SULFUR-CONTAINING AMINO ACID REQUIREMENT OF RAPIDLY GROWING STEERS

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ABSTRACT

Eight ruminally cannulated steers (294 kg, ADG = 1.3 kg/d) were used in a N retention study (8 × 8 latin-square design) to evaluate sulfur-containing (S) amino acid (AA) requirements for growth. Treatments were abomasal infusions of seven levels of L-methionine (0, 3, 6, 9, 12, 15 and 18 g/d) and one level of DL-methionine (6 g/d). All steers were fed a semipurified diet based on ammoniated corn cobs (DMI = 6.56 kg/d) and were abomasally infused with 400 g/d dextrose and 296.4 g/d of crystalline AA that simulated the non-S-AA pattern of casein. Infusion of 3 g/d supplemental L-methionine maximized N retention in steers. Intestinal flows of absorbable S-AA were determined to be 1.89 g/kg DM. Breakpoint analysis of retained N as a function of total absorbable S-AA yielded a total S-AA requirement of 14.7 g/d. Nitrogen retention for DL-methionine (36.4 g/d) was not different (P > .05) from that for 6 g/d L-methionine (38.8 g/d), but because this value was not in the linear response range, the efficacy of DL-methionine in meeting S-AA needs could not be evaluated. Plasma methionine concentrations increased linearly (P < .05) in response to L-methionine infusion and were greater (P < .05) for steers infused with 6 g/d DL-methionine (45.3 μM) than for steers receiving 6 g/d L-methionine (30.5 μM). Plasma cystine increased when up to 9 g/d L-methionine was infused. Plasma taurine increased rapidly when more than 9 g/d L-methionine was infused; taurine may be a significant sink for excess sulfur. The total S-AA requirement of steers in this study was estimated to be less than the amount that typically would be supplied by diets containing corn-based proteins.

(Key Words: Steers, Methionine, Requirements, Nitrogen Retention, Plasma, Amino Acids.)


Introduction

Most estimates of requirements for sulfur-containing (S) amino acids (AA) in growing cattle have utilized circulating, jugular plasma methionine concentrations as a response criterion (Williams and Smith, 1974; Fenderson and Bergen, 1975; Ahmed and Bergen, 1983; Bitterly and Foulds, 1985; Titgemeyer et al., 1988). Research supporting the validity of plasma AA responses for determination of AA requirements of growing cattle has not been published. Moreover, estimates of S-AA requirements have been determined in experiments utilizing both DL- and L-methionine, although no direct comparisons of utilization of DL- and L-methionine have been conducted with cattle.

Ideally, AA requirements would be measured using a production-related response (such as N retention) under experimental conditions in which the AA of interest is deficient and all other nutrients are supplied to meet or exceed requirements. Titgemeyer and Merchen (1989) developed a method for measuring S-AA requirements of growing steers that fulfilled these criteria. A mixture of AA containing no S-AA was infused abomasally into growing steers fed a diet

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periods were conducted such that samples were collected at each 2-h interval over a 24-h day. Three periods were conducted such that six total observations were obtained. For statistical analyses, repeated measurements on the same animal were regarded as independent experimental units.

Experiment 2. Eight Limousin-cross steers (avg initial wt 294 ± 6 kg) fitted with permanent ruminal cannulas (10 cm i.d.) were used in a N retention study designed as a \( 8 \times 8 \) Latin-square balanced for carryover effects. Treatments were abomasal infusions of seven graded levels of L-methionine (0, 3, 6, 9, 12, 15 and 18 g/d) and one level of DL-methionine (6 g/d). Total N and S intakes differed among treatments due to the methionine infused. One missing observation occurred for each of the 0 and 6 g/d L-methionine treatments.

Steers were fed a semipurified diet based on ammoniated corn cobs (Table 1). The diet contained little true protein so that microbial protein would be the major source of AA available for absorption from the small intestine. Urea and casein were included so that ruminal microbial protein synthesis would be limited by energy available for fermentation rather than by ammonia N (NH\(_3\)N) or peptide availability. Thus, any treatment-induced changes in N recycling should not alter ruminal yield of microbial protein or flow of absorbable AA to the small intestine. We assumed that quantities of AA disappearing in the small intestine of steers in Exp. 2 would have similar composition of AA as measured in Exp. 1 but total quantity would be proportional to DMI; steers were fed the same diet at similar levels of intake (% BW basis).

Steers were housed in a temperature-controlled room (20°C) under continuous lighting in individual metabolism crates designed to allow total collection of feces and urine. Steers were fed 12 times daily with automatic feeders. Flows of AA at the duodenum and ileum were measured with reference to chronic oxide using procedures described by Titgemeyer and Merchen (1989). Steers were initially adapted to the diet for 10 d and then were involved in three 13-d collection periods. Within each collection period, digesta samples (duodenal, ileal, fecal) were collected 12 times, with samples collected at 26-h intervals such that samples were collected at each 2-h interval over a 24-h day. Three periods were conducted such that six total

### Materials and Methods

Experiment 1. To determine total AA requirements of rapidly growing steers using N retention as the response criterion, 2) to compare plasma AA responses to N retention and 3) to determine the efficacy of DL-methionine in providing S-AA to steers.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>% DM</th>
</tr>
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<tbody>
<tr>
<td>Ammoniated(^a) corn cobs</td>
<td>55.6</td>
</tr>
<tr>
<td>Corn starch</td>
<td>23.8</td>
</tr>
<tr>
<td>Molasses</td>
<td>15.9</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>2.0</td>
</tr>
<tr>
<td>Casein</td>
<td>1.4</td>
</tr>
<tr>
<td>Urea</td>
<td>1.0</td>
</tr>
<tr>
<td>Trace mineralized salt(^b)</td>
<td>2.2</td>
</tr>
<tr>
<td>Vitamin mix(^c)</td>
<td>1.1</td>
</tr>
</tbody>
</table>

\(^a\)Ground corn cobs ensiled with 3% (dry basis) anhydrous ammonia.

\(^b\)Composition (g/100g): NaCl, 95 to 99; Mn, > .8; Fe, > 3; Cu, > .033; Zn, > .01; 1 > .001; Co, > .003.

\(^c\)Provided 3,300 IU vitamin A, 330 IU vitamin D, and 22 IU vitamin E/kg diet.

Limiting in protein, creating a situation in which S-AA were deficient but non-S-AA did not limit N retention.

This study was conducted 1) to determine S-AA requirements of rapidly growing steers using N retention as the response criterion, 2) to compare plasma AA responses to N retention and 3) to determine the efficacy of DL-methionine in providing S-AA to steers.
TABLE 2. NITROGEN INTAKE, EXCRETION AND RETENTION OF STEERS ABOMASALLY INFUSED WITH GRADED LEVELS OF L-METHIONINE OR 6 GRAMS/DAY DL-METHIONINE

<table>
<thead>
<tr>
<th>Nitrogen</th>
<th>L-methionine, g/d</th>
<th>Intake&lt;sup&gt;bc&lt;/sup&gt;</th>
<th>Urinary&lt;sup&gt;d,e&lt;/sup&gt;</th>
<th>Pecal</th>
<th>Retained&lt;sup&gt;d,e&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0  3  6  9  12  15  18  DL-6  SEM&lt;sup&gt;a&lt;/sup&gt;</td>
<td>163.0  169.2  167.9  168.5  166.6  172.6  172.1  168.9  2.1</td>
<td>76.4  71.9  71.2  70.0  71.3  70.0  70.5  73.2  1.2</td>
<td>55.8  58.4  57.8  60.8  57.1  59.8  60.0  59.3  1.5</td>
<td>30.9  38.9  38.8  37.7  37.6  42.0  41.6  36.4  1.9</td>
</tr>
</tbody>
</table>

<sup>a</sup>Standard error of mean (n = 8).
<sup>b</sup>Feed plus infusion.
<sup>c</sup>Linear effect of L-methionine (P < .05).
<sup>d</sup>Quadratic effect of L-methionine (P < .05).
<sup>e</sup>Rightmost plateau with breakpoint at 3 g/d L-methionine (P < .05).

were solubilized in water with (quantity/d) 14.4 g NaOH, 14.4 g KOH and 30 ml 6 N HCl such that final pH was near 5. Each steer was infused with a total volume of 4 liters/d. Solutions were infused continuously through polyvinylchloride tubing with peristaltic pumps. Tubing was placed through the ruminal cannula and the reticulo-omasal orifice into the abomasum and held in place with a small rubber flange.

Dextrose was supplied to increase the available energy supply to the steers without increasing microbial protein synthesis and to ensure an adequate supply of absorbable glucose such that gluconeogenesis would not become a large AA sink. Crystalline AA were infused 1) to allow steers to deposit protein at near maximal rates, 2) to ensure that S-AA were first-limiting and 3) to ensure that non-S-AA did not limit protein deposition, thereby leading to a methionine response only to the point at which other AA became limiting (Tiggesmeyer and Merchen, 1989).

All steers were fed the experimental diet for 14 d before beginning the first period. Each period was 6 d long, within which 4-d collections were preceded by 2-d adaptation to each treatment. The short adaptation is justified by research that demonstrates that ruminants that were maintained totally by gastric infusion of nutrients adapted rapidly to changes induced by postruminal infusion of nutrients (Hovell et al., 1983).

Urine was collected into HCl to prevent NH₃N loss; a representative aliquot (1% of daily excretion) was frozen and composited. Feces were collected daily with 10% saved and composited. Nitrogen content of urine and wet feces was determined by Kjeldahl analysis (AOAC, 1984). Samples of the diet and orts were collected and subsamples were acidified with 1 N HCl (1 ml/g) before drying at 55°C to retain volatile N components. The acidified feed and orts were utilized to determine N intake.

Jugular blood samples were taken by venipuncture at 1 h postfeeding on d 6 of each period. Blood samples (10 ml) were placed immediately on ice and centrifuged (2,000 × g) to remove cells. Plasma was deproteinized with an equal volume of 3.5% sulfosalicylic acid and frozen until analyzed for AA on a Beckman<sup>3</sup> 6300 AA analyzer.

Statistics. No carryover effects were observed (P > .05); therefore, data were analyzed without carryover effects included in the model. Data were analyzed by analysis of variance for a latin-square design, using the GLM procedure of SAS (1982). Treatment sums of squares were partitioned into single degree of freedom comparisons for linear, quadratic and cubic effects of L-methionine, and for comparing 6 g/d DL-methionine to 6 g/d L-methionine. For N retention data (Table 2), single degree of freedom comparisons also were performed to determine whether (and where) plateaus occurred in response to L-methionine supplementation; coefficients were computed similar to the regression procedure of Carmer et al. (1980) for linear splines. To more precisely define the S-AA requirement of

<sup>3</sup>Beckman Instruments, Inc., Palo Alto, CA.
steers, N retention was regressed against total flow of absorbable S-AA to the small intestine for each individual steer with a model involving two linear splines with the rightmost segment being a plateau (Carmer et al., 1980). Plasma concentrations of S-AA (methionine, cystine, cystathionine and taurine) were regressed against L-methionine and DL-methionine infusion level. A model involving two linear splines (Carmer et al., 1980) was utilized to describe responses of plasma taurine and plasma cystine.

Results and Discussion

Experiment 1. Dry matter intake was 13.94 ± .13(SD) kg/d. Apparent ruminal OM digestibility was 37.5 ± 2.1%. Apparent OM digestibility before the ileum was 60.6 ± 1.7%. Apparent total tract OM digestibility was 63.9 ± .8%. Total quantities of N intake, N reaching the duodenum and N disappearing from the small intestine were (g/kg DMI) 19.6 ± 38, 21.5 ± .70 and 11.2 ± .56, respectively. Total flows of AA to the small intestine were 101.9 ± 4.1 g/kg DMI, with 59% disappearing before the terminal ileum. Quantities of individual AA disappearing from the small intestine were (g/kg DMI) as follows: methionine, 1.20; cysteine, 1.29; lysine, 5.53; histidine, 1.14; arginine, 3.01; threonine, 2.91; valine, 3.52; isoleucine, 3.51; leucine, 5.10; phenylalanine, 2.88; tyrosine, 2.48; and nonessential AA, 28.50. Values for AA disappearing from the small intestine are similar to those reported previously for steers fed a similar diet at a similar level of intake (Carmer and Merchen, 1989); all estimates for essential AA disappearing from the small intestine (g/kg DMI) were within 15% of the values reported in that experiment. Based on these values, amounts of individual AA estimated to disappear from the small intestine of steers in Exp. 2 (DMI = 6.56 kg/d) would be (g/d) as follows: methionine, 7.9; cystine, 4.5; lysine, 36.3; histidine, 7.5; arginine, 19.8; threonine, 19.1; valine, 23.1; isoleucine, 23.0; leucine, 33.5; phenylalanine, 18.9; tyrosine, 16.3; and nonessential AA, 187.0.

Experiment 2. Dry matter intake increased linearly (P < .05) in response to L-methionine supplementation. Because of higher feed refusals, steers receiving no supplemental S-AA consumed .3 kg DM/d less than the 6.56 ± .10 kg/d average for steers receiving the seven treatments containing S-AA. Total tract OM digestibility was 68.2 ± .62% and was not affected by treatment (P > .5). This digestibility is slightly higher than that obtained in Exp. 1 when total tract digestibility was measured by reference to chromic oxide.

Nitrogen intake, excretion and retention of steers abomasally infused with graded levels of L-methionine or 6 g/d DL-methionine are presented in Table 2. Nitrogen intake increased linearly (P < .05) in response to L-methionine infusion. This was a result of both decreased DMI of steers receiving no supplemental methionine and the additional N infused as methionine. Urinary N decreased (P < .05) when 3 g/d or more L-methionine was abomasally infused. This response was best described by a rightmost plateau with a breakpoint at 3 g/d L-methionine. Fecal N excretion was not affected (P > .4) by treatment. Retained N increased (P < .05) when 3 g/d or more L-methionine was abomasally infused. Similar to urinary N, the response was best described by a rightmost plateau with a breakpoint at 3 g/d L-methionine.

Urinary N excretion and N retention when steers received 6 g/d DL-methionine were not different (P > .25) than when they received 6 g/d L-methionine. However, this level of supplementation was not in the ascending portion of the linear response range; hence, the efficacy of DL-methionine in meeting S-AA requirements could not be evaluated from these data.

Responses to L-methionine infusion clearly indicate that, under these experimental conditions, N retention and, presumably, steer performance were limited by available S-AA. Based on results of Exp. 1, basal supplies of S-AA disappearing from the small intestine were 12.4 g/d. Maximal response to L-methionine was achieved at the lowest level of infusion (3 g/d). From these values alone, the requirement can be placed between 12.4 and 15.4 g/d absorbable S-AA. Breakpoint analysis using individual animal data was used to more precisely define the S-AA requirement of steers in this study. Nitrogen retention of steers was regressed against calculated intestinal flow of absorbable S-AA of each steer using a model fitting two linear splines with the rightmost segment being a plateau. All individual data points (62) were used. Estimates of absorbable S-AA supply were calculated from
DMI based on results of Exp. 1 and the assumption that infused methionine was completely absorbed. The model included animal and period effects as well as a separate line to remove the effects of the DL-methionine treatment. The model that best described the response to changes in absorbable S-AA supply (model \( r^2 = .64 \)) was: [retained N (g/d) = \(-17.1 + 3.875 (\pm .74) \times \) absorbable S-AA (g/d)] when absorbable S-AA \( \leq 14.7 \) g/d and [retained N (g/d) = 39.8 (\( \pm .71 \))] when absorbable S-AA \( > 14.7 \) g/d. Thus, requirements for total absorbable S-AA would be 14.7 g/d. This conclusion is dependent on efficient conversion of methionine-S to cysteine, which has been demonstrated for cattle (Ahmed and Bergen, 1983; Buttery et al., 1984) and sheep (Pisulewski and Buttery, 1985). Because methionine may be converted to cysteine but the reverse reaction does not occur, our estimates of total S-AA requirements require the assumption that cysteine supply is deficient; this appears to be reasonable because methionine provided over 63% of absorbable S-AA when no methionine was infused. Ahmed and Bergen (1983) suggested that for steers only 42% of the total S-AA requirement must be supplied as methionine. The calculation of total S-AA requirements via summation of methionine and cysteine supplies suffers from lack of knowledge regarding the percentage of this requirement that may be met by cysteine. However, the change in the estimated requirement due to the differences in the molecular weights of methionine and cysteine will be small compared with the total amount.

Extrapolation of the linear response surface (from the regression analysis) may be used to calculate both maintenance requirements and requirements for any level of N retention. Maintenance requirements of steers in this experiment (N retention = 0) would be 4.4 g/d absorbable S-AA. This estimated maintenance requirement is approximately 50% greater than that suggested by Owens (1986). Based on extrapolation of the linear response surface obtained in our trial, steers (325 kg) retaining 20, 40 and 60 g N/d would require 9.6, 14.7 and 19.9 g/d S-AA. These estimates clearly are dependent upon the response to S-AA remaining linear and a genetic ability of steers to deposit the prescribed amount of protein. Moreover, these responses could be expected only when other AA do not limit performance.

The slope of the linear response surface would indicate that absorbed S-AA were utilized very efficiently. Using the assumption that body weight gain contained .0384 g S-AA/g CP (FAO, 1970), above maintenance 93% (3.875 \times 6.25 \times .0384) of absorbed S-AA was retained. This efficiency is much greater than values of 21, 47 and 50% utilized by Hutton and Annison (1972), Burroughs et al. (1974) and Owens (1986), respectively, in factorial estimates of methionine requirements of steers. The steady-state conditions induced by feeding 12 times per day and continuous infusion of exogenous glucose, the supply of excess quantities on non-S-AA and the assumption that N balance equals tissue CP retention may have led to the apparently high efficiency with which methionine was utilized in the current study.

In this study, steers infused with 3 g/d or more L-methionine retained an average of 39.6 g N/d. In previous work (Titgemeyer and Merchén, 1989), steers maintained under similar conditions and infused with 12 g/d L-methionine retained 56.2 g N/d. This probably reflects differences in the genetic capacity of steers to deposit lean tissue. Differences in the maximal performance capacity of experimental animals will alter estimates of AA requirements and must be considered when making comparisons among experiments.

Steers gained 1.30 \( \pm .07 \) kg BW/d (steers were weighed at the beginning and end of the experiment). This level of performance is consistent with N retention near 40 g/d. This level of performance can be considered representative of production situations. The requirement of 14.7 g/d S-AA probably would be met by typical feedlot diets containing large portions of corn or corn silage (Titgemeyer et al., 1988).

Based on plasma methionine responses, Fenderson and Bergen (1975) concluded that 274-kg steers gaining .73 kg BW/d required 18.6 g/d absorbable S-AA. Williams and Smith (1974) also utilized plasma AA responses and determined that 135-kg steers gaining .4 kg BW/d required 14.7 g/d S-AA (not corrected for small intestinal digestibility). Considering the size and performance level of steers in the current study, our estimates for S-AA requirements are less than predicted based on those results. Differences in methodology among studies may explain some of the discrepancies in estimation of requirements. The use of plasma AA responses by Fenderson and Bergen (1975) and Williams and Smith (1974)
Figure 1. Plasma concentrations of sulfur-containing amino acids [(a) methionine, (b) cystine, (c) cystathionine, (d) taurine] of steers abomasally infused with L-methionine (open symbols) or DL-methionine (closed symbols). Regression equations are for responses to L-methionine infusion. Model R^2 are: (a) methionine, .87; (b) cystine, .66; (c) cystathionine, .87; and (d) taurine, .79.

may not have accurately assessed methionine requirements of steers.

Bergen (1979) discussed the use of the two-phase broken line plasma AA response curve as a method of determining the AA requirements of ruminants. This approach is based on the theory that plasma concentrations of an AA will not increase in response to increasing supply until an amount greater than the animal's requirement is supplied. However, this technique has not been directly compared to one utilizing a response such as N retention which presumably is indicative of protein accretion.

In response to L-methionine infusion, plasma methionine concentration increased linearly (Figure 1). The lack of a definitive breakpoint is not surprising because 3 g/d L-methionine led to maximal N retention. The first increment of L-methionine supplementation led to the smallest increase in plasma methionine concentrations (from 17.1 to 20.2 µM; Table 3), perhaps indicating that a breakpoint could have been detected here and
thus a two-phase broken line response curve would yield similar estimates of methionine requirements if smaller increments between 0 and 3 g/d L-methionine were infused.

However, changes in plasma methionine concentrations in response to postruminally supplied methionine infusion must be carefully analyzed in studies designed to assess requirements. The magnitude of plasma methionine responses over both the ascending portion and the plateau region of a two-phase broken line response curve must be considered. Fenderson and Bergen (1975) observed a very flat plateau region with a slope of only .3 µM/g L-methionine with a slope for the ascending portion of the curve of 4.7 µM/g L-methionine. This upward slope is of similar magnitude to that of 2.5 µM/g L-methionine measured in the current study (Figure 1). Williams and Smith (1974) observed a plateau region with a slope of approximately 4 µM/g L-methionine, a value similar to that observed for the ascending slope by Fenderson and Bergen (1975).

A tremendous increase in plasma methionine concentrations following this first ascending portion of the curve has been demonstrated for calves (DL-methionine) by Tzeng and Davis (1980) and for sheep by Reis et al. (1973). In the latter study, plasma methionine accounted for 63% of total plasma AA when excessive levels (10 g/d) of DL-methionine were infused.

Our results and data from the literature indicate that plasma methionine responses to postruminally supplemented methionine may follow a three-phase response curve, which includes 1) a plateau region within which plasma concentrations remain unchanged (observed when methionine supply is less than the animal's requirement), 2) an intermediate range within which plasma concentrations increase at moderate rates (2 to 5 µM/g L-methionine: Williams and Smith, 1974; Fenderson and Bergen, 1975; current study) and 3) an excess range in which plasma concentrations (perhaps D-methionine) skyrocket and may account for more than one-half of the total plasma AA (Reis et al., 1973; Tzeng and Davis, 1980).
In this study, infusion of 6 g/d DL-methionine elicited plasma methionine increases that were clearly larger than those demonstrated by steers receiving 6 g/d L-methionine (Table 3; Figure 1). Presumably, the increased plasma methionine concentrations of steers receiving DL-methionine is due to slower uptake and(or) metabolism of the D-isomer by the liver. The use of DL-methionine in conjunction with plasma methionine responses to determine S-AA requirements likely would lead to inappropriate estimates. Direct comparisons of effects of L-methionine and DL-methionine on N retention or plasma methionine concentrations in ruminants are not available in the literature. In separate experiments, Reis et al. (1973) observed somewhat higher levels of plasma methionine when DL-methionine was infused than when L-methionine was infused postruminally into sheep. Titgemeyer et al. (1988) reported linear increases in plasma methionine when increasing amounts of DL-methionine were abomasally infused in steers. Tzeng and Davis (1980) used DL-methionine to determine S-AA requirements of preruminant calves. In that study, plasma AA breakpoint analysis yielded estimates of methionine requirements similar to those obtained when N retention was utilized, but the slope of the plateau region was greater than the ascending slope observed for DL-methionine in the current study (9 μM/g vs 5 μM/g).

Plasma cystathionine concentration increased \( (P < .05) \) in response to L-methionine infusion in a linear fashion (Figure 1; Table 3) and reflects the increased flux of methionine-S through cystathionine to cysteine. Plasma cystine increased quadratically \( (P < .05) \) with increases in quantity of L-methionine infused. Plasma cystine concentrations nearly doubled as L-methionine infusion increased from 0 to 9 g/d. However, when more than 9 g/d L-methionine was infused, plasma cystine concentrations increased at a much slower rate (Figure 1; Table 3). The plateau in plasma cystine concentrations probably did not occur because of saturation of the transulfuration pathway, but rather because of a shift in products of methionine metabolism appearing in the blood. Plasma taurine concentrations increased rapidly when more than 9 g/d L-methionine were infused (Figure 1; Table 3), implying that the cysteine produced from methionine was being converted to taurine.

Apparently, taurine is an important intermediate in catabolism of excess S-AA in cattle. Reis et al. (1973) previously demonstrated increases in plasma taurine in sheep abomasally infused with either methionine or cysteine.

Serine concentrations in jugular plasma decreased from 140.4 μM when no methionine was infused to an average of 90.0 μM when 6 g/d or more L-methionine was infused (Table 3). Similar responses were observed in sheep by Reis et al. (1973). Serine is required for the conversion of methionine-S to cysteine; thus, it is surprising that plasma serine concentrations plateaued when 6 g/d L-methionine was infused despite a probable increase in transulfuration activity beyond this point. This may be the result of increased production or decreased degradation of serine in response to an increased requirement for transulfuration or it may be an example of plasma concentrations being poorly related to metabolic flux rates.

Assuming that excess methionine is cleared from the body following transulfuration and that 3 g/d infused methionine provided enough total S-AA to meet the steers' needs, similar amounts of DL- and L-methionine would be expected to undergo transulfuration. That plasma concentrations of cystine, cystathionine, taurine and serine were not different \( (P > .20) \) when steers received 6 g/d DL-methionine vs 6 g/d L-methionine (Table 3) supports this hypothesis.

Arginine concentrations increased linearly \( (P < .05; \text{Table 3}) \) with infusion of increasing quantities of L-methionine; this may reflect the reduction in urinary N excretion and an associated reduction in arginine use for urea cycle activity. Reasons for linear increases in plasma alanine (Table 3) and linear decreases in plasma concentrations of the branched-chain AA (leucine, valine, isoleucine; Table 3) are unknown, although similar trends for the branched-chain AA were observed in sheep infused with either L- or DL-methionine (Reis et al., 1973).

Plasma concentrations of total AA (data not shown), ornithine, citrulline, threonine, glutamate, glutamine, glycine, tyrosine, phenylalanine, lysine and histidine were unaffected \( (P > .05) \) by methionine infusion. Infusion of 6 g/d DL-methionine led to higher \( (P < .05) \) plasma concentrations of aspartate than did infusion of 6 g/d L-methionine; the reason for this response is unknown.
Implications

Absorbable sulfur-containing amino acid requirements of 325-kg steers gaining 1.3 kg BW/d (40 g/d retained N) were 14.7 g/d. This amount probably would be supplied by diets containing either corn or corn silage as the primary energy source. Further investigation into the requirements of rapidly growing steers for the nonsulfur-containing amino acids will be required before we can expect to economically improve performance of growing cattle via manipulation of amino acid supply.

Literature Cited