21 also resulting in more ($P < .05$) protein reaching the intestine (AP). In trial

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[1]Journal article of the Agriculture Experiment Station, Oklahoma State University, Stillwater.

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2, MP/DDM for rations SF-O, SF-21, DR-O and DR-21 were 5.2, 8.7, 7.3 and 13.8. N was absorbed from the rumen on all rations but loss was less ($P < .01$) on the 21% CSH rations. BPN and AP were higher ($P < .05$) on 21% roughage rations and tended to be higher for DR than SF corn.

Introduction

The ruminant is unique in its ability to convert dietary nitrogen to microbial protein which can subsequently be utilized by the animal. When dietary protein is in a non-protein nitrogen (NPN) form or of poor amino acid balance, this interchange is advantageous to the animal. However, this cycle is a disadvantage when dietary protein is of high quality.

Numerous factors affect the extent of microbial protein synthesis in the rumen (Thomas, 1973), but few studies have quantitated microbial protein synthesis, primarily due to difficulties involved with measurement of digesta flow and with separating feed protein from microbial protein. Most studies have used sheep fed high roughage or purified rations. Little data is available on beef cattle fed high concentrate rations.

The purpose of this study was to determine the extent of microbial protein synthesis in the rumen of steers fed high concentrate rations varying in corn processing method and roughage level.

Experimental Procedures

Details of feeding, sampling, analytical and statistical procedures used in these studies have been previously described (Cole et al., 1975a, b). Ration compositions are listed in Table XVI for the roughage level

TABLE XVI

COMPOSITION OF RATIONS[a]

Item	IRN[b]	Ration Identification			
	Trial 1[c]	0	7	14	21
	Trial 2[d]	0	-	--	21
Corn, dent yellow, grain (4)	4-02-935	90.0	82.0	74.0	66.0
Cotton, seed hulls (1)	1-01-599	--	7.0	14.0	21.0
Cotton, seed w some hulls, solv-extd grd mn 41 prot mx 14 fbr mn 0.5 fat (5)	5-01-621	--	1.0	2.0	3.0
Premix[e]		10.0	10.0	10.0	10.0

[a]Percent on a dry matter basis.

[b]International reference number.

[c]In trial 1, rations designated by percent added roughage.

[d]In trial 2, steam flaked or dry rolled corn grain were fed at 0 or 21% roughage, designated as SF-0, DR-0, SF-21 and DR-21, respectively.

[e]To provide as a % of total ration: corn, yellow, grain, grnd, 4-02-992, 1.1; cottonseed meal, 5-01-621, 3.2; calcium carbonate, commercial mn 38% Ca, 6-01-069, .63; calcium phosphate dibasic, commercial, 6-01-080, .45; trace mineralized salt, .45; urea, mn 45% nitrogen, 5-05-070, .63; acid hydrolyzed wood residue, 3.6; per kg of ration: aurofac-50, 22 mg chlortetracycline; vitamin A palmitate, commercial, 7-05-143, 4950 IU, vitamin D_3, commercial, 440 IU.

(trial 1) and corn processing (trial 2) experiments.

Additional procedures of feed, abomasal and fecal sample analysis included nitrogen by macro-Kjeldahl (AOAC, 1965), ammonia-N (NH_3-N) by distillation over MgO_4 (AOAC, 1965), urea-N (U-N) (urease and MgO_4) and ribonucleic acid (RNA) (McAllen and Smith, 1969). Lignin was used as a marker for determination of digesta passage through the abomasum. Microbial N was estimated from abomasal RNA assuming that RNA-N represented 10% of total microbial-N. This value was determined by analysis of mixed rumen bacteria from steers fed each ration (Males, unpublished data) and tends to agree with reported values (Smith, 1969). Non-ammonia-nitrogen (NAN) was calculated as total N minus NH_3-N and U-N. Feed protein nitrogen bypassing the rumen (BPN) was calculated as NAN minus microbial-N.

In trial 2, U-N was omitted from the analysis since it was a very minor constituent of abomasal digesta.

To calculate ruminal turnover rates, the amount of digesta passage from the rumen was estimated from lignin intake, abomasal lignin and abomasal DM. Assuming a constant rumen volume of 50 liters, the rumen dilution rate and turnover time was estimated. The validity of these assumptions and estimates is based on a solid phase marker (lignin), so may not directly indicate flow of liquid digesta.

Results and Discussion

Trial 1

The daily intakes of nitrogen (N), dry matter (DM) and fermented DM (DDM) are shown in Table XVII. Due to the increase in DM intakes with increasing roughage levels, N intakes increased with added roughage. DDM intakes were similar for all rations.

TABLE XVII

INTAKES OF NITROGEN, DM AND RUMINAL DIGESTED DRY MATTER : TRIAL 1[a]

Ration	Item[b]		
	Nitrogen	DM	DDM
0	88.2[d]	4458[d]	2625
7	102.7[e]	5230[e]	2734
14	112.1[f]	5688[f]	2497
21	117.4[f]	5932[g]	2576
SE[c]	3.8	267	261

[a]Grams per head per day.

[b]DM - dry matter, DDM - fermented DM.

[c]Standard error of the mean.

[d,e,f]Means in the same column with different superscripts are significantly different ($P < .05$).

The chemical composition of the abomasal digesta is shown in Table XVIII. Digesta from ration 7 tended to have a lower content of N, NAN and BPN while ration 14 tended to have a lower microbial-N content. Urea-N was a minor fraction for the digesta of all rations.

Table XIX presents the total amount of N passing the abomasum in each N fraction. On rations 0 and 7 less than 80% of total N intake passed the abomasum whereas over 100% of consumed N passed the rumen on rations 14 and 21. The high values for rations 14 and 21 suggest that more extensive recycling of N had occurred on these rations.

Rations 14 and 21 had about 75% more crude protein ($P < .05$) and NAN ($P < .05$) and over 100% more feed BPN ($P < .01$) passing the abomasum than rations 0 and 7. These values indicate a higher N recycling, feed protein bypass and increased microbial protein synthesis in the rumen of animals fed rations 14 and 21. N utilization for microbial protein synthesis (ENU) tended to be greater for rations 14 and 21 than rations 0 and 7.

Microbial protein synthesis per 100 gms. of DM fermented in the rumen was almost 60% greater ($P < .10$) for rations containing 14 and 21% CSH than for rations 0 and 7. NAN accounted for about 94% of total digesta N (Table XX) on all rations. Of the NAN, about half was microbial-N and half BPN, except on ration 14, in which a greater fraction of the NAN was BPN.

Total N digestibility (Table XXI) was highest ($P < .05$) for ration 0, and ration 14 tended to be lower than all other rations primarily due to lower ($P < .05$) intestinal N digestion for ration 14. The total quantity of N digested in the intestine, however, was higher for rations 14 and 21 (44, 42, 51 and 84 gms, for rations 0, 7, 14 and 21, respec-

TABLE XVIII

NITROGEN FRACTIONS IN ABOMASAL DRY MATTER : TRIAL 1[a]

Item	Ration[b] 0	7	14	21	SE[c]
Total-N	43.85	35.98	41.53	40.76	3.10
NH_3-N	2.44	2.16	2.33	2.02	.23
Urea-N	.00	.10	.10	.10	.20
NAN[d]	38.96	31.73	36.96	36.86	2.71
Micr-N[e]	21.24	18.34	14.73	18.22	2.11
BPN[f]	30.8	24.50	31.70	29.60	3.10
RNA	8.04	6.95	5.58	6.90	1.60

[a] mg per g dry matter.

[b] Identified by level of cottonseed hulls.

[c] Standard error of the mean.

[d] Non ammonia nitrogen.

[e] Microbial nitrogen.

[f] Feed bypass nitrogen.

TABLE XIX

TOTAL ABOMASAL PASSAGE IN NITROGEN FRACTIONS : TRIAL 1[a]

Item[i]	Ration[b] 0	7	14	21	SE[c]
N Intake	88.2	102.7	112.1	117.4	3.8
Abomasal Passage					
Total N	70.3[d]	78.8[d]	132.6[e]	126.3[e]	10.7
NH_3-N	3.9	4.7	7.5	6.2	.9
NAN	66.2[d]	74.0[d]	124.9[e]	119.9[e]	9.9
Microbial Nitrogen	34.0	40.3	47.1	57.4	6.9
BPN	32.1[d]	33.6[d]	77.8[f]	62.5[e]	4.3
NLR	17.9[d]	23.9[d]	-20.5[e]	-9.0[e]	9.2
Microbial-CP/DDM	7.46[g]	8.02[g]	11.78[h]	12.68[h]	1.3
ENU (%)	70.0	55.8	114.8	99.4	7.6

[a]Grams per day unless indicated.

[b]Identified by level of cottonseed hulls.

[c]Standard error of the mean.

[d,e,f]Means on same row with differing superscripts are significantly different ($P < .05$).

[g,h]Means on the same row with differing superscripts are significantly different ($P < .10$).

[i]NAN - non ammonia N; BPN - bypass N; NLR - N lost in the rumen; microbial-CP/DDM - microbial protein synthesis per 100 gms of DM fermented; ENU - efficiency of N utilization.

TABLE XX

PROPORTION OF ABOMASAL NITROGEN PASSING THE ABOMASUM IN EACH NITROGEN FRACTION[a]

	Item[b]			
Ration	Microbial-N	NAN	BPN	NH_3 + Urea
Trial 1				
0	48.4[d]	94.5	45.3	5.5
7	51.2[d]	94.1	45.0	5.9
14	35.6[e]	94.4	58.3	5.6
21	47.0[d]	94.9	48.7	5.1
SE[c]	3.1	0.5	4.6	0.5
Trial 2				
SF	46.4	95.6	49.2	4.4
DR	44.6	96.0	51.4	4.1
0	42.6	95.0[d]	52.4[d]	5.0[d]
21	48.5	96.6[e]	48.2[e]	3.5[e]
SE	3.0	0.4	1.0	0.4

[a]Percent of total N passing the abomasum.

[b]NAN - non ammonia N; BPN - feed bypass N.

[c]Standard error of the mean.

[d,e]Means in same column within the same trial and treatment group with differing superscripts are significantly different ($P < .05$).

TABLE XXI

SITE AND EXTENT OF NITROGEN DIGESTION

Ration	Ruminal[a]	Intestinal[b]	Total[a]
		Trial 1	
0	20.3[c]	62.9[c]	71.4[c]
7	23.3[c]	53.1[c]	64.0[d]
14	-14.3[d]	38.7[d]	60.5[d]
21	- 5.0[d]	66.9[c]	64.4[d]
SE[f]	4.3	7.2	2.0
		Trial 2	
SF	28.8	62.4	73.4[c]
DR	20.6	59.0	67.5[d]
0	39.2[c]	60.0	75.5[c]
21	10.3[d]	61.4	65.4[d]
SE[f]	2.8	6.1	1.3

[a]Percent of N intake.

[b]Percent of N entering the intestine.

[c,d,e]Means in the same column within the same trial with differing superscripts are significantly different ($P < .05$).

[f]Standard error of the mean.

tively), despite the decreased total percent digestibility.

Trial 2

Table XXII shows the daily intakes of N, DM and DDM. N and DM intakes were higher for rations containing roughage but DDM intakes were similar within corn processing method. SFC had about 25% higher ($P < .05$) DDM intakes than DRC.

The chemical composition of abomasal digesta is shown in Table XXIII. No significant differences were noted in total abomasal N, NAN or NH_3-N although the 21% CSH rations tended to have higher values for N and NAN and lower values for NH_3-N than the all concentrate rations. Ration DR-O had a lower ($P < .05$) content of RNA and thus lower ($P < .05$) values for microbial N and microbial protein. Ration SF-O tended ($P < .10$) to have a lower concentration of RNA and microbial-N than ration SF-21.

Total N passing the abomasum per day (Table XXIV) was 67% higher ($P < .01$) for rations containing roughage and 17% higher ($P < .05$) for DR than SF corn. The lower passage of N on the all concentrate rations could be due to the lower N intakes with the diet and less N recycling due to decreased saliva flow. About 70% more NAN ($P < .01$), 89% more microbial-N ($P < .01$) and 55% more feed-N ($P < .01$) passed the rumen with 21% CSH than 0% CSH. Some 18% more NAN ($P < .05$), 14% more microbial-N ($P < .20$) and 21% more feed-N ($P < .05$) passed through the abomasum with DR than SF corn. More ($P < .01$) N was lost in the rumen with all concentrate diets than with 21% CSH rations and more ($P < .10$) was lost with SF than DR corn. Microbial protein synthesized per 100 gms. of DM apparently fermented was over 50% higher ($P < .01$) with 21% CSH rations

TABLE XXII

INTAKES OF NITROGEN, DM AND RUMINAL DIGESTED DRY MATTER : TRIAL 2[a]

Ration	Item[b]		
	Nitrogen	DM	DDM
SF-O	91.5[d]	4362[d]	2901[d]
SF-21	103.8[ef]	5326[e]	3058[d]
DR-O	96.0[de]	4354[e]	2347[e]
DR-21	109.4[f]	5352[e]	2345[e]
SE[c]	2.8	146	142

[a]Grams per head per day.

[b]DM - dry matter; DDM - fermented dry matter.

[c]Standard error of the mean.

[d,e,f]Means in same column with differing superscripts are significantly different ($P < .05$).

TABLE XXIII

NITROGEN FRACTIONS IN ABOMASAL DRY MATTER : TRIAL 2[a]

Item[d]	Ration[b]				
	SF-O	SF-21	DR-O	DR-21	SE[c]
Total-N	36.46	39.16	31.84	34.54	2.2
NH_3-N	1.98	1.36	1.43	1.18	.2
NAN	34.48	37.79	30.41	33.36	1.9
Microbial Nitrogen	16.28	18.72	12.98	16.31	.8
BPN	17.75	19.39	17.27	16.67	1.2
RNA	12.33	14.18	9.83	12.36	.6

[a] Mg per gm of dry matter.

[b] SF - steam flaked; DR - dry rolled; 0 and 21 - level of cottonseed hulls.

[c] Standard error of the mean.

[d] NAN - non ammonia N; BPN - feed bypass N.

TABLE XXIV

TOTAL ABOMASAL PASSAGE IN NITROGEN FRACTIONS : TRIAL 2[a]

Item[g]	Ration Main Effects[b]				
	SF	DR	0	21	SE[c]
N Intake	97.6[d]	102.7[e]	93.8[D]	106.6[E]	2.0
Abomasal Passage					
Total-N	70.4[d]	82.6[e]	57.2[D]	95.8[E]	3.1
NH_3-N	2.9	3.2	2.8	3.3	0.4
NAN	67.4[d]	79.4[e]	54.3[D]	92.5[E]	2.8
Microbial nitrogen	32.5	37.0	24.0[D]	45.4[E]	1.9
BPN	35.0[D]	42.4[E]	30.2[D]	47.0[E]	1.6
NLR	27.2	20.2	36.6[D]	9.3	2.5
Microbial-CP/DDM	6.96[D]	10.54[E]	6.26[D]	11.24[E]	.6
ENU (%)	55.2	65.6	39.9[D]	80.8[E]	3.9
BPN/TNI (%)	35.3[d]	40.8[e]	32.0[D]	44.0[E]	1.4

[a]Grams per day unless indicated.

[b]SF - steam flaked; DR - dry rolled; 0 and 21 - level of cottonseed hulls.

[c]Standard error of the mean.

[d,e]Means on the same row with differing superscripts are significantly different ($P < .05$).

[D,E]Means on same row with differing superscripts are significantly different ($P < .01$).

[f]NAN - non ammonia N; BPN - feed bypass N; NLR - N lost in the rument; Microbial-CP/DDM - microbial protein synthesis per 100 gms. DM fermented; ENU - efficiency of N utilization; BPN/TNI - % of total N intake bypassing the rumen.

thus resulting in a greater ($P < .01$) efficiency of ruminal N utilization. Heat treatment of SF corn during processing might be expected to denature some of the corn protein, render it less soluble in the rumen and cause more rumen bypass. Galyean et al. (1975) have reported that less of the total corn N was soluble when SF than DR (8% vs 12% for SF corn and DR corn, respectively). Conversely, however, the process of gelatinization may expose more of the protein in the corn grain to microbial attack and explain the difference observed. Potter et al. (1970) reported that more of the dietary N bypassed the rumen with dry ground and micronized milo than with SF and reconstituted milo, suggesting that the addition of moisture during steam flaking may also be important in affecting the susceptibility of the grain protein to microbial attack. The coarseness of the DR corn used in this study, with about 5% of the corn still in the whole form, may also have rendered the protein in the DR corn less available to microbial attack than SF corn.

The proportion of N passing the abomasum in each N fraction is shown in Table XX. No significant difference was noted in NAN as a percent of total abomasal N with corn processing, although more ($P < .05$) of the abomasal N was NAN with 21% CSH than with all concentrate rations. The all concentrate rations had less ($P < .20$) microbial-N and more ($P < .05$) BPN than 21% CSH rations. Significantly more N was absorbed from the rumen with the rations containing no roughage, with a trend ($P < .10$) toward more ruminal N loss with SF than DR corn.

Total N digestibility (Table XXI) was 15% lower ($P < .05$) for rations containing roughage. Steam flaked corn had higher ($P < .05$) total N digestibility than DR corn. Digestibility of N reaching the intestine was similar for all rations, although SF corn tended to be

higher than DR corn. The higher total N digestibilities on the all concentrate rations is attributable to a greater ($P < .01$) loss of N in the rumen. But, due to the greater passage of protein to the intestine on 21% CSH rations, more total amino acids would be available to the steers fed the 21% CSH rations, despite this lowered total N digestibility.

Discussion

The results of both trials indicate that microbial protein synthesis per unit of DM fermented and bypass of dietary protein was higher at the higher roughage levels and also higher with WS and DR than with SF corn. With heifers, Neudoerffer et al. (1971) obtained similar amounts of total microbial protein passing the abomasum at similar N intakes using total duodenal collection and lignin as a marker. Rations in their study were composed of corn and hay in ratios of 2:1 and 1:2.25. On all rations, efficiency of microbial protein synthesis was lower than the average value of 17 g per 100 gm DDM obtained with sheep (Thomas, 1973), and are more in line with calculated values of Hungate (1966).

Lindsay and Hogan (1972) reported that defaunation increased microbial protein synthesis 20 to 35% while Hume (1970) reported a significant negative correlation between ruminal acetate production and microbial protein synthesis. Also, Ishaque et al. (1971) and Jackson et al. (1971) have reported positive relationships between ruminal propionate levels and passage of total N and diaminopimelic acid to the duodenum. With the hourly feeding system used in these studies, ruminal acetate concentrations were high (> 60 molar %) and propionate levels were low (< 20 molar %) in comparison to many values for high concentrate diets (Cole et al., 1975a, b). Although direct counts of rumen protozoa were

not made, a very high number of protozoa were observed microscopically in the rumen fluid of steers on all treatments. Protozoal presence may account for the relatively low values for efficiency of microbial protein synthesis obtained in this study. Furthermore, protozoa appear to have a lower RNA-N to total-N ratio than do rumen bacteria (Smith, 1969). Since the RNA-N to total-N ratios were determined on isolated rumen bacteria alone, this would further underestimate true microbial protein synthesis.

Apparently degraded N was used more efficiently for protein resynthesis with the higher roughage rations in both trials. This increase in N recycling at the higher roughage levels may reflect increased saliva flow or urea flux through the rumen wall. Alternatively, this efficiency simply reflects N intake relative to microbial needs, a protein balance in the rumen. N addition beyond the need of the rumen bacteria for ammonia will depress this efficiency. Thus ENU is probably a value of little relevance.

In both trials, rations which should have a more rapid fermentation rate (SF corn and lower roughage rations) had lower microbial protein synthesis per unit of DM fermented.

Calculated dilution rates for the various rations are presented in Table XXV. In trial 1, dilution rate increased ($P < .05$) between 0 and 14% roughage then decreased at 21% CSH indicating that the initial low levels of roughage increased the flow of digesta from the rumen while 21% CSH slowed the rate of passage from the rumen. In trial 2 the dilution rate was increased by about 50% ($P < .05$) with roughage addition and was about 15% higher for DR than SF corn.

Dilution rates for all rations are lower than normally accepted

TABLE XXV

DIGESTA PASSAGE THROUGH THE ABOMASUM AND ESTIMATED RUMEN DILUTION RATE

Ration	Digesta Passage (l/dy)	Dilution Rate (%) Per Hr.	Rumen Turnover Time (Days)
		Trial 1	
0	34.0[b]	2.8[b]	1.47
7	52.9[bc]	4.4[bc]	0.95
14	59.8[c]	5.0[c]	0.84
21	51.5[bc]	4.3[bc]	0.97
SE[a]	5.5	0.5	0.09
		Trial 2	
SF-0	28.2[b]	2.3	1.78
SF-21	43.5[cd]	3.6[cd]	1.15
DR-0	33.6[bc]	2.8[bc]	1.48
DR-21	48.5[d]	4.0	1.03
SE[a]	3.4	0.3	0.15

[a]Standard error of the mean.

[b,c,d]Means in same column within same trial with different superscripts are significantly different ($P < .05$).

values for the rumen liquid fraction but are similar to values for rumen dry matter dilution rates (Hungate, 1966). With young steers fed 2.5 kg of an 85% barley diet, Topps et al. (1968) reported dilution rates of 5 to 6% per hour using chromic oxide as a marker.

In both trials, rumen turnover times were longer with all concentrate diets than with the diets containing roughage. This has been noted previously by Rogerson (1958) with sheep fed grass hay or corn and by Topps et al. (1968) with steers fed hay or barley. Whether feeding level influences turnover time is unclear although data suggests that higher intake levels increase the rate of passage from the rumen (Balch and Campling, 1965).

In the present study, the regression of microbial protein synthesis on dilution rate yielded a straight line with the equation:

$$MP/DDM = 2.414\ (DR/hr) - 0.56 \qquad (r = .75)$$

in which MP/DDM is microbial protein synthesis per 100 gm DM fermented and DR/hr is the dilution rate in % per hour (Figure 1). The correlation coefficient was equal to .75 and was significant ($P < .05$). Using a continuous fermentation system and dilution rates of 2 to 12% per hour, Isaacson et al. (1975) noted a Michaelis-Menten type saturation curve when microbial yield per mole of glucose was plotted against dilution rate per hour. A straight line would also fit their data but was not biologically explainable. A double reciprocal plot of protein synthesis vs dilution rate of this data yielded a negative value for maximum microbial protein synthesis, thus a Michaelis-Menten type curve could not be determined for dilution rate and microbial protein synthesis. One possible explanation for the lack of a Michaelis-Menten type

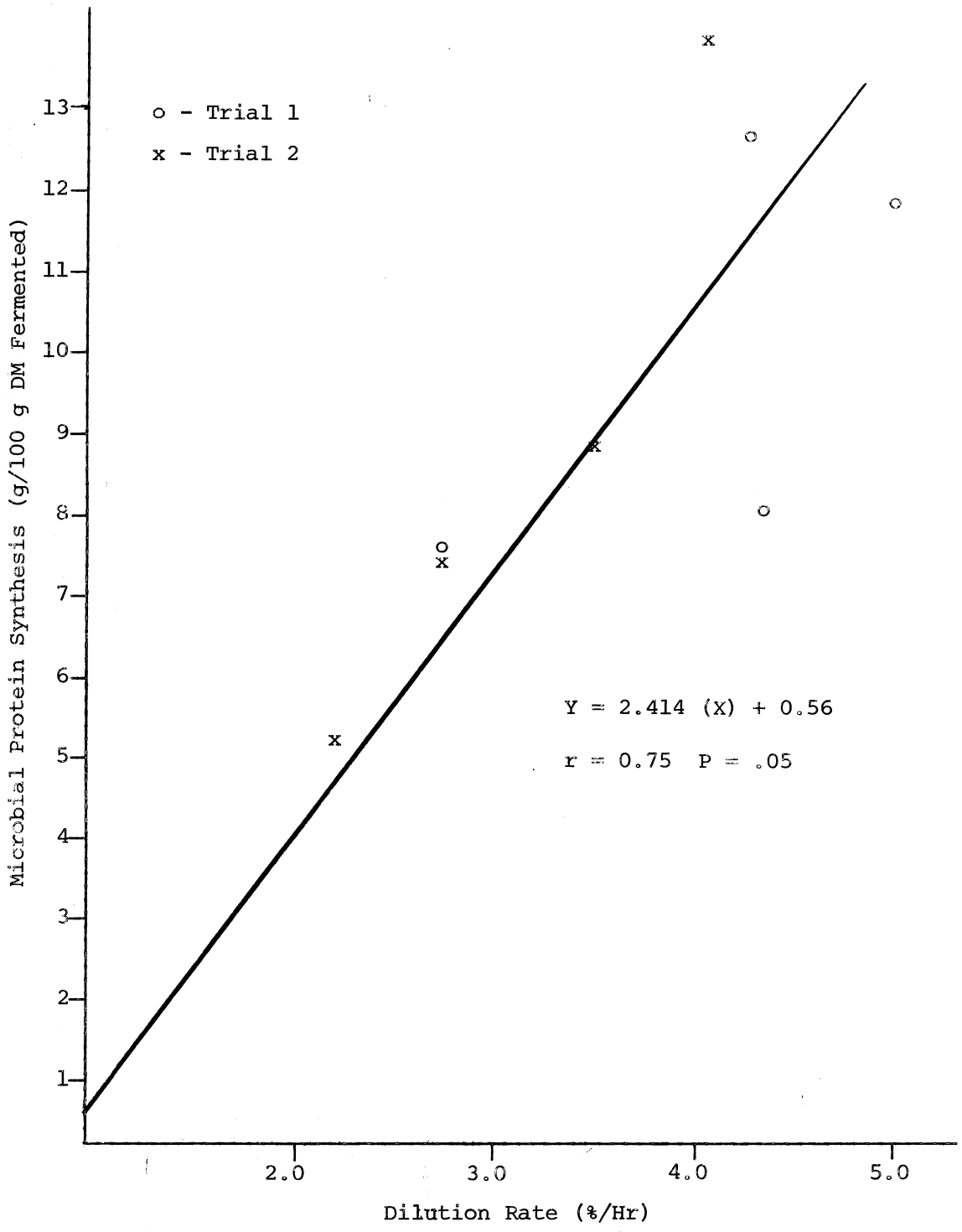

Figure 1. Relationship Between Microbial Protein Synthesis and Rumen Dilution Rate

saturation curve in this study may be due to the narrow range of dilution rates. Isaacson et al. (1975) obtained values approaching V_{max} only with dilution rates above approximately 6% per hour. The data indicate that at low dilution rates, ruminal microbial protein synthesis is highly dependent upon the rumen dilution rate. This agrees with the results of Isaacson et al. (1975). Correlations were low between MP/DDM and other factors including molar % acetate, propionate and acetate to propionate ratio but within trial 2, ruminal VFA levels appeared to increase as efficiency of microbial protein synthesis increased (Figure 2). Although total protein synthesis and total VFA production should be correlated, faster dilution rates and more efficient bacterial growth would be expected to decrease total ruminal VFA levels. Hence, explanation for this relationship is unclear.

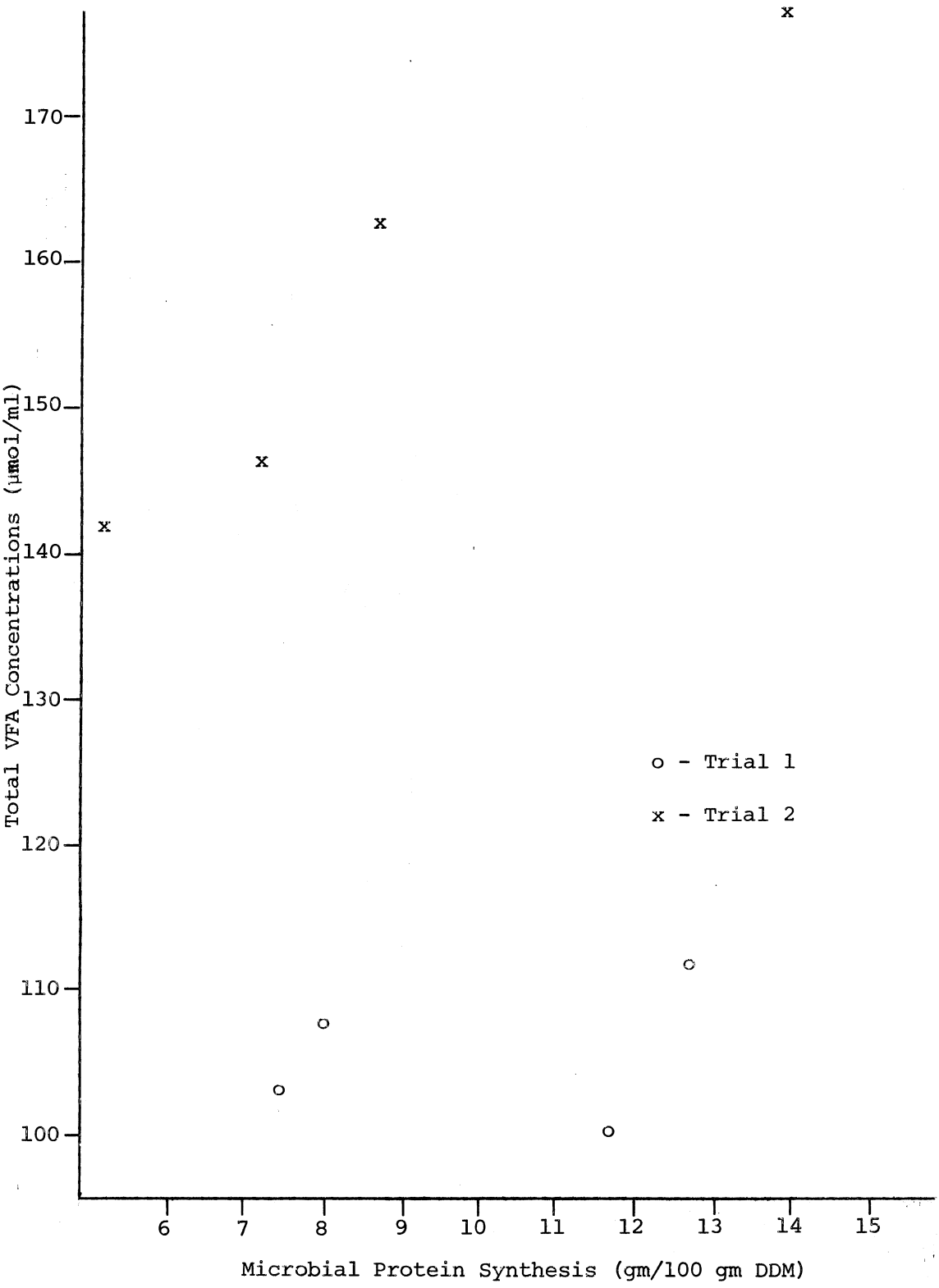

Figure 2. Relationship Between Total VFA Concentrations and Microbial Protein Synthesis

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A P P E N D I X

TABLE XXVI

ORGANIC MATTER DIGESTION SIMPLE EFFECTS : TRIAL 2

Item	Ration				
	SF-O	SF-21	DR-O	DR-21	SE
Intake, g	4201^{A}	5113^{B}	4195^{A}	5129^{B}	43.8
Ruminal digest., g	3230^{A}	3204^{A}	2470^{B}	2566^{B}	81.6
Intestinal digest., g	487^{a}	876^{ab}	979^{b}	1144^{b}	127.4
Total digest., g	3720^{a}	4078^{b}	3449^{c}	3733^{a}	63.2
Entering intestine, g	971^{A}	1908^{B}	1725^{B}	2563^{C}	92.6
Ruminal digest., % of intake	76.9^{A}	62.7^{B}	59.0^{BCa}	50.0^{Cb}	2.1
Intestinal digest., % of entering	47.5	45.4	54.5	43.0	4.6
Total digest., %	88.5^{A}	79.8^{B}	82.3^{B}	72.8^{C}	1.1
Ruminal digest., % of total	85.8^{a}	78.5^{ab}	72.1^{b}	69.0^{b}	3.7
Intestinal digest., % of total	14.2^{a}	21.5^{ab}	27.9^{b}	31.0^{b}	3.7

^{a,b,c}Means on same row with differing superscripts are significantly different ($P < .05$).

^{A,B,C}Means on same row with different superscripts are significantly different ($P < .01$).

TABLE XXVII

DRY MATTER DIGESTION SIMPLE EFFECTS : TRIAL 2

Item	Ration				
	SF-O	SF-21	DR-O	DR-21	SE
Intake, g	4362^{A}	5327^{B}	4354^{A}	5352^{B}	45.4
Ruminal digest., g	2901^{a}	3059^{a}	2347^{b}	2342^{b}	142.4
Intestinal digest., g	892	1106	1153	1464	204.2
Total digest., g	3794^{Aa}	4165^{B}	3499^{Ab}	3806^{Aa}	66.2
Entering intestine, g	1461^{a}	2268^{b}	2007^{b}	3005^{c}	161.4
Ruminal digest., % of intake	66.6^{a}	57.4^{ab}	54.0^{bc}	43.8^{c}	3.4
Intestinal digest., % of entering	55.3	48.2	55.1	47.5	6.7
Total digest., %	86.9^{A}	78.2^{B}	80.5^{B}	71.2^{C}	1.2
Ruminal digest., % of total	77.1^{a}	73.4^{ab}	66.9^{ab}	61.4^{b}	4.5
Intestinal digest., % of total	22.9^{a}	26.6^{ab}	33.1^{ab}	38.6^{b}	4.5

^{a,b,c}Means on same row with differing superscripts are significantly different ($P < .05$).

^{A,B,C}Means on same row with differing superscripts are significantly different ($P < .01$).

TABLE XXVIII

STARCH DIGESTION SIMPLE EFFECTS : TRIAL 2

Item	Ration				
	SF-O	SF-21	DR-O	DR-21	SE
Intake, g	2703	2560	2647	2386	76.6
Ruminal digest., g	2509^{Aa}	2310^{ABa}	1874^{BCb}	1739^{Cb}	95.5
Intestinal digest, g	180^{A}	212^{A}	612^{B}	482^{B}	54.5
Total digest, g	2690^{a}	2522^{a}	2486^{a}	2221^{b}	70.8
Entering intestine, g	194^{A}	250^{A}	773^{B}	645^{B}	49.8
Ruminal digest, % intake	92.8^{A}	90.3^{A}	70.6^{B}	72.8^{B}	2.0
Intestinal digest, % enter. intest.	92.6^{Aa}	84.2^{ABb}	78.4^{Bbc}	74.0^{Bc}	2.0
Total digest., %	99.5^{A}	98.6^{A}	93.9^{B}	93.3^{B}	0.3
Ruminal digest., % of total	93.2^{a}	91.6^{a}	75.1^{b}	78.8^{b}	3.0
Intestinal digest., % of total	6.7^{a}	8.4^{a}	24.9^{b}	21.2^{b}	3.0

^{a,b,c}Means in same row with differing superscripts are significantly different ($P < .05$).

^{A,B,C}Means in same row with differing superscripts are significantly different ($P < .01$).

TABLE XXIX

CELLULOSE DIGESTION : TRIAL 2

Item	Ration				
	SF-O	SF-21	DR-O	DR-21	SE
Intake, g	159.4^{A}	672.5^{B}	159.7^{A}	709.5^{B}	22.5
Ruminal digest., g	110.0^{A}	359.8^{B}	111.3^{A}	367.6^{B}	21.3
Intestinal digest., g	4.1	30.2	5.5	46.3	18.9
Total digest., g	114.2	390.0	116.8	414.5	16.3
Entering intestine, g	49.3^{A}	312.7^{B}	48.4^{A}	341.9^{B}	13.2
Ruminal digest., % of intake	69.1^{A}	53.4^{B}	69.7^{A}	52.0^{B}	1.9
Intestinal digest., % of entering	2.4	6.2	0.8	7.1	9.6
Total digest., %	71.6^{a}	58.1^{b}	72.9^{a}	57.5^{b}	2.7
Ruminal digest., % of total	97.0	93.8	95.8	92.9	7.0
Intestinal digest., % of total	3.0	6.2	4.2	7.1	7.0

^{a,b,c}Means on same row with differing superscripts are significantly different ($P < .05$).

^{A,B,C}Means on same row with differing superscripts are significantly different ($P < .01$).

TABLE XXX

RUMEN pH, TOTAL AND MOLAR CONCENTRATIONS OF VOLATILE FATTY ACIDS SIMPLE EFFECTS : TRIAL 2

		Volatile Fatty Acids					
			Molar %				
Ration	Rumen pH	Total Conc. micromoles/ml	Acetic	Propionic	Butyric	Other	Acetic / Propionic
SF-O	6.0	132.71	64.23	17.73	8.95	9.08[a]	3.79
SF-21	6.0	153.01	69.17	16.81	8.69	5.33[b]	4.29
DR-O	6.0	137.59	64.76	20.11	9.06	6.06[b]	3.70
DR-21	6.0	165.73	68.50	17.17	8.64	5.68[b]	4.27
SE[c]	.1	12.20	2.18	2.55	0.64	0.57	0.62

[a,b] Means in same column with differing superscripts are significantly different ($P < .05$).

[c] Standard error of the mean.

TABLE XXXI

SITE AND EXTENT OF NITROGEN DIGESTION-
SIMPLE EFFECTS : TRIAL 2

Ration	Ruminal[a]	Intestinal[b]	Total[a]
		Trial 1	
0	20.3[c]	62.9[c]	71.4[c]
7	23.2[c]	53.1[c]	64.0[d]
14	-14.3[d]	38.7[d]	60.5[d]
21	- 5.0[d]	66.9[c]	64.4[d]
SE[f]	4.3	7.2	2.0
		Trial 2	
SF-0	43.6[c]	61.2	78.0[c]
SF-21	14.1[d]	63.6	68.8[d]
DR-0	34.7[c]	58.8	73.0[cd]
DR-21	6.5[d]	59.2	61.9[e]
SE[f]	4.0	8.6	1.9

[a]Percent of N intake.

[b]Percent of N entering the intestine.

[c,d,e]Means in same column within the same trial with differing superscripts are significantly different ($P < .05$).

[f]Standard error of the mean.

TABLE XXXII

PROPORTION OF ABOMASAL NITROGEN PASSING THE ABOMASUM IN EACH NITROGEN FRACTION[a]

Ration	Item[b]			
	Microbial-N	NAN	BPN	NH_3 + Urea
Trial 1				
0	48.4[d]	94.5	45.3	5.5
7	51.2[d]	94.1	45.0	5.9
14	35.6[e]	94.4	58.3	5.6
21	47.0[d]	94.9	48.7	5.1
SE[c]	3.1	0.5	4.6	0.5
Trial 2				
SF-O	44.5	94.6[d]	50.2	5.4[d]
SF-21	48.4	96.6[e]	48.3	3.4
DR-O	40.7	95.4[de]	54.7	4.6[de]
DR-21	48.6	96.5[e]	48.0	3.6[e]
SE[c]	4.2	0.5	1.4	0.5

[a]Percent of total N passing the abomasum.

[b]NAN - non ammonia N; BPN - feed bypass N.

[c]Standard error of the mean.

[d,e]Means in same column within the same trial with differing superscripts are significantly different ($P < .05$).

TABLE XXXIII

TOTAL ABOMASAL PASSAGE IN NITROGEN FRACTIONS
SIMPLE EFFECTS : TRIAL 2[a]

Item[g]	Ration[b]				
	SF-O	SF-21	DR-O	DR-21	SE[c]
N Intake	91.5	103.8	96.0	109.4	2.8
Abomasal Passage					
Total N	51.6^{D}	89.2^{E}	62.7^{D}	102.4^{E}	4.4
NH_3-N	2.7	3.1	2.9	3.5	.6
NAN	48.8^{D}	86.1^{E}	59.8^{D}	98.9^{E}	3.9
Microbial Nitrogen	22.9^{D}	42.1^{E}	25.2^{D}	48.8^{E}	2.7
BPN	25.9^{d}	44.0^{f}	34.6^{e}	50.1^{f}	2.3
NLR	39.9^{D}	14.6^{E}	33.3^{D}	7.0^{E}	3.6
Microbial-CP/DDM	5.23^{Dd}	8.69^{De}	7.28^{Dde}	13.79^{Ef}	.9
ENU (%)	37.0^{D}	73.3^{E}	42.8^{D}	88.3^{E}	5.5
BPN/TNI (%)	28.2^{Dd}	42.4^{EFe}	35.8^{DEf}	45.7^{Fe}	2.0

[a] Grams per day unless indicated.

[b] SF - steam flaked; DR - dry rolled; 0 and 21 - level of cottonseed hulls.

[c] Standard error of the mean.

[d,e,f] Means on the same row with differing superscripts are significantly different ($P < .05$).

[D,E,F] Means on the same row with differing superscripts are significantly different ($P < .01$).

[g] NAN - non ammonia N; BPN - feed bypass N; NLR - N lost in the rumen; Microbial-CP/DDM - microbial protein synthesis per 100 gms DM fermented; ENU - efficiency of nitrogen utilization; BPN/TNI - % of total N intake bypassing the rumen.

TABLE XXXIV

DETERMINATION OF RNA IN ABOMASAL CONTENTS

Reagents:

1. 18% (w/v) TCA in ethanol.
2. 9% (w/v) aqueous TCA.
3. Ethanol saturated with Na acetate
4. Chloroform in ethanol (1:2).
5. Ether in ethanol (1:3).
6. 4 N perchloric acid.
7. 1 N KOH.
8. 7 N KOH.
9. .025 M tris buffer (2-amino-2[hydroxy methyl]-1,3-propanediol), pH 7.8 (pH adjusted with 3N HCl).
10. 0.5 N HCl.
11. BioRadAg 1 x 10 (50 - 100 mesh) Cl^- resin.

Procedure:

1. Weigh out 25 g of homogenized abomasal fluid.
2. Following extractions at 0 to 4 C.

a. Rehomogonize sample with 25 ml of 18% TCA in ethanol then centrifuge two 25 ml portions for 15 minutes at 35,000 x g. Save residue.

b. Wash residue successively with 25 ml of:

1) 9% aqueous TCA (twice).

2) Ethanol saturated with sodium acetate.

3) Chloroform in ethanol (1:2) (twice).

TABLE XXXIV (Continued)

4) Ether in ethanol (1:3).

5) Ether (room temperature).

6) Make all separations by centrifuging for 15 minutes at 35,000 x g. Save residue.

c. Dry residue from ether washing at 50 C for two hours under vacuum. Store at 4 C.

3. Shake 0.1 g of dry residue with 10 ml of 1 N KOH for 18 hours at 37 C. Centrifuge at 35,000 x g for 15 minutes.

a. Save Supernatant.

b. Rewash with 1 ml of 1 N KOH and centrifuge.

c. Combine supernatants.

4. Add to supernatant 4.4 ml of 4 N perchloric acid, leave 30 minutes and centrifuge at 35,000 x g for 15 minutes. Save supernatant and neutralize with 7 N KOH (3.5 ml) and 1 N KOH (to pH 7 to 8).

5. Filter supernatant through Whatman No. 40 filter paper and wash with approximately 10 ml of water.

6. Dilute filtrate to 50 ml with .025 M tris buffer.

7. Place 50 ml on resin column prepared by washing with 10 ml of 0.5 N HCl and 30 ml of tris buffer.

8. Wash with 30 ml of .025 M tris buffer. Discard this liquid.

9. Elute with 100 ml of 0.5 N HCl.

10. Read HCl elution at 260 nm on UV absorption.

TABLE XXXV

DETERMINATION OF STARCH IN FEED, DIGESTA AND FECES

Reagents:

1. Agidex enzyme (Gollard-Schlesinger Chemical Mfg. Co., Long Island, New York.
2. 0.2 M acetate buffer solution, pH 4.5.
3. 5% (w/v) solution of $ZnSO_4 \cdot 7H_2O$.
4. 0.3 N solution of $Ba(OH)_2$.
5. Glucostat (4x) (Worthington Biochemical Corp., Freehold, New Jersey).
6. Liquid paraffin.

Procedure:

1. Add a weighted sample to a 125 ml erlenmeyer flask (0.2 g feed, 0.5 g ingesta and 1.0 g feces.
2. Weigh flask and contents.
3. Add 50 ml distilled water and autoclave at 124 C and 14 atm pressure for 90 minutes. Place on liquid cool till pressure drops to 1 atm.
4. Cool to room temperature.
5. Add 50 ml of acetate buffer solution and 0.4 g Agidex enzyme.
6. Reweigh flask and contents.
7. Cover with a thin layer of paraffin oil.
8. Incubate flask and contents at 60 C for 24 hours.
9. Cool to room temperature in water bath.
10. Using 0.2 ml aliquots from flask in place of blood, serum or plasma, determine the glucose concentration using Glucostat.

TABLE XXXV (Continued)

Calculations:

1. alpha linked glucose polymers = $GC \times \frac{V}{100} \times \frac{1}{W}$.

a. alpha linked glucose polymer concentrations in mg/g of sample.

b. GC = glucose concentration in mg per 100 ml determined from standard curve.

c. V = flask volume in ml assuming unity density.

d. W = sample dry weight.

2. % starch = $\frac{\text{alpha linked glucose polymers (mg/g)}}{1110}$

TABLE XXXVI

DETERMINATION OF ABOMASAL AMMONIA-N

Reagents:

1. Magnesium Oxide (MgO_4)
2. Pumice
3. 25% $CaCl_2$ solution
4. Kjeldahl boric acid solution
5. 1/14 N HCl

Procedures:

1. To kjeldahl flask add 3 to 4 g of MgO_4, approximately 1 g of pumice, 1 ml $CaCl_2$ solution and 0.5 ml octanol.
2. Add 10 ml of abomasal fluid and 250 ml water.
3. Distill approximately 200 ml into 50 ml of boric acid solution.
4. Titrate with HCl to neutrality.
5. Ml of HCl equals mg of ammonia-N in 10 ml sample.

TABLE XXXVII

DETERMINATION OF ABOMASAL UREA-N

Reagents:

1. Phosphate buffer - pH 7.0.

   a. 4.36 g KH_2PO_4 + 10.54 g Na_2HPO_4

   b. Dilute to 1 liter.

2. Jack Beam Urease (Type III. 3490 units per gram; Sigma Chemical Company, St. Louis) Solution. 1 mg/ml phosphate buffer.

3. Abomasal ammonia-N determination reagents.

Procedure:

1. Incubate 10 ml of abomasal sample with 10 ml of urease solution in a pH 7 phosphate buffer solution for one hour.

2. Run MgO_4 distillation for ammonia-N determination.

3. Urea nitrogen is taken as the increase over ammonia-N.

VITA

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