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SPLANCHNIC NITROGEN METABOLISM BY GROWING BEEF STEERS FED SORGHUM GRAIN FLAKED AT VARIOUS DENSITIES

by

Abdoulaye Alio

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DEDICATION

This dissertation is dedicated to the memory of my father, the late Hamidou G. Zama who wished all his life to see me reach the highest level of education I could possibly reach. Thanks for the guidance and inspiration, your wish is well followed.

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ABSTRACT

Growing beef steers were used in completely randomized block designs to evaluate effect of processing method, dry-rolled (DR) versus steam-flaked (SF) sorghum, and degree of processing (flaking density) of corn and sorghum grain on nitrogen (N) digestion and post-absorptive N metabolism. In experiments (Exp.) 1 and 2, seven duodenally and ileally cannulated steers were used to investigate N digestibilities. Experimental diets contained 77% grain: Exp.1, DR or SF sorghum at densities of 437, 360 and 283 g/L (SF34, SF28, SF22); Exp.2, corn at two flake densities (SF34 and SF22). Nitrogen intakes by steers fed sorghum (142 g/d) and corn (149 g/d) diets were similar among treatments. Steers fed SF compared to DR, increased ruminal ($P = .04$) DM digestibility. Microbial protein flow to the duodenum averaged 10% greater for SF vs DR. Reducing flaking density of sorghum grain linearly increased ($P < .05$) ruminal DM and tended to increase linearly ruminal feed N ($P = .11$), total tract DM and N digestibilities and microbial efficiency ($P < .08$). Unexpectedly, flake density did not affect DM or N digestibilities of SF corn diets by steers. In Exp. 3, eight steers implanted with indwelling catheters were used to measure blood flow, net absorption and uptake of ammonia-N, urea-N (UN) and α-amino N (AAN) across portal-drained viscera (PDV), hepatic and total splanchnic tissues. Experimental diets were the same as those in Exp.1. Six arterial, portal and hepatic blood samples were collected per day at 2 h intervals for each diet and steer. Daily DM and N intakes averaged 7.0 kg and 142 g, respectively. Decreasing flake density of SF sorghum linearly increased net absorption of AAN ($P = .04$) and UN

recycling to the gut (P = .02). Net UN recycling to the gut averaged 38% of N intake across treatments. Steers fed SF compared to DR decreased (P = .03) net splanchnic UN output (33 vs 50 g/d). The improved N retention and lower splanchnic UN output, contingent with greater ruminal microbial protein synthesis and flow to intestines may explain in part the observed higher performance of cattle fed SF compared to DR sorghum. Based on improved total tract N digestibilities and greater net absorption of AAN and UN recycling to the gut, optimum flake density for SF sorghum grain was 283 g/L (SF22).

CHAPTER 1

INTRODUCTION

Production (growth, lactation), reproduction and maintenance functions require constant supply of necessary nutrients. Nutrients enter the body after extensive digestive, absorptive and metabolic processes through the gut and the liver, commonly termed splanchnic tissues. Nitrogen containing compounds, primarily amino acids (AA) constitute key nutrients necessary to support maintenance and productive functions in all animal species. In ruminants, more than in any other species, nitrogen metabolism is complex, in part due to intricate relationships between ruminal microorganisms (bacteria and protozoa) and the host animal. Ruminant postabsortive metabolism of AA, ammonia (NH_3) and urea includes their release or uptake from the gut, subsequent transformation in the liver (urea, AA, protein and glucose synthesis), reutilization of urea by ruminal microorganisms (recycling) or its excretion, and AA availability for protein synthesis in extrasplanchnic tissues (i.e, muscle).

Ammonia absorbed from the gut originates from two major microbial processes: degradation of dietary nitrogenous compounds (proteins, amino acids, nucleic acids , non-protein nitrogen), and hydrolysis of endogenous urea across the rumen wall. Extent of degradation and amounts of ammonia absorbed into the portal-drained viscera (PDV) vary with sources and amounts of compounds and levels of fermentable carbohydrates in diets. High protein (Reynolds et al. ,1992) and low fermentable carbohydrates diets (Reynolds et al., 1991; Huntington, 1989) have been positively correlated to high ammonia absorption concomitant with high hepatic urea release. Ruminal volatile fatty acid (VFA) concentrations and energy level of the diet have also been reported to affect splanchnic nitrogen metabolism. Increasing energy level of the diet increases ruminal microbial ammonia fixation and decreases net ammonia absorption across the PDV. In addition, high energy intake enhances PDV absorption, hepatic uptake and total splanchnic amino acid release, and improves urea recycling to the gut.

Grains, in most feedlot diets fed at 75 to 90%, are the major energy and crude protein sources. However, when intact, corn and sorghum grains are highly resistant to microbial and animal digestive enzymes. Therefore, these grains are processed for optimal use in cattle feeding programs. The most common processing methods used are grinding or cracking, dry-rolling, steam-rolling, reconstitution to higher moisture, and steam-flaking. Digestibility and production performance results vary with grain types and processing methods.

Huntington (1997) and Theurer et al. (1996a,b) have summarized recent digestion trials which show consistent increases in ruminal and total tract starch digestibility with steam-flaked compared to dry-rolled grains. Huntington (1997) concluded that all feed grains respond positively to processing; both authors agree that sorghum by corn grain have more dramatic responses to flaking than all other grains.

Extensive grain processing (steam-flaking) shifts the proportion of starch digested from the small intestine to the rumen and alters end products of fermentation (Theurer et al., 1996a,b). This shifting of the site of starch digestion from the small intestine to the rumen has the definite advantage of producing more microbial protein flowing into the small intestine and more VFA for absorption from the gut. Studies conducted at the University of Arizona with lactating dairy cows (Theurer et al., 1996b) and feedlot steers (Swingle, 1992; Xiong et al., 1991) showed improved performance with steam-flaked compared to DR sorghum grain. It can be theorized from these studies that increasing ruminal starch fermentation by steam-flaking, improves availability of nutrients for absorption from the gut and increases nutrient output from splanchnic tissues to the rest of the body.

Multicatherized animals fitted with permanent catheters into appropriate vessels were successfully used in blood flow measurement by Katz and Bergman (1969). Since then, many researchers have used or modified the technique to measure blood flow and net fluxes (release or uptake) of various metabolites across gut and total splanchnic tissues. Most research hascompared different dietary regimens such as roughage vs concentrates, protein sources and levels, or effect of energy levels on net nutrient fluxes (Burrin et al., 1991; Huntington, 1987; Reynolds et al., 1991, 1992; Theurer et al., 1990, 1997). Except for Gross et al. (1988) and Theurer et al. (1990, 1997), no research has reported the effect of sorghum grain processing on starch and protein digestion within the gastrointestinal tract and net nutrient absorption across the portal drained viscera and total splanchnic tissues in the same animals (or as companion studies). No studies have measured the effect of varying flake densities of steam processed grains on net nutrient fluxes across splanchnic tissues of ruminants. From feedlot performance studies optimal flakes densities for sorghum and corn grain appear to be about 309 to 360 g/L or 24 to 28 pounds per bushel (lb/bu; Theurer et al., 1996a). The objectives of the present studies were conduct companion studies to:

1) Determine the effect of feeding beef steers steam-flaked sorghum grain at various densities on splanchnic nitrogen metabolism, including net absorption, output and uptake of ammonia-N, urea-N, and α-amino-N across gut and liver tissues.

2) Determine the effect of flake density on DM and CP digestibility, and to measure microbial protein flow to the intestines of steers fed diets containing 77% corn or sorghum grain.

3) Relate results from the two studies (postabsorption and digestibility trial data) to improve our understanding of nutrient needs under production situations.

CHAPTER 2

LITERATURE REVIEW

INTRODUCTION

Since the publication of Katz and Bergman's work in 1969 on the method of simultaneous portal and hepatic blood flow measurements with multicatherized animals, many studies have been conducted not only to ascertain the validity of the technique but also to elucidate mechanisms of nutrient absorption and metabolism across splanchnic tissues (gut and liver) of ruminant animals at various stages of production. The technique, used on calves (McGilliard and Thorp, 1971; McGilliard et al., 1971), sheep and goats (Hume et al., 1972; Tagari and Bergman, 1978; Heitman and Bergman, 1980), lactating and nonlactating dairy cows (Huntington, 1981; Lomax and Baird, 1983; Huntington et al., 1984,1989), beef steers and heifers (Sniffen and Jacobson, 1975; Prior et al., 1981a; Guerino et al., 1991) proved to be a powerful method for blood flow measurements and the study of net nutrient absorption and metabolism in vivo with normal conscious animals. Initial ruminant postabsorptive studies focused on absorption and metabolism of energy yielding nutrients (glucose, lactate and VFA). However, in the last two decades several studies have been conducted to investigate nitrogen metabolism in splanchnic and other organs using either postabsorptive partitioning techniques or a combination of postabsorptive with radioactive compound labeling methods.

In ruminants, splanchnic nitrogen metabolism is controlled by many factors, among which are level of energy intake and level and source of protein in the diet. In most feedlot and dairy diets, grains constitute the major energy and protein sources. However, intact grains, especially corn and sorghum, resist enzymatic attack and must be processed for optimum use in cattle feeding programs. It is now known from classical digestion trials that grain processing, particularly steam-flaking, shifts the site of starch digestion from the small intestine to the rumen and alters the end products of fermentation (VFA and microbial protein synthesis) in the rumen-reticulum (Theurer, 1986), which may influence splanchnic nitrogen metabolism. Although much information has accumulated, there is still a great need to relate that information to production situations and appreciate its meaning. The objective of this present review is to summarize and discuss key studies pertaining to corn and sorghum grain processing, processing effects on site and extent of nutrient digestibility, and absorption and metabolism of ammonia-N (NH_3-N), urea-N (UN), and α-amino N (AAN) across splanchnic tissues, with emphasis on beef animals.

Feed Grains: Composition and Processing Methods

Corn and sorghum are the major feed grains in the U.S.A., constituting the principal feed ingredients (75 to 90%) in most growing-finishing diets, and are *de facto* the major suppliers of energy and protein in the ration. Corn and sorghum grain contain an average of 70 to 72% starch, and 8 to 10% crude protein (CP) on a DM basis.

The starch fraction, essentially granular, is made of two polymers: amylose and amylopectin. Amylose is a straight chain polymer made of glucose units linked by $\alpha(1\rightarrow4)$

covalent bonds and amylopectin is a branched chain molecule composed of glucose units linked in α (1→4) glycosidic bonds with branch points at an α (1→6) linkage, every 20 to 25 units. Molecular details and characteristics of starch molecules have been described by Rooney and Pflugfelder (1986). The relative abundance of each polymer changes within and among grain type and with variety (waxy, heterowaxy, and nonwaxy) of grain. On average, grain starch contains 15 to 30% amylose, except for corn starch which ranges between 22 and 28%. Corn and sorghum starch granules are embedded in protein bodies; each granule is surrounded by a protein matrix, which decreases amylolytic and proteolytic enzymatic access.

Whole grains with intact pericarp resist bacterial attachment (McAllister et al., 1994; Beauchemin et al., 1994) and hence are of limited feeding value to cattle. Therefore, to improve their utilization, it is necessary to alter their natural form to facilitate bacterial attachment and enhance enzymatic attack (bacterial and animal). This alteration can occurs with proper grain processing. Common processing methods are: reconstitution, popping, micronizing, high moisture, dry-or steam-rolling and steam-flaking. These various processing methods use, in most instances, a single or combined effect of heat, pressure, moisture and mechanical action to alter the chemical and(or) physical structure of the grains, and consequently affect the digestibility of their components, i.e., starch and protein.

Processing and Nutrient Digestibility

Nutrient digestibility improvements vary with grain source, processing methods and animal species. Huntington (1997) and Theurer et al. (1996a,b) reviewed recent metabolic and digestion studies with different feed grains and various processing methods. Across all feed grains and processing methods, they showed a positive digestibility response of all grains to processing (with sorghum grain having the most dramatic response), and concluded that processing improves the feeding value of grains. Similar conclusions were drawn on the effect of processing for sorghum by Hale (1973), and for corn and sorghum by Theurer (1986) in earlier reviews. The latter stated that proper processing improves starch utilization by increasing ruminal fermentation and small intestine starch digestion, with concomitant decrease in cecal fermentation. These conclusions contradict results reported by Hinman and Johnson (1974) who found no difference in ruminal starch fermentation between dry-rolled, steam-flaked, micronized or ground sorghum. However, their results on small intestinal starch digestibility are in agreement with most reported data. They showed higher total digestibility for extensive processing methods (steam-flaking and micronizing) compared to minimally processed grains (dry-rolled and ground). It was therefore postulated that enzymatic attack on raw starch is lower than on cooked starch. Because ground sorghum had higher starch digestibility values than dry-rolled, the authors concluded that particle size must play an important role in starch digestion.

Steam-flaking is a processing method which combines heat, moisture and mechanical pressure to alter the grain's natural structure, i.e. the pericarp, the starch granule and the protein matrix around and between these granules. Grains are steamed for 40 to 60 min in large vertical chambers to increase the moisture content to 18-20%, and then passed between large rollers set at a specified distance to produce desired flake densities; the closer the setting, the thinner the flake and the lighter the bulk density. Heat is created both by steaming and by the pressure of the rollers, which become very hot during the rolling process. Steaming causes the starch granules to swell and increase the degree of gelatinization and dextrinization while the flaking or rolling action disrupts the starch granules and the protein matrix around them (Harbers, 1975). It has been suggested that the disruption of the starch structure occurs due to chemical alteration of the starch granule and protein matrix during the gelatinization process and physical action of flaking by expanding the surface area of the granule. This disruption results in improved bacterial attachment and enzymatic degradation and might explain the consistent improvement in digestibility of steam-flaked compared to dry-rolled or ground grains (Hinman and Johnson, 1974; McAllister et al., 1994; Beauchemin et al., 1994).

Steam-flaking of sorghum and corn, shifts the site of digestion of a large portion of the starch from the small intestine into the rumen (Theurer,1986), and alters the amount and proportion of the end products of fermentation. Steam-flaking, compared to dry-rolling, increases ruminal starch digestibility of both corn and sorghum grains by 10 and 26 percentage units, respectively (Huntington, 1997), lowers the rumen pH, increases total VFA concentrations, decreases the acetate:propionate ratio (Hinman and Johnson, 1974) and decreases the amount of undigested starch presented to the small intestine (Theurer, 1986). In recent literature reviews, Theurer et al. (1996a,b) reported improvement of over 20 percentage units in ruminal starch digestibility of steam-flaked compared with rolled grains (corn and sorghum) in both dairy and beef animals.

Integrating steer ruminal starch digestibility values (low vs high) based on degree of processing across all feed grains, Theurer et al. (1996a) showed a negative correlation between amount of ruminal and small intestinal starch digestion and a positive correlation of both to efficiency of gain. Published results of titration studies, coupled with performance trial data, tend to support the concept of higher feed efficiency (high gain/feed or FCM/DMI) in feedlot and dairy cattle when animals are fed diets high in ruminally-fermentable grain, contrary to the proposed theory of superior energetic efficiency of starch digested and absorbed as glucose from the small intestine (Owens et al., 1986).

Flake density exerts a profound influence on starch digestibility. In vitro (Osman et al., 1970; Frederick et al., 1973) and in vivo studies (Zinn, 1990b; Xiong et al., 1991; Swingle, 1992) showed continuous increases in starch digestibility as flake density decreased, but there was a less defined effect on feedlot performance. However, Xiong et al. (1991) concluded from their feedlot study that decreasing bulk density to 283 g/L (22 lb/bu) improved economic efficiency of sorghum grain. Flaking sorghum grain to lower densities may depress feed intake by 3 to 8%, without any deleterious effect on weight gain, and still allow for an improved feed efficiency of about 5% (Xiong et al., 1991).

Steam-flaking, compared to dry-rolling, of corn and sorghum grains increased, respectively, ruminal (85 vs 75, 78 vs 52%), total tract (99 vs 92, 98 vs 87%), and small intestinal (93 vs 66, 90 vs 62%; Huntington, 1997) starch digestibilities as percent entering the duodenum. Similar results were reported by Theurer et al. (1996a, b) in their review of literature of beef steers and dairy cows fed steam-flaked vs dry-rolled sorghum grain, and for steam-flaked vs steam-rolled and dry-rolled corn.

Improvement in ruminal starch fermentation has a double advantage. First, because ruminal starch fermentation increases available energy in the rumen, it enhances production and outflow of microbial cells from the rumen to the small intestine (Spicer et al., 1986; Streeter et al., 1989; Zinn, 1988; 1993a, b; Theurer et al., 1996a, b;). Second, it improves small intestinal starch digestion as a result of an increase in pancreatic amylase secretion in response to higher protein supply to the small intestine (Croom et al.,1992). Although results vary greatly among reported data it appears that processing improves microbial protein synthesis. Published data summarized by Theurer et al. (1996a,b) showed an average increase of 10% in microbial protein flow to the duodenum for beef steers and dairy cows fed diets which increase ruminal starch digestibility by about 20%.

Proteins of grain origin show minimum digestibility response to processing. It is noteworthy to indicate that unlike starch, the protein component of feed grain has received limited attention in terms of detailed digestibility studies within the gastrointestinal tract (GIT). Synoptic data summary (Spicer, 1983) on apparent total crude protein digestibility with beef animals fed diets containing 70% or more grain, averaged by type of grain across all comparison trials and processing methods, revealed a mean value of 59, 69 and

72% for sorghum, corn and barley grains, respectively. When averaged by processing method, dry-rolled vs steam-flaked or steam-rolled, the respective values for sorghum, corn and barley were: 55 vs 64, 69 vs 70 and 73 vs 72%. It appears from that summary that corn and barley protein exhibits a minimal or no response to processing, but sorghum grain protein responds favorably, similar to effect of flaking on starch digestibility of the respective grains. Ruminal true protein digestibility (averaged by processing method) for dry-rolled vs steam-flaked or rolled grains were 44 vs 50, 56 vs 52 and 57 vs 54% for sorghum, corn and barley, respectively. It is important to note that protein digestibility values show wide variation among trials. This variation is possibly due to grain sources and varieties, or due to techniques used for determination, total collection vs digestion markers and internal vs external markers, because marker recovery is never complete. Overall, based on the different results reviewed, a general conclusion can be drawn relative to feed grain crude protein digestibilities: grain nitrogen digestion parallels starch digestion in the gastrointestinal tract in most cases; the higher the starch digestibility, the higher the protein digestibility. These observations are in agreement with results reported by Spicer et al. (1986) who found ruminal and total tract starch and nitrogen digestibility values were highest for barley, followed by corn, and least for sorghum grain. Axe et al. (1987) reported similar digestibility relationships for wheat vs high moisture sorghum.

Ruminal Fermentation and Nutrient Absorption

Feeding diets with high vs low ruminal dry matter digestibility improves net absorption of nutrients. Theurer et al. (1990, 1997) and Gross et al. (1988) investigated the effect of feeding steam-flaked (SF) sorghum or wheat (highly fermentable in the rumen) vs dry-rolled (DR) sorghum (less fermentable) to growing beef steers on net nutrient absorption. These authors showed 20% and 11%, respectively, improvements in energy absorption for SF sorghum and wheat, compared to DR sorghum. The improvements were attributed largely to higher net absorption of VFA, principally acetate and propionate. Their results also showed a substantial increase (39 and 42% respectively) in urea recycling to the gut which may enhance microbial protein synthesis in the rumen-reticulum resulting in higher microbial protein flow to the duodenum and potentially more amino acids for absorption across the portal-drained viscera (PDV). These results are compatible with those observed for improved feedlot performance in cattle fed diets that are extensively fermented in the rumen (Theurer et al., 1996a) and supports the conclusion drawn by MacRae and Lobley (1986) that weight gain and milk production improve as protein supply increases, but maximum response is determined by the availability of energy.

Blood Flow Measurement

The portal-drained viscera (PDV) is the interface between the diet the animal consumes and its tissues. Following digestion, absorbed nutrients are transferred to the the liver via PDV. The liver, is the organ in series with the PDV which exerts central metabolic changes on nutrients drained by the PDV before they circulate in the rest of the body. To determine the magnitude of nutrient absorption and utilization across the PDV and splanchnic tissues (gut +liver) and nutrient release to the rest of the body for maintenance and productive functions, blood flows are measured at discrete locations, namely portal and hepatic veins. Common methods used to measure blood flows are downstream dye dilution or ultrasonic transit-time.

Blood flow measurements have evolved from single vessel assessement with a dye, such as sulfobromophthalein(BSP) introduced first by Bradley et al. (1945), to the simultaneous measurement (portal and hepatic veins together) with para-amino hippuric acid (PAH) introduced by Roe et al. (1966) and modified by Katz and Bergman (1969). Downstream dye dilution technique has the advantage over the transit-time method of coupling blood flow measurements with nutrient concentration measurements and estimation of net nutrient fluxes (venous-arterial concentration differences x blood flow). Use of PAH for blood flow determination, while reliable as a technique, requires placement of permanent indwelling catheters into mesenteric veins for constant infusions.

Data summarized by Huntington (1990) showed positive direct relationship between PDV blood flow and ME intake in cattle and sheep. He concluded that level of nutrition, energy density of the diet and physiological state of the animal influence blood flow. There is however, controversy over the magnitude of effect of the factors on blood flow. Katz and Bergman reported decreased blood flow in pregnant ewes compared to non-pregnant ewes. A recent study with steers fed various levels of roughage and concentrate (Huntington et al., 1996) showed decreases in both portal and hepatic blood flows as level of concentrate increased in the diet. Similar effects were reported in beef heifers by Reynolds et al. (1991). Lomax and Baird (1983) reported 52% higher hepatic blood flow with lactating compared to non-lactating dairy cows and a general decrease in both groups when fasting. Across dietary regimens and physiological states, portal and hepatic blood flows averaged 630 and 725 L/h and 1177 and 1914 L/h for beef and dairy cattle, respectively. Corresponding values for animals implanted with both portal and hepatic catheters are 618 and 725 L/h and 1509 and 1914 L/h, with an average ratio of portal:hepatic of .85 and .79, respectively (Table 3).

Nitrogen Absorption and Metabolism

Ruminants absorb dietary nitrogen as ammonia, small peptides, free amino acids and nucleic acids. Ammonia, urea and amino acids constitute the focal points in ruminant splanchnic nitrogen metabolism. Absorption and release of these metabolites is measered by venous-arterial concentration differences time blood flow.

Ammonia Absorption

Ruminants, unlike monogastric animals, absorb substantial amounts of dietary nitrogen as ammonia. The amount absorbed across the PDV varies with diet composition (roughage vs concentrate), level of feed intake and the production state. Absorbed ammonia comes essentially from microbial degradation of dietary nitrogenous compounds (protein, amino acids and non-protein nitrogen) and from hydrolysis of blood urea transferred to the gut by diffusion across the rumen wall or from the salivary secretions (Huntington, 1986; Parker et al., 1995). Free ammonia passively diffuses into and from the gastrointestinal lumen because of its lipid solubility and the lack of charge. This is in contrast to the protonated NH_4^+ ion which, as a charged molecule, is not soluble in lipids and cannot cross cell membranes (Visek, 1969; Parker et al., 1995).

Net ammonia absorption across the PDV is controlled by many factors is positively correlated to free (Siddons et al, 1985a) and total NH_3 concentrations (Remond et al., 1993a) within the gastrointestinal tract. These findings agree with most reported postabsorptive results which show an increase in portal NH_3-N concentrations when animals consume roughage diets (Reynolds et al, 1991; Seal et al, 1991) or have high feed and(or) nitrogen intakes (Reynolds et al, 1992; Reynolds et al., 1991).

Roughage compared to concentrate based diets increase net ammonia absorption. Reynolds and Huntington (1988), Huntington (1989), Seal et al. (1992) and Reynolds et al. (1991), reported higher NH_3-N absorption for animals fed roughage compared with those fed concentrate diets. Data summarized in Table 1 clearly show differences in blood NH_3N concentrations for animals fed roughage compared to concentrate diets. For beef cattle, average arterial, portal, and hepatic NH_3N concentrations on roughage and concentrate diets were .32 vs .27, .75 vs .52, and .26 vs .29 mM, respectively. Portal NH_3N concentrations for roughage diets are on average 44% higher than concentrate diets (.75 vs .52 mM; Table 1). Data from trials with animals implanted simultaneously (matched means, Table 1) with both portal and hepatic catheters showed no difference in arterial and hepatic concentrations (.37 and .36 mM respectively), but portal concentations (.73 mM) were double those of arterial and hepatic blood. The same trend was observed with dairy cows, (.39, .72, and .39 mM for arterial, portal, and hepatic blood). Within trial comparisons of average PDV ammonia fluxes for roughage diets ranged from 1.7 to 2.3 times that of concentrate diets with a mean value of 1.58 (Table 2). In addition, Reynolds et al. (1991) showed that within type of diet, ammonia absorption increases with ME, N and feed intake levels.

The difference in NH_3N fluxes between roughage and concentrate is essentially because of the portal-arterial concentration difference, .43 vs .24, a 79% increase for forage over concentrates (Table 1). It is also important to note that the NH_3N portal-arterial concentration difference for beef cattle fed roughage is three times higher than the portal-arterial concentration difference of AAN (.43 vs .14 mM, respectively). In contrast, beef animals receiving concentrate diets had similar portal-arterial concentration differences for NH_3N and AAN (.24 and .20 mM, respectively) as did dairy cows, (.33 vs .26 mM, respectively).

High intakes of crude protein result in a high net NH_3 absorption, but energy intake appears to have a greater impact than nitrogen intake. Reynolds et al. (1992) observed about a 60% increase in PDV ammonia absorption for a 45% dietary CP increase (11 vs 16%). Within each protein level the amount of NH_3N absorbed increased by 23% or more as energy level increased by 37% (168 vs 230 kcal/kg $BW^{.75}$). Similar effects of energy on net NH_3-N absorption were reported by Theurer et al. (1990,1997) who showed a 48% increase in ammonia-N absorption resulting from 28% increase in ME and N intakes. In an extensive review of literature on net metabolite flux across the PDV and liver, Huntington and Reynolds (1987) reported that net NH_3-N flux represents 16 to 80% of the total nitrogen absorbed across the PDV. All these results demonstrate the importance of ammonia absorption in ruminant nitrogen metabolism.

Net ammonia-N absorption almost always exceeds net AAN absorption. Net PDV absorption of NH_3N and AAN (summarized by animal type across all dietary treatments; Table 2) show average values of 179 vs 120 mmol/h respectively, for beef animals, and 339 vs 414 mmol/h respectively, for dairy cows for NH_3N and AAN. The ratio NH_3N/AAN ranged from .53 to 4.45 in beef animals and .78 to 1.44 in dairy cows (Table 3). Ammonia absorbed across the PDV is almost entirely removed by the liver, as indicated by the negligible hepatic-arterial concentration differences (-.01 and zero) for beef and dairy cattle, (Table 1), and similar net PDV and net liver flux values (matched means) for beef animals (213vs -218 mmol/h, respectively; Table 2).

Urea Synthesis and Recycling

Ammonia absorbed into the PDV enters the liver where essentially all of it is removed and synthesized into urea. According to Huntington (1989) and Reynolds et al., (1988) NH_3N removed by the liver accounts for only 70-80% of urea-N synthesized. Data summarized in Table 3 indicates about 66% of UN synthesized can be acounted for by NH_3N removal. Blood UN concentrations vary widely for both beef and dairy cattle. Ranges of arterial, portal and hepatic concentrations for beef animals were 1.71 to 15.06, 1.69 to 14.71 and 3.18 to 15.68 mM, respectively. Corresponding values for dairy cows were 5.22 to 9.06, 5.03 to 8.86 and 6.79 to 8.79 mM. When pooled by dietary treatments, the average arterial, portal, and hepatic UN concentrations for roughage vs concentrate were 10.42 vs 6.51, 10.26 vs 6.06, and 8.54 vs 5.65 mM, respectively. Higher concentrations for roughage diets are probably due to the higher N intake from alfalfa hay, which is usually a major ingredient of roughage-based diets. The differences of UN concentrations between dietary regimens correspond to similar effect of diet on NH_3N absorption. Endogenously synthesized urea exits the liver into the general systemic circulation with two potential fates: either cycling to the gastrointestinal tract (rumen and hind gut) via blood and saliva, or excretion from the body in urine or other body secretions. Urea recycling into the gut is used to sustain microbial growth in the rumen-reticulum and hind gut, a process called "protein regeneration cycle" (Houpt, 1970), play an important and fundamental role in nitrogen economy of ruminant animals. Urea recycling is important not only when nitrogen supply is low, but also to maintain stable NH_3 levels during high production when nitrogen supply is adequate.

The site and extent of urea recycling depends on dietary regimen and level of nitrogen intake. Diet composition, i.e, concentrate vs roughage diets, affects site and extent of urea transfer across the PDV of ruminants. Data summarized by Huntington (1990) clearly showed that for animals fed high concentrate diets, urea transfer occurs mostly into the rumen, while those consuming roughage diets cycle a greater proportion of their urea into the post-stomach region. However, ruminants recycle urea to the gut under all feeding regimens. This fact has been clearly demonstrated through postabsorptive studies which showed constantly a negative flux (uptake) of urea across the PDV (average of -97 and -367 mmol/h for beef and dairy cattle, respectively; Table 2), and tracer studies (Dixon and Milligan, 1984) which demonstrated presence of radio-labeled N in microbial cells after injection of labeled urea into jugular veins. The magnitude of recycling is 10 to 42% of N intake (Huntington, 1986), and 10 to 70% for more recent data (table 3). Expressed as fraction of hepatic synthesis, UN recycling averages 35% and 52% for beef and dairy animals, respectively (Table). The magnitude of UN recycling is physiologically regulated by various factors. Low ruminal pH, increased ruminal fluid osmolality, changes in ruminal fluid ammonia concentrations and increased dietary content of ruminally fermentable carbohydrates, all associated with fermentation rate, CO_2 and VFA production, enhance urea recycling to the gut (Rumsey et al., 1970; Houpt, 1970; Kennedy, 1980; Norton et al., 1982). Other factors, especially those interfering with salivary flow such as high non-protein N intake, decrease urea transfer to the gut.

Alpha Amino Nitrogen Absorption and Metabolism

To maintain vital functions, sustain growth, lactation and reproduction, animals need to absorb substantial amounts of amino acids (AA). Amino acids available for absorption come from the hydrolysis of feed, microbial, and endogenous proteins in the lumen of the small intestine. Upon hydrolysis, free amino acids and some small peptides are absorbed across the PDV following extensive metabolism in the intestinal cells before reaching the liver.

Net absorption of individual amino acids as percent of N intake increases with levels of protein or feed intake (Sniffen and Jacobson, 1975; Tagari and Bergman, 1978; Huntington and Prior, 1985). However the following AA, glutamic acid, glutamine, and other urea cycle related AA (citrulline, ornithine) show lower or negative net absorption. In addition, large discrepancies were found between AA disappearance from the lumen of the gut and their subsequent appearance in portal blood. Tagari and Bergman (1978) reported that only 30 to 80% of the essential amino acids disappearing from the lumen of the intestine appear in portal blood. It has been theorized that missing amino acids may have been used by intestinal cells or certain glands for lipoprotein or enzyme synthesis or ultimately for energy production after transamination. Glutamine is a major source of energy for enterocytes in cattle (Okine et al., 1995).

While arterial and hepatic concentrations of AAN appear to be maintained within relatively narrow ranges (2.86 ± .27 SD and 2.92 ± .26 SD, respectively; Table 1), net absorption of AAN across the PDV increases with increased dietary protein or nitrogen consumption in all roughage (Sniffen and Jacobson, 1975; Huntington et al., 1985; Reynolds et al., 1991) and high energy diets (Huntington and Prior, 1985; Reynolds et al., 1991). Portal-arterial concentration differences averaged .18 mM, with values of .20 and .14 mM for concentrate and roughage diets, respectively (Table 1).

Net AAN flux across the PDV increases with increased protein flow into the duodenum. Guerino et al.(1991) and Taniguchi et al., (1995) reported higher PDV flux of

AAN following casein infusion into the abomasum of growing steers. It is noteworthy that these two studies, despite the common findings of increased AAN absorption following casein infusion, reported variable responses in net total splanchnic output of AAN. In the study by Guerino et al., (1991), the increase in PDV net AAN flux was neutralized by the subsequent increase in net hepatic AAN removal, resulting in no appreciable increase in AAN release by splanchnic tissues. Taniguchi et al. (1995), on the other hand, not only observed increased AAN absorption across the PDV, and higher net hepatic uptake, following infusion 200 g of casein into the abomasum, but also showed an increase in splanchnic AAN release to the rest of the body, as would be normally expected. Reynolds (1992) reviewed the literature on metabolism of nitrogenous compounds by ruminant liver and stated that in growing cattle increased dietary intake increases PDV absorption and liver AAN uptake, but the increase in liver removal is usually less than the increase in PDV absorption, which explains increased net release of AAN by splanchnic tissues for production usage.

Total splanchnic release of AAN as percent of PDV absorption varies widely with type of diets. For steers fed all roughage diets Huntington et al. (1989) and Reynolds et al. (1991) reported that net release of AAN as percent of PDV absorption varies from 20 to 24%, while for animals fed high concentrate diets the variation ranged from 31 to 73%. Results from Reynolds et al. (1992; 32%) and Theurer et al. (1990; 48%) for concentrate and Taniguchi et al. (1995; 27%) for 100% alfalfathese conclusions.

The liver exerts a differential removal rate on incoming amino acids and modulates their outflow into the extra splanchnic tissues. Some amino acids (alanine, glycine, serine, glutamine, arginine, asparagine, etc..) show negative splanchnic fluxes, while the liver releases glutamate and most of the branched chain amino acids (valine, leucine, isoleucine). Amino acids removed by the liver have three fates: protein synthesis, gluconeogenesis and urea synthesis all under complex hormonal control.

Summary and Research Justification

Extensive grain processing (i.e.,steam-flaking vs dry-rolling) shifts a greater proportion of digestion from the small intestine to the rumen-reticulum. Steam-flaking appears to improve ruminal, postruminal, and total tract starch digestibility. Flaking increases microbial protein synthesis in the rumen, but has limited effect on crude protein digestibility. Studies comparing grain processing methods and grain type have shown improved performance (weight gain and milk production) by steam-flaking vs dry-rolling or steam-rolling. Very few studies have investigated the effect of grain processing on nutrient absorption and post-absorptive metabolism. No research has been found that has investigated the effect of flake density on splanchnic nitrogen metabolism and the digestion of crude protein within the various segments of the gastrointestinal tract of beef animals. Measuring net nutrient fluxes across PDV, hepatic and splanchnic tissues, and relating them to nutrient digestibility in the gastrointestinal tract could provide greater insight into mechanisms altering nitrogen metabolism and help explain observed increases in efficiency of performance of cattle fed diets containing processed grains.

Table 1. Summary of arterial (A), portal (P) and hepatic (H) vein concentrations (mM) of nitrogenous compounds in bovine blood

Citation	Wt kg	Diet	Ammonia-N A	 P	 H
Beef animals					
Huntington (1983)		silage	.18	.38	
		92% concentrate	.15	.21	
Huntington and Prior (1983)		78% corn low	.12	.24	
		78% corn medium	.14	.23	
		78% corn high	.14	.21	
Huntington and Reynolds (1986)	330	water infusion	.31	.71	
		glucose infusion	.28	.70	
		starch infusion	.32	.63	
Huntington (1987)	424	starch + casein	.12	.32	
		starch + SBM	.11	.33	
		starch +MGM	.11	.28	
		starch + BM	.12	.31	
Reynolds and Huntington (1988)	389	time fed lucerne	.25	.66	
	401	meal fed lucerne	.29	.82	
	408	meal concentrate	.36	.56	
Gross et al. (1988)	280	77% DR wheat(W)	.22	.56	
		77% W:S	.21	.56	
		77% DR sorghum(S)	.20	.57	
Huntington (1989)	240	alfalfa hay	.29	.75	.29
		concentrate	.33	.55	.33

Table 1. Summary of arterial (A), portal (P) and hepatic (H) vein concentrations (mM) of nitrogenous compounds in bovine blood *continued*

	Wt		Ammonia-N		
Citation	kg	Diet	A	P	H
Reynolds et al. (1991)		75% alfalfa low	.37	.75	.36
		75% alfalfa high	.40	.76	.39
		75% concentrate low	.41	.74	.40
		75% concentrate high	.40	.73	.39
Reynolds & Tyrell (1991a)	443	lucerne	.34	.82	.34
		lucerne + alanine	.41	.95	.40
		concentrate	.36	.70	.35
		concentrate + alanine	.45	.82	.45
Guerino et al. (1991)	284	78% corn +300 c	.38	.72	.38
		78% corn + 150 c	.34	.64	.33
		78% corn + water	.32	.57	.31
Seal et al. (1992)	116	pelleted grass	.21	.54	
		flaked corn +grass	.17	.37	
Taniguchi et al. (1995)	253	alfalfa	.38	.85	.38
		SACA	.36	.74	.35
		SACR	.37	.86	.37
		SRCA	.35	.76	.35
		SRCR	.35	.82	.35
Whitt et al. (1996)	474	64:36 corn:grass	.30	.54	
	306	100% alfalfa	.31	.80	

Table 1. Summary of arterial (A), portal (P) and hepatic (H) vein concentrations (mM) of nitrogenous compounds in bovine blood *continued*

Citation	Wt	Diet	Ammonia-N		
	kg		A	P	H
Theurer et al.(1997)	348	77% DR sorghum	.42	.61	.41
		77% SF sorghum	.43	.61	.42
Overall mean beef animals			.29	.60	.36
Matched means beef			.37	.73	.36
Mean beef forage diets			.32	.75	.26
Mean beef concentrate			.27	.52	.29
Dairy cows					
Huntington (1982)	472	orchard & clover silage	.17	.35	
Huntington et al. (1983)	493	60:40 silage:grain	.09	.34	
	488	60:40 silage grain	.09	.32	
Huntington (1984)	513	60:40 4 weeks	.44	.80	
		60:40 20weeks	.30	.67	
Reynolds et al. (1988)	640	60:40 4 weeks	.40	.72	.40
		60:40 8 weeks	.41	.76	.41
Whitt et al. (1996)	506	50:35 alfalfa: corn	.36	.67	.37
Overall mean dairy cows			.28	.58	.39
Matched means cows			.39	.72	.39

Table 1. Summary of arterial (A), portal (P) and hepatic (H) vein concentrations (mM) of nitrogenous compounds in bovine blood- *continued*

	Urea-N			α-amino-N		
Citation	A	P	H	A	P	H
Beef animals						
Hunington (1983)	7.70	7.61				
	2.50	2.45				
Huntington and Prior (1983)	4.24	4.18				
	2.91	2.82				
	3.22	3.12				
Huntington and Reynolds (1986)	8.92	8.73		2.38	2.63	
	9.04	8.85		2.18	2.45	
	8.25	8.13		2.49	2.80	
Huntington (1987)	7.32	7.10		2.02	2.27	
	8.64	8.33		2.20	2.59	
	7.19	6.94		2.17	2.49	
	6.47	6.21		2.27	2.68	
eynolds and Huntington (1988)	10.17	10.02		2.41	2.55	
	11.57	11.42		2.68	2.83	
	5.51	5.38		3.17	3.33	
Gross et al. (1988)	6.59	6.47		1.95	2.12	
	7.72	7.62		1.91	2.08	
	7.91	7.82		1.73	1.90	
Huntington (1989)	10.5	10.4	10.9	2.60	2.70	2.62
	4.57	4.44	4.69	2.49	2.66	2.59

Table 1. Summary of arterial (A), portal (P) and hepatic (H) vein concentrations (mM) of nitrogenous compounds in bovine blood *continued*

Citation	Urea-N			α-amino N		
	A	P	H	A	P	H
Reynolds et al. (1991)	10.1	9.84	10.5	3.11	3.12	3.16
	12.3	12.1	12.7	3.23	3.47	3.29
	9.76	9.62	10.1	2.81	3.00	2.87
	10.3	10.0	10.6	3.11	3.36	3.18
Reynolds and Tyrell (1991a)	12.48	12.23	12.93	2.80	2.97	2.83
	15.06	14.71	15.68	2.88	3.15	2.92
	10.42	10.14	10.68	2.63	2.83	2.67
	11.49	11.23	11.93	2.70	3.02	2.77
Guerino et al. (1991)	7.43	7.26	7.71	2.95	3.14	3.04
	5.72	5.58	5.96	2.55	2.72	2.61
	4.57	4.44	4.75	2.66	2.80	2.74
Seal et al. (1992)	3.53	3.48				
	1.71	1.69				
Taniguchi et al. (1995)	10.57	10.47	11.02	3.26	3.44	3.30
	9.78	9.67	10.13	3.16	3.35	3.23
	11.53	11.36	11.86	3.13	3.24	3.17
	9.66	9.52	10.10	3.32	3.54	3.39
	11.37	11.23	11.76	3.08	3.19	3.11
Whitt et al. (1996)	5.30	5.11	5.61	2.50	2.76	2.35
	10.0	9.88	10.6	2.49	2.74	2.38

Table 1. Summary of arterial (A), portal (P) and hepatic (H) vein concentrations (mM) of nitrogenous compounds in bovine blood *continued*

Citation	Urea-N			α-amino N		
	A	P	H	A	P	H
Theurer et al. (1997)	3.64	3.50	3.85	2.67	2.78	2.71
	3.10	2.90	3.18	2.77	2.84	2.81
Overall beef animal mean	7.88	7.65	9.41	2.64	2.84	2.92
Matched beef means	9.08	8.89	9.41	2.86	3.04	2.92
Mean forage diets	10.42	10.26	8.54	2.54	2.68	2.24
Mean concentrate diets	6.51	6.35	5.65	2.25	2.48	2.15
Dairy cows						
Huntington (1982)	6.68	6.56				
Huntington et al 1983)	6.27	6.15				
	5.22	5.03				
Huntington (1984)	8.77	8.53		2.87	3.21	
	9.06	8.86		1.95	2.37	
Reynolds et al. (1988)	7.73	7.52	7.91	3.03	3.25	3.14
	6.63	6.31	6.79	3.02	3.30	3.14
Whitt et al. (1996)	8.60	8.41	8.79	2.45	2.85	2.35
Overall dairy cows mean	7.37	7.17	7.83	2.66	3.00	2.98
Matched means	7.65	7.41	7.83	2.83	3.13	2.98

Table 2 Summary of blood flow (L/h) and net fluxes[a](mmol/h) of nitrogenous compounds across portal-drained viscera (PDV), hepatic (H) and total splanchnic (SPL) tissues of beef and dairy cattle

Citation	Diet	Blood flow		Ammonia-N flux		
		PBF	HBF	PDV	H	SPL
Beef animals						
Huntington (1983)	silage	642		101		
	92% conc.	880		44		
Huntington & Prior 1983	78% corn low	444		36		
	78% corn med	660		40		
	78% corn high	782		44		
Hunting. Reynolds 1986	water infusion	790		197		
	glu. infusion	873		200		
	starch infusion	903		171		
Huntington 1987	starch + casein	570		114		
	starch + SBM	520		116		
	starch + MGM	536		90		
	starch +BM	454		83		
Gross et al. 1988	77%wheat(W	741		209		
	77%W:S	817		208		
	77% sorghum	774		201		
Reynolds Hunting. 1988	time F lucerne	588		242		
	meal F lucerne	657		348		
	meal F concent	752		154		
huntington 1989	alfalfa hay	624	781	291	-290	1
	concentrate	575	713	128	-129	-1

Table 2. Summary of blood flow (L/h) and net fluxes[a] (mmol/h) of nitrogenous compounds across PDV, H and SPL tissues of beef and dairy cattle *continued*

		Blood flow		Ammonia fluxes		
Citation	Diet	PBF	HBF	PDV	Liver	SPL
Reynolds et al. (1991)	75% alfalfa low	488	539	186	-194	-7
	75% alfalfa high	907	963	340	-353	-15
	75% conc. low	452	514	143	-148	-4
	75% conc. high	763	842	250	-260	-10
Guerino et al.	78% corn +300 c	565	643	190	-193	-2
	78% corn + 150 c	471	575	140	-144	-5
	78% corn + water	488	602	122	-126	-2
Reynolds Tyrell (1991a)	lucerne	714	858	344	-350	-6
	lucerne + alanine	752	778	408	-414	-7
	concentrate	634	777	214	-217	-3
	conc. + alanine	632	726	233	-232	1
Seal et al. (1992)	pelleted grass	312		96		
	flaked corn+grass	297		58		
Taniguchi et al. (1995)	alfalfa	422	499	198	-202	-3
	SACA	540	648	208	-214	-5
	SACR	604	700	294	-298	-3
	SRCA	501	600	206	-209	-3
	SRCR	547	659	260	-260	0
Huntington et al. (1996)	27% concentrate	721	860	123	-125	-2
	63% concentrate	638	776	124	-127	-3

Table 2. Summary of blood flow (L/h) and net fluxes[a] (mmol/h) of nitrogenous compounds across PDV, H and SPL tissues of beef and dairy cattle *continued*

		Blood flow		Ammonia-N		
Citation	Diet	PBF	HBF	PDV	Liver	SPL
Whitt et al. (1996)	64:36 corn:grass	538	642	131	-135	-3
	100% alfalfa	499	591	245	-248	-3
Theurer et al. (1996)	77% DR sorghum	859	1071	158	-185	-9
	77% SF sorghum	894	1052	167	-176	-11
Overall beef mean		632	725	179	-218	-4
Matched mean		618	725	213	-218	-4
Mean forage diets		611	489	244	-181	-4
Mean concentrate		640	607	154	-161	-3
Dairy cows						
Huntington (1982)	orchard & clover	836		121		
Huntington al. (1983)	60:40 silage:grain	632		121		
	60:40 Sil.:gr + C_2	652		118		
Huntington (1984)	60:40 4 weeks	1328		360		
	60:40 20 weeks	1438		502		
Reynolds et al. (1988)	60:40 silage:corn	1645	1940	517	-517	0
Whitt et al. (1996)	60:40 silage:corn	1621	2141	578	-591	-12
		1262	1662	392	-376	15
Overall dairy cows		1177	1914	339	-495	1
Matched means		1509	1914	496	-495	1

Table 2. Summary of blood flow (L/h) and net fluxes[a] (mmol/h) of nitrogenous compounds across PDV, H and SPL tissues of beef and dairy cattle *continued*

Citation	Urea-N			α-amino-N		
	PDV	Liver	SPL	PDV	Liver	SPL
Beef animals						
Huntington (1983)	-40					
	-36					
Huntington and Prior (1983)	-20					
	-44					
	-51					
Huntington and Reynolds (1986)	-97			144		
	-91			133		
	-69			163		
Huntington (1987)	-125			139		
	-157			189		
	-135			170		
	-120			168		
Reynolds and Huntington (1988)	-89			85		
	-96			97		
	-101			121		
Gross et al. (1988)	-78			111		
	-58			102		
	-55			87		
Huntington (1989)	-79	366	288	98	-78	20
	-76	159	83	93	-25	68
	-209	593	376	223	-172	52

Table 2. Summary of blood flow (L/h) and net fluxes[a] (mmol/h) of nitrogenous compounds across PDV, H and SPL tissues of beef and dairy cattle *continued*

Citation	WT	Urea-N			α-amino N		
		PDV	Liver	SPL	PDV	Liver	SPL
Reynolds et al. (1991)	335	-113	354	244	96	-76	23
	315	-209	593	376	223	-172	52
	325	-61	235	176	82	-58	29
	308	-203	491	289	188	-130	59
Reynolds & Tyrell (1991a)	443	-117	563	386	118	-95	22
		-264	743	479	200	-171	28
		-194	388	194	127	-98	30
		-166	480	314	192	-145	47
Guerino et al. (1991)	284	-95	275	182	108	-53	60
		-67	202	139	80	-49	35
		-63	184	114	68	-12	51
	116	-45					
		-7					
Taniguchi et al. (1995)	253	-41	266	226	75	-55	20
		-62	290	228	102	-59	43
		-101	330	229	66	-39	28
		-72	335	263	110	-69	41
		-79	336	256	61	-42	18
Huntington et al. (1996)	421	-104	106	2	94	-49	45
		-77	135	58	106	-50	56

Table 2. Summary of blood flow (L/h) and net fluxes[a] (mmol/h) of nitrogenous compounds across PDV, H and SPL tissues of beef and dairy cattle *continued*

Citation	WT	Urea-N			α-amino N		
		PDV	Liver	SPL	PDV	Liver	SPL
Whitt et al. (1996)	474	-104	198	93	139	-94	45
	306	-59	346	289	123	-67	55
Theurer et al. (1997)	348	-123	251	117	90	-26	44
		-171	236	69	100	-60	48
Overall beef animals mean		-97	328	212	120	-74	40
Matched means beef		-115	328	212	114	-74	40
Mean forage diets		-110	278	191	101	-64	22
Mean concentrate diets		-92	238	148	112	-53	37
Dairy cows							
Huntington (1982)	472	-52					
Huntington et al. (1983)	493	-56					
	488	-100					
Huntington (1984)	513	-269			321		
		-251			424		
Reynolds et al. (1988)	640	-348	674	325	359	-136	222
	651	-516	892	375	463	-218	245
Whitt et al. (1996)	506	-236	552	317	504	-173	330
Overall means cows		-229	706	339	414	-176	266
Matched means cows		-367	706	339	442	-176	266

[a] positive values indicate absorption or release, negative values indicate uptake or utilization

Table 3. Summary of N intake and relationships of ammonia-N (NH_3N), urea-N (UN) and α-amino -N (AAN) absorption across portal-drained viscera (PDV)[a]

Citation	NI, g/d	NH_3N /NI	NH_3N /UN	UN /NI	NH_3N /AAN	AAN /NI
Beef animals						
Huntington and Prior (1983)	34	.35	1.79	.20		
	64	.21	.92	.23		
	93	.16	.85	.19		
Huntington (1987)	115	.33	.91	.37	.82	.41
	125	.31	.74	.42	.61	.51
	125	.24	.67	.36	.53	.46
	126	.22	.69	.32	.49	.45
Reynolds & Huntington (1988)	153	.53	2.72	.20	2.85	.19
	153	.76	3.63	.21	3.59	.21
	83	.62	1.52	.41	1.27	.49
Huntington (1989)	162	.60	3.68	.16	2.97	.20
	95	.45	1.68	.27	1.38	.33
Reynolds et al.(1991)	209	.55	1.63	.34	1.52	.36
	133	.47	1.65	.29	1.94	.24
	98	.49	.70	.70	.76	.64
	174	.48	4.10	.12	3.05	.16
Guerino et al. (1991)	65	.99	2.00	.49	1.76	.56
	54	.86	2.09	.41	1.75	.49
	45	.90	1.94	.47	1.79	.50
	150	.47	3.35	.14	2.04	.23

Table 3. Summary of N intake and relationships of NH_3N, UN and AAN absorption across portal-drained viscera (PDV)[a] *continued*

Citation	NI, g/d	NH_3N /NI	NH_3N /UN	UN/ NI	NH_3N /AAN	AAN /NI
Taniguchi et al. (1995)	119	.56	4.83	.12	2.64	.21
	150	.47	3.35	.14	2.04	.23
	150	.66	2.91	.23	4.45	.15
	150	.46	2.86	.16	1.87	.25
	150	.58	3.29	.18	4.26	.14
Huntington et al. (1996)	99	.42	1.18	.35	1.31	.32
	100	.42	1.61	.26	1.17	.36
Whitt et al. (1996)	141	.31	1.26	.25	.94	.33
	197	.42	4.15	.10	1.99	.21
Theurer et al. (1997)	141	.38	1.28	.29	1.76	.21
	138	.41	.98	.42	1.67	.24
Overall mean beef cattle	121	.48	1.78	.27	1.52	.31
Mean forage diets[b]	153	.54	2.93	.22	2.35	.24
Mean concentrate diets[b]	106	.39	1.52	.30	1.50	.35
Dairy cows						
Huntington (1982)	166	.25	2.33	.11		
Huntington et al. (1983)	139	.29	2.16	.14		
	139	.29	1.18	.24		
Huntington (1984)	360	.34	1.34	.25	1.12	.30
	502	.42	2.00	.21	1.18	.35
Reynolds et al. (1988)	363	.48	1.49	.32	1.44	.33
	421	.46	1.12	.41	1.25	.37

Table 3. Summary of N intake and ammonia-N, urea-N and AAN absorption across portal-drained viscera (PDV)[a] *continued*

Citation	NI g/d	NH_3/ NI	NH_3/ UN	UN /NI	NH_3/ AAN	AAN /NI
Whitt et al. (1996)	512	.26	1.66	.15	.78	.33
mean dairy cows	313	.36	1.48	.25	1.15	.34

[a] from PDV values in table 2 times .336 to convert to g/d

[b] infusion studies not included in the average

CHAPTER 3

MICROBIAL PROTEIN SYNTHESIS, DRY MATTER AND NITROGEN DIGESTION BY STEERS FED PROCESSED CORN AND SORGHUM GRAIN

SYNOPSIS

Seven crossbred steers (400 kg, Exp. 1; 420 kg, Exp. 2) fitted with t-type cannulas into the proximal duodenum and distal ileum were used in a completly randomized block design to examine effects of processing method, dry-rolled (DR) versus steam-flaked (SF) of sorghum grain and degree of processing (flaking density) of corn and sorghum grain on dry matter (DM) and nitrogen (N) digestion characteristics and to measure extent of microbial N flow to the duodenum. In experiment 1, diets contained 77% DR or SF sorghum flaked at densities of 437, 360 and 283 g/L (SF34, SF28, SF22). In experiment 2, corn grain was flaked at densities of either 437 or 283 g/L. Daily dry matter (DM) and nitrogen intakes, 6.7 kg and 142 g for sorghum and N intakes for corn (149 g) were similar among treatments. Steers fed SF compared to DR sorghum increased ($P < .05$) ruminal DM and apparent small intestinal DM, % of intake, digestibilities. Decreasing flake density of sorghum linearly increased ($P < .05$) ruminal DM digestion and tended to increase linearly ($P < .08$) microbial effeciency and apparent small intestinal DM and total tract N digestibilities. Unexpectedly flake density did not alter digestion characteristics of corn diets.

INTRODUCTION

Corn and sorghum grains are major feed ingredients in feedlot and dairy diets. At 40 to 95% of the diet, grains contribute major portions of daily crude protein (CP) intakes. Histological investigation of grains' molecular and structural composition have revealed distinctive differences among and between grains and fueled debate on probable cause of differences in their respective digestibility and feeding values. The presence and relative abundance of protein bodies and protein matrixes around and between starch granules in sorghum grain limits enzymatic attack on grain and seems to explain its relatively low ruminal and total tract digestibilities (Rooney and Pflugfelder, 1986). Corn on the other hand, because of its low amylose content and higher protein digestibility, is usually preferred in feeding programs. However, Beauchemin et al. (1994) demonstrated limited DM disappearence of whole corn grain following a 96 h incubation. For optimum use in cattle feeding, both corn and sorghum grain need to be processed. Performance and digestion trials (Xiong et al., 1991; Zinn, 1990) have demonstrated superiority of extensive processing methods (steam-flaking) over minimal processing (dry or steam-rolling). Steam-flaking combines heat, moisture, pressure and mechanical actions to alter the chemical and physical structure of the grain and impacts on its digestibility. Reviews of literature on grain processing (Huntington, 1997; Theurer et al., 1996a, b) have shown improved performance and microbial protein flow to the duodenum from feeding steam-flaked sorghum. In most studies starch digestibility was the focal point. However, while flaking improves sorghum crude protein digestibility, it might have a detrimental effect on the corn protein utilization. Prigge (1975) found that steam-flaking decreased the soluble nitrogen from 12% to 7% which may negatively affect ruminal N digestion.Only a few studies (Zinn, 1990, 1991) have investigated the effect of steam-flaking corn and sorghum grain on nitrogen (N) digestibility in all segments of the gastrointestinal tract (GIT). No study has reported effect of degree of sorghum grain processing on N digestibility in steers fitted with both duodenal and ileal cannulas. The objective of the present study was to examine effect of processing methods, dry-rolling (DR) vs steam-flaking (SF) of sorghum grain; and degree of flake density of corn and sorghum grains, on site and extent of dry matter (DM) and N digestibility in various segments of the GIT and on ruminal microbial protein synthesis and flow to the small intestine.

MATRIAL AND METHODS

Two experiments were conducted under a research protocol approved by the University of Arizona Institutional Animal Care and Use committee. The University of Arizona is accredited by the American Association of Laboratory Care for Farm Animals. Both experiments were conducted using completly randomized block designs.

Experiment 1.

Animals, diets and feeding. This experiment is a companion study to the post-absorptive metabolism study (chapter 4). Steers for each study were obtained from the same pool of 32 animals, housed in the same pens and fed the same diets (except for substitution of Cr_2O_3 for .3% grain). Seven halter-broken crossbred steers (400 kg) were fitted with t-type cannulas into the proximal duodenum (~ 6 cm from the pylorous) and distal ileum (20 cm from the ileal-cecal valve) according to the procedure of R. A. Zinn (personal communication). Steers were offered four dietary treatments: DR or SF sorghum grain flaked at three densities (437, 360 and 283 g/L) referred to as SF34, SF28 and SF22, respectively, reflecting bushel weight in lb, typical of field studies. Diets (Table 4) contained 77% sorghum grain and were formulated to be isonitrogenous (12% CP). All diets contained .3% added chromium oxide as an indigestible flow marker.

Steers were housed in individual (2.5 x 5 m) partially shaded pens with concrete floors. Steers were given ad libitum access to feed, which was offered twice daily at 12 h intervals at 0700 h and 1900 h; had free access to water and were allowed free movement at all times except during sampling.

Sample Collection and Analyses. Experimental periods (four) were 14 d in length with 11 d for adjustement to diets and 3 d for sample collection. Sampling protocol and nutrient analysis were identical in both experiments. Feed and ort grab samples were collected from d 10 through d 14 of each period, and individual steer feed intakes were based on the same days. Duodenal (250 ml) and ileal (100 ml) digesta and fecal samples (200 g) were collected 12 times from d 12 through 14, on each steer at 6 h intervals. Collection times were advanced by 2 h every 24 h of the collection period; thus providing representative samples every 2 h of a 24 h period. An extra duodenal digesta sample was collected at each sampling time, and pooled by steer every 24 h for bacterial cell isolation. All samples, except those intended for bacterial cell isolation, were frozen at -10 °C immediately after collection.

Frozen duodenal, ileal and fecal samples for each steer were thawed at the end of each collection period and homogenized. Representative subsamples for each steer were dried in a forced-air oven at 55 °C. Dried composited feed and orts samples, duodenal, ileal and fecal samples were ground in a Wiley mill (2 mm screen; Arthur H. Thomas, Philadelphia, Pa) and then in a cyclone mill (Tecator 1093 Cyclotec Sample Mill, Hoganas, Sweden) to pass through a 1 mm screen.

Feed, orts, duodenal, ileal, and fecal samples were analyzed for DM and ash (AOAC, 1984), nitrogen (N) by automated procedures (Bran and Luebbe, Analyzing Technologies, Elmsford, NY) after Kjeldahl digestion (AOAC, 1984) and for chromium using atomic absorption spectrophotometry according to the procedure of Fenton and

Fenton (1979).

Pooled duodenal digesta samples collected for bacterial cell isolation were homogenized for 1 min in a mixer to dislodge particle-associated bacteria. Homogenized samples were strained between three layers of cheesecloth and one layer of foam. Bacterial cells were isolated by differential centrifugation as described by Smith and McAllan (1974). Isolated bacterial cells (IBC) were then freeze dried and analyzed for DM and N content, the same as for feed, orts, fecal and digesta samples. Purine content of IBC, duodenal, ileal and fecal samples were measured according to the procedure of Zinn and Owens (1986). The proportion of digesta and fecal N of bacterial origin was determined by dividing the N:purine ratio of bacteria by the N:purine ratio of the respective samples. Total microbial N flowing into the various segments of the (GIT) was estimated by multiplying total N flows at the site by the proportion of N attributed to bacteria. Feed N flow was calculated by difference. Extent of ruminal, small intestinal and total tract digestibilities of DM and N were calculated from changes in chromium and N concentrations in feed and in digesta at the various sites. True DM and N digestion were computed by substracting the bacterial DM and N contributions from total respective values at targeted sites.

Statistical Analyses. Data were analyzed by Minitab GLM procedures (Minitab release 11, 1996) as a completely randomized block design using steers and period as blocking criteria according to the following model $Y_{ijk} = \mu + \tau_i + \beta_j + \delta_l + \varepsilon_{ijk}$, where Y_{ijk} is the response variable, μ is the overall mean, τ_i is the treatment effect, β_j is the animal effect, δ_l is the period effect and ε_{ijk} is the random experimental error. Final statistical analysis of the data was performed with homogenized data after extreme values (values, two standard deviation greater or lower than treatment mean) were taken out. All values presented in tables are GLM least square generated means. Preplanned comparisons of means (DR vs SF) and level of processing effects (linear or quadratic due to flake density) were tested by orthogonal polynomials. Statistically significant differences between treatments were declared for $P \leq .05$ and a tendency for $.05 < P \leq .15$.

Experiment 2.

During two periods, the same steers (420 kg) were offered two dietary treatments: steam-flaked corn at densities of 437 and 283 g/L (SF34 and SF22). Diets (Table 5), period length, sampling protocol and laboratory procedures were the same as described in Exp. 1. Data were analyzed by Minitab GLM procedures (Minitab release 11, 1996) as a completely randomized block design similar to in Exp. 1. Treatment effects were tested by simple two mean comparisons with the t-test. Statistically significant differences between treatmeant means were declared for $P \leq .05$ and a tendency for $.05 < P \leq .15$.

RESULTS AND DISCUSSION

Experiment 1

Intakes of DM (6.7 kg/d) and N (136 g/d) were similar among sorghum grain treatments and met the daily N requirements for growing beef steers gaining 1.0 kg/d (NRC, 1984). Feeding flaked (SF34, SF28, SF22) compared to DR sorghum grain did not alter DM flow into the duodenum (3,785 vs 4,275 g/d). Steers fed SF compared to DR sorghum grain, increased (P = .04; Table 6) ruminal DM digestion, corrected for microbial DM, and tended to increase (P = .15) the apparent ruminal DM digestion . The improvement of SF over DR in DM digestion were 17.3 and 19.8% (61 vs 52% and 44 vs 37%) for corrected and apparent DM digestion, respectively. Decreasing flake densities linearly increased ($P \leq .05$; Table 6) both corrected and apparent ruminal DM digestion. Eck (1991) investigated effects of flaking density on DM digestilities.

Decreasing flake density of sorghum grain from .41 to .26 kg/L for sorghum grain (Eck, 1991) did not alter ruminal DM digestion, eventhough starch digestibility increased (P = .05) linearly. However, Axe et al. (1987) demonstrated an increase (P =.01) in ruminal DM digestion as proportion of ruminally fermentable grain increased in the diets (wheat vs sorghum or mixture of the two grains). In the present study, the significant increase in corrected ruminal DM digestibility (P = .03) may be associated with the substantial increase (23%) in ruminal starch digestion (82 vs 67%) for SF compared to DR (77, 82, 89 and 67% for SF34, SF28, SF22 and DR, respectively; Lozano, 1997).

Our hypothesis, consistent with previously published results on ruminal fermentation of different grain types (Spicer et al., 1986; Axe et al., 1987; Zinn, 1991) or grain processing (Zinn, 1990; Theurer et al., 1990) and in vitro fermentation (Osman et al., 1970; Frederick et al., 1973), predicted increased ruminal fermentation as flake density decreased, with a concomittant increase in microbial protein synthesis and flow to the intestines. Surprisingly, processing methods (DR vs SF) and degree of processing (flake density) did not alter microbial N or feed N flow to the duodenum. Microbial N flows, 85.6, 91.2, 85.2 and 79.6 g/d for SF34, SF28, SF22, and DR sorghum respectively, were similar among treatments. Nonetheless, reducing flake density tended to increase linearly (P = .11) feed N digestion in the rumen. Steers fed SF compared to DR did not increase ruminal feed N degradation (33 vs 29.5) and but tended to improve (P =.19) microbial protein flow (g/d) by 9.7% (87.3 vs 79.6 g/d for SF and DR, respectively). Flaking to an intermediate density (SF28) numerically improved microbial protein flow by 14.6% (91.2 vs 79.6 g/d, respectively). The numerical increase in microbial protein flow agrees with data summarized by Theurer et al. (1996a, b), which showed on average a 10% increase in microbial protein flow by both beef cattle fed diets greater in rumen starch degradation, and dairy cattle fed SF compared to DR diets.

Processing did not alter apparent and corrected ruminal N digestion of sorghum diets. Previous studies on effect of steam-processing and flaking on digestibility of grain structural components (i. e., starch and protein) summarized by Huntington (1997), Theurer (1986) and Theurer et al. (1996a,b) have shown a dramatic improvement in starch digestibility due to processing. Steam-processing which disrupts the protein bodies around the starch granules increases not only starch fermentation but also protein digestibility. Spicer et al. (1986) demonstrated a consistent increase in feed protein digestibility with increased ruminal starch fermentation. This indeed, supports findings of Rooney and Pflugfelder (1986) who identified protein bodies and the protein matrix as the major cause of low sorghum grain digestion They concluded that processing alters protein structures of the grain and facilitates enzymatic access to starch granules; consequently it alters the digestibility of both starch and protein components. There are very limited data reporting microbial N flow to the duodenum in cattle fed high sorghum grain diets. Results of the present study on microbial N flow to the small intestines (87 and 80 g/d for SF and DR, respectively) are similar to results reported by Spicer et al. (1986; 80.8 g/d) for DR sorghum, slightly lower than those reported by Rahnema et al. (1987; 99.5 and 90.2 g/d for SF and DR sorghum, respectively), but substantially higher than results reported by Wanderley et al. (1987; 52.2 g/d) and Streeter et al. (1989; 54.3 g/d; 1990; 53.5 g/d) for sorghum grain based diets.

Percentage of microbial N in duodenal digesta steers (46 and 50% for DR and SF diets, respectively) for the present experiment are similar to most results reported in previous trials with sorghum grain using purine as the microbial marker. Values reported by Cole et al. (1976), Prigge et al. (1978) Wanderley et al. (1987) and Zinn (1990, 1991) averaged 50% across processing method (ranging from 46% to 52%).

Microbial efficiency (g microbial N/kg DM truly fermented in the rumen) tended to decrease linearly (P = . 07) as flake densities decreased (25.3, 20.4 and 15.6 g/kg for

SF34, SF28 and SF22, respectively). Microbial efficiencies in the present study are similar to the microbial efficiencies calculated from results of studies cited in the previous paragraph which averaged 23%. Protein efficiency (N entering the duodenum/N intake) was not altered by the processing method, but tended to decrease linearly as flake density decreased (P = .07; Table 6). Decrease in microbial and protein efficiencies in response to lowering flake density may be due to ruminal disturbances associated with high fermentation rates when animals are fed lower density flakes, which may increase acidity.

Processing (SF versus DR) increased (P = .05; Table 6) apparent small intestinal DM digestion as a percent of intake. Apparent small intestine DM digestibility (% of entry and % of intake) tended to decrease linearly (P = .07, Table 6) with decreasing flake densities. Flaking sorghum grain to the lowest density (SF22), compared to DR did not alter N digestion in the small intestine but resulted in a 5% numerical improvement.

Extensive processing (SF) did not alter post-ruminal DM and N digestion, but there was a tendency for a linear increase (P = .12) in apparent total DM digestion.Total tract DM digestibility results of the present experiment are similar to values reported by other researchers (Spicer et al., 1986; Rahnema et al., 1987; Zinn, 1991) Corrected total tract N digestion exhibited a linear increase (P = .04; Table 6), while the apparent digestion showed a tendency for a linear increase (P = .06).

Experiment 2.

Nitrogen intake (149 g/d) was similar between treatments and met the daily requirement of growing-finishing steers (NRC, 1984). Steers fed corn grain flaked at 283 g/L had greater (P = .002) DM intakes than those fed diets with corn flaked at 437 g/L (8,255 vs 7,984 g/d for SF22 and SF34, respectively). The difference in intake was unexpected and contrary to previously reported data on feed intake of beef animals fed processed grains. Swingle (1992) summarized data on effects of flake density on feed consumption and performance in feedlot steers and concluded that flaking to lower densities linearly decreased feed intakes.

Flaking corn grain to the lower density (from SF34 to SF22) did not alter ruminal, ileal and fecal DM flows(Table 7). Lowering flake density from .40 to .30 g/L (Zinn, 1990), reducing particle size from 7.94 to 3.18 mm (Galyean et al., 1979) or varying the levels of intake from 1 to 2 x maintenance (Galyean et al., 1979), also did not alter ruminal corn DM digestibility. Corrected and apparent ruminal DM digestibility reported by Galyean et al., (1976), Galyean et al. (1979), Spicer et al. (1986) Zinn (1990, 1991) and Cecava et al. (1991) pooled across processing methods and levels of intake, averaged 52.9% (range = 28.4 to 66.2%) and 62.8% (range = 59.0 to 65.9%) respectively. Corresponding values for only steam-flaked corn were 45.3% and 62.8% (range = 61.9 to 69.6, all on an organic matter basis). Results of the present study (37 and 52% for apparent and corrected digestibilities, respectively) were lower than than average reported values by 21% (37 vs 45 and 52 vs 63, respectively). Two possible reasons may explain such low values: level of feed intake or chromium oxide determination in digesta and fecal samples. First, steers in the present experiment, unlike in most cited studies, were given ad libitum access to feed. It is well documented that high levels of feed intake increase rate of passage and decrease digestibility. Second, inacuracy in chromium oxide determination can bias DM flows and consequently it can bias digestibilities. Because samples retained for laboratory analyses were subsampled from collected digesta and fecal samples, it is possible that the "representative samples" did not reflect accurately the duodenal chromium oxide concentrations and may have caused an overestimation of DM flow and an underestimation of the digestibility.

Flaking to lower density (SF22) compared to moderate flake density (SF34) did not alter microbial protein sythesis (104.5 vs 97 g/d) and ruminal feed N degradation (16.04 vs 15.58%) in the rumen (Table 7). Microbial efficiency (25.34 vs 26.06) and protein efficiency (1.51 vs 1.52) also were similar between treatments. Apparent N digestibility (-51.5%) and the microbial N flow to the intestines were much greater than average reported values (-8.1 and 63 g/d, respectively). The reason for the low value is not known. However, because total and microbial N are calculated as the mathematical product of DM flow x percent N content of the digesta, overestimation of DM flow automatically overestimates all N flows and digestion characteristics. It is worth noting that Zinn (1990) also reported a wide variation of ruminal N digestibility by steers fed steam-flaked corn diets.

Apparent small intestinal DM digestibility, % of entry and % of intake (50.08 vs 54.36 and 33.07 vs 31.43, respectively), and total tract DM digestibility, apparent and corrected (75.25vs 76.53 and 84.86 vs 84.89, respectively) were similar between treatments. Corn digestibility data from previously cited studies averaged 18.9% for DM in the small intestine (% of intake) and 82.7% for total tract. Results of the present experiment are slightly lower for the total tract, but much higher (70% greater) for the small intestine than average published values. The reason for such a high intestinal digestibility is not known. Flaking to lower density decreased ($P < .04$) large intestinal apparent DM digestibility (% of entry and % of intake), despite the similarity in DM flow from the ileum. These DM digestibility results agree with previous findings that processing shifts proportions of starch digestion to the rumen with less flow to, but greater digestion in the large intestine(Theurer, 1986).

Implications

Steam-flaking compared to DR of sorghum grain improves DM digestibilities. Steam-flaking numerically increased (10%) microbial protein synthesis and flow to the intestines. Lowering flake density of sorghum grain not only increased linearly DM digestion but also tended to increase total tract DM and N digestibilities. Results of the present study suggest that steam-flaking may improve substantially nutrient digestibility and improve performance as observed in published performance trials. However, for corn grain results of the present study did not show improvements due flaking density.

Table 4. Diet composition and chemical analyses (DM basis; Exp. 1)

	DIETS[a]			
Item	DR	SF34	SF28	SF22
Ingredient				
Sorghum grain	77.0	77.0	77.0	77.0
Alfalfa hay	15.0	15.0	15.0	15.0
Cottonseed meal	2.3	2.3	2.3	2.3
Molasses	4.0	4.0	4.0	4.0
Limestone	.9	.9	.9	.9
Salt	.5	.5	.5	.5
Vitamin A[b]	+	+	+	+
Urea	.3	.3	.3	.3
Chromium oxide	.3	.3	.3	.3
Analysis, %				
Dry matter, %	89.6	87.3	86.6	86.7
Crude protein, %	12.2	13.1	12.8	12.7

[a] DR= dry-rolled; SF34, SF28, SF22 = steam-flaked at densities of 437, 360 and 283 g/L, respectively.

[b] added at 3,300 IU/kg

Table 5. Diet composition and chemical analyses (DM basis; Exp. 2)

	DIETS[a]	
Item	SF34	SF22
Ingredients		
Corn grain	77.0	77.0
Alfalfa hay	15.0	15.0
Cottonseed meal	2.3	2.3
Molasses	4.0	4.0
Limestone	.9	.9
Salt	.5	.5
vitamin A[b]	+	+
Urea	.3	.3
Chromium oxide	.3	.3
Analysis, %		
Dry matter	87.9	88.4
Crude protein	11.9	11.4

[a] SF34 = steam-flaked at density of 437 g/L, SF22 = steam-flaked at density of 283 g/L.

[b] added at 3,300 IU/kg.

Table 6. Dry matter and nitrogen flow and digestion in the gastrointestinal tract of steers fed dry-rolled or steam-flaked sorghum at three densities

	Treatment[a]					Probability		
Item	DR	SF34	SF28	SF22	SEM	DR vs SF	L[b]	Q[c]
Intakes, g/d								
DM	6761	6456	6895	6700	255	.78	.40	.39
N	132	136	140	137	6	.38	.76	.61
Flow to duodenum, g/d								
DM	4275	4055	3961	3339	450	.23	.17	.86
Total N	176	192	208	167	14.9	.39	.25	.15
Microbial N	79.6	85.6	91.2	85.2	6.3	.19	.89	.35
Feed N	92.6	93.4	100	83	8.3	.95	.22	.67
Total N/NI[d]	1.31	1.37	1.31	1.23	.1	.92	.16	.90
Microbial efficiency[e]	17.5	25.3	20.5	15.7	3.1	.41	.07	.84
Ruminal digestion, %								
DM, apparent	36.8	37.5	44.2	50.4	4.6	.15	.03	.82
DM, corrected[f]	52	55.8	61.8	65.3	3.7	.04	.05	.64
N, apparent	-31	-37	-31	-23	7.7	.92	.16	.90
Feed N	29.1	31.5	28.5	39.2	4.6	.38	.11	.18
Flow from ileum, g/d								
DM	1749	1698	1721	1688	181	.81	.94	.94
Total N	45.8	53.2	48.4	43.3	5.1	.68	.27	.95
Small intestine digestion, %								
DM, % entry	58.5	55.5	57.1	49.3	3.4	.22	.32	.33
DM, % intake	37.2	33	31.3	24.7	3.7	.07	.07	.60
Total N	72.6	72.6	73.9	76	1.7	.42	.21	.81

Table 6. Dry matter and nitrogen flow and digestion by steers fed 77% sorghum grain dry-rolled or flaked at three densities *continued*

	Treatment[a]					Probability		
Item	DR	SF34	SF28	SF22	SEM	DR Vs SF	L[b]	Q[c]
Fecal output g/d								
DM	1528	1479	1291	1181	145	.23	.18	.66
Total N	48.1	52.7	50	42.1	4.5	.97	.14	.78
Large intestine digestion, %								
DM, % of entry	14.6	21.4	21.2	27.5	4.3	.09	.40	.67
DM, % of intake	3.8	6.6	6	7.3	1.5	.13	.86	.74
Total tract digestion, %								
DM, apparent	77.6	77.2	80.1	82.5	1.8	.28	.07	.76
DM, corrected[f]	80.8	80.4	82.7	84.8	1.6	.33	.07	.80
Total N, apparent	63.5	61.1	62	69.3	2.7	.85	.06	.43
Feed N	76.7	7338	72	78.8	1.7	.38	.08	.10

[a] DR = dry-rolled; SF34, SF28, SF22 = steam-flaked at densities of of 437, 360 and 283 g/L, respectively.

[b] linear.

[c] quadratic.

[d] total N/ NI.

[e] Microbial N, g/kg DM truly fermented in the rumen.

[f] corrected for bacterial DM flow.

Table 7. Dry matter and nitrogen flow and digestion by steers fed 77% corn flaked at two densities

	Treatments[a]			
Item	SF34	SF22	SEM	P
Intakes, g/d				
DM	7,984	8,255	78.7	.06
N	149.7	148.1	2.4	.63
Flow to duodenum, g/d				
DM	5,249	4,940	219.5	.41
Total N	240.6	221.8	9.4	.27
Microbial N	104.5	97.0	7.1	.52
Total N/NI[b]	1.5	1.5	.1	.94
Microbial efficiency[c]	25.3	26.1	3.6	.90
Rumen digestion, %				
DM, apparent	34.2	39.8	3.9	.34
DM, corrected[e]	50.3	54.4	3.6	.44
N, apparent	-51.1	-52	10.0	.95
Feed N	16	15.6	8.3	.90
Flow from ileum, g/d				
DM	2,446	2,390	200.0	.86
Total N	60.9	56.6	4.0	.46
Small intestine digestion, %				
DM, % entry	50.1	52.2	1.6	.35
DM, % intake	33.1	31.4	2.6	.65
Total N	73	74.9	1.1	.25

Table 7. Dry matter and nitrogen flow and digestion by steers fed 77% corn grain flaked at two densities *continued*

	Treatment			
Item	SF34	SF22	SEM	P
Fecal output, g/d				
DM	2004	1933	108.8	.64
Total N	61.2	56.8	3.1	.35
Large intestine digestion, %				
DM, % entry	26	20.3	1.1	.02
DM, % intake	7.7	5.4	.6	.04
Post-ruminal digestion, %				
DM, % entry	61.2	61.3	1.5	.98
DM, % intake	41	36.8	3.1	.36
N, % entry	72.8	74.7	1.7	.42
Total tract digestion, %				
DM, apparent	75.3	76.5	1.3	.48
DM, corrected[e]	84.9	84.9	.9	.98
Total N, apparent	59.7	61.6	1.7	.45
Feed N	72.4	73.4	1.8	.68

[a] SF34 and SF22 = steam-flaked at densities of 437 and 283 g/L, respectively.

[b] total N/N intake.

[c] Microbial N, g/kg DM truly fermented in the rumen.

[e] corrected for bacterial DM flow.

CHAPTER 4

SPLANCHNIC NITROGEN METABOLISM BY GROWING BEEF STEERS FED DIETS CONTANING SORGHUM GRAIN FLAKED AT DIFFERENT DENSITIES

SYNOPSIS

Eight crossbred steers (340 kg initial weight) implanted with indwelling catheters into portal, hepatic and mesentric veins and mesenteric artery were used in a completly randomized block design to determine the effect of processing method, dry-rolled (DR) versus steam-flaked and degree of processing (flake density) of sorghum grain on gut and liver (splanchnic) N metabolism. Blood flows, net absorption or release and net uptake or utilization (blood flow x venoarterial concentration difference) of ammmonia-N (NH_3N), urea-N (UN) and α-amino N (AAN) were measured across portal-drained viscera (PDV), hepatic and total splanchnic tissues of growing beef steers. Also plasma arterial, portal and hepatic concentrations of individual amino acids were determined. Diets contained 77 % DR or SF sorghum at densities of 437, 360 and 283 g/L (SF34, SF28 and SF22). Six arterial, portal and hepatic blood samples were collected per day at 2 h intervals for each diet and steer. Daily DM and N intakes were similar across treatments (6.7 kg and 142 g, respectively). Compared to DR, SF sorghum grain tended ($P = .12$) to lower portal (782 vs 879 L/h) but not hepatic (978 ± 45 L/h) blood flows. There was a quadratic response ($P = .03$) of hepatic blood flows to flaking densities. Decreasing flake densities of SF sorghum linearly increased net absorption of AAN (51, 73 and 78 g/d; $P = .04$) and UN recycling to the gut (48, 49 and 64 g/d; $P = .02$) for SF34, SF28 and SF22, respectively.

Net UN recycling to the gut averaged 38% of N intake across all treatments. Steers fed SF compared to DR decreased (P = .03) net splanchnic UN output (33 vs 50 g/d). Flaking to the lowest density (SF22), compared to DR appear to improve net AAN output (36%) and reduce net UN release (33%) from splanchnic tissues. Steers fed SF compared to DR tended to increase (P = .12) hepatic plasma concentrations of essential amino acids . Lowering flake densities linearly increased (P = .06) plasma glutamine hepatic-arterial and glutamate hepatic-portal concentration differences (P < .04). Steers receiving SF20 or SF22 vs DR sorghum (two trial summary) increased (16%) net absorption of AAN (% of N intake), improved (27%) net recycling of UN to the gut and reduced (37%) net UN release from splanchnic tissues. This improvement in amino acid absorption and N conservation (via more recycling and less excretion of urea) may explain in part the observed greater performance of cattle fed SF compared to DR sorghum grain. Based on improved total tract N digestibility and greater absorption of amino acids and urea recycling to the gut, optimum flake density for SF sorghum grain was 283 g/L (SF22), which compares favorably with published values (300 to 360 g/L) for growing-finishing beef cattle studies.

INTRODUCTION

Ruminants evolved with a complex splanchnic nitrogen (N) metabolism, due in part to intricate symbiotic relationships between rumen microflora and the host animal. Cattle absorb substantial amounts of dietary N as ammonia which is almost entirely removed by the liver via urea synthesis. In ruminants endogenously synthesized urea is either excreted via body secretions or recycled to the gut lumen. Steam-flaking compared to dry-rolling, increases proportion of starch fermented in the rumen (Theurer, 1986; Huntington, 1997), increases urea cycling to the gut (Theurer et al.,1997), and microbial protein flow to the duodenum (Theurer et al., 1996a,b). Increased protein flow to the intestine in response to abomasal protein infusion (Guerino et al., 1991; Taniguchi et al., 1995) or to higher protein and(or) energy intakes (Reynolds et al., 1992; Theurer et al., 1997) increases net absorption of α-amino N (AAN) across portal drained-viscera (PDV), and subsequent hepatic utilization. Feedlot performance trials (Zinn, 1990; Xiong et al., 1991) have demontrated increased efficiency of gain by steers fed corn or sorghum grain flaked to lower densities. Measuring net nutrient absorption across splanchnic tissues may help explain differences among diets formulated with grain flaked at various densities and provide greater insight into mechanisms altering N metabolism. No research has been conducted to evaluate the effect of sorghum grain flake density on N metabolism across ruminant splanchnic tissues. The objective of the present study was to investigate effect of feeding growing beef steers diets containing 77% sorghum grain either dry-rolled (DR) or steam-flaked (SF) at three densities (283, 360 and 437 g/L), on net absorption or release, and uptake of ammonia-N (NH_3N), urea-N (UN), and AAN across the PDV, hepatic and splanchnic tissues.

MATERIAL AND METHODS

Animals, Diets and Feeding. This experiment was conducted with approval and under the supervision of the University of Arizona Institutional Animal Care and Use Committee. The University of Arizona is accredited by the American Association of Laboratory Animal Care for Farm Animals. Eight crossbred, halter-broken steers (300 kg initial weight) were surgically prepared with chronic indwelling catheters implanted into portal, hepatic, and two mesenteric veins, and a mesenteric artery. Surgery, catheter preparation and implantation were according to Huntington et al. (1989) with the following modifications: steers were withdrawn from feed for 24 h and from water for 12 h prior to surgery and the hepatic vein was catherized using a linear ultrasound scanner equipped with a 5.0 MHZ probe (Aloka-500V, Corometrics Medical Systems Inc., CT, USA), first to locate the vein and then to confirm normal placement of the catheter.

Before and after surgery, steers were housed in individual (2.5 x 5 m) partially shaded pens with concrete floors. Steers had free access to water and were allowed free movement at all times except during sampling. After surgery, steers were brought back to full feed gradually, starting with alfalfa hay to stimulate gastric and intestinal motility and function, and then switched progressively to experimental diets. All steers resumed full feed by approximately one week after surgery.

Diets (Table 4) contained 77% sorghum grain DR or SF at three different densities, 283, 360 and 437 g/L (referred to respectively as SF22, SF28 and SF34, reflecting bushel weight in lb, typical of field studies). Grains were steamed for 40-60 min in a vertical steam chamber and flaked to desired density through preheated 61 cm x 76 cm corrugated steel rollers. Steers were given ad libitum access to feed and the feed was offered twice daily at 0700 h and 1900 h to simulate normal feeding practice in most feedlot operations. Diets were isonitrogenous and formulated to contain 12% crude protein (CP; Table 4). The experimental model was a completely randomized block design with four dietary treaments and four periods. During the trial, steers were switched from one diet to the next over a period of five days, and maintained on the experimental diet for at least 7 d before blood sampling.

Catheter patency was checked 7 to 10 d post surgery, and at least every 7 d throughout the experiment. Portal and hepatic blood flows were checked 10 to 14 d post-surgery. As outlined by Huntington et al. (1989), a 10% (wt/vol) para-aminohippuric acid (PAH) solution (pH = 7.4) was infused into one mesenteric vein catheter. Infusion started with a priming dose, 15 times normal rate for 2 min, followed by the normal infusion rate of 100 to 120 mg/min for each mesenteric vein catheter (proximal and distal) and then for both. At the end of each sequence 5 to 10 ml of blood were withdrawn simultaneously from portal and hepatic veins, and the mesenteric artery for analysies of PAH concentrations and blood flow determination. Choice of infusion site for experimental blood sampling was based on blood flow check results.

Blood Sampling and Analyses. Blood sampling for the experiment started when animals were fully recovered, usually about three weeks post-surgery. Each sampling day, six simultaneous blood samples were drawn from portal and hepatic veins, and from the mesenteric artery. Sampling started 1 h before morning feeding at 0700 h and continued every 2 h until 1700 h. Blood samples (10 ml) were slowly (~ 2 min) drawn into heparinized tubes. Priming dose of PAH (15 x normal rate for 2 min) was given initially via one of the mesenteric veins, followed by continuous infusion of PAH at a rate of 6,000 mg/h . Infusion rate was changed to 7,200 mg/h as steers become heavier. Forty minutes after infusion arterial, portal and hepatic blood samples were simultaneously collected, immediately placed on ice, and transported to the laboratory for analyses. Samples remained on ice until analyses were completed usually less than 2 h after sampling. Aliquots of blood and plasma samples were frozen at - 80 ^{0}C and kept for later use.

Whole blood was analyzed for concentrations of PAH, NH_3N, UN, and AAN. Concentrations of NH_3N, UN, PAH and AAN were determined by automated procedures (Bran + Luebbe Analyzing Techn., Elmford, NY) as described by Huntington and Reynolds (1986): NH_3N was determined by the hypochlorite method, UN by the acetyl-monoxime method, blood PAH as described by Eiseman et al. (1987) and AAN by the trinitrobenze sulfonate (TNBS) method, modification of Palmer and Peters (1969) as outlined by Harmon (personal communication). Daily composite of plasma samples for each steer and treatment were analyzed for individual amino acid concentrations by the HPLC procedure (K.E. Webb Jr. Personal communication). However, due to insufficient plasma samples, plasma AAN and PAH concentrations were not analyzed. Grab samples of feed collected, 2 d before and on sampling day, were composited and analyzed for DM and N (AOAC, 1984) and for total starch and for 30 min starch hydrolysis (Poore et al., 1990).

Hepatic and portal blood flows were determined by down stream dilution of PAH as described by Katz and Bergman (1969). Net nutrient fluxes were calculated as the mathematical product of the venous-arterial concentration differences times blood flow. Negative values indicate net nutrient uptake or utilization, and positive values denote net absorption or release of nutrient.

Statistical analyses. Data were analyzed with daily means of each steer and treatment by General Linear Model procedure of Minitab (Minitab release 11, 1996) using steers as the blocking criteria in a completely randomized block design with the following model: $Y_{ijk} = \mu + \tau_i + \beta_j + \varepsilon_{ijk}$ where μ = grand mean, τ_i = treatment effect, β_j = block effect and ε_{ijk} = error.

Treatment effects were initially tested using steer, period and diet sum of square as main effects against residual sum of squares. Because period was not significant, steer and diet effects were finally tested against residual sum of squares with period sum of squares included in experimental error. Treatment significance level was set at $P \leq .10$, and tendency for an effect at $P \leq .20$. Due to incomplete data (lack of or improper functioning of catheters) on certain animals, all values reported in tables are least square generated means.

RESULTS AND DISCUSSION

Nutrient Intakes and Blood Flow

Daily DM (6.9 kg/d), starch (4.5 kg/d) and N (142 g/d) intakes were similar among treatments (Table 9). Diets were isonitrogenous (12.8% CP, Table 8) and met the daily N requirements of growing beef steers gaining 1.0 kg/d (NRC, 1996). Steam-flaking (SF34, SF28 SF22) compared to dry-rolling (DR) tended to decrease (P = .12) portal blood flow flow of growing steers (782 vs 879 L/h) but did not alter hepatic blood flow (978 L/h ; Table 8). However, there were a tendency for higher (P < .12; Table 12) portal flows on DR vs SF (879 vs 782 L/h). Hepatic blood flows exhibited a quadratic response (P = .03) to flake density with the intermediate flake (SF28) having the lowest flow. The reason for this quadratic response is not known. Huntington (1990) summarized data from beef, dairy cattle and sheep and showed a positive linear and curvilinear relationship between portal blood flow and ME intakes. From the results of a companion study which showed greater starch digestibility for SF vs DR (P = .01) and a linear increase (P = .02) in starch digestibility with decreasing flake density (Lozano, 1997), andfrom other performance studies with beef steers fed processed sorghum grain (Xiong et al., 1991; Swingle, 1992), it was anticipated that SF diets would yield more absorbable energy and a consequent increase portal blood flows. However, estimated net absorption of energy by the steers in this present sudy was not greater for SF compared to DR. Surprisingly, there a tendency for the latter to have the highest values (Lozano, 1997). Other researchers investigating the effect of feeding high vs low ruminally fermentable diets (Gross et al., 1988; Theurer et al., 1990, 1997) also found no difference in blood flow due to dietary treatment, even though Theurer et al. (1990, 1997) measured greater DE intakes for steers fed SF vs DR. The portal-hepatic flow ratio of the present study, .83, compares favorably with published data for beef cattle (.85; Table 2).

Concentrations of Blood α-Amino N and Plasma Amino Acid

Steam-flaking (SF34, SF28 and SF22) compared to dry-rolling of sorghum grain did not alter concentrations or venoarterial concentration differences of AAN in whole blood (Table 6) of growing beef steers. Portal-arterial and hepatic-arterial concentration differences averaged .26 and .081 mM, respectively which agree with previously pusblished studies of .20 and .05 for beef animals fed concentrate diets. Lowering flake density (more extensive processing) linearly increased (P =.01) portal-arterial concentration differences for blood AAN from .18 to .31 mM, but did not alter other concentrations.

Total concentrations of free amino acids (essentially plasma AAN) represented 72% of that of whole blood (verifier concentration avec Heitman et Hanigan). Processing (DR vs SF) of sorghum grain did not alter plasma arterial, portal, and hepatic concentrations or venoarterial concentration differences of total, essential and non-essential free amino acids; except a tendency for higher (P = .12) hepatic concentrations of essential amino acids for steers fed SF compared to DR diets (Table 11) was observed. Plasma concentrations and venoarterial concentration differences for alanine, glutamine and glutamate were also not affected by processing, except SF vs DR decreased the hepatic-arterial concentration difference for glutamate (-.018 vs -.035 mM; P = .06) and hepatic-portal concentration difference for glutamate (-.041 vs -.055 mM; P = .04). Varying flaking densities did not alter plasma concentrations and venous-arterial concentration differences for total essential and non-essential AA, except for a quadratic tendency (P = .11) for essential hepatic amino acid concentrations . However, as flake density decreased, there was a linear increase (P = .10) in arterial concentrations of alanine and a quadratic response for hepatic-arterial concentration differences (P =.10) for alanine and for arterial, portal and hepatic glutamine concentrations (P ≤ .11), and for portal-arterial concentration differences for glutamine and glutamate (P ≤ .08). The high portal-arterial concentration differences (overall mean = .17 mM) indicate considerable absorption of free amino acids across PDV tissues. Koeln et al. (1993) and Huntington and Prior, (1983, 1985) reported substantial absorption of all amino acids across PDV of cattle, with the exception of glutamine and glutamate, which exhibited negative fluxes possibly due to extensive utilization by gut tissues. Negative portal-arterial concentration differences for glutamine and glutamate in the present study indicate utilization by the gut tissues and agree with results of the previously cited experiments. Other researchers (Sniffen and Jacobson, 1975; Tagari and Bergman, 1978; Huntington and Prior, 1985) reported differences in free amino acid absorption as a result of different levels of energy or protein intake.

Alpha Amino Nitrogen

Extensive processing of sorghum grain (SF34, SF28 and SF22), compared to minimal processing (DR) did not alter net PDV absorption (67.4 and 73.2 g/d), liver uptake (44.6 vs 52.2 g/d), and total splanchnic tissue release of AAN by steers (27.7 vs 23.5 g/d Table 13). This may have been due in part to the 12% lower portal blood flow for steers fed SF vs DR diets, since blood concentrations of AAN did not differ (Table 12). Theurer et al. (1990, 1997) found no difference in net absorption of AAN by growing steers fed diets with similar levels of DR or SF sorghum grain (256 g/L; SF20; 20 lb/bu), but hepatic uptake of AAN was greater ($P < .04$) for SF20 vs DR, contrary to the present study. Decreasing flake density of steam-processed grain linearly increased ($P =.04$) net AAN absorption across the PDV from 51 to 78 g/d, either 53% (Table 8). Because portal blood flows did not differ among steers fed SF, this linear increase in AAN absorption was largely attributed to the linear increase in portal-arterial concentration differences with lower flake density ($P = .01$; Table 10). Guerino et al. (1991) and Taniguchi et al. (1995) reported higher AAN absorption with infusion of casein protein into the abomasum of steers fed alfalfa. There is limited data on the effect of grain proceesing on net nutrient absorption. Theurer et al. (1990, 1997) found no difference in net AAN absorption by growing beef steers fed DR or SF sorghum grain. Gross et al. (1988) investigated the effect of feeding a rapidly fermented grain (DR wheat), a slowly fermented grain (DR sorghum) and a 50:50 mixture of two grains on net nutrient absorption. The difference in AAN absorption among diets was not significant, but there was a numerical linear increase of AAN absorption as amount of rapidly fermentable grain increased in the diet (87, 102, 111 mmol/h for DR sorghum, 50:50 mixture and DR wheat, respectively).

Diets containing more ruminally fermentable starch may provide higher AAN for absorption across PDV. Our hypothesis is that decreasing flake density of sorghum grain fed to growing steers increases ruminal starch digestibility and microbial protein flow to the duodenum resulting in greater AAN absorption and UN recycling. In a companion study with steers fed indentical diets, ruminal starch digestibility was greater for all flakes compared to DR sorghum. As flake density decreased, ruminal and total starch digestibilities and total and corrected N digestibility increased linearly (Lozano, 1997; Chapter 3). Even though not significant statistically, digestion trial results of the companion study showed a 9.7% numerical increase in microbial protein flow to the duodenum, which agrees with recent reviews by Theurer et al. (1996a,b), showing that microbial protein flow to the duodenum was increased 10% for both beef and dairy cattle fed SF corn or sorghum grain compared to DR sorghum or steam-rolled corn. Also, in a companion study to the post-absorptive study by Gross et al.(1988), Axe et al. (1987) reported greater ruminal starch digestion and increased efficiency of gain by steers as amount of rapidly fermentable grain was increased in similar diets

Mean AAN absorption expressed as percent of N intake was similar between DR and all SF treatments (48%), but linearly increased (P = .05) as flake density decreased (38, 50, and 56% for SF34, SF28 and SF22, respectively; Table 13). The mean values (48%) of the present study is similar to results (49%) of Reynolds and Huntington (1988), but greater than that for cited beef studies, across all dietary regimen (31%; Table 3) and also higher than for most steers fed high concentrate diets (21 to 36%; Huntington, 1989; Theurer et al., 1991; Huntington et al., 1996; Whitt et al., 1996). An exceptions is the data of Reynolds et al. (1991), which averaged 63%. Hepatic uptake (64%) and splanchnic release of AAN (32%), expressed as percent of PDV absorption, were each similar among diets (Table 8). Corresponding values for cited references are 65% and 35% respectively (Table 2). Only about 18% of N intake by steers was released by splanchnic tissues as AAN for use by the rest of the body (Table 13). This is greater than values for DR (10%) and SF20 sorghum grain treat reported by Theurer et al. (1990, 1997), but similar to previously reported studies for beef animals mean = 15%, range = 4 to 38% (Table 3).

Ammonia Nitrogen.

Processing sorghum grain, (SF vs DR) and varying flake density did not alter PDV absorption (74 g/d), liver uptake (-76 g/d), or splanchnic release of NH_3N (-4.5 g/d; Table 13), reflecting lack of or minimal blood concentration changes among treatments (Table 6). Paired t-test of mean splanchnic NH_3N release for all treatments did not differ from zero. Complete liver removal suggests that absorption was well under the upper limit capacity of hepatic detoxification of NH_3N. Previous studies comparing grain effect (Gross et al., 1988) and processing effect (Theurer et al., 1990, 1997) also found no differences in NH_3N metabolism across PDV, hepatic or splanchnic tissues.

Ruminant animals absorb substantial amounts of dietary N as NH_3N, as is clearly documented in this study (52%), and in previous studies for beef (48%) and dairy cattle (36%), without consideration of dietary regimens (Table 3). Moreover, net absorption of NH_3N usually exceeds net AAN. The ratio of absorbed NH_3N/absorbed AAN averaged 1.09 for the present experiment, and 1.52 for beef animals in previous studies (ranging from .49 to 3.59; Table 3). The ratio NH_3N/AAN may be used as indicator of rumen fermentation, ammonia fixation and microbial growth. A net reduction in NH_3N absorption has been shown as concentrate level in the diet increases (Huntington and Reynolds, 1986; Huntington, 1983), and AAN absorption increases with higher protein flow to the intestines (Guerino et al., 1991; Taniguchi et al., 1995). Thus the lower NH_3N/AAN ratios from the present study may suggest extensive fermentation in the rumen-reticulum, active microbial growth with concommittant increase in ammonia fixation and greater outflow of microbial cells to the small intestine. This possible scenario is consistant with the results of the companion study with steers fed indentical diets (Lozano, 1997; chapter 3), which showed higher ruminal starch digestibility (P = .01) and microbial protein flow to the duodenum (87 vs 80 g/d) for steers fed SF vs DR diets (Table 15, Chapter 3).

Urea Nitrogen

Proceesing, DR vs SF, did not alter arterial, portal, and hepatic concentrations or portal-arterial concentration differences (Table 10) and net UN transfer to the PDV (53 g/d) and hepatic UN synthesis (89 g/d; Table 8) tissues (Tables 10 and 12). Theurer et al.

(1990, 1997) demonstrated a 40% increase (P = .07) in urea cycling to the gut for animals fed SF20 vs DR sorghum diets (58 vs 41 g/d). Lowering flaking density linearly increased portal-arterial concentration differences for urea-N from -.17 to -.25 (P = .01; Table 6) and net UN cycling the PDV (P = .02; Table 13). The UN cycling to the gut was 48.7, 47.7, and 63.5 g/d for SF34, SF28 and SF22, respectively. The reason for quadratic responses (P = .04; Table 6) of arterial and portal UN concentrations, due to low values for treatment SF28 is not known. Urea cycling is important in N conservation for the ruminant when N supply is low and for high producing and rapidly growing animals. Studies investigating effect of dietary regimen on urea cycling have reported higher UN cycling to the gut occurs for for animals fed concentrate vs roughage diets (Huntington and Reynolds, 1986; Huntington, 1989; Whitt et al., 1996). Their results agree with previously reported results by Kennedy (1980) who demonstrated an increase in urea cycling to the gut with increased ruminally fermentable organic matter intake. Nonetheless, Gross et al. (1988) showed no effect on urea recycling for diets varying in ruminally fermentable starch (wheat, sorghum or a mixture of the grains). Reynolds et al. (1991) investigated the combined effect of diet type (concentrate vs roughage) and energy intake levels (low vs high), and concluded that urea cycling to the gut was strictly related to ME intake, not diet composition or N intake. While results of the present experiment did not show that steam-flaking (SF34, SF28 and SF22) compared to dry-rolling affected urea cycling there appears to be a net difference in amount of urea cycled (53 vs 63.5 g/d Table 8) between DR and the lowest flake density, SF22..

Urea-N cycling to the gut, expressed as percent of N intake, was not affected by processing method (DR vs SF; 36 vs 39%), but showed both linear and quadratic responses to flake density (P = .09; Table 15). Corresponding values for previously reported studies averaged 27% for beef, and 25% for dairy cattle ranging from 10 to 68% (Table 3). Values from the present study fall within this range, and agree with most reported results relative to high concentrate diets. There was a tendency for higher (P = .11) UN cycling for SF vs DR when expressed as percent of hepatic synthesis (64 vs 50%; Table 15); these values are similar to previous studies (62%), but greater than the average of 35% (Table 2).

Steam-flaking compared to dry-rolling of sorghum grain, decreased (P = .03; Table 13) total splanchnic UN output by 40% (30 vs 51 g/d), due largely to a lower (P = .01) hepatic-arterial concentration difference for SF than for DR (.10 vs .17). A similar trend was reported by Theurer et al. (1990, 1997) for steers fed SF20 vs DR. For SF vs DR, splanchnic UN release, as percent of N intake, decreased (22 vs 36%; P = .04), and there was a tendency for decreased (P = .13) splanchnic release of UN expressed as percent of liver synthesis (36 vs 50%; Table 15). Corresponding values for previous studies average 27% (range = 10 to 70%) and 35% (Table 3). Decreased splanchnic UN output suggests a higher N retention when animals are fed SF vs DR sorghum diets. This rationale is consistent with the trend for greater N retention (percent of N intake) with SF20 compared to DR treatment reported by Theurer et al. (1990, 1997). It is also consistent with the 9.7% (87 vs 80 g/d) increase in microbial protein flow to the duodenum for steers fed SF vs DR diets which are reported in the companion digestion study (Chapter 3). These findings may explain in part the improved performance of feedlot cattle fed SF compared to DR sorghum grain.

Summary of two Studies with Steers fed Similar Diets

In two experiments, Theurer et al. (1990,1997) and present experiment, effect of grain processing (steam-flaking, SF vs dry-rolling,DR) on on blood flow and net nutrient absorption was investigated. Flaking sorghum grain flaked at densities of 256 and 283 gL (SF20 and SF22, respectively) compared to DR did alter blood flow. Portal and hepatic flows (917 vs 859 and 1010 vs 1038 L/h, respectively) were similar between treatments. There no difference in AAN absorption across PDV eventhough SF diets had greater (P = .06; Table 16) portal-arterial concentration differences. However, processing increased net absorption of AAN, percent of N intake (P = .04; Table 11) and liver uptake (P =.01; -34.6 vs -25.8 g/d; Table 14). Flaking did not alter net release of AAN to the rest of the body. Flaking increased by 27% (P =.06) UN cycling to the gut (-61.2 vs -48.2 g/d) and UN cycling , %of hepatic synthesis (P = .03) and decreased (P =.07) net total splanchnic UN release by 58%. The increase in UN cycling to the gut and the decrease were largely due respectively to the higher (P =.01) portal-arterial and the lower (P =.06) hepatic-arterial concentration differences. Results agree with the conclusion drawn by Reynolds et al. (1991) that amount of ME intake determines UN cycling to the gut.

In summary flaking sorghum grain to lower densities (SF20 or SF22) compared to

DR did not alter blood flow but increased net absorption of AAN, % of N intake and hepatic AAN, % of PDV absorption. Flaking increased UN cycling toi the gut and decreased total splanchnic UN release. The combine effects of these metabolic processes result in higher N retention and may explain the better performance of animals fed processed compared to minimally or unprocessed grains as reported by some researchers (Zinn, 1990; Xiong et al., 1991).

Implications

Steam-flaking sorghum compared to DR may increase N retention of growing beef steers by reducing splanchnic release of UN. Flaking to lower densities increased net absorption of AAN and net UN recycling to the gut. Optimum flake density appears to be 360 to 283 g/L. Overall results of the present study in conjunction with the companion study suggest that steam-flaking improves nutrient availability for absorption and nutrient partioning by gut and liver, which explains in part the observed superior performance of cattle fed SF diets.

Table 8. Diet composition and chemical analyses (DM basis; Exp.3)

	DIETS[a]			
Item	DR	SF34	SF28	SF22
Ingredient				
Sorghum grain	77.0	77.0	77.0	77.0
Alfalfa hay	15.0	15.0	15.0	15.0
Cottonseed meal	2.3	2.3	2.3	2.3
Molasses	4.0	4.0	4.0	4.0
Limestone	.9	.9	.9	.9
Salt	.4	.4	.4	.4
Vitamin A[b]	+	+	+	+
Urea	.3	.3	.3	.3
Analysis, %				
Dry matter, %	88.9	85.7	85.3	85.2
Crude protein, %	12.8	12.8	12.9	12.8
Starch, %	63.1	65.1	64.3	63.9

[a] DR = dry-rolled; SF34, SF28, SF22 = steam-flaked at densities of 437, 360 and 283g/L, respectively.

[b] added at 3,300 IU/kg.

Table 9. Dry matter, Crude Protein, Starch, and Nitrogen Intakes[a]

Item	Diet[b]					Probability		
	DR	SF34	SF28	SF22	SEM	DR vs SF	L[c]	Q[d]
DM, kg/d	7.10	6.72	6.92	6.97	.28	.48	.65	.87
Starch, kg/d	4.48	4.37	4.45	4.45	.18	.79	.82	.90
Nitrogen, g/d	145.0	137.2	142.4	142.6	5.76	.52	.63	.79

[a] eight animals/treatment

[b] DR = dry-rolled; SF34, SF28, SF22 = steam-flaked at densities of 437, 360, and 283 g/L respectively.

[C] linear

[d] quadratic

Table 10. Least square means of arterial, portal, and hepatic concentrations and venoarterial concentration differences for nitrogenous compounds.

	Treatment[a]					Probability		
Item	DR	SF34	SF28	SF22	SEM[b]	DR vs SF	L	Q
α-amino nitrogen concentrations, mM								
Artery (A)[c]	2.73	2.79	2.82	2.72	.07	.52	.46	.40
Portal (P)[d]	3.01	2.92	3.10	3.00	.09	.98	.49	.18
Hepatic (H)[e]	2.81	2.95	2.85	2.80	.10	.54	.30	.92
P-A[d]	.25	.18	.28	.31	.03	.74	.1	.27
H-A[e]	.080	.072	.075	.096	.021	.96	.27	.55
H-P[f]	-.186	-.148	-.181	-.212	.049	.89	.36	.66
Ammonia nitrogen concentrations, mM								
Artery[c]	.36	.35	.37	.34	.011	.54	.64	.10
Portal[d]	.64	.60	.62	.65	.024	.61	.15	.99
Hepatic[e]	.35	.36	.36	.32	.013	.84	.09	.19
P-A[d]	.27	.25	.26	.31	.030	.99	.16	.49
H-A[e]	-.015	-.014	-.008	-.013	.007	.59	.84	.55
H-P[f]	-.29	-.23	-.27	-.31	.040	.68	.32	.80
Urea Nitrogen concentrations, mM								
Artery (A)[c]	4.98	4.85	3.16	4.91	.59	.34	.94	.04
Portal (P)[d]	5.24	4.56	3.01	5.20	.69	.22	.57	.04
Hepatic	4.68	4.91	3.71	4.16	.70	.54	.35	.43
P-A[d]	-.181	-.147	-.187	-.246	.019	.33	.002	.28
H-A[e]	.167	.083	.091	.098	.027	.01	.81	.90
H-P[f]	.330	.236	.282	.366	.049	.49	.12	.98

[a] DR = dry-rolled; SF34, SF28, SF22 =steam-flaked at densities of 437, 360, and 283 g/L.
[b] Used larger SEM with unequal number of observations; [c] n = 8 animals for all treatments.
[d] n = 6, 7, 7, and 6 animals; [e] n = 7, 5, 6, and 6 animals; and [f] n = 5, 4, 5, and 4 animals for

DR, SF34, SF28, and SF22 respectively.

Table 11. Pooled arterial, portal and hepatic plasma amino acid concentrations

	Treatment[a]					Probability		
Item	DR	SF34	SF28	SF22	SEM[b]	Contr	L[f]	Q[g]
Total amino acid concentrations, mM								
Artery (A)[c]	1.906	1.963	2.001	2.054	.074	.26	.31	.92
Portal (P)[d]	2.090	2.120	2.207	2.178	.111	.54	.78	.66
Hepatic (H)[e]	1.931	2.145	2.097	2.143	.103	.90	.94	.65
P-A[d]	.166	.158	.206	.145	.049	.94	.84	.31
H-A[e]	.034	.084	.100	.070	.072	.51	.90	.68
H-P[e]	-.106	-.123	-.119	-.093	.089	.95	.70	.97
Essential								
Artery[c]	.888	.878	.808	.896	.043	.22	.74	.10
Portal[d]	.881	.949	.907	.976	.056	.33	.71	.37
Hepatic[e]	.833	.985	.857	.955	.057	.12	.55	.11
P-A[d]	.066	.071	.099	.069	.025	.64	.98	.32
H-A[e]	.027	.057	.046	.049	.033	.50	.85	.96
H-P[e]	-.031	.036	-.055	-.015	.043	.91	.69	.62
Non essential amino acid concentration, mM								
Artery[c]	1.018	1.084	1.193	1.158	.052	.54	.32	.27
Portal[d]	1.209	1.172	1.300	1.202	.072	.85	.76	.19
Hepatic[e]	1.099	1.161	1.241	1.188	.075	.24	.73	.49
P-A[d]	.099	.087	.107	.076	.026	.75	.70	.31
H-A[e]	.007	.028	.054	.021	.040	.52	.95	.44
H-P[e]	-.075	-.086	-.064	-.078	.048	.98	.72	.68

Table 11. Pooled arterial, portal and hepatic plasma amino acid concentrations (mM) *continued*

	Treatment[a]					Probability		
Item	DR	SF34	SF28	SF22	SEM[b]	DR vs SF	L[f]	Q[g]
Alanine concentrations, mM								
Arterial[c]	.180	.177	.188	.200	.010	.46	.10	.99
Portal[d]	.212	.205	.224	.220	.016	.83	.43	.48
Hepatic[e]	.179	.183	.204	.218	.013	.17	.14	.90
P-A[d]	.034	.028	.036	.027	.007	.68	.92	.33
H-A[e]	.003	.003	.017	.005	.007	.47	.71	.10
H-P[e]	-.031	-.031	-.019	-.026	.010	.52	.60	.27
Glutamine								
Arterial[c]	.218	.190	.238	.171	.016	.34	.44	.02
Portal[d]	.209	.191	.224	.167	.017	.52	.38	.06
Hepatic[e]	.182	.176	.268	.161	.018	.97	.78	.11
P-A[d]	-.004	.001	-.014	-.005	.007	.91	.66	.04
H-A[e]	-.035	-.023	-.021	-.011	.008	.06	.21	.78
H-P[e]	-027	-.026	-.015	-.015	.010	.51	.36	.67

Table 11. Pooled arterial, portal and hepatic plasma amino acid concentrations (mM) *continued*

	Treatment[a]					Probability		
Item	DR	SF34	SF28	SF22	SEM	DR vs SF	L[f]	Q[g]
Glutamate								
Arterial[c]	.112	.106	.109	.135	.012	.74	.14	.48
Portal[c]	.105	.097	.109	.111	.014	.95	.43	.70
Hepatic[e]	.144	.134	.150	.167	.017	.73	.21	.96
P-A[d]	-.010	-.009	.001	-.014	.005	.68	.50	.80
H-A[e]	.040	.036	.040	.028	.007	.49	.43	.35
H-P[e]	.055	.042	.036	.044	.005	.04	.80	.40

[a]DR = dry-rolled; SF34,SF28, SF22 = steam-flaked at densities of 437,360 and 283 g.L

[b]Used larger SEM with unequal number of observations

[c]n = 8 animals for all treatments

[d]n = 6, 7, 7, and 6 animals for DR, SF34, SF28, and SF22, respectively

[e]n = 7, 5, 6, and 6 animals for Dr, SF34, SF28, and SF22, respectively

[f]linear

[g]quadratic

Table 12. Least square means for blood flow and net fluxes of nitrogenous compounds across splanchnic tissues.

Site	Treatment[a]					Probability		
	DR	SF34	SF28	SF22	SEM[b]	DR vs SF	L	Q
Blood flow, L/h								
Portal[c]	879	800	769	778	53	.12	.86	.80
Hepatic[d]	963	1050	886	1015	45	.64	.39	.03
α-amino ntrogen fluxes, g/d								
PDV[ce]	73.2	51.1	73.2	78.0	8.0	.52	.04	.35
Hepatic[ef]	-52.2	-41.5	-40.0	-54.4	11.1	.56	.42	.97
Splanchnic[d]	23.5	28.2	23.1	31.9	5.8	.46	.43	.16
Ammonia ntrogen fluxes,g/d								
PDV[ce]	79.4	68.9	67.0	78.8	8.8	.43	.35	.48
Hepatic[ef]	-82.3	-72.2	-67.2	-82.6	12.8	.54	.75	.63
Splanchnic[d]	-5.7	-4.3	-3.0	-4.9	2.0	.41	.93	.43
Urea nitrogen fluxes, g/d								
PDV[ce]	-53.0	-48.7	-47.7	-63.5	6.7	.97	.02	.20
Hepatic[ef]	100.5	76.6	72.7	105.9	17.4	.40	.31	.49
Splanchnic[d]	50.7	27.8	29.2	33.7	8.7	.03	.78	.75

[a] DR = dry-rolled; SF34, SF28, and SF22 = steam-flked at densities of 437, 360 and 283 g/L.

[b] used larger SEM with unequal number of observations

[c] n = 6, 7, 7, and 6 animals for DR, SF34, SF28, and SF22, respectively.

[d] n = 7, 5, 6, and 6 animals for DR, SF34, SF28, and SF22, respectively.

[e] Positive net fluxes indicate absorption or release, negative fluxes indicate uptake or recycling

[f] n = 5, 4, 5, and 4 animals for DR, SF34, SF28, and SF22, respectively.

Table 13. Absorption and release of α-amino nitrogen, urea nitrogen cycling and release across splanchnic tissues as a ratio of percent N intake or hepatic synthesis.

	Treatment[a]					Probability		
ITEM	DR	SF34	SF28	SF22	SEM[b]	DR vs SF	L[c]	Q[d]
N. intake, g/d	145	137	142	143	5.8			
Nitrogen absorbed								
NH_3N + AAN, g/d	152.7	120	140.1	156.7	14.6	.41	.09	.84
AAN absorb. g/d	73.2	51.1	73.2	78.0	8.0	.52	.04	.40
% NH_3N + AAN	48.2	41.3	52.4	50.0	3.6	.41	.08	.9
% N. intake	48.8	38.1	49.7	56.2	5.2	.89	.05	.64
Hep. AAN, g/d	-52.2	-41.5	-40.0	-54.4	11.1	.56	.42	.97
% AAN absorb	67.4	59.3	61.1	66.5	9.0	.60	.60	.68
Spl. AAN g/d	23.5	28.2	23.1	31.9	5.8	.46	.44	.16
% NH_3N + AAN	17.0	18.8	13.8	15.7	4.3	.96	.72	.61
% AAN absorb	34.0	36.3	29.1	29.9	7.5	.79	.61	.68
% N intake	16.9	19.2	13.9	20.8	4.2	.79	.54	.34
Hep UN, g/d	100.5	76.6	72.7	105.9	17.4	.41	.31	.49
PDV UN, g/d	-53.0	-48.7	-47.7	-63.5	6.7	.97	.02	.20
% N intake	35.9	37.4	33.0	45.3	4.3	.58	.09	.09
% Hep synthesis	50.1	61.0	63.1	67.0	7.5	.11	.64	.94
Spl. UN, g/d	50.7	27.8	29.2	33.7	8.7	.03	.78	.75
% Hep synthesis	50.1	38.4	35.6	32.5	8.1	.13	.63	.95
% NH_3N + AAN	33.43	23.0	24.0	22.5	7.5	.24	.90	.97
% N intake	35.6	22.7	20.9	21.6	6.3	.04	.87	.75

[a] DR=dry-rolled; SF34, SF28, SF22 = steam-flaked at density of 437, 360 and 283 g/L respectively.

[b] used larger SEM with unequal number of observations.

[c] linear.

Table 14. Blood Flow and net fluxes of nitrogenous compounds across splanchnic tissues from two trials with steers fed diets containing 77% dry-rolled or steam-flaked sorghum grain

Site	Treatment[a]			
	DR	SF	SEM[b]	P
Blood flow, L/h				
Portal	917[c]	859[c]	44.5	.38
Hepatic	1010[d]	1038[d]	31.5	.53
α-amino N fluxes, g/.d				
PDV	52.2[c]	56.4[c]	2.9	.35
Hepatic	-27.2[d]	-37.5[d]	1.8	.006
Splanchnic	189	22.0[f]	2.3	.35
Ammonia N fluxes, g/d				
PDV	66.2[c]	67.1[c]	6.0	.92
Hepatic	-69.4[d]	-69.8[d]	6.9	.96
Splanchnic	-4.5	-4.7[f]	.8	.87
Urea N fluxes, g/d				
PDV	-48.2[c]	-61.2[c]	4.3	.06
Hepatic	92.6[d]	82.5[d]	14.8	.66
Splanchnic	451	28.5[f]	6.0	.07

[a] DR = dry-rolled; SF = steam-flaked at 256 or 283 g/L;

[b] used larger SEM with unequal number of observations;

[c] n = 12 animals;

[d] n = 10 animals;

[e] n = 11 animals;

[f] n = 13 animals

Table 15. Summary of arterial, portal and hepatic concentrations and venoarterial concentration differences of nitrogenous compounds from two trials with steers fed diets containing 77% dry-rolled or steam-flaked sorghum grain

	Treatment[a]			
Site	DR	SF	SEM[b]	P
α-amino nitrogen concentrations, mM				
Artery (A)[c]	2.70[c]	2.74[f]	.05	.59
Portal (P)[d]	2.90[d]	2.92[d]	.05	.78
Hepatic (H)[d]	2.77[d]	2.80[6]	.07	.72
P-A[d]	.17[d]	.20[d]	.01	.6
H-A[d]	.06[d]	.06[g]	.009	.96
H-P[e]	-.11[e]	-.13[e]	.011	.16
Ammonia nitrogen concentrations, mM				
Artery (A)[f]	.39[c]	.38[f]	.008	.40
Portal (P)	.61[d]	.62[d]	.015	.69
Hepatic (H)	.38[d]	.37[g]	.01	.27
P-A	.22[d]	.24 [d]	.019	.40
H-A	-.013[d]	-.013[g]	.003	.85
H-P	-.23[e]	-.24[e]	.024	.80
Urea nitrogen concentrations, mM				
Artery	4.34[c]	4.06[f]	.322	.54
Portal	4.06[d]	3.76[d]	.33	.54
Hepatic	4.25[d]	3.69[g]	.31	.21
P-A	-.16[d]	-.21[d]	.010	.003
H-A	.14[d]	.09[g]	.018	.06
H-P	.28[e]	.31[e]	.026	.46

[a] DR = dry-rolled ; SF = steam-flaked 20 and 22lb/bu;

[b] used larger SEM with unequal number of observations

[c] n =14 animals; [d] n = 12 animals; [e] n = 10 animals; [f] n = 15 animals ; [g] n = 13 animals

Table 16. Summary of nitrogen intake, α-amino nitrogen absorption and release, endogenous urea recycling and release across splanchnic tissues of beef steers fed diets containg 77% dry-rolled or steam-flaked sorghum grain in two trials.

Item	DR[a]	SF[a]	SEM	P
Nitrogen intake, g/d	143.2	140.3	2.9	.49
Nitrogen absorbed				
NH_3N + AAN, g/d	115.3	118.7	7.3	.75
AAN absorbed, g/d	48.1	51.9	2.6	.34
% NH_3N + AAN	38.4	40.1	2.3	.61
% Nitrogen intake	31.5	36.6	1.5	.04
Liver AAN uptake, g/d	-25.8	-34.6	1.7	.34
% AAN absorbed	45.8	61.9	3.8	.02
Splanch. AAN release, g/d	16.4	20.0	2.0	.22
% NH_3N +AAN	15.6	15.3	3.1	.94
% AAN absorbed	43.4	40.8	5.3	.74
% Nitrogen intake	11.9	13.9	1.5	.35
Liver urea synthesis, g/d	90.2	94.4	9.8	.78
Urea cycling to gut, g/d	-48.2	-61.2	4.3	.06
% Liver synthesis	52.3	68.9	4.5	.03
% Nitrogen intake	32.6	43.4	2.4	.009
Splanch urea output, g/d	45.1	28.5	6.0	.07
% Liver synthesis	47.6	30.8	4.5	.04
% NH_3N + AAN	41.3	26.9	5.5	.11
% Nitrogen intake	312	19.3	4.1	.04

[a] DR = dry-rolled; SF = steam-flaked at 256 or 283 g/L (SF20 or SF22, respectively)

CHAPTER 5

SUMMARY AND CONCLUSIONS

Two companion studies in three experiments were conducted with crossbred beef steers in completly randomized block designs to investigate effect of sorghum grain processing methods, dry-rolled (DR) versus steam-flaked (SF) and degree of flaking of corn and sorghum grains (flake densities) on dry matter (DM) and nitrogen (N) digestion and microbial protein synthesis and post-absorptive N metabolism.

In expriment 1, seven crossbred steeers equipped with t-types cannulas fitted into proximal duodenum and distal ileum were fed four diets containing 77% sorghum grain DR or SF at densities of 437, 360 and 283 g/L (SF34, SF28, SF22, respectively). In experiment 2, the same steers were fed corn grain flaked at densities of 437 and 283 g/L (SF34 and SF22, respectively).

Flaking sorghum grain compared to dry-rolling, increased ($P = .03$) corrected ruminal and apparent small intestine DM, % of intake digestibilies. Flaking sorghum grain linearly increased ($P < .05$) corrected ruminal DM, total tract feed N and apparent small intestine DM digestibilities. Flaking tended to increase linearly microbial protein efficiency ($P = .07$). These findings are consistent with previous reports on nutrient digestion by beef cattle fed processed grains except in the present experiment steam-flaking did not alter microbial protein synthesis and flow to intestines. There was however, a numerical increase, 9.7%, in microbial protein flow for SF compared to DR diets. Surprisingly, steam-flaking corn grain to lower density (SF22 vs SF34) had no effect on both DM and

N digestion.

In experiment 3, eight crossbred beef steers implanted with indwelling catheters into portal, hepatic and two mesenteric veins and one mesenteric artery were fed four diets identical to the sorghum digestion trial diets. Diets contained 77% sorghum grain DR or SF at three densities (SF34, SF28, SF22). Blood flows and net nutrient absorption or release and net uptake or utilization were measured across the portal-drained viscera (PDV), hepatic and total splanchnic tissues (PDV + liver). Flaking compared to DR tended to decrease ($P = .12$) portal blood but did not alter hepatic blood flow. Huntington (1990) demonstrated a direct and positive relationship between ME intake and portal blood flows. Lomax and Baird (1983) had suggested earlier positive relationships between portal and hepatic blood flows and ME intake in lactating and nonlactating cows. Hypothesis of the present experiment predicted higher ME for SF vs DR diets, based on previous performance and digestion studies. On the contrary, calculated absorbed ME in the present study tended to be greater for the DR compared to SF diets (11.9 vs 9.87 Mcal/d; Lozano, 1997) and agree with conclusions of Huntington (1990). Decrease in portal flow would agree with recent findings (Huntington et al., 1996) which showed decrease in portal and hepatic flows as concentrate levels of the increased.

Flaking compared to DR decreased ($P < .04$) net splanchnic UN release to the rest of the body, g/d and % N intake. Flaking linearly increased ($P = .04$) net absorption of AAN and UN recycling across the PDV. These results are in agreement with previously published data which showed increased Un recycling to the gut with higher ruminally fermentable diets (Kennedy, 1980; Theurer et al., 1990, 1997).

Flaking compared to DR decreased ($P < .06$) hepatic-portal glutamate and hepatic-arterial concentration differences indicating net glutamine removal by the liver.

Overall, results of the present study show quality improvement of nutrient absorbed across PDV due to flaking sorghum grain more AAN absorbed, higher N retention (more recycling and less splanchnic release of UN) and numerically higher microbial protein synthesis in the rumen flowing to intestines. There is however need for more integrated research (digestion, performance and post-absorption) in the same station to fine tune effect of steam-flaking sorghum grain on net nutrient absorption to better explain higher performance generally observed in the field.

APPENDIX A. INDIVIDUAL STEER DATA

SORGHUM DIGESTION TRIAL

Appendix A. Table 1. Dry matter (DM) and nitrogen (N) intakes and flow through the gastrointestinal tract with steers fed diets containing 77% sorghum grain

	STEERS						
Item	410	411	412	418	419	420	427
Period	4	2	2	3	4	1	3
DR DIET							
Intakes							
Dry matter, kg/d	7.613	6.087	5.894	6.468	7.587	6.245	7.616
Nitrogen, g/d	152.9	117.1	112.1	123.2	154.0	118.0	150.1
Flow to duodenum							
Dry matter, kg/d	5.206	5.283	3.030	4.019	4.101	3.636	4.633
Total N, g/d	218.3	196.2	121.2	151.6	180.2	157.3	188.1
Feed N, g/d	100.2	102.3	68.5	94.5	105.6	77.7	105.0
Microbial N, g/d	118.1	93.8	52.7	57.0	74.5	79.6	83.1
IBC, % CP	.5551	.4962	.4483	.5215	.5047	.5034	.4554
Flow from ileum							
Dry matter, kg/d	2.221	1.645	1.445	1.811	1.880	1.369	1.909
Total N, g/d	60.4	47.1	35.7	48.7	46.7	29.5	52.1
Fecal output							
Dry matter, kg/d	2.201	1.102	.890	1.695	1.546	1.272	1.898
Total N, g/d	62.9	40.8	31.3	49.4	49.8	40.3	59.3

Appendix A. Table 1. Dry matter (DM) and nitrogen (N) intakes and flow through the gastrointestinal tract with steers fed diets containing 77% sorghum grain-*Continued*

	STEERS						
Item	410	411	412	418	419	420	427
Period	1	3	3	2	1	4	2
SF34 DIET							
Intakes							
Dry matter, kg/d	6.407	5.873	6.415	5.509	6.467	6.788	7.509
Nitrogen, g/d	130.9	121.2	131.6	117.8	135.0	143.7	162.0
Flow to duodenum							
Dry matter, kg/d	5.206	2.792	4.609	2.836	4.284	4.022	4.631
Total N, g/d	246.5	133.2	190.4	147.1	222.5	198.7	213.1
Feed N, g/d	100.6	61.6	101.3	81.6	80.5	99.0	127.9
Microbial N, g/d	----	71.7	89.1	65.4	----	99.7	85.15
IBC, % CP	.5314	.5047	.4767	.5636	.5272	.5388	.5271
Flow from ileum							
Dry matter, kg/d	----	.973	1.816	1.886	1.654	1.730	1.889
Total N, g/d	----	30.1	54.9	48.7	45.2	50.9	60.2
Fecal output							
Dry matter, kg/d	2.622	.802	1.549	1.065	1.233	1.738	1.207
Total N, g/d	84.1	29.5	54.7	43.5	43.0	62.8	48.0

Appendix A. Table 1. Dry matter (DM) and nitrogen (N) intakes and flow through the gastrointestinal tract with steers fed diets containing 77% sorghum grain-*Continued*

	STEERS						
Item	410	411	412	418	419	420	427
Period	2	4	4	1	2	3	1
SF28 DIET							
Intakes							
Dry matter, kg/d	6.971	6.679	7.326	----	6.970	6.974	6.901
Nitrogen, g/d	140.7	135.3	150.7	----	146.1	140.0	138.2
Flow to duodenum							
Dry matter, kg/d	4.214	4.342	3.959	----	4.093	3.721	----
Total N, g/d	209.6	194.2	199.0	---	191.1	192.0	---
Feed N, g/d	115.4	86.9	98.0	---	99.7	106.2	----
Microbial N, g/d	94.2	107.3	101.1	58.1	91.3	85.8	105.9
IBC, % CP	.5622	.4815	.5155	.4108	.5109	.567	.5476
Flow from ileum							
Dry matter, kg/d	2.123	1.805	1.408	.839	1.962	1.563	2.323
Total N, g/d	60.7	57.1	37.7	28.4	46.5	45.8	62.0
Fecal output							
Dry matter, kg/d	1.546	1.436	1.270	.849	1.134	1.332	1.486
Total N, g/d	59.0	57.8	47.0	35.8	41.1	50.9	60.1

Appendix A. Table 1. Dry matter (DM) and nitrogen (N) intakes and flow through the gastrointestinal tract with steers fed diets containing 77% sorghum grain-*Continued*

	STEERS						
Item	410	411	412	418	419	420	427
Period	3	1	1	4	3	2	4
SF22 DIET							
Intakes							
Dry matter, kg/d	6.740	6.360	6.864	6.977	7.422	6.929	5.758
Nitrogen, g/d	137.1	127.2	139.8	142.4	150.7	146.1	115.3
Flow to duodenum							
Dry matter, kg/d	3.046	3.004	3.551	3.432	4.190	3.946	2.189
Total N, g/d	169.0	163.2	156.7	156.1	220.0	197.0	116.4
Feed N, g/d	74.5	75.4	76.0	89.6	78.9	106.1	74.2
Microbial N, g/d	94.5	87.8	80.7	66.5	----	90.9	-----
IBC, % CP	.5381	.5545	.4636	.5044	.5157	.5506	.5622
Flow from ileum.5545							
Dry matter, kg/d	1.850	1.309	2.203	1.488	2.229	1.571	1.090
Total N, g/d	43.3	36.2	53.4	37.5	60.0	44.9	26.5
Fecal output							
Dry matter, kg/d	1.103	1.060	1.557	1.386	1.174	1.340	.857
Total N, g/d	38.9	42.8	52.5	46.5	42.4	45.5	31.2

Appendix A. Table 2. Ruminal, intestinal and total tract dry matter and nitrogen digestibilities with steers fed diets containing 77% sorghum grain

	STEERS						
Item	410	411	412	418	419	420	427
Period	4	2	2	3	4	1	3
DR DIET							
Ruminal digestion, %							
Dry matter, apparent	31.62	13.21	48.58	37.86	45.95	41.79	39.16
Dry matter, corrected	49.08	32.63	61.04	48.43	58.11	57.60	54.13
Total N, apparent	-42.76	-67.58	-8.12	-22.98	-16.96	-33.28	-25.28
Feed N	34.48	12.58	38.89	23.31	31.42	34.14	30.05
Small intestine digestion, %							
Dry matter, % entry	57.34	68.85	52.31	54.93	54.16	62.34	58.80
Dry matter, % intake	39.21	59.75	26.90	34.13	29.27	36.28	35.77
Total N, % entry	72.33	76.00	70.53	67.89	74.09	81.24	72.28
Total tract digestion, %							
Dry matter, apparent	71.08	81.88	84.91	73.79	79.62	79.63	75.08
Dry matter, corrected	74.04	85.43	87.39	76.73	82.50	82.80	79.00
Total N, apparent	58.84	65.17	72.10	59.94	67.67	65.89	60.50
Feed N	71.96	79.82	81.47	72.82	79.11	79.37	74.97

Appendix A. Table 2. Ruminal, intestinal and total tract dry matter and nitrogen digestibilities with steers fed diets containing 77% sorghum grain-*Continued*

	STEERS						
Item	410	411	412	418	419	420	427
Period	1	3	3	2	1	4	2
SF34 DIET							
Ruminal digestion, %							
Dry matter, apparent	18.75	52.47	28.14	48.53	33.75	40.74	38.33
Dry matter, corrected	45.53	67.58	46.35	61.70	59.79	57.78	51.77
Total N, apparent	-----	-9.91	-44.67	-24.87	-64.78	-38.27	-31.58
Feed N	23.16	49.20	23.02	30.70	40.42	31.13	21.00
Small intestine digestion, %							
Dry matter, % entry	-----	65.13	60.59	-----	61.40	56.99	59.21
Dry matter, intake	28.14	30.96	43.54	17.24	40.68	33.77	36.51
Total N, %entry	65.91	77.40	71.14	66.86	79.69	74.38	71.76
Total tract digestion, %							
Dry matter, apparent	59.08	86.34	75.86	80.67	80.92	74.39	83.92
Dry matter, corrected	64.48	88.73	79.74	82.86	84.01	77.40	86.24
Total N, apparent	35.78	75.67	58.46	63.08	68.14	56.31	70.34
Feed N	58.27	85.02	72.90	72.35	80.62	68.56	79.44

Appendix A. Table 2. Ruminal, intestinal and total tract dry matter and nitrogen digestibilities with steers fed diets containing 77% sorghum grain-*Continued*

	STEERS						
Item	410	411	412	418	419	420	427
Period	2	4	4	1	2	3	1
SF28 DIET							
Ruminal digestion, %							
Dry matter, apparent	39.55	34.99	45.96	51.86	41.28	46.64	-----
Dry matter, corrected	54.57	55.84	62.69	74.75	57.30	60.20	-----
Total N, apparent	-48.99	-43.52	-32.02	-4.19	-30.76	-37.08	-----
Feed N	17.98	35.76	35.02	------	31.73	24.18	-----
Small intestine digestion, %							
Dry matter, % entry	49.62	58.41	64.44	54.85	52.06	58.00	62.67
Dry matter, % intake	29.99	37.97	34.82	26.41	30.57	30.95	----
Total N, % entry	56.82	57.80	74.97	64.83	68.15	67.30	55.13
Total tract digestion, %							
Dry matter, apparent	77.83	78.49	82.65	78.00	83.72	80.89	78.47
Dry matter, corrected	80.04	82.33	84.60	82.02	85.70	82.56	80.84
Total N, apparent	58.08	57.30	68.84	55.75	71.85	63.68	56.57
Feed N	67.93	71.87	76.63	68.35	79.55	71.22	66.94

Appendix A. Table 2. Ruminal, intestinal and total tract dry matter and nitrogen digestibilities with steers fed diets containing 77% sorghum grain-*Continued*

	STEERS						
Item	410	411	412	418	419	420	427
Period	3	1	1	4	3	2	4
SF22 DIET							
Ruminal digestion, %							
Dry matter, apparent	54.81	52.77	48.25	50.80	43.54	43.05	61.98
Dry matter corrected	71.10	68.34	64.09	62.61	66.59	57.95	70.11
Total N, apparent	-23.31	-28.30	-12.07	-9.58	-46.02	-34.80	-.88
Feed N	45.66	40.75	45.62	37.09	47.65	27.41	35.65
Small intestine digestion, %							
Dry matter, % entry	39.24	56.40	37.96	56.66	46.80	60.16	50.20
Dry matter, % intake	17.74	26.64	19.65	27.88	26.42	34.26	19.09
Total N, % entry	74.37	77.79	65.93	75.97	72.75	77.18	77.20
Total tract digestion, %							
Dry matter, apparent	83.63	83.33	77.31	80.14	84.18	80.66	85.11
Dry matter, corrected	85.64	85.85	80.63	82.54	86.69	82.99	86.55
Total N, apparent	71.59	66.38	62.47	67.37	71.89	68.83	72.96
Feed N	80.09	77.57	74.56	76.86	82.10	78.59	79.42

APPENDIX B: INDIVIDUAL STEER DATA

CORN DIGESTION TRIAL

Appendix B: Dry matter (DM) and nitrogen (N) intakes and flow through the gastrointestinal tract of steers fed diets containing 77% corn grain

	STEERS						
Item	410	411	412	418	419	420	427
Period							
SF34 DIET							
Intakes							
Dry matter, kg/d	7.042	6.926	8.587	8.798	8.035	7.655	8.784
Nitrogen, g/d	125.3	131.9	165.6	166.1	152.1	140.0	165.0
Flow to duodenum							
Dry matter, kg/d	-----	5.271	----	5.327	5.366	4.801	5.934
Total N, g/d	----	246.5	270.6	205.7	260.4	214.8	244.5
Microbial N, g/d	----	121.4	108.8	86.9	126.3	81.4	124.1
IBC, % CP	.5183	.5261	.4566	.5358	.4538	.5432	.4565
Flow from ileum							
Dry matter, kg/d	-----	2.291	-----	-----	2.488	2.170	2.879
Total N, g/d	39.4	55.8	86.4	68.3	58.8	52.2	62.8
Fecal output							
Dry matter, kg/d	1.300	1.488	2.750	2.733	1.795	1.657	2.089
Total N, g/d	38.1	49.7	82.8	76.5	57.3	53.4	64.6

Appendix B: Table 1. Dry matter (DM) and nitrogen (N) intakes and flow through the gastrointestinal tract of steers fed diets containing 77% corn grain-*Continued*

	STEERS						
Item	410	411	412	418	419	420	427
Period							
SF22 DIET							
Intakes							
Dry matter, kg/d	7.661	6.943	8.889	8.822	8.586		8.895
Nitrogen, g/d	135.9	122.8	159.0	161.1	159.8		157.7
Flow to duodenum							
Dry matter, kg/d	4.389	4.129	5.151	5.260	5.422		5.851
Total N, g/d	210.4	170.0	257.0	225.6	248.7		257.8
Microbial N, g/d	76.7	104.7	97.3	101.1	134.7		89.1
IBC, % CP	.5388	.4561	.5436	.5232	.4917		.5188
Flow from ileum							
Dry matter, kg/d	2.039	1.908	2.470	2.676	2.679		2.861
Total N, g/d	49.1	42.8	61.9	70.2	63.1		58.7
Fecal output							
Dry matter, kg/d	1.884	1.621	1.874	2.104	2.170		2.071
Total N, g/d	48.9	47.8	56.6	57.9	69.7		61.9

Appendix B: Table 2. Ruminal, intestinal and total tract DM and N digestibilities with steers fed diets containing 77% corn grain

	STEERS						
Item	410	411	412	418	419	420	427
Period	1	1	2	2	1	1	2
SF34 DIET							
Ruminal digestibility, %							
Dry matter, apparent	53.39	23.89	21.02	39.46	33.22	37.28	32.44
Dry matter, corrected	62.34	44.72	38.36	50.98	54.86	49.51	51.78
Total N, apparent	-15.27	-86.91	-63.47	-23.86	-71.24	-53.45	-48.19
Feed N	26.47	5.17	2.26	28.48	11.79	4.70	27.04
Small intestine digestibility, %							
Dry matter, % entry	50.22	56.53	47.89	37.48	53.63	54.79	51.49
Dry matter, % intake	23.41	43.03	37.82	22.69	35.81	34.37	34.79
Total N, % entry	72.71	77.38	68.09	66.80	77.41	75.70	74.31
Total tract digestibility, %							
Dry matter, apparent	81.54	78.52	67.98	68.93	77.66	78.36	76.22
Dry matter, corrected	88.05	87.04	81.17	79.07	87.48	86.39	86.28
Total N,apparent	69.62	62.34	49.98	53.98	62.30	61.82	60.87
Feed N	77.16	74.24	65.01	72.10	73.66	71.49	73.45

Appendix B: Table 2. Ruminal, intestinal and total tract dry matter and nitrogen digestibilities with steers fed diets containing 77% corn grain-*Continued*

	STEERS						
Item	410	411	412	418	419	420	427
Period	2	2	1	1	2		1
SF22 DIET							
Ruminal digestibility, %							
Dry matter, apparent	42.70	40.53	42.05	40.37	36.84		34.21
Dry matter, corrected	54.32	61.19	54.64	54.06	56.78		46.28
Total N, apparent	-54.75	-38.47	-61.62	-40.06	-55.64		63.49
Feed N	1.70	46.79	-.42	22.72	28.66		-6.99
Small intestine digestibility, %							
Dry matter, % entry	53.55	53.79	52.04	49.12	50.60		51.10
Dry matter, % intake	30.69	31.99	30.16	29.29	31.96		33.62
Total N, % entry	76.66	74.84	75.91	68.89	74.61		77.23
Total tract digestibility, %							
Dry matter, apparent	75.41	76.66	78.92	76.14	74.72		76.71
Dry matter, corrected	82.81	86.09	86.24	83.99	85.04		85.09
Total N, apparent	64.01	61.04	64.41	64.05	56.38		60.76
Feed N	73.14	80.41	73.99	73.45	70.78		70.31

APPENDIX C. INDIVIDUAL STEER DATA

ABSORPTION TRIAL

Appendix C: Table 1. Dry matter (kg/d), starch (kg/d) and nitrogen (g/d) intakes

Diet	Steer	Dry Matter	Starch	Nitrogen
DR	401	6.13	3.87	125.05
	402	7.33	4.63	149.74
	403	8.47	5.35	172.97
	404	4.71	2.97	96.19
	406	7.63	4.81	155.73
	408	6.53	4.12	133.40
	423	8.89	5.61	181.50
	428	7.13	4.50	145.56
SF34	401	6.06	3.95	123.82
	402	7.27	4.73	148.48
	403	8.03	5.23	164.04
	404	4.21	2.74	86.04
	406	6.83	4.44	139.38
	408	6.21	4.04	126.79
	423	8.93	5.81	182.23
	428	6.19	4.03	126.44

Appendix C: Table 1. Dry matter, starch and nitrogen intakes - *Continued*

Diet	Steer #	DM, kg/d	Starch, kg/d	N
SF28	401	6.89	4.43	141.69
	402	7.49	4.82	154.15
	403	7.65	4.92	157.49
	404	5.89	3.79	121.15
	406	6.42	4.13	132.03
	408	8.18	5.26	168.38
	423	6.93	4.46	142.57
	428	5.91	3.80	121.67
SF22	401	6.99	4.47	143.00
	402	7.64	4.88	156.43
	403	6.06	3.87	123.99
	404	5.75	3.68	117.72
	406	7.22	4.61	147.71
	408	6.31	4.03	129.05
	423	8.18	5.23	167.42
	428	7.58	4.85	155.21

Appendix C: Table 2. Portal and hepatic blood flows

	Portal Vein				Hepatic Vein			
Steer	DR	SF34	SF28	SF22	DR	SF34	SF28	SF22
401	-----	552.1	695.1	-----	962.7	-----	-----	1119.7
402	978.2	848.3	992.9	960.0	1170.0	-----	1243.1	1263.2
403	982.2	-----	774.0	683.6	1183.8	1196.8	911.5	-----
404	------	612.2	598.2	-----	573.8	681.0	619.8	788.3
406	1028.2	1068.9	-----	773.3	1048.9	1128.4	966.2	824.8
408	1060.1	898.3	948.2	834.5	-----	-----	-----	-----
423	863.4	767.2	696.6	1053.9	1005.3	1028.0	905.2	1124.8
428	704.4	851.2	539.2	700.5	795.5	895.0	619.7	842.9

Appendix C: Table 3. Ammonia concentrations and fluxes

		Concentrations, mM			Fluxes, g/d		
Diet	Steer #	Artery	Portal	Hepatic	PDV	Liver	Splan.
DR	401	.347	-----	.323	-----	-----	-7.76
	402	.415	.540	.375	41.08	-56.81	-15.72
	403	.360	.605	.328	80.85	-93.58	-12.73
	404	.349	-----	.360	-----	-----	2.12
	406	.321	.639	.317	109.86	-111.27	-1.41
	408	.351	.677	-----	116.12	-----	-----
	423	.326	.571	.318	71.08	-73.78	-2.70
	428	.409	.695	.402	67.69	-69.56	-1.87
SF34	401	.325	.612	-----	53.24	-----	-----
	402	.319	.591	-----	77.53	-----	-----
	403	.377	-----	.372	-----	-----	-2.01
	404	.366	.644	.334	57.18	-64.51	-7.32
	406	.335	.679	.324	123.55	-127.72	-4.17
	408	.337	.610	-----	82.40	-----	-----
	423	.353	.488	.347	34.80	-36.87	-2.07
	428	.369	.577	.376	59.49	-57.38	2.10

Apendix C: Table 3. Ammonia concentrations and fluxes - *Continued*

		Concentrations, mM			Fluxes, g/d		
Diet	Steer #	Artery	Portal	Hepatic	PDV	Liver	Splan.
SF28	401	.375	.607	-----	54.19	-----	-----
	402	.408	.622	.403	71.39	-73.48	-2.09
	403	.360	.544	.360	47.85	-47.85	.00
	404	.341	.774	.344	87.04	-88.08	-1.04
	406	.369	-----	.363	-----	-----	-1.95
	408	.395	.670	-----	87.62	-----	-----
	423	.303	.549	.298	57.57	-59.10	-1.52
	428	.395	.574	.382	32.43	-35.14	-2.71
SF22	401	.377	-----	.351	-----	-----	-9.75
	402	.320	.665	.298	111.28	-120.62	-9.34
	403	.369	.712	-----	78.78	-----	-----
	404	.320	-----	.319	-----	-----	-.27
	406	.300	.630	.269	85.74	-94.34	-8.59
	408	.377	.708	-----	92.81	-----	-----
	423	.348	.465	.348	41.43	-41.43	.00
	428	.310	.618	.314	72.50	-71.36	1.13

Appendix C: Table 4. Alpha amino N concentrations and fluxes

		Concentrations, mM			Fluxes, g/d		
Diet	Steer #	Artery	Portal	Hepatic	PDV	Liver	Splan.
DR	401	2.62	-----	2.65	-----	-----	7.30
	402	2.78	2.95	2.86	56.84	-24.32	32.51
	403	2.95	3.29	2.97	111.66	-105.68	5.98
	404	2.51	-----	2.68	-----	-----	31.89
	406	2.66	2.92	2.75	88.31	-56.52	31.80
	408	2.70	2.92	-----	77.67	-----	-----
	423	2.38	2.60	2.48	63.26	-30.24	33.02
	428	3.20	3.49	3.28	69.40	-47.30	22.11
SF34	401	2.56	2.70	-----	26.50	-----	-----
	402	2.55	2.63	-----	23.57	-----	------
	403	3.35	-----	3.47	-----	-----	48.38
	404	2.73	2.89	2.75	34.02	-28.86	5.16
	406	2.76	3.04	2.83	99.92	-74.26	25.66
	408	2.73	2.85	-----	36.31	-----	-----
	423	2.74	2.98	2.81	62.02	-33.46	28.57
	428	2.86	3.05	2.97	53.76	-19.84	33.91

Apeendix C: Table 4. Alpha amino nitrogen concentrations and fluxes - *Continued*

		Concentrations, mM			Fluxes, g/d		
Diet	Steer #	Artery	Portal	Hepatic	PDV	Livetr	Splan.
SF28	401	2.95	3.26	-----	70.24	-----	-----
	402	2.92	3.14	3.04	72.74	-25.63	47.11
	403	2.87	3.18	3.01	80.17	-38.72	41.45
	404	2.66	2.97	2.74	61.97	-46.31	15.66
	406	2.71	-----	2.78	-----	-----	21.97
	408	2.99	3.31	-----	100.61	-----	-----
	423	2.61	2.92	2.66	73.91	-57.90	16.01
	428	2.84	2.99	2.89	27.24	-17.85	9.39
SF22	401	2.87	-----	2.93	-----	-----	22.57
	402	2.33	2.59	2.41	82.46	-47.36	35.10
	403	3.05	3.47	-----	96.70	-----	-----
	404	2.59	-----	2.71	-----	-----	33.86
	406	2.47	2.82	2.51	89.87	-58.61	31.25
	408	2.85	3.12	-----	75.90	-----	-----
	423	2.78	2.98	2.87	69.22	-35.12	34.10
	428	2.80	3.15	2.90	81.41	-53.73	27.68

Appendix C: Table 5. Urea-N concentrations and fluxes

		Concentrations, mM			Fluxes, g/d		
Diet	Steer #	Artery	Portal	Hepatic	PDV	Liver	Splan.
DR	401	5.13	-----	5.29	-----	-----	51.76
	402	2.50	2.42	2.55	-26.29	45.95	19.66
	403	4.44	4.19	4.58	-82.50	138.19	55.69
	404	5.04	-----	5.31	-----	-----	52.05
	406	4.82	4.62	4.98	-69.10	125.48	56.39
	408	8.25	8.04	-----	-74.80	-----	-----
	423	4.61	4.50	4.82	-31.91	102.85	70.94
	428	5.05	4.84	5.23	-49.70	97.82	48.11
SF34	401	5.93	5.78	-----	-27.82	-----	-----
	402	5.19	4.97	-----	-62.71	-----	-----
	403	5.65	-----	5.73	-----	-----	32.17
	404	7.52	7.36	7.66	-32.91	64.94	32.03
	406	3.98	3.74	4.05	-86.20	112.74	26.54
	408	4.15	3.96	-----	-57.35	-----	-----
	423	2.76	2.69	2.81	-18.05	35.31	17.27
	428	3.59	3.40	3.73	-54.34	96.44	42.10

Appendix C: Table 5. Urea-N concentrations and net fluxes

		Concentrations, mM			Fluxes, g/g		
Diet	Steer #	Artery	Portal	Hepatic	PDV	Liver	Splan.
SF28	401	2.90	2.67	-----	-53.72	-----	-----
	402	3.40	3.23	3.45	-56.71	77.60	20.88
	403	1.75	1.63	1.80	-31.21	46.52	-----
	404	5.23	5.00	5.34	-46.23	69.14	22.91
	406	2.26	-----	2.33	-----	-----	22.73
	408	2.47	2.30	-----	-54.16	-----	-----
	423	3.35	3.22	3.55	-30.42	91.25	60.83
	428	3.92	3.72	4.01	-36.23	54.98	18.74
SF22	401	7.02	-----	7.08	-----	-----	22.51
	402	2.84	2.61	2.97	-73.92	129.36	55.17
	403	7.84	7.60	-----	-55.12	-----	-----
	404	2.47	-----	2.55	-----	-----	21.19
	406	4.95	4.62	5.06	-85.74	116.23	30.49
	408	6.70	6.45	-----	-70.10	-----	-----
	423	1.81	1.66	1.84	-53.11	64.45	11.34
	428	5.65	5.40	5.85	-58.85	115.49	56.65

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