

# Establishment of the Minimum Biological Capacity for Nitrogen Excretion in Pigs

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### Summary and Implications

To determine the minimum biological capacity for nitrogen (N) excretion for pigs, dietary regimens were created and fed that were designed to eliminate fecal excretion of undigested feed N, minimize endogenous N secretions and minimize intakes of nitrogenous compounds (amino acids) above those of the pigs biological needs. Excretion of undigested fecal N was eliminated by feeding ingredients containing highly digestible ( $\approx 100\%$ ) sources of nitrogen and by eliminating compounds that bind N. Endogenous secretions were minimized by eliminating antinutritional factors from the diet and by minimizing enteric bacterial populations. Intakes of amino acids above the animal's needs were minimized by providing a pattern of amino acids that closely matched that needed by the pig. Furthermore, dietary amino acids were provided to the pigs in amounts above, at, and below their biological needs based on the amounts of urea N excreted in the urine and the amounts of N accrued in the body. From two-slope breakpoint analysis, apparent digestible N intake resulting in maximum N retention ( $2.58 \text{ g}\cdot\text{kg}^{-1}\text{BW}^{.75}\cdot\text{d}^{-1}$ ) was determined to be  $3.66 \text{ g}\cdot\text{kg}^{-1}\text{BW}^{.75}\cdot\text{d}^{-1}$ . When daily apparent digestible nitrogen intakes were below the pigs' determined need, the amount of digestible N ( $\text{mg}\cdot\text{kg}^{-1}\text{BW}^{.75}\cdot\text{d}^{-1}$ ) lost for body maintenance processes was estimated as .239 in urine and .080 in feces. The amount lost in urine as unusable for body N accretion was  $.206 \text{ g}\cdot\text{kg}^{-1}\text{BW}^{.75}\cdot\text{d}^{-1}$  of each gram of digestible N consumed above body maintenance needs. When daily apparent digestible N intakes were above the pigs determined need, .900 g of each gram of additional N consumed above that needed for body N accretion was excreted. The minimum biological capacity for N excretion in pigs, defined as total (urinary plus fecal) obligatory losses of N, is estimated to be  $.287 \text{ g}\cdot\text{kg}^{-1}\text{BW}^{.75}\cdot\text{d}^{-1}$  to support pigs at N maintenance and  $1.11 \text{ g}\cdot\text{kg}^{-1}\text{BW}^{.75}\cdot\text{d}^{-1}$  for pigs at maximum body N accretion.

Using these estimates, the minimal biological capacity for N excretion can be calculated for pigs at various stages of growth. For example, in 60 kg pigs, minimum capacity for N excretion is estimated at .10 and .39 g/kg body weight/day in pigs in states of N maintenance and maximum body N accretion, respectively. These values are 12 and 44%, respectively, of N excretion relative to published standards (ASAE D384.1). Similarly, the N content of excreta from

animals excreting N at their biological minimum was determined to be 2.57 g N/liter, or 18% of standard excreta N content (corrected for volatilization, ASAE D384.1). Based on these data, the minimum biological capacity for the excretion of N in pigs is substantially less than current estimates of N excretion and can be achieved by eliminating dietary factors that contribute to N excretion. Furthermore, dietary regimens that allow the minimum biological capacity for N excretion to be achieved are biologically capable of supporting maximum rates of body accretion (i.e., lean tissue growth) in pigs.

### Introduction

Historically, agriculture systems relied heavily on the application of animal excreta to land because of its beneficial effects as a fertilizer. Today, however, the development of larger production units on concentrated land areas has led to public concern regarding the potential for animal excreta to act as an environmental pollutant. This potential for animal excreta to harm the environment has led to governmental regulations designed to ensure proper use of manure to minimize the impact of animal agriculture on the environment. Measures that minimize the excretion of nutrients, especially N and P, by pigs are needed to address these societal and regulatory concerns. The amount of nutrients excreted by pigs and the odors associated with this excreta are related to the amount and form of nutrients provided in the animals' dietary regimen.

Excretion of nitrogen in pigs is largely dependent on the proportion of nitrogenous compounds in feed ingredients that are digested and absorbed by the animal, the amount of endogenous nitrogenous compounds secreted by the animal, and the amount of these nitrogenous compounds consumed in relation to the animal's biological needs. The minimum biological capacity for N excretion is hypothesized to be substantially lower than estimates of N excretion of animals fed under common production systems. The low digestibility of nitrogenous compounds in many common feed ingredients, the presence of dietary factors that increase the endogenous N losses in feces and urine, and consumption of amino acids in excess of the pig's biological need all contribute to increasing the amount of N excreted above the minimal biological capacity of the pig.

The objectives of the study were to define the minimum biological capacity of pigs for nitrogen excretion, and to determine if minimal N excretion is compatible with maximum rates of body N (lean tissue) accretion.

### Materials and Methods

*Dietary Regimens.* To determine the minimum biological capacity of pigs for N excretion, dietary regimens were created and fed that were designed to 1) eliminate fecal excretion of undigested fecal N, 2) minimize endogenous N secretions and, 3) minimize intakes of amino acids (essential

and nonessential) above those of the animals biological needs. Specifically, excretion of undigested fecal N was eliminated by feeding diets consisting of semipurified, highly digestible ( $\approx 100\%$ ) sources of nitrogen. The presence of N binding compounds (i.e., phytate, neutral detergent fiber) in the diet also were largely eliminated. Endogenous N secretions were minimized by eliminating antinutritional factors (i.e., trypsin inhibitors, lectins, saponins, and tannins) from the diet, and by minimizing enteric bacterial populations and their associated excretions via the inclusion of a broad-spectrum antibiotic and minimizing the availability of nutrients (proteins and fiber) for microbial growth in the hind gut. The intakes of amino acids above the animals needs were minimized by providing all dietary amino acids (essential and nonessential) in a pattern that closely matched that needed by the pig. Dietary N (amino acids) was provided to the pigs in an amount above, at, and below their biological needs based on the amounts of the urea N excreted in the pig's urine and the amount of N accrued in the body. Finally, the pigs also were provided dietary intakes of phosphorus at amounts above, at, and below their biological needs to determine the effect of dietary P regimen on minimum N excretion and accretion in pigs.

**Animals and Feeding Regimens.** The basal diet contained four component mixtures identified as an energy mix, nitrogen (protein) mix, calcium-phosphorus mix, and trace mineral and vitamin mix. The composition of the four component mixes used to make the diets is shown in Tables 1 - 4. The energy sources (non-nitrogen calories) consisted of corn starch (B700 Grain Processing Corporation), dextrin (Grain Processing Corporation), corn oil, and corn bran (Cargill, Inc.). Nitrogen sources in the diet consisted of casein (Alacid 710 Edible Acid Casein from New Zealand Milk Products, Inc.), whey protein concentrate (AMP 8000 from AMPC, Inc.), and crystalline amino acids (Heartland Lysine, Inc.; Nutri Quest, Inc.). The phosphorus sources consisted of monosodium phosphate, casein, and whey protein concentrate. The energy sources (non-nitrogen calories) were obtained by isolating the highly digestible carbohydrate (starch) and lipid (oil) fractions in corn. The less digestible carbohydrate (corn bran) also was isolated and included in the diet at low amounts to provide the minimum neutral detergent fiber (2%) needed for maintenance of gastrointestinal tract integrity. Nitrogen sources were obtained by isolating the highly digestible casein and whey proteins from cows' milk. The phosphorus sources consisted of monosodium phosphate and to a lesser extent casein and whey protein concentrate. These nutrient sources are free of N binding compounds (i.e., phytate). The dietary ingredients also are free of antinutritional factors (i.e., soy trypsin inhibitors, saponins, lectins, and fibrous compounds) that stimulate endogenous N secretions. Dietary fiber content also was minimized to limit N production and secretion via enteric bacteria. The vitamin-trace mineral mixes were included in a corn starch, rather than a traditional fibrous carrier, to minimize presence of compounds that enhance endogenous N secretions and N binding. The diets were formulated to provide an estimated ideal pattern of each essential and

nonessential amino acid (Bunce and King, 1969; Fuller *et al.*, 1989; Chung and Baker, 1992) to minimize excretion of nitrogenous compounds in the urine. Glycine was provided at only 80% of the ideal pattern with the remainder estimated to be synthesized from the N in those amino acids provided slightly in excess of their ideal patterns. Specific amino acid ratios as a percentage to lysine (100) were as follows: tryptophan (18.1), threonine (63.3), methionine + cysteine (56.1), isoleucine (63.6), histidine (32.0), valine (68.1), phenylalanine + tyrosine (93.6), leucine (117.7), arginine (38.4), glycine (51.2), serine (64.3), proline (99.1), alanine (45.6), aspartic acid (102.6), and glutamic acid (210.6). The nitrogen (protein) and energy mixes (Tables 1 and 2) were formulated to be isocaloric with the same amount of calories being supplied by corn bran fiber and corn oil in each mix. Calories supplied by cornstarch in the energy mix (Table 1) were substituted with isocaloric amounts of whey protein concentrate, casein and crystalline amino acids in the protein mix (Table 2). Dietary concentrations of all other nutrients were estimated to meet or exceed the estimated nutrient needs of high lean pigs (NRC, 1998).

**Table 1. Energy mix composition (%).**

Ingredient	% of Mix
Corn starch	83.50
Dextrin	5.27
Corn bran <sup>a</sup>	4.46
Corn oil	6.59
Calcium carbonate	0.16
Ethoxyquin	0.02

<sup>a</sup> Contained the following (%): 1.8 lipid, 56.6 neutral detergent fiber, 1.5 nitrogen, .03 calcium, .02 phosphorus.

**Table 2. Protein mix composition (%).**

Ingredient	% of Mix
Casein	24.46
Whey protein concentrate <sup>a</sup>	43.12
Crystalline amino acids	3.25
Corn starch	16.29
Corn bran <sup>b</sup>	5.80
Corn oil	5.40
Calcium carbonate	1.67
Ethoxyquin	0.01

<sup>a</sup> Contained the following (%): 4.6 lipid, 12.5 nitrogen, .29 calcium, .49 phosphorus.

<sup>b</sup> Contained the following (%): 1.8 lipid, 56.6 neutral detergent fiber, 1.5 nitrogen, .03 calcium, .02 phosphorus.

**Table 3. Calcium-phosphorus mix composition (%).**

Ingredient	% of Mix
Calcium carbonate, reagent grade	41.61
Monosodium phosphate	30.07
Corn starch	28.32

**Table 4. Trace mineral-vitamin mix composition (%).**

Ingredient	% of Mix
Trace mineral mix <sup>a</sup>	3.75
Magnesium oxide	3.75
Potassium sulfate	30.00
Sodium chloride	3.13
Monosodium phosphate	4.32
Selenium premix (.06%)	1.25
Vitamin mix <sup>b</sup>	12.50
Choline chloride, 60%	6.00
Antibiotic <sup>c</sup>	12.50
Corn starch	22.81

<sup>a</sup> Provided the following per kg of diet: Iron 262.5 mg, zinc 225 mg, Manganese 90 mg, Copper 26.3 mg, Iodine .3 mg.

<sup>b</sup> Provided the following per kg of diet: Biotin .3 mg, Folic acid 1.8 mg, Niacin 85.1 mg, Pantothenic acid 57.9 mg, Riboflavin 19.6 mg, Thiamin 6 mg, Vitamin A 11, 125.7 IU, Vitamin D 1196.9 IU, Vitamin K 3 mg, Vitamin E 78.6 IU, vitamin B<sub>12</sub> .09 mg, Vitamin B<sub>6</sub> 8.8 mg.

<sup>c</sup> Provided the following per kg of diet: chlortetracycline 110 mg, sulfamethazine 100 mg, penicillin 50 mg.

Six sets of four littermate barrows from a genetic strain with a moderate to high capacity for protein accretion were used. Pigs were weaned at  $12 \pm 2$  d of age via a segregated early weaning scheme and penned individually in  $.61 \times 1.50$  m stainless steel metabolism pens. Pigs were fed a milk-based pelleted diet for 18 d. Pigs were then fed a semipurified, basal diet containing 3.41% N (1.50% apparent ileal digestible lysine) and .70% available P (NRC, 1998) for 4 d. These dietary concentrations of digestible lysine and available P met or exceeded the biological needs of the pigs based on previous evaluations using the same genetic strain at similar body weights and health status (Williams *et al.*, 1997b; Stahly and Cook, 1996). After this 4-d adaptation period, pigs were randomly allotted within litter to one of four feeding regimens. The feeding regimens consisted of providing 1) constant concentrations of dietary N and P (CN, CP); 2) constant dietary N and dietary P adjusted to reduce urinary P (CN, AP); 3) dietary N adjusted

to reduce urinary N and constant dietary P (AN, CP); and 4) dietary N and P adjusted to reduce both urinary N and P (AN, AP). Dietary N and P adjustment were made by lowering N and P concentrations at 2-d intervals until minimal excretion of urea N and inorganic P, respectively, in the urine were achieved. Once minimum excretion was achieved, dietary N and P concentrations were again adjusted at 2-d intervals until dietary concentrations of these nutrients again achieved the same levels as in the basal diet. Dietary adjustments were made every third day according to the amounts of urea N and inorganic P excreted in the urine during the initial day of each 2-d collection period. The concentration of N in the basal (CN) diet was raised to 3.74% at the initiation of collection period three. The concentration of available P in the basal (CP) diet was raised to .77% and then to .85% at the initiation of collection period three and five, respectively. These nutrient concentrations were increased in response to low urinary excretion of these nutrients by the pigs fed the basal CN and CP diets that indicated that the N and P intakes were not consistently exceeding the pigs needs during these stages of the study. The feeding regimens were initiated at BW of  $15.8 \pm 2.2$  kg and ended at BW of  $28.28 \pm 3.7$  kg.

**Animal Care.** The pigs were individually penned in metabolism stalls and allowed *ad libitum* access to feed and water. Room temperature was maintained between 21.1 and 30.0°C for the duration of the study. Pigs were injected intramuscularly with 1 ml of Naxcel on day 12, 13, and 14 of the experiment. Pig weights and feed consumption were determined at 2-d intervals throughout the trial. Feed wastage was collected daily on trays below the feeder, dried and weighed, and the weight was subtracted from feed disappearance to determine net feed consumption. The experimental protocol was approved by the Iowa State University Animal Care Committee.

**Sample Collection and Analysis.** Nitrogen concentrations in the ingredients, diets, waste feed, urine and feces were determined in triplicate using the Kjeldahl procedure (AOAC, 1990). Ingredients, diets and waste feed subsamples were ground through a .5-mm screen prior to nitrogen analysis. Urine was collected daily for each 2-d adjustment period throughout the trial. Urea N concentration of the urine was analyzed on the first day of each 2-d collection period to determine the nitrogen adjustment of the diet by colorimetrically measuring the product formed in the direct reaction of urea and diacetyl monoxime as described by Marsh *et al.* (1957). Urine collected from the second day of each collection period was pooled with that from the first day for analysis of total nitrogen content. Urine was first passed through a cloth filter and then collected in 18.9-liter containers in 50 ml each of concentrated HCl and toluene as preservatives. Urine was refiltered before measurement in an attempt to remove any waste feed in the urine sample. Any feed wastage collected from the filter was added back to the feed wastage for each pig and then dried and weighed.

A 500-ml aliquot of the urine sample was retained for N analysis. Feces were collected every second day of each collection period and preserved in 1 N HCl. Fecal collections were freeze-dried to determine DM content. Dried fecal samples were allowed to air equilibrate and then ground through a .5-mm screen for analysis of N content.

**Statistical Analysis.** To determine the response to constant and adjusted concentrations of dietary N and P, data were analyzed within period as a  $2 \times 2$  factorial design by analysis of variance techniques using the GLM procedure of SAS (1998). The pig was considered the experimental unit. Data are reported as least square means. Additionally, two-slope breakpoint analysis was used to estimate dietary digestible nitrogen intakes needed to maximize body nitrogen retention as well as the dietary digestible phosphorus intakes needed to maximize body nitrogen retention. Regression analysis was then used to determine the amount of dietary N lost as undigested feed N in the feces, the amount of endogenous N lost in the feces and urine, and the amounts of digested nitrogen unused for body N accretion and subsequently excreted in the urine.

### Results and Discussion

**Estimates of the Minimum Biological Capacity for N Excretion.** Because the composition of the N sources was constant in all feeding regimens, the proportion of dietary N that was excreted in the feces was not expected to be altered by N intake. Two-slope breakpoint analysis was used to confirm this expectation. Because there was not a breakpoint (Figure 1), all observations were used in the regression analysis of fecal N excretion,  $\text{g} \cdot \text{kg}^{-1} \text{BW}^{.75} \cdot \text{d}^{-1}$  vs total daily nitrogen intake,  $\text{g} \cdot \text{kg}^{-1} \text{BW}^{.75} \cdot \text{d}^{-1}$ . The regression for this analysis was:  $y = .040 (\text{SE } .014) + .033 (\text{SE } .004)x$ , where the intercept is the amount endogenous fecal N losses,  $\text{g} \cdot \text{kg}^{-1} \text{BW}^{.75} \cdot \text{d}^{-1}$ , and the slope is undigested fecal N in grams per gram of digested N consumed per  $\text{kg}^{.75}$  per day. Because the diets fed consisted of digestible N sources free of antinutritional factors, it was expected that the amount of fecal excretion necessary to support maintenance would be at a minimum. In the current study, fecal endogenous losses due to cell sloughing, N recycling, waste feed, and other maintenance processes are estimated to be  $.040 \text{ g} \cdot \text{kg}^{-1} \text{BW}^{.75} \cdot \text{d}^{-1}$  (Table 6). Chung and Baker (1992) assumed that fecal N excretion was entirely of endogenous origin when pigs are fed purified diets in which 100% of the dietary N was absorbed. Based on their data, fecal endogenous losses total  $.042 \text{ g} \cdot \text{kg}^{-1} \text{BW}^{.75} \cdot \text{d}^{-1}$ .

Using two-slope breakpoint analysis, the amount of apparent digestible nitrogen intake (R) needed to maximize body N retention (L) was determined to be  $3.66 \text{ g} \cdot \text{kg}^{-1} \text{BW}^{.75} \cdot \text{d}^{-1}$  (SE .107) (Figure 2, Table 5). When daily digestible nitrogen intakes were below the pigs estimated needs ( $3.66 \text{ g} \cdot \text{kg}^{-1} \text{BW}^{.75} \cdot \text{d}^{-1}$ ), the amount of digestible N excreted in the urine from body maintenance processes is estimated as  $.239 \text{ g} \cdot \text{kg}^{-1} \text{BW}^{.75} \cdot \text{d}^{-1}$  (SE .126) and the amount excreted in the urine as being unusable for body N accretion

is  $.206 \text{ g} \cdot \text{kg}^{-1} \text{BW}^{.75} \cdot \text{d}^{-1}$  (Table 6) for each gram of digestible N consumed above body maintenance needs. When daily N intakes were above the pigs estimated need for body N accretion,  $.900 \text{ g}$  of each gram of additional N consumed above that needed for body N accretion was excreted.

Based on these data, the maintenance need for lysine is calculated to be  $37.3 \text{ mg} \cdot \text{kg}^{-1} \text{BW}^{.75}$  assuming that lysine represents 2.5% of body protein. This estimation of the maintenance requirement for lysine agrees closely with literature estimates ranging from 36 to  $42 \text{ mg} \cdot \text{kg}^{-1} \text{BW}^{.75}$  (Fuller *et al.*, 1989; Stahly, 1990). Above maintenance, pigs were 79.4% (1.00/1.26) efficient in retaining apparent digestible N in the body. Chung and Baker (1992), in their determination of the ideal amino acid pattern, also determined that nitrogen intake was used with 80% gross efficiency for N retention when daily amino acid intakes were equal to or below the animals daily needs. Based on these data, the dietary amino acid profile fed in the current study provided an amino acid protein necessary for optimal utilization of dietary N. Above the break point, the slope was  $.103x$  (SE .083), where the slope is the efficiency of nitrogen retention. Therefore, at N intakes above the pigs daily needs, the dietary N consumed in excess of the requirement was essentially (90%) excreted.

**Table 5. Estimation of the apparent digestible N intake,  $\text{g} \cdot \text{kg}^{-1} \text{BW}^{.75} \cdot \text{d}^{-1}$ , needed to maximize body N retention ( $\text{g} \cdot \text{kg}^{-1} \text{BW}^{.75} \cdot \text{d}^{-1}$ ) and the gross efficiency (u,v) of utilization of digestible N for body N accretion at digestible N intakes below and above the digestible N requirement, respectively.**

Criteria	Symbol	Value	Standard Error
Dietary N intake, $\text{g} \cdot \text{kg}^{-1} \text{BW}^{.75} \cdot \text{d}^{-1}$			
At maximum retention	R	3.66	.107
Body N retention, $\text{g} \cdot \text{kg}^{-1} \text{BW}^{.75} \cdot \text{d}^{-1}$			
At maximum retention	L	2.58	.053
Efficiency of N utilization			
Body N retention, g/g of digestible N intake			
At N intakes below R	U	0.62	.033
Body N retention g/g of digestible N intake above maintenance			
At N intakes below R	UC	.80	.059
At N intakes above R	V	.10	.069

Based on these data, the minimum biological capacity for N excretion is, therefore, estimated to be  $.287 \text{ g} \cdot \text{kg}^{-1} \text{BW}^{.75} \cdot \text{d}^{-1}$  in pigs at N maintenance and  $1.11 \text{ g} \cdot \text{kg}^{-1} \text{BW}^{.75} \cdot \text{d}^{-1}$  in pigs at maximum body N accretion. A maintenance estimate of  $.268 \text{ g} \cdot \text{kg}^{-1} \text{BW}^{.75} \cdot \text{d}^{-1}$  was obtained by Fuller *et al.*, (1989) as a result of feeding a protein-free diet to pigs. However, there is concern that maintenance estimates

determined by feeding N-free diets underestimate the amount of endogenous N loss when practical diets are fed (Nyachoti *et al.*, 1997).

**Table 6. Estimation of the minimum biological capacity for N excretion at body N maintenance and at maximum body N accretion<sup>a</sup>.**

Excreta source	Minimum N Excretion	
	At N maintenance	At maximum N accretion
Feces N, g·kg <sup>-1</sup> BW <sup>.75</sup> /day		
Endogenous N	.040	.040
Undigested feed N	.008	.120
Urine N, g·kg <sup>-1</sup> BW <sup>.75</sup> /day		
Endogenous N	.239	.239
Unused digested feed N	.000	.705
Total Excreta N, g·kg <sup>-1</sup> BW <sup>.75</sup> /day		
Total N	.287	1.104

<sup>a</sup> Daily digestible N intakes needed to achieve body N maintenance and maximal body N accretion were .239 and 3.66 g·kg<sup>-1</sup>BW<sup>.75</sup>·d<sup>-1</sup>, respectively.

A comparison of the N balance of pigs in the present experiment with that of pigs from a related study in which corn-soybean meal-whey based diets with moderate N digestibility, moderate amounts of endogenous N secretion, and a moderate to good amino acid balance were fed is outlined in Table 7. Pigs were from the same genetic strain and farm of origin in both studies. Pigs in both studies had the same average BW; however, pigs in the present study grew faster and accrued body N more rapidly. The responses of pigs to dietary amino acid (N) intakes that maximized body N accretion (at N requirement) and to those exceeding the N requirement (above N requirement) are reported. The elimination of the undigestible component of feed and the minimization of endogenous excretions lowered fecal N excretion by 3.7 and 4.2 g/d at the N requirement and above the N requirement, respectively. Minimizing the amounts of unusable amino acids by matching the pattern of dietary amino acids to that accrued in the pig's body as well as the presence of antinutritional factors lowered urinary N excretion by 5.0 g/d at the N requirement. Lowering the intake of amino acids from above the N requirement to the requirement lowered urinary N excretion by an additional 8.2 g/d.

The elimination of undigestible feed N, elimination of antinutritional factors, and minimization of intakes of amino acids above the pigs' needs was associated with greater rates of body weight and protein accretion. Thus, fecal and urinary N excretion expressed per kg of BW gain is further

reduced. Total N excreted per kilogram of BW gain is reduced from 61.1 g N excreted per kilogram BW gain when pigs are fed common commercial diets containing amino acid contents above the pigs need (Table 8) to 40.7 g N excreted per kilogram BW gain when pigs are fed moderately balanced diets above the N requirement to 14.2 g N per kilogram BW gain when pigs are fed highly digestible N sources in which amino acids intakes are matched to the pigs' biological need for growth. This is equivalent to a 77% reduction in excretion.

*Composition of Excreta at Minimum Excretion.* The amounts of total excreta and the solids and N content of the excreta produced in pigs expressing minimal N accretion are reported in Table 8. These amounts are contrasted to those of the ASAE standards. Feeding the highly digestible ingredients and minimizing antinutritional factors resulted in the excreta solids production of 7.9 g·kg<sup>-1</sup>BW<sup>.75</sup>/d. This value is 26% of standard excreta solid production of 30.1 g·kg<sup>-1</sup>BW<sup>.75</sup>/d.

In Table 8, the N content of excreta in pigs expressing a minimal N excretion is compared with the standard excreta N content used in Iowa to establish regulatory policy as well as the ASAE standard. Pig excreta contained 2.57 g N/liter of excreta when pigs were expressing minimum N excretion and maximum N accretion. This value represents 26, 22, and 18% of the Iowa Adopted Standard, concentrations measured in pits of commercial swine finishing facilities (Lorimor *et al.*, 1997) and the ASAE standard of 10.0, 11.62, and 14.4 g N/liter of excreta, respectively, after ammonia volatilization is accounted for. The form that the N was excreted also differed in pigs expressing minimal N excretion. At minimum N excretion urea nitrogen represented 39% of urinary N compared with 70% in pigs fed excess intakes of dietary amino acids. As the proportion of urea N in the urine is reduced, it is hypothesized that the volatilization of N as NH<sub>3</sub> and, therefore, odor also would be reduced.

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**Table 7. Responses of pigs to dietary amino acid intakes that maximized body N accretion at the N requirement and above the N requirement.**

Item	Dietary Amino Acid Intakes			
	At N Requirement <sup>a</sup>	Above N Requirement <sup>a</sup>	At N Requirement <sup>b</sup>	Above N Requirement <sup>b</sup>
Dietary regimen components				
N digestibility	High	High	Moderate	Moderate
Antinutritional factors	Low	Low	Moderate	Moderate
Amino acid balance	Good	Good	Moderate	Moderate
Amino acid intake	Optimal	Even	Optimal	Even
Mean pig weight, kg	22.0	22.3	21.6	21.5
BW gain and feed utilization				
Feed intake, g/d	1172 <sup>c</sup>	1224 <sup>d</sup>	1272	1215
BW gain, g/d	782 <sup>c</sup>	775 <sup>d</sup>	674	663
Gain:feed, g/g	667	633	537	520
N intake, g/d				
Total N	38.4	48.0	41.4	48.0
Digestible N	37.1	46.4	36.1	41.9
N accretion, g/d				
	26.2	27.1	21.5	21.0
N excretion, g/d				
Fecal N	1.6	1.9	5.3	6.1
Urinary N	9.6	17.8	14.6	20.9
Total N	11.2	19.7	19.9	27.0
N excretion, g·kg <sup>-1</sup> BW gain				
Fecal N	2.0	2.4	7.9	9.2
Urinary N	12.3	23.0	21.7	31.5
Total N	14.3	25.4	29.6	40.7

<sup>a</sup> Pigs fed dietary N regimens containing highly digestible N sources at intakes that resulted in the achievement of minimum N excretion and maximum N accretion.

<sup>b</sup> Pigs fed corn-soybean meal-whey based diets (Williams et al. 1997c).

<sup>c</sup> Daily feed intake and BW gains of pigs consuming 37 g digestible N per day.

<sup>d</sup> Daily feed intake and BW gains of pigs consuming 46g digestible N per day.



**Table 8. Excreta production and composition.**

Item	Excreta Source			
	Minimum capacity N excretion <sup>a</sup>	Iowa standard <sup>b</sup>	Commercial standard <sup>c</sup>	ASAE standard <sup>d</sup>
Excreta produced, g·kg <sup>-1</sup> ·BW <sup>-0.75</sup> /d				
Total				
As sampled	432			234
Evaporated <sup>e</sup>				?
Total	432			?
Solids	7.9			30.1
Excreta composition, g/liter				
Solids	18.4			128.6
N				
As sampled	2.57	6.00	6.97	10.30
Volatilized <sup>f</sup>	--	4.00	4.65	4.10
Total	2.57	10.00	11.62	14.40
N excreted, g/kg BW gain/day				
Total N	14.3			61.10 <sup>g</sup>

<sup>a</sup> Pigs fed dietary regimen containing highly digestible feedstuffs at intakes that resulted in the achievement of minimum N excretion and maximum N accretion.

<sup>b</sup> The N concentration of excreta of finishing pigs assumed for fertilizer value and regulatory policies in Iowa (Lorimor *et al.* 1997).

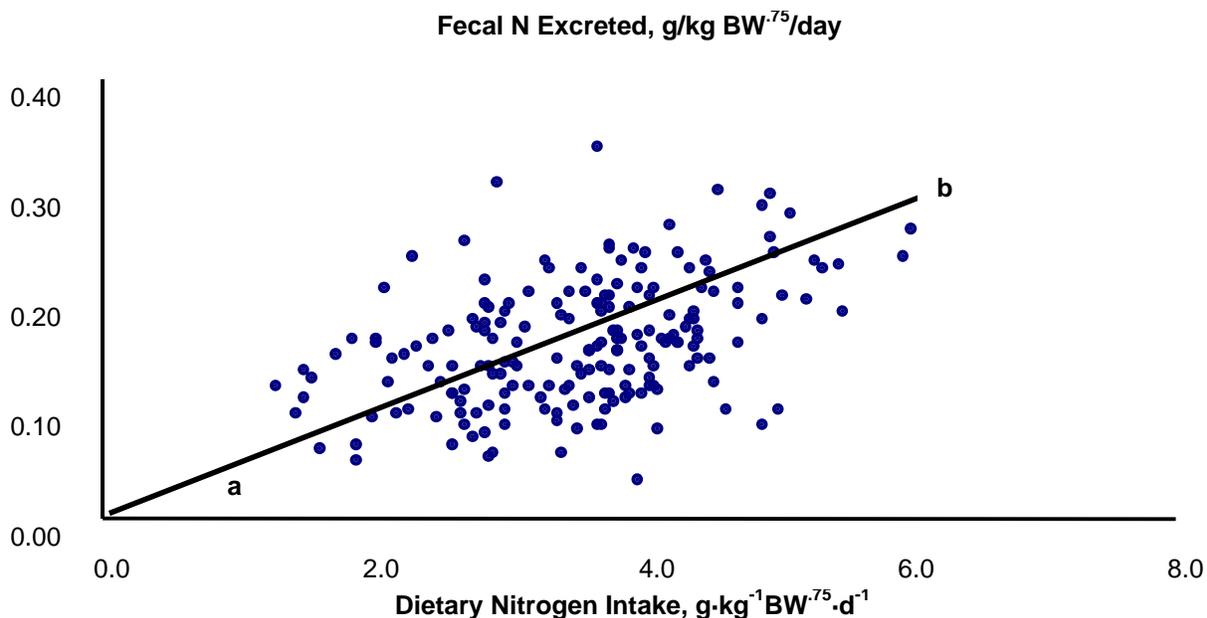
<sup>c</sup> The N concentration in excreta from concrete pits from 37 commercial swine finishing facilities (Lorimor *et al.* 1997).

<sup>d</sup> The N concentration assumed in standard swine excreta (ASAE D384.1).

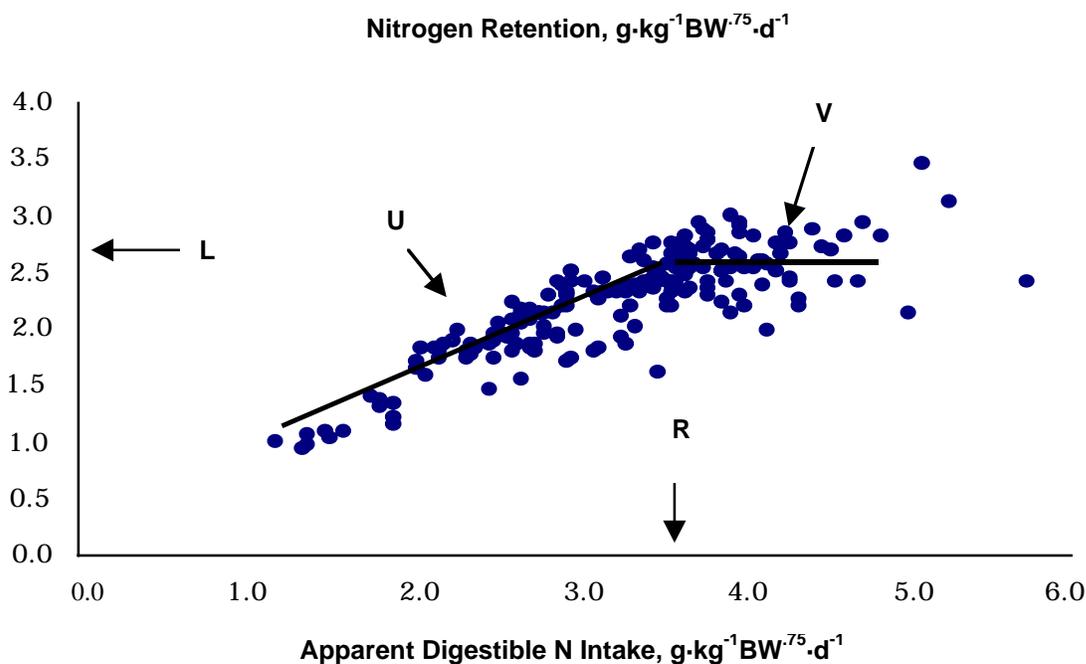
<sup>e</sup> No evaporation assumed for excreta at minimum N excretion because urine collected twice daily and frozen.

<sup>f</sup> Forty percent of excreta nitrogen assumed volatilized for pits (Peterson *et al.* 1998). No volatilization assumed for excreta at minimum N excretion because excreta N was trapped in acid and toluene.

<sup>g</sup> Adapted from Berth *et al.* (1999). Pigs assumed to gain 680 g BW/day while consuming a corn-soybean meal diet *ad libitum*.



**Figure 1.** Estimation of the amount of endogenous fecal N excretion (a, g·kg<sup>-1</sup>BW<sup>0.75</sup>·d<sup>-1</sup>) and the amount (b) of undigested feed N excreted in the feces for each gram of dietary N intake, g·kg<sup>-1</sup>BW<sup>0.75</sup>·d<sup>-1</sup>. n=190 observations.



**Figure 2.** Estimation of the amount of apparent digestible N intake (R, g·kg<sup>-1</sup>BW<sup>0.75</sup>·d<sup>-1</sup>) needed to maximize N retention (L, g·kg<sup>-1</sup>BW<sup>0.75</sup>·d<sup>-1</sup>) and the relative efficiency (U, V) of utilization of digestible N for body N accretion at digestible N intakes below and above R, respectively. n=190 observations.