# Developing Model Equation to Subdivide Methionine + Cystine Requirements into Requirements for Growth and Maintenance in Pigs

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**ABSTRACT** : Purified diets containing 5 graded levels of methionine + cystine were fed to young, growing and finishing pigs to determine the methionine + cystine requirement for growth and maintenance. A model was developed to subdivide the methionine + cystine requirement for maintenance from requirement for growth. From this model, the methionine + cystine requirement for growth was 8.633, 10.260 and 9.293 g/kg live weight gain and the maintenance requirement was 0.049, 0.016 and 0.019 g per unit of metabolic body size at each stage of growth, respectively. In the young pigs, the methionine + cystine requirement for growth was 0.491 g/g N gain and the maintenance requirement was 0.059 g per unit of metabolic body size. The breakpoint of plasma methionine + cystine concentrations was 3.888, 6.935 and 8.116 g/d, respectively. Expected requirements obtained from these formulae were in general agreement with previous estimates. Based on the weight gain vs N gain equation, about 4.44% of the retained protein was comprised of methionine+cystine and compared to 3.31%, the mean methionine+cystine content of pig muscle CP.
(**Key Words** : Methionine + Cystine, Requirement, Maintenance, Growth, Body Composition, Plasma Concentration, Purified Diets, Pigs)

## INTRODUCTION

The maintenance requirement determined for methionine + cystine was 150% of the maintenance requirement for lysine (Fuller et al., 1989). The dietary methionine + cystine requirement for growing pigs suggested by NRC (1988) was 0.48% for 10-20 kg, 0.41 % for 20-50 kg and 0.34% for 50-110 kg of body weight. The methionine + cystine requirement determined by serum free methionine + cystine concentrations was 0.46 % of diet (Keith et al., 1972). The methionine + cystine requirements determined by blood urea N concentrations were 0.45-0.48% of diet (Taylor et al., 1983).

The dietary methionine + cystine requirement for the accretion of 1 g body protein in the growing pig was 0.036 g. In contrast, from the relationship between N retention and amino acid intake, the daily methionine + cystine maintenance requirement for N equilibrium was estimated to be 49 mg per metabolic body size (Fuller et al., 1989). The maintenance requirement for methionine + cystine estimated in the similar N balance studies was 26 $mg/W_{kg}^{0.75}$ per day in nongravid gilts averaging 145 kg weight (Baker et al., 1966). However, these studies seemed to use diets containing inadequate amino acids for maximum growth and protein accretion, and protein turnover.

The growth and maintenance requirements for methionine + cystine can vary with response criterion and mathematical models. Nutrient limitations, environmental conditions, genetic potential influencing feed intake and protein deposition should also be considered as important factors. Therefore, it seems desirable to express amino acid requirements for maintenance, like energy requirements, on metabolic body size because daily N loss should be a result of surface and intestinal protein losses and, basal metabolic rate should be proportional to body weight. The objective of this study was to divide the methionine + cystine requirement into two portions in young (10 kg), growing (40 kg) and finishing (70 kg) pigs, respectively : one portion for maintenance and the other portion for growth. Estimated requirements for growth and maintenance were compared to previous data.

## MATERIALS AND METHODS

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Received February 14, 1996; Accepted November 15, 1996

### Animals and General Procedures

Four-week-old, male weanling, pure (Landrace) pigs were used in all experiments. Individual pigs based on ancestry and weight were initially fed standard corn-soybean meal diets, which were followed by gradual introduction of a chemically defined, amino acid diets for 7 days (table 1) until they attained an average weight of 10 kg (experiment 1), 40 kg (experiment 2) and 70 kg (experiment 3). In all experiments, pigs were housed individually in 1.2×2.5 m pens (containing a self-feeder and nipple waterer) in an environmentally controlled room (20 to 24℃) in which a 24 h constant light schedule was maintained. Before initiation and termination of the experiment, the pigs were fasted overnight and weighed the following morning. All animals were meal-fed to satiation twice daily, once in the morning and once in the evening. Fresh and cool diet was provided at every feeding. Diets were fed dry without moistening. Feed intakes were monitored daily and body weights were recorded weekly.

### Experimental Diets

The composition of the basal diet for pigs of an average weight of 10 kg (experiment 1), 40 kg (experiment 2) and 70 kg (experiment 3), respectively, is shown in table 1. Experimental diets were formulated to contain either 25, 50, 75, 100 or 125% of methionine + cystine requirement suggested by NRC (1988); all amino acids except methionine + cystine were formulated to meet or exceed 100% of NRC nutrient requirements (1988). To make the experimental diets isocaloric, L-methionine and L-cystine were substituted for L-glutamic acid in the basal diet. The methyl-donor compounds (choline, folate and vitamine $B_{12}$) were included to meet the requirement. Pigs had ad libitum access to water and their test diets, which were kept at −20℃ throughout the experimental period to prevent spoilage or any other change after mixing and during storage.

### Blood amino acid analysis

On the final day of the experiment, blood plasma samples were collected from three pigs in each treatment of all experiments. Samples were centrifuged at 3,000 rpm for 20 min to obtain plasma samples. The plasma was frozen in two aliquots. One aliquot was analyzed for plasma urea N and total plasma protein concentration using blood analyzer (Ciba-Coming Model, Express Plus, Ciba Coming Diagnostics Co.). The other aliquot was deproteinized with the sulfosalicylic acid, and analysed for plasma free amino acid concentration with ion-exchange chromatography (Hitachi Model 835, Amino Acid Analyzer, Hitachi Ltd., Tokyo, Japan).

**Table 1.** Composition of the chemically defined amino acid diet (% of diet)

| | Young | Growing | Finishing |
|---|---|---|---|
| Ingredients : | | | |
| Cornstarch | 37.24 | 50.44 | 52.44 |
| Amino acid mixture | 18.00 | 15.00 | 13.00 |
| Lactose | 15.00 | – | – |
| Sucrose | 15.00 | 20.00 | 20.00 |
| Mineral mixture[a] | 5.28 | 5.28 | 5.28 |
| Corn oil | 5.00 | 5.00 | 5.00 |
| Cellulose | 3.00 | 3.00 | 3.00 |
| $NaHCO_3$ | 1.20 | 1.00 | 1.00 |
| Vitamin mixture[b] | 0.04 | 0.04 | 0.04 |
| Choline chloride | 0.20 | 0.20 | 0.20 |
| Antibiotic mixture[c] | 0.03 | 0.03 | 0.03 |
| DL-α-tocopheryl acetate | ( 20 mg/kg) | ( 20 mg/kg) | ( 20 mg/kg) |
| Ethoxyquin | (125 mg/kg) | (125 mg/kg) | (125 mg/kg) |
| Total | 100.00 | 100.00 | 100.00 |
| Amino acid mixture : | | | |
| L-Arginine | 0.40 | 0.25 | 0.10 |
| L-Histidine HCL $H_2O$ | 0.35 | 0.31 | 0.25 |
| L-Isoleucine | 0.53 | 0.46 | 0.38 |
| L-Leucine | 0.70 | 0.60 | 0.50 |
| L-Lysine HCl | 1.19 | 0.94 | 0.75 |
| L-Methionine | 0.24 | 0.21 | 0.17 |
| L-Cystine | 0.24 | 0.21 | 0.17 |
| L-Phenylalanine | 0.46 | 0.40 | 0.33 |
| L-Tyrosine | 0.31 | 0.26 | 0.22 |
| L-Threonine | 0.56 | 0.48 | 0.40 |
| L-Tryptophan | 0.14 | 0.12 | 0.10 |
| L-Valine | 0.56 | 0.48 | 0.40 |
| L-Proline | 0.40 | 0.33 | 0.29 |
| L-Glycine | 1.20 | 1.00 | 0.87 |
| L-Glutamic acid | 10.72 | 8.96 | 8.07 |
| Total | 18.00 | 15.00 | 13.00 |

[a] Mineral mixture provided per kilogram of diet: $CaCO_3$, 3 g; $Ca_3(PO_4)2$, 28 g; $K_2HPO_4$, 9 g; NaCl, 8.8 g; $MgSO_4 \cdot H_2O$, 2.6 g; $MnSO_4 \cdot H_2O$, 0.65 g; $FeSO_4$, 0.5 g; $ZnCO_4$, 0.15 g; $CuSO_4 \cdot H_2O$, 15 mg; $H_3BO_3$ 9 mg; $Na_2MoO_4 \cdot 2H_2O$, 9 mg; KI, 40.6 mg; $CoSO_4 \cdot 7H_2O$, 1 mg; $Na_2SeO_3$ 0.66 mg.

[b] Vitamin mixture provided per kilogram of diet: thiamin HCl, 20 mg; niacin, 50 mg; riboflavin, 10 mg; D-calcium pantothenate, 30 mg; vitamin $B_{12}$, 0.04 mg; pyridoxine HCl, 6 mg; D-biotin, 0.6 mg; folic acid, 4 mg; menadione, 2 mg; ascorbic acid, 250 mg; retinyl acetate, 5,200 IU; cholecalciferol (200,000 IU per g), 600 IU.

[c] Antibiotic mixture provided per kilogram of diet: chlortetracycline, 110 mg; sulfamethazine, 110 mg; procaine penicillin, 55 mg.

### Preparation of carcass sample

In experiment 1, the pigs were weighed before they were transported to the Meat Laboratory. They were killed by hammer stunning, after which the blood was allowed to clot inside the body before evisceration. An incision through the abdominal wall was made between both hams to facilitate removal of the gastrointestinal tract, which was emptied of its contents and rinsed with a minimal amount of water. The intact whole carcass including head and all organs and the washed gastrointestinal tract were combined, weighed, packaged in a heavy-duty plastic bag and frozen at −20℃. The weight obtained before freezing was recorded as empty body weight.

After deep freezing, whole carcasses and gastrointestinal tract were cut while frozen into 2.5 × 2.5 × 5 cm shape and after mixing, ground two times through a 1 cm die and ground two times again through a 0.5 cm die, with hand mixing between grindings to have homogeneous sample. Subsamples (~4 kg) were taken and frozen again. After deep freezing, samples were sliced while frozen into 0.5 cm strips and ground through a 0.1 cm die until a homogeneous, finely minced paste was obtained. One subsample was taken and frozen at −20℃ for dry matter and ash determination. The other subsample was freeze-dried at −40℃ for 36 h and frozen at −20℃ until chemical analysis.

### Analysis of body composition

Dry matter was obtained by drying wet samples for 24 h at 105℃. The dried samples were then extracted in ether for determination of whole-body lipid. For ash determination, wet carcass samples were dry-ashed for 24 h at 550℃. Whole-body nitrogen was analyzed on wet samples by the Kjeldahl procedure (AOAC 1990).

### Development of model equation and statistical analysis

The methionine + cystine requirement for growth and maintenance was calculated using a model based on metabolic body size. The mathematical equation for this model was :

$$y = ax + b \quad \cdots\cdots (1)$$

where $y = R/W_{kg}^{0.75}$; $x = I/W_{kg}^{0.75}$; a = upslope to plateau; b = y intercept; I = amino acid intake in g/day; R = response (weight gain in kg/day or nitrogen gain in g/day). By incorporating these variables into equation (1), the following new model was generated.

$$I = 1/a \cdot (R - bW_{kg}^{0.75}) \quad \cdots\cdots (2)$$

$-b/aW_{kg}^{0.75}$ is the requirement of methionine + cystine (g/day) at maintenance. The upslope, 1/a, represents the growth requirement (g/day) per 1 kg live weight gain or 1 g nitrogen gain. Two linear regression equations, one for some of the upslope portion and the other one for upslope plus some plateaus portion, were determined as intersecting at the point at which the residual sum of square is minimized by the nonlinear least square method (SAS, 1985). The data points covering the plateau portion beyond 125% of methionine+cystine requirement by NRC (1988) were excluded from the equations because, by definition, some nutrient or energy other than methionine + cystine was limiting response in that region.

All experimental data were subjected to ANOVA procedures appropriate for a completely randomized design. Orthogonal single degree of freedom comparisons were made to test for linear and quadratic methionine + cystine effects and for other treatment differences of interest (Steel and Torrie, 1980).

## RESULTS AND DISCUSSION

Responses of young pigs fed diets containing graded levels of methionine + cystine are shown in table 2.

**Table 2.** Responses of young pigs fed diets containing five graded levels of methionine + cystine for 14 days[1]

| Methionine + cystine (50:50) | Mean[2] $W^{0.75}$ | Feed intake | Weight gain | Methionine + cystine intake | Body nitrogen retention | Gain / Feed |
|---|---|---|---|---|---|---|
| (%) | (kg) | (kg/d) | (kg/d) | (g/d) | (g/d) | |
| 0.12 | 6.31 ± 0.31 | 0.47 ± 0.03 | 0.05 ± 0.02 | 0.56 ± 0.08 | 0.69 ± 0.21 | 0.09 ± 0.02 |
| 0.24 | 6.85 ± 0.32 | 0.70 ± 0.03 | 0.24 ± 0.03 | 1.67 ± 0.06 | 4.53 ± 0.32 | 0.34 ± 0.02 |
| 0.36 | 7.57 ± 0.24 | 1.06 ± 0.03 | 0.50 ± 0.02 | 3.83 ± 0.12 | 9.25 ± 0.42 | 0.47 ± 0.01 |
| 0.48 | 7.83 ± 0.22 | 1.11 ± 0.05 | 0.59 ± 0.04 | 5.33 ± 0.28 | 10.23 ± 0.95 | 0.53 ± 0.01 |
| 0.60 | 7.72 ± 0.18 | 1.10 ± 0.07 | 0.56 ± 0.03 | 6.62 ± 0.44 | 9.54 ± 0.25 | 0.50 ± 0.01 |

[1] Values are mean ± S.E. of 3 pigs of each treatment.
[2] $W^{0.75}$ is (initial weight + final weight)/2)$^{0.75}$.
[3] Average initial weight was 11.35 ± 0.83 kg.

Weight gain and nitrogen gain increased rapidly by supplementing up to 0.48% methionine + cystine. Responses beyond 0.48% methionine + cystine were minor. To maintain body weight approximately 0.12% methionine+cystine was needed. Feed intake increased to the plateau at 0.48%, and gain/feed ratio continued to increase up to 0.48% methionine+cystine levels.

Performances of growing pigs fed diets containing graded levels of methionine+cystine are recorded in table 3. Weight gain increased rapidly by supplementing up to 0.41% methionine + cystine. Changes in weight gain were minor beyond 0.41%. Feed intake increased up to 0.21% but gain/feed ratio was increased with increasing in methionine+cystine level up to 0.31%.

**Table 3.** Responses of growing pigs fed diets containing five graded levels of methionine + cystine for 13 days[1]

| Methionine + cystine (50:50) | Mean[2] $W^{0.75}$ | Feed intake | Weight gain | Methionine + cystine intake | Gain / Feed |
|---|---|---|---|---|---|
| (%) | (kg) | (kg/d) | (kg/d) | (g/d) | |
| 0.10 | 16.36 ± 0.09 | 1.54 ± 0.08 | 0.28 ± 0.03 | 1.58 ± 0.08 | 0.18 ± 0.02 |
| 0.21 | 17.66 ± 0.20 | 2.31 ± 0.05 | 0.91 ± 0.05 | 4.74 ± 0.11 | 0.40 ± 0.02 |
| 0.31 | 17.50 ± 0.24 | 2.06 ± 0.11 | 0.99 ± 0.04 | 6.33 ± 0.34 | 0.48 ± 0.02 |
| 0.41 | 17.71 ± 0.13 | 2.31 ± 0.07 | 1.08 ± 0.04 | 9.49 ± 0.29 | 0.47 ± 0.01 |
| 0.51 | 17.54 ± 0.38 | 2.35 ± 0.09 | 1.00 ± 0.06 | 12.06 ± 0.49 | 0.43 ± 0.02 |

[1] Values are mean ± S.E. of 3 pigs of each treatment.
[2] $W^{0.75}$ is (initial weight + final weight)/2)$^{0.75}$.
[3] Average initial weight was 39.39 ± 1.22 kg.

Responses of finishing pigs fed diets containing graded levels of methionine+cystine are presented in table 4. Weight gain increased rapidly up to 0.26%. Changes in weight gain were minor beyond 0.26%. Feed intake increased up to 0.26% but gain/feed ratio continued to increase up to 0.34%.

**Table 4.** Responses of finishing pigs fed diets containing five graded levels of methionine + cystine for 14 days[1]

| Methionine + cystine (50:50) | Mean[2] $W^{0.75}$ | Feed intake | Weight gain | Methionine + cystine intake | Gain / Feed |
|---|---|---|---|---|---|
| (%) | (kg) | (kg/d) | (kg/d) | (g/d) | |
| 0.09 | 23.83 ± 0.37 | 1.49 ± 0.44 | 0.17 ± 0.09 | 1.26 ± 0.38 | 0.09 ± 0.05 |
| 0.17 | 24.93 ± 0.33 | 2.62 ± 0.04 | 0.80 ± 0.05 | 4.46 ± 0.06 | 0.30 ± 0.01 |
| 0.26 | 25.70 ± 0.18 | 3.23 ± 0.24 | 1.12 ± 0.08 | 8.23 ± 0.61 | 0.35 ± 0.02 |
| 0.34 | 25.03 ± 0.40 | 3.02 ± 0.41 | 1.17 ± 0.10 | 10.25 ± 1.39 | 0.39 ± 0.02 |
| 0.43 | 25.64 ± 0.36 | 3.19 ± 0.06 | 1.20 ± 0.05 | 13.58 ± 0.24 | 0.38 ± 0.01 |

[1] Values are mean ± S.E. of 3 pigs of each treatment.
[2] $W^{0.75}$ is (initial weight + final weight)/2)$^{0.75}$.
[3] Average initial weight was 66.96 ± 2.34 kg.

Water content of carcasses increased in the same manner as protein content increased up to 0.48% as shown in table 5. However, the ratio of protein content to water content remained constant over all treatments except for 0.12 and 0.24%. This means that the ratio of protein to water content would not be changed by moderate deficiency or excess of methionine + cystine in the diet. Serious deficiency of methionine + cystine in the diet changed the body composition of pigs in this study.

Table 6 shows plasma amino acid, urea N and protein concentrations of young pigs fed five graded levels of methionine + cystine. Plasma isoleucine, valine, alanine, aspartic acid, cystine, glutamic acid and glycine concentrations changed in a linear pattern as the dietary methionine + cystine level increased, while methionine concentrations in plasma followed a quadratic pattern.

Plasma urea N concentration showed a quadratic pattern with increasing methionine + cystine. The pattern was smilar to plasma urea N conentrations of pigs fed diets containing graded levels of lysine in the study by Coma et al. (1995).

**Table 5.** Body composition of young pigs fed five graded levels of methionine + cystine for 14 days

| Methionine + cystine (50:50) | Live weight gain | Dry weight gain | Water gain | Protein gain | Protein gain / water gain |
|---|---|---|---|---|---|
| (%) | (kg/14 days) | (g/14 days) | (g/14 days) | (g/14 days) | |
| 0.12 | 0.69$^{c}$ | 0.48$^{c}$ | 0.21$^{c}$ | 0.06$^{c}$ | 0.295$^{a}$ |
| 0.24 | 3.35$^{b}$ | 1.68$^{b}$ | 1.66$^{b}$ | 0.40$^{b}$ | 0.244$^{b}$ |
| 0.36 | 7.01$^{a}$ | 3.18$^{a}$ | 3.84$^{a}$ | 0.81$^{a}$ | 0.211$^{b}$ |
| 0.48 | 7.58$^{a}$ | 3.25$^{a}$ | 4.33$^{a}$ | 0.90$^{a}$ | 0.212$^{b}$ |
| 0.60 | 7.77$^{a}$ | 3.73$^{a}$ | 4.04$^{a}$ | 0.83$^{a}$ | 0.207$^{b}$ |

$^{abc}$ Means in a column with different superscripts are different ($p < 0.05$).

Plasma amino acid, urea N and protein concentration of growing pigs fed five graded levels of methionine + cystine are presented in table 7. Plasma arginine, histidine, methionine, phenylalanine and tyrosine concentrations changed in a quadratic pattern as dietary methionine + cystine increased. Urea N concentrations in plasma decreased linearly.

Table 8 represents plasma amino acid, urea N and protein concentrations of finishing pigs fed five graded levels of methionine + cystine. Isoleucine, methionine, valine, alanine, cystine, proline, total nonessential amino acid and total amino acid concentrations changed in a

**Table 6.** Plasma amino acid, urea N and protein concentrations of young pigs fed five graded levels of methionine + cystine (mg / 100 ml)

| AA | Methionine + cystine (%) (50:50) | | | | | Mean | SE |
|---|---|---|---|---|---|---|---|
| | 0.12 | 0.24 | 0.36 | 0.48 | 0.60 | | |
| ARG | 1.14$^{ab}$ | 1.11$^{ab}$ | 0.64$^{b}$ | 2.16$^{a}$ | 0.75$^{b}$ | 1.16 | 0.20 |
| HIS | 1.23$^{b}$ | 1.25$^{b}$ | 0.96$^{b}$ | 1.30$^{a}$ | 0.96$^{ab}$ | 1.14 | 0.06 |
| ILE$^{l}$ | 0.78$^{b}$ | 1.82$^{b}$ | 2.32$^{b}$ | 4.55$^{b}$ | 2.35$^{b}$ | 2.36 | 0.38 |
| LEU | 1.10 | 1.49 | 1.19 | 1.52 | 1.57 | 1.37 | 0.16 |
| LYS | 3.07 | 3.28 | 2.94 | 3.27 | 3.01 | 3.11 | 0.40 |
| MET$^{q}$ | 0.16$^{b}$ | 0.19$^{b}$ | 0.20$^{b}$ | 0.37$^{b}$ | 0.71$^{a}$ | 0.33 | 0.07 |
| PHE | 1.21$^{b}$ | 0.82$^{b}$ | 0.92$^{b}$ | 2.32$^{a}$ | 1.02$^{b}$ | 1.26 | 0.18 |
| THR | 7.74 | 9.71 | 7.33 | 9.96 | 8.34 | 8.62 | 0.60 |
| VAL$^{l}$ | 2.10$^{c}$ | 2.79$^{bc}$ | 3.36$^{bc}$ | 5.00$^{a}$ | 3.92$^{ab}$ | 3.43 | 0.31 |
| Total Ess. | 18.52$^{b}$ | 22.46$^{ab}$ | 19.85$^{b}$ | 30.45$^{a}$ | 22.63$^{ab}$ | 22.78 | 1.54 |
| ALA$^{l}$ | 5.70$^{b}$ | 6.27$^{b}$ | 9.65$^{b}$ | 14.27$^{a}$ | 11.91$^{a}$ | 9.56 | 1.04 |
| ASP$^{l}$ | 0.40$^{c}$ | 0.74$^{bc}$ | 0.80$^{abc}$ | 1.23$^{a}$ | 0.90$^{ab}$ | 0.82 | 0.09 |
| CYS$^{l}$ | 0.04$^{b}$ | 0.06$^{bc}$ | 0.09$^{b}$ | 0.21$^{a}$ | 0.26$^{a}$ | 0.13 | 0.02 |
| GLU$^{l}$ | 4.44$^{b}$ | 5.84$^{b}$ | 8.35$^{b}$ | 10.99$^{a}$ | 8.60$^{a}$ | 7.64 | 0.78 |
| GLY$^{l}$ | 5.72$^{b}$ | 8.08$^{b}$ | 8.00$^{ab}$ | 11.94$^{a}$ | 9.39$^{ab}$ | 8.63 | 0.69 |
| PRO | 2.98 | 2.41 | 3.05 | 3.98 | 2.93 | 3.07 | 0.24 |
| SER | 1.57 | 2.42 | 1.55 | 2.48 | 1.68 | 1.94 | 0.16 |
| TYR | 1.04$^{ab}$ | 0.76$^{b}$ | 0.91$^{ab}$ | 1.60$^{a}$ | 1.07$^{ab}$ | 1.08 | 0.12 |
| Total Noness. | 21.89$^{c}$ | 26.59$^{bc}$ | 32.40$^{bc}$ | 46.69$^{a}$ | 36.74$^{ab}$ | 32.86 | 2.65 |
| Grand total$^{l}$ | 40.41$^{b}$ | 49.05$^{b}$ | 52.25$^{b}$ | 77.14$^{a}$ | 59.37$^{ab}$ | 55.64 | 3.96 |
| PUN (mg/dl)$^{q}$ | 21.13$^{a}$ | 13.87$^{b}$ | 9.67$^{c}$ | 7.23$^{c}$ | 9.17$^{c}$ | 12.21 | 1.39 |
| Protein (g/dl) | 5.83$^{a}$ | 3.40$^{ab}$ | 3.93$^{ab}$ | 3.20$^{b}$ | 3.13$^{b}$ | 3.90 | 0.40 |

$^{abc}$ Means in a row with different superscripts are different ($p < 0.05$).
$^{l}$ Linear relationship among treatment means ($p < 0.05$).
$^{q}$ Quadratic relationship among treatment means ($p < 0.05$).

**Table 7.** Plasma amino acid, urea N and protein concentrations of growing pigs fed five graded levels of methionine + cystine (mg / 100 ml)

| AA | Methionine + cystine (%) (50:50) | | | | | Mean | SE |
|---|---|---|---|---|---|---|---|
| | 0.10 | 0.21 | 0.31 | 0.41 | 0.51 | | |
| ARG[q] | 0.65[b] | 0.57[b] | 0.60[b] | 0.30[b] | 1.21[a] | 0.67 | 0.10 |
| HIS[q] | 1.07[b] | 1.04[b] | 0.87[b] | 1.37[b] | 2.55[a] | 1.38 | 0.18 |
| ILE | 1.02 | 1.53 | 1.85 | 1.15 | 2.26 | 1.56 | 0.27 |
| LEU | 1.14 | 1.30 | 1.38 | 0.95 | 2.06 | 1.36 | 0.16 |
| LYS | 2.01[ab] | 1.53[b] | 2.43[ab] | 1.94[ab] | 3.60[a] | 2.30 | 0.28 |
| MET[q] | 0.13[c] | 0.15[c] | 0.24[c] | 0.41[b] | 0.61[a] | 0.31 | 0.05 |
| PHE[q] | 0.92[b] | 0.87[b] | 0.92[b] | 0.83[b] | 1.80[a] | 1.07 | 0.13 |
| THR | 4.41 | 4.54 | 4.51 | 2.53 | 5.39 | 4.27 | 0.49 |
| VAL | 1.93 | 2.27 | 2.77 | 1.80 | 4.09 | 2.57 | 0.35 |
| Total Ess. | 13.28[ab] | 13.80[ab] | 15.58[ab] | 11.27[b] | 23.56[a] | 15.50 | 1.74 |
| ALA | 2.47 | 3.80 | 4.82 | 3.23 | 5.94 | 4.05 | 0.52 |
| ASP | 0.15 | 0.18 | 0.25 | 0.12 | 0.05 | 0.15 | 0.03 |
| CYS | 0.07[bc] | 0.06[c] | 0.06[c] | 0.15[b] | 0.26[a] | 0.12 | 0.02 |
| GLU | 2.32 | 2.69 | 3.76 | 2.13 | 5.37 | 3.25 | 0.54 |
| GLY | 4.04 | 5.68 | 7.23 | 4.15 | 7.68 | 5.75 | 0.87 |
| PRO | 1.42[ab] | 1.58[ab] | 1.84[ab] | 1.19[b] | 2.59[a] | 1.72 | 0.19 |
| SER | 1.06 | 1.07 | 0.94 | 0.51 | 1.12 | 0.94 | 0.11 |
| TYR[q] | 0.75[b] | 0.67[b] | 0.69[b] | 0.69[b] | 1.36[a] | 0.83 | 0.09 |
| Total Noness. | 12.27 | 15.73 | 19.59 | 12.15 | 24.37 | 16.83 | 2.22 |
| Grand total | 25.55 | 29.54 | 35.17 | 23.42 | 47.93 | 32.32 | 3.89 |
| PUN (mg/dl)[l] | 11.93 | 8.33 | 7.60 | 7.53 | 8.00 | 8.68 | 0.68 |
| Protein (g/dl) | 3.50 | 2.40 | 4.23 | 3.80 | 2.93 | 3.37 | 0.45 |

[ab] Means in a row with different superscripts are different ($p < 0.05$).
[l] Linear relationship among treatment means ($p < 0.05$).
[q] Quadratic relationship among treatment means ($p < 0.05$).

linear shape as dietary methionine + cystine level increased, while arginine, leucine, phenylalanine and total essential amino acid concentrations formed a quadratic shape as increasing methionine + cystine levels in the diet. Plasma urea N concentrations decreased in a linear pattern. However, protein concentrations in plasma remained unchanged as dietary methionine + cystine increased shown in table 6, 7 and 8.

The predicted equation to separate the methionine + cystine requirement of young pigs (10 kg of body weight) into one portion for maintenance and a second portion for growth is shown in figure 1. The estimated methionine + cystine requirement for growth was 8.633 g per kg of weight gain while the estimated requirement for maintenance was 0.049 g/d per unit of metabolic body size. The total methionine + cystine requirement is the

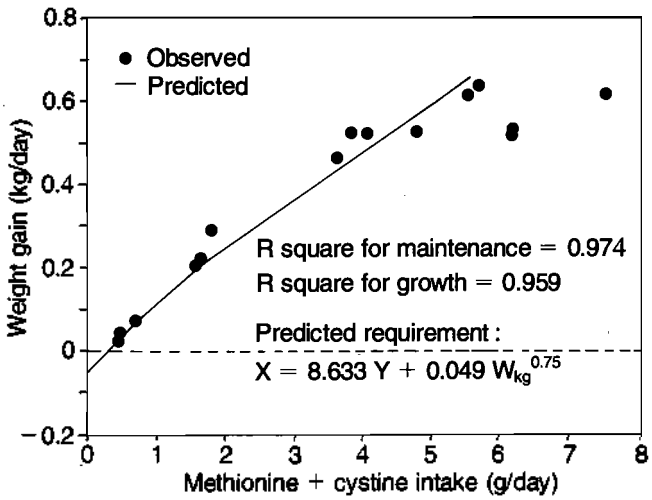


**Figure 1.** Weight gain response to graded methionine + cystine intake in young pigs.

**Table 8.** Plasma amino acid, urea N and protein concentrations of finishing pigs fed five graded levels of methionine + cystine (mg / 100 ml)

| AA | Methionine + cystine (%) (50:50) | | | | | Mean | SE |
|---|---|---|---|---|---|---|---|
| | 0.09 | 0.17 | 0.26 | 0.34 | 0.43 | | |
| ARG[q] | 1.24[a] | 1.10[ab] | 0.62[b] | 0.64[b] | 1.14[a] | 0.95 | 0.09 |
| HIS | 1.70[ab] | 1.72[ab] | 1.56[b] | 1.64[ab] | 1.86[a] | 1.69 | 0.04 |
| ILE[l] | 1.75[b] | 2.12[b] | 2.09[b] | 2.97[b] | 3.12[a] | 2.41 | 0.19 |
| LEU[q] | 1.91[a] | 1.76[b] | 1.67[b] | 1.70[b] | 2.57[a] | 1.92 | 0.11 |
| LYS | 4.22 | 3.74 | 3.37 | 3.63 | 4.48 | 3.89 | 0.17 |
| MET[l] | 0.23[c] | 0.26[c] | 0.39[bc] | 0.57[b] | 0.93[a] | 0.48 | 0.08 |
| PHE[q] | 1.93 | 1.79 | 1.28 | 1.55 | 1.93 | 1.69 | 0.10 |
| THR | 8.05 | 6.94 | 5.81 | 6.15 | 7.55 | 6.90 | 0.41 |
| VAL[l] | 3.24[b] | 3.47[b] | 3.40[b] | 4.19[ab] | 4.82[a] | 3.82 | 0.19 |
| Total Ess.[q] | 24.28[ab] | 22.89[ab] | 20.18[b] | 23.03[ab] | 28.40[a] | 23.76 | 0.99 |
| ALA[l] | 3.99[c] | 6.73[bc] | 8.46[ab] | 10.62[a] | 10.65[a] | 8.09 | 0.76 |
| ASP | 0.25[bc] | 0.32[abc] | 0.20[c] | 0.43[a] | 0.34[ab] | 0.31 | 0.03 |
| CYS[l] | 0.05[b] | 0.03[b] | 0.06[b] | 0.15[b] | 0.33[a] | 0.12 | 0.03 |
| GLU | 3.63 | 5.10 | 3.90 | 5.50 | 5.76 | 4.78 | 0.42 |
| GLY | 6.03 | 7.08 | 10.68 | 9.98 | 10.52 | 8.85 | 0.60 |
| PRO[l] | 2.14[b] | 2.72[ab] | 2.72[ab] | 3.06[ab] | 3.64[a] | 2.85 | 0.18 |
| SER | 1.77 | 1.70 | 1.52 | 1.37 | 1.58 | 1.59 | 0.08 |
| TYR | 1.58 | 1.33 | 1.00 | 1.15 | 1.42 | 1.30 | 0.10 |
| Total Noness.[l] | 19.43[c] | 25.00[bc] | 28.54[ab] | 32.26[ab] | 34.25[a] | 27.90 | 1.66 |
| Grand total[l] | 43.71[b] | 47.89[b] | 48.72[b] | 53.30[ab] | 62.65[a] | 51.65 | 2.33 |
| PUN (mg/dl)[l] | 12.07[a] | 11.97[a] | 6.93[b] | 6.40[b] | 8.50[ab] | 9.17 | 0.86 |
| Protein (g/dl) | 5.60 | 6.03 | 5.60 | 4.07 | 5.87 | 5.43 | 0.30 |

[abc] Means in a row with different superscripts are different ($p < 0.05$).
[l] Linear relationship among treatment means ($p < 0.05$).
[q] Quadratic relationship among treatment means ($p < 0.05$).

sum of growth and maintenance requirements. For example, if a young pig weighe 15 kg and gains at a rate of 0.45 kg per day, the growth requirement would be 3.885 g per day and the maintenance requirement would be 0.373 g per day. Thus, the total requirement for methionine + cystine needed by this young pig would be 4.258 g per day. This means that about 8.76% of the total requirement would be utilized for maintenance. If feed intake is 0.95 kg per day, the dietary level of methionine + cystine required for growth would be 0.41%, and maintenance would be 0.04% for a total requirement of 0.45%. This value is almost the same as previously reported methionine + cystine requirements for total as shown in table 9.

The predicted equation for methionine+cystine requirement of growing pigs (40 kg of body weight) for maintenance and for growth is shown in figure 2. The estimated methionine + cystine requirement for growth was 10.260 g per unit of kg weight gain while the estimated requirement for maintenance was 0.016 g/d per unit of metabolic body size. The total requirement is the sum of the growth and maintenance requirement. For example, if a growing pig weighs 45 kg and gains 0.7 kg per day, the growth requirement would be 7.182 g per day and the maintenance requirement would be 0.280 g per day. Thus, the total requirement for methionine+cystine needed by this growing pig would be 7.462 g per day. This means that about 4% of the total requirement would be utilized for maintenance. If feed intake is 1.9 kg per day, the dietary level of methionine + cystine required for

growth would be 0.38%, for maintenance would be 0.02% and therefore, total requirement would be 0.40%. This value is slightly lower than the previous total methionine + cystine requirements expressed as a percentage of the diet 0.44 ± 0.06% as shown tn table 9.

**Table 9.** Previously published methionine+cystine requirements for young, growing and finishing pigs

| Dietary level of methionine + cystine | Live weight | Response criterion | Methionine + cystine requirement | Sources |
|---|---|---|---|---|
| (%) | (kg) | | (%) | |
| | 10-20 | Growth | 0.48 | NRC (1988) |
| 0.23-0.79 | 10 | N retention, PUN | 0.55 (C) | Balogun and Fetuga (1981) |
| 0.23-0.79 | 10 | N retention, PUN | 0.47 (G) | Balogun and Fetuga (1981) |
| 0.24-0.64 | 10 | Growth | 0.46 (G) | Chung and Baker (1992b) |
| 0.31-0.63 | 10-20 | Growth | 0.51 (D) | Chung and Baker (1992a) |
| Mean | | | 0.49 | |
| STD | | | 0.04 | |
| | 20-30 | Growth | 0.41 | NRC (1988) |
| 0.23-0.5 | 21-40 | Growth and PER | 0.23 | Oestemer et al. (1970) |
| 0.25-0.60 | 20-40 | Serum free methionine | 0.46 | Keith et al. (1972) |
| 0.32-0.57 | 20-50 | Growth, PER, PAA | 0.32 | Stockland et al. (1971) |
| 0.47-0.67 | 20-60 | Growth and carcass | 0.47 (C) | Rerat and Henry (1970) |
| 0.47-0.67 | 20-60 | Growth and carcass | 0.52 (G) | Rerat and Henry (1970) |
| 0.27-0.87 | 20-60 | Growth, N retention | 0.43 | Braude and Esnaola (1973) |
| 0.35-0.57 | 25-55 | Growth, BUN | 0.47 | Taylor et al. (1983) |
| Mean | | | 0.44 | |
| STD | | | 0.06 | |
| | 50-110 | Growth | 0.34 | NRC (1988) |
| 0.14-0.24 | 57 | N retention | 0.24 | Allee and Trotter (1974) |
| 0.23-0.35 | 50-80 | Growth | 0.36 (D) | Chung et al. (1989) |
| Mean | | | 0.31 | |
| STD | | | 0.06 | |
| Maintenance requirement | | | | |
| | 145 | N balance | 26 mg/$W_{kg}^{0.75}$ | Baker (1966) |
| | 46 | Growth | 49 mg/$W_{kg}^{0.75}$ | Fuller (1989) |

PUN : plasma urea nitrogen, PAA : plasma amino acids, D : digestible requirement, C : castrates, G : gilts.

The predicted equation for methionine + cystine requirement of finishing pigs (70 kg of body weight) for maintenance and for growth is shown in figure 3. The estimated methionine+cystine requirement for growth was 9.293 g per unit of kg weight gain while the estimated requirement for maintenance was 0.019 g/d per unit of metabolic body size. The total requirement is the sum of growth and maintenance requirement. For example, if a finishing pig weighs 80 kg and gains 0.82 kg per day, the growth requirement would be 7.621 g per day and the maintenance requirement would be 0.501 g per day. Thus, the total requirement for methionine+cystine needed by this young pig would be 8.122 g per day. This means that about 6.19% of the total requirement would be utilized for maintenance. If feed intake is 3.11 kg per day, the dietary level of methionine+cystine required for growth would be 0.25%, for maintenance would be 0.02% and therefore, total requirement would be 0.27%. This value is near the

previously reported methionine + cystine requirements of 0.31 ± 0.06% (table 9).

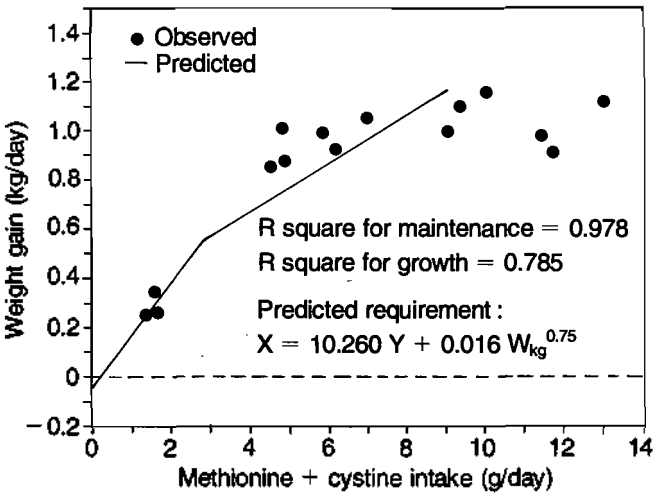


**Figure 2.** Weight gain response to graded methionine + cystine intake in growing pigs.

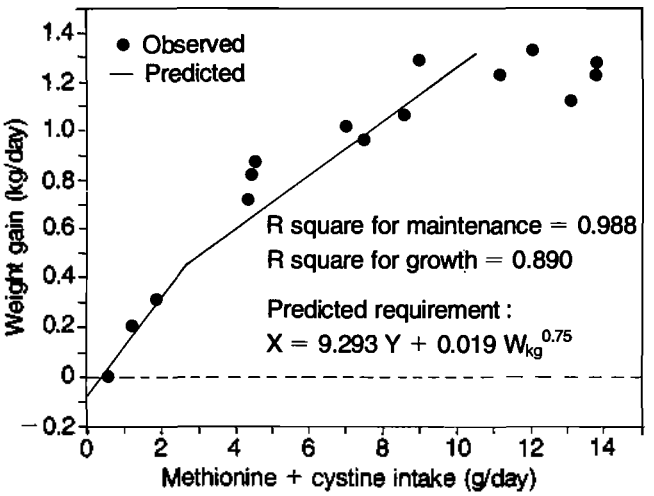


**Figure 3.** Weight gain response to graded methionine + cystine intake in finishing pigs.

Daily methionine + cystine intakes of young pigs are plotted against daily nitrogen gains in figure 4; the prediction line and equation are also included. The estimated methionine + cystine requirement for growth was 0.491 g per g nitrogen gain and the estimated requirement for maintenance was 0.059 g per unit of metabolic body size. The total methionine+cystine requirement is the sum of growth and maintenance requirement. For instance, a pig weighing 15 kg and gaining N at a rate of 8.5 g N/day would require 4.173 g of methionine+cystine per day for growth. The maintenance requirement for methionine+cystine for this young pig would be 0.452 g per day. Thus, the total daily amount needed by this growing pig will be 4.625 g per day. This means that about 9.77% of the total requirement would be utilized for maintenance. When the total requirement expressed as daily intake basis is converted to the dietary percentage assuming a feed intake of 0.95 kg per day, the requirement would be 0.49%. Considering the natural forms of amino acids in practical diets are lower in degestibility than synthetic forms, the direct comparison with NRC requirements would be illogical.

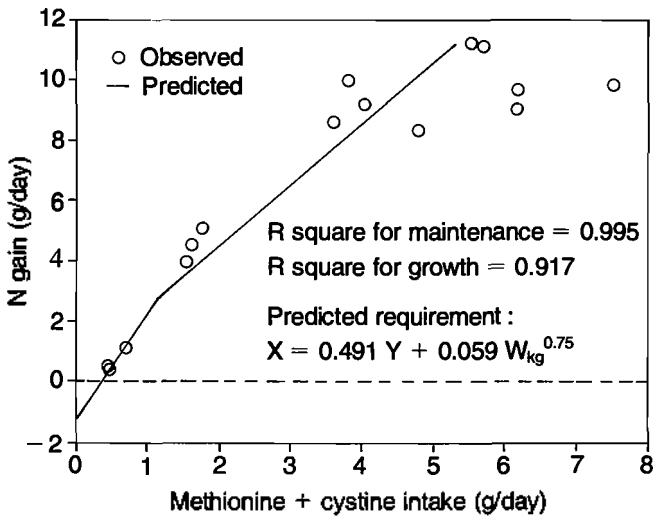


**Figure 4.** Nitrogen gain as influenced by methionine + cystine intake in young pigs.

Previously determined methionine + cystine requirement for the accretion of 1 g body N (protein × 6.25) in growing pigs (46 kg) was 0.225 g. In contrast, from the relationship between N retention and amino acid intake the daily methionine + cystine requirements for N equilibrium were estimated to be 0.049 g/W$_{kg}^{0.75}$ per day (Fuller et al., 1989). The maintenance requirements for methionine + cystine estimated in N balance studies were 0.026 g/W$_{kg}^{0.75}$ per day in nongravid gilts averaging 145 kg weight by Baker et al. (1966). These requirements from equation are generally close to requirements for growing pig (40 kg) values. The same predicted equation would underestimate the methionine + cystine requirement for the maintenance and the accretion of 1 g body N in young pigs, while the same predicted equation would overestimate the methionine + cystine requirement for the maintenance and the accretion of 1 g body N in finishing pigs.

From the relationship of weight gain to N gain, the N percentage of retained body weight was 2.00% (5.602/

279). Multiplied by 6.25, the protein content of weight gained was 12.55%. Based on N retention and weight gain responses, as a proportion of CP (N × 6.25) gained, methionine + cystine calculated to be 4.4%. This can be compared with mean methionine + cystine content of muscle protein in young pig of 3.08% (Chung and Baker, 1992b).

The daily level of net protein synthesis increases in a curvilinear fashion until a genotypic maximum rate is obtained, and then it begins to decline (Tullis, 1980). As a result, dietary amino acid requirements for protein accretion also increase in a curvilinear fashion as metabolic body size increases. Dietary amino acid requirements for maintenance, in contrast, respond linearly with increases in metabolic body size until mature body weight is achieved (Hahn and Baker, 1995).

The maintenance requirement determined for methionine+cystine (Fuller et al., 1989) is 150% of the maintenance requirement for lysine. As with all of the other essential amino acids, a significant portion of the methionine + cystine maintenance for requirement results from obligatory oxidation and gastrointestinal losses. Unlike most other amino acids, however, the methionine and cystine required to produce specialized products of metabolism may be important to the maintenance requirement for methionine+cystine. The transsulfuration pathway provides labile methyl groups necessary for the synthesis of creatine, catecholamines, carnitine, and phosphatidylcholine. Cysteine is used to synthesize taurine, glutathione and active sulfate. Losses of cystine also result from the normal epidermal and integument tissue losses (Hahn and Baker, 1995).

Plasma methionine + cystine concentrations of young pigs fed diets containing these 5 graded levels of methionine + cystine are presented in figure 5. Plasma methionine + cystine content remained constant up to the inflection point and then rose up abruptly. The inflection point (3.888 g/d) could be regarded as methionine+cystine requirement for growth. If the methionine + cystine intake at that inflection point is converted to a dietary percentage, assuming that feed intake is 0.95 kg per day, the requirement is 0.41% of diet. This value is slightly below previous estimates of 0.49 ± 0.04% as shown in table 9. Plasma amino acid concentrations to 5 graded levels of methionine + cystine are presented in table 6. Plasma methionine + cystine concentration changed in the quadratic fashion as dietary methionine + cystine supply was elevated.

Plasma methionine + cystine concentrations of growing pigs fed diets containing these 5 graded levels of methionine + cystine are presented in figure 6. Plasma methionine + cystine content showed the same trend as shown with young pigs. The inflection point (6.935 g/d) could be regarded as methionine + cystine requirement for growth. If the methionine + cystine intake at that inflection point is converted to a dietary percentage assuming, that feed intake is 1.9 kg per day, the requirement is 0.37% of diet. This value is slightly below the values previous estimated 0.44±0.06% as shown in table 9.

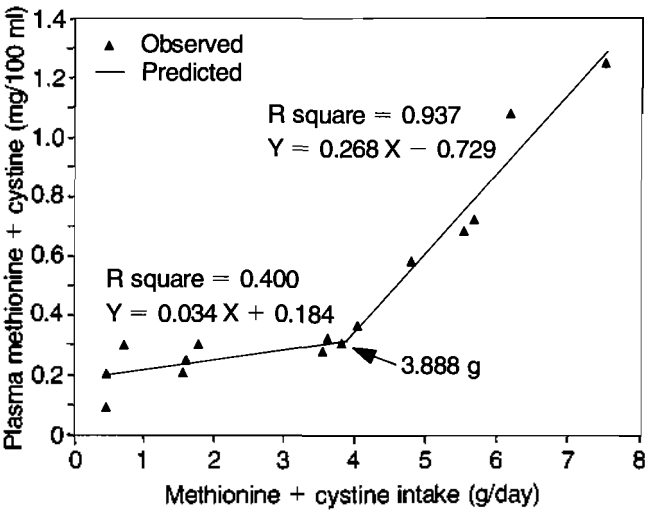


**Figure 5.** Plasma methionine + cystine concentration as influenced by methionine + cystine intake in young pigs.

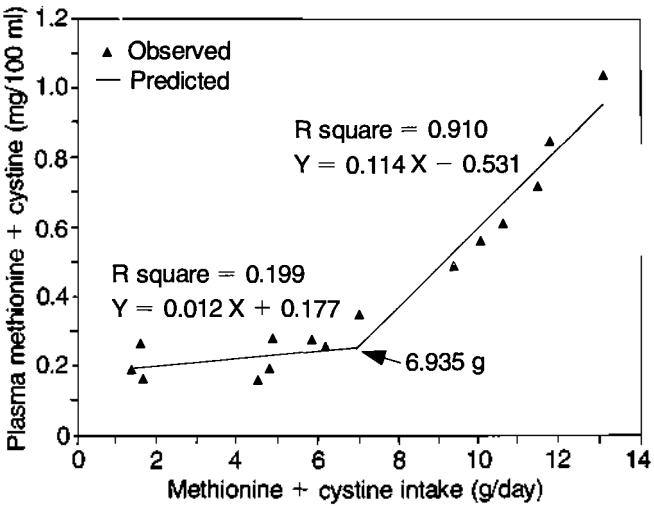


**Figure 6.** Plasma methionine + cystine concentration as influenced by methionine + cystine intake in growing pigs.

Plasma methionine + cystine concentrations of finishing pigs fed diets containing these 5 graded levels of methionine + cystine are presented in figure 7. Plasma

methionine + cystine content remained constant up to the inflection point and then rose up abruptly. The inflection point (8.116 g/d intake) could be regarded as methionine + cystine requirement for growth. If the methionine + cystine intake at that inflection point is converted to a dietary percentage, assuming that feed intake is 3.11 kg per day, the requirement is 0.26% of diet. This value is slightly below previous estimates (0.31 ± 0.06%) as shown in table 9.

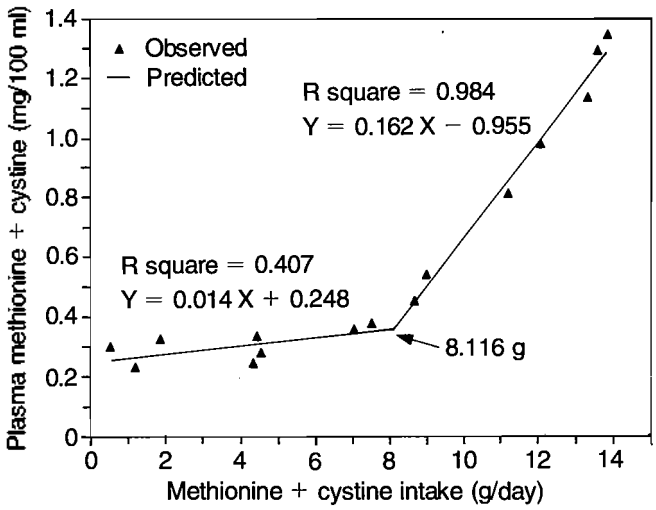


**Figure 7.** Plasma methionine + cystine concentration as influenced by methionine + cystine intake in finishing pigs.

Plasma amino acid concentrations of finishing pigs fed with 5 graded levels of dietary methionine + cystine are presented in table 8. Plasma methionine + cystine concentration changed in the quadratic fashion as dietary methionine + cystine supply was elevated. table 10 shows methionine+cystine requirement estimations based on model equations for 10, 40 and 70 kg pigs and lists of methionine+cystine requirements calculated from NRC (1988) nutrient requirements for each corresponding pigs. Total methionine + cystine requirements summing growth and maintenance are in close agreement with NRC (1988) requirements. The proportion of methionine + cystine needs for maintenance were greater for young and adult pigs than for growing pigs. Pigs weighing 20 to 50 kg body weight, which grow at more rapid rate, tended to need less methionine + cystine for maintenance compared to smaller or larger body weight of pigs as suggested by Hahn and Baker (1995).

**Table 10.** Requirement estimates derived from model equations for 10, 40 and 70 kg pigs

| Body weight | Weight gain | Feed intake | Requirement | | Total needs | NRC needs | Maintenance/ Total |
|---|---|---|---|---|---|---|---|
| | | | Growth | Maintenance | | | |
| (kg) | (kg/d) | (kg/d) | (g/d) | (g/d) | (g/d) | (g/d) | (%) |
| 3.0 | 0.20 | 0.25 | 1.727 | 0.112 | 1.838 | 1.700 | 6.1 |
| 7.5 | 0.25 | 0.46 | 2.158 | 0.222 | 2.380 | 2.700 | 9.3 |
| 15.0 | 0.45 | 0.95 | 3.885 | 0.373 | 4.258 | 4.600 | 8.8 |
| 45.0 | 0.70 | 1.90 | 7.182 | 0.278 | 7.460 | 7.800 | 3.7 |
| 80.0 | 0.82 | 3.11 | 7.620 | 0.508 | 8.129 | 10.600 | 6.2 |

## IMPLICATIONS

Based upon growth rate, the methionine + cystine requirement for young pigs weighing 15 kg and gaining 0.45 kg/d is 0.45% of the diet. From the data of N gain, the requirement was estimated to be 0.49% of the diet. Similar requirement (0.41%) for methionine + cystine was obtained from the plasma methionine + cystine breakpoint. About 8 to 10% of these requirements were utilized for maintenance.

Based upon growth rate, the methionine + cystine requirement for growing pig weighing 45 kg and gaining 0.7 kg/d is 0.40% of the diet. Similar requirement (0.37%) for methionine + cystine was obtained from the plasma methionine+cystine breakpoint. About 4% of these requirements was utilized for maintenance.

Based upon growth rate, the methionine+cystine requirement for finishing pigs weighing 80 kg and gaining 0.82 kg/d is 0.27% of the diet. Similar requirement (0.26 %) for methionine + cystine was obtained from the plasma methionine + cystine breakpoint. Approximately 6 to 7% of these requirements were utilized for maintenance.

## REFERENCES

Allee, G. L. and R. C. Trotter. 1974. Sulfur amino acid requirement of the finishing pig. J. Anim. Sci. 39:974.

(Abstr.)
AOAC. 1990. Official Methods of Analysis (15th Ed.). Association of Official Analytical Chemists, Arlington, VA.
Baker, D. H., D. E. Becker, H. W. Norton, A. H. Jensen and B. G. Harmon. 1966. Quantitative evaluation of the tryptophan, methionine and lysine of adult swine for maintenance. J. Nutr. 89:441.
Balogun, O. O. and B. L. Fetuga. 1981. Methionine requirement of weanling large white Landrace pigs as determined by plasma urea concentration, nitrogen retention and some urinary nitrogenous components. Anim. Prod. 33:305.
Braude, R. and M. A. Esnaola. 1973. Methionine+cystine requirements of growing pigs. Br. J. Nutr. 30:437.
Chung, T. K., O. A. Izquierod, K. Hashimoto and D. H. Baker. 1989. Methionine requirement of the finishing pig. J. Anim. Sci. 67:2677.
Chung, T. K. and D. H. Baker. 1992a. Methionine requirement of pigs between 5 and 20 kilograms body weight. J. Anim. Sci. 70:1857.
Chung, T. K. and D. H. Baker. 1992b. Maximal portion of the young pig's sulfur amino acid requirement that can be furnished by cystine. J. Anim. Sci. 70:1182.
Chung, T. K. and D. H. Baker. 1992c. Efficiency of dietary methionine utilization by young pigs. J. Nutr. 122:1862.
Coma, J., D. Carrion and D. R. Zimmerma. 1995. Use of plasma urea nitrogen as rapid response criterion to determine the lysine requirement of pigs. J. Anim. Sci. 73:472.
Fuller, M. F., R. McWilliam, T. C. Wang and L. R. Giles. 1989. The optimum dietary amino acid pattern for growing pigs. 2. Requirements for maintenance and for tissue protein accretion. Br. J. Nutr. 62:255.
Hahn, J. D. and D. H. Baker. 1995. Optimum ratio to lysine of threonine, tryptophan and sulfur amino acids for finishing swine. J. Anim. Sci. 73:482.
Keith, M. O., D. A. Cjrosensen and B. D. Owen. 1972. Determination of the methionine requirement of growing pigs using serum free amino acids. Can. J. Anim. Sci. 52:163.
NRC. 1988. Nutrient Requirements of Swine (9th Ed.). National Academy Press. Washington. DC.
Oestemer, G. A., R. J. Meade, W. L. Stockland and L. E. Hanson. 1970. Methionine supplementation of Opaque-2 corns for growing swine. J. Anim. Sci. 31:1133.
Shin, I. S. and F. N. Owens, J. E. Pettigrew and J. W. Oltjen. 1994a. Apportioning threonine requirements for maintenance versus growth for rats. Nutr. Res. 14:93.
Shin, I. S., F. N. Owens, J. E. Pettigrew and J. W. Oltjen. 1994b. Apportioning methionine requirements for maintenance versus growth of rats. Nutr. Res. 14:229.
Steel, R. G. D. and J. H. Torrie. 1980. Principles and procedures of statistics. McGraw-Hill, New York, NY.
Stockland, W. L., R. J. Meade and J. W. Nordstrom. 1971. Lysine, methionine and threonine supplementation of a corn-meat and bone meal diet for growing swine. J. Anim. Sci. 32:262.
Taylor, S. J., D. J. A. Cole and D. Lewis. 1983. Amino acid requirements of growing pigs. Anim. Prod. 37:265.
Tullis, J. B. 1981. Protein growth in pigs. Ph.D. Thesis. Univ. of Edinburgh.