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Project Title

Establishment of the Minimum Biological Capacity for Nitrogen Excretion in Pigs

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Abstract

To determine the minimum biological capacity for 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 amino acids above those of the pigs biological needs. Excretion of undigested fecal N was eliminated by feeding ingredients containing highly digestible (≈100%) sources of nitrogen and by eliminating compounds which 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 $g{\cdot}kg^{-1}BW^{.75}{\cdot}d^{-1}$) was determined to be 3.66 $g{\cdot}kg^{-1}BW^{.75}{\cdot}d^{-1}$. When daily apparent digestible nitrogen intakes were below the pigs' determined need, the amount of digestible N ($mg{\cdot}kg^{-1}BW^{.75}{\cdot}d^{-1}$) 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 $g{\cdot}kg^{-1}BW^{.75}{\cdot}d^{-1}$ 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 $g{\cdot}kg^{-1}BW^{.75}{\cdot}d^{-1}$ to support pigs at N maintenance and 1.11 $g{\cdot}kg^{-1}BW^{.75}{\cdot}d^{-1}$ 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 on 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 protein accretion 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 large 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 assure proper use of manure in order 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 urinary and fecal endogenous losses of N, 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.

Objectives

Develop economical feed ingredients and nutritional regimen that will allow the minimum biological capacity of pigs for nitrogen excretion to be achieved.

Procedures

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) minimized 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 semi-purified, highly digestible (≈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, 2, 3, and 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 casein and whey proteins from cows' milk. Initially, efforts were made to isolate the highly digestible, amino acid balanced proteins(globulin, glutelin, and albumen) from the lowly digestible, unbalanced zein proteins in the germ fraction of corn. We were unsuccessful in identifying a suitable source of these proteins or developing an extraction procedure that allowed economical extraction of the desired corn proteins from the zein protein and the cell wall fiber present in the corn germ fraction. The presence of the unextracted zein proteins result in an amino acid pattern that does not match the desired pattern. The cell wall fiber functions to bind N as well as increase endogenous N secretions. Thus, casein and whey proteins were selected to be included as the N sources. The phosphorus sources consisted of monosodium phosphate and to a lesser extent casein and whey protein concentrate. These sources are free of N binding compounds (i.e., phytate). The vitamin trace minerals 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 these 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 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). Table 5 contains the analyzed N and available phosphorus concentrations of the experimental diets. Dietary concentrations of all other nutrients were estimated to meet or exceed the estimated nutrient needs of high lean pigs (NRC, 1998).

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 ± 2-d of age via a segregated early weaning scheme and penned individually in .61 x 1.50 m stainless steel metabolism pens. Pigs were fed a milk-based pelleted diet for 18-d. Pigs were then fed a semi-purified, 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 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 which 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 ± 2.2 kg and ended at BW of 28.28 ± 3.7 kg.

Animal Care

The pigs were individually penned in metabolism cages and allowed *ad libitum* access to feed and water. Room temperature was maintained between 21.1 and 30.0° for the duration of the study. Pigs were injected intramuscularly with 1 ml of Naxcel on d-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 re-filtered 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.

For determination of immune status, one pig from each replication was bled via the orbital sinus at the initiation and termination of the trial to determine the presence of serum antibody titers for *Actinobacillus pleuropneumoniae* (APP), *Mycoplasma hyopneumoniae* (MP), porcine reproductive and respiratory syndrome (PRRS), swine influenza virus (SIV), and transmissible gastroenteritis virus (TGE) and to determine serum concentrations of the acute phase protein alpha-1-acylglycoprotein (AGP). Serum antibody titers and serum AGP concentrations were determined as outlined by Williams, *et al.,* (1997a; 1997b).

Statistical Analysis

To determine the response to constant and adjusted concentrations of dietary N and P, data were analyzed within period as a 2 x 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. Data from one pig during the first 2-d collection period was deleted from the analysis because the pig did not initially consume feed. Also, data from one pig in collection period six and from one pig in collection period seven was deleted from the analysis due to excretion values being greater than four standard deviation units from the mean.

Results

Effect of N and P Feeding Regimens on Body N Accretion and Excretion

As expected, the adjustments of dietary N concentrations resulted in lower ($P < .07$) dietary N intakes in collection periods three through eight (Table 7). As dietary N intakes were lowered, urinary N excretions also were lowered ($P < .07$) in collection periods four through eight whereas fecal N excretions were not affected (except for collection period seven). Adjustments of dietary N concentrations did not lower ($P > .05$) daily body N retention, except in collection periods four and five during which N intakes were the lowest. In the current study, digestible dietary N intakes were lowered by up to 8 g N/d resulting in an equal reduction in urinary N excretion without affecting body N accretion.

Because the proportion of each amino acid source in the protein mix was constant, the true digestibility of the N should be relatively unaltered by adjustment of dietary N concentrations. The lower apparent digestibility of N in collection periods four and six likely is due in part to the lower intake of dietary N during these periods which results in endogenous N representing a greater proportion of fecal N and thus a lower apparent N digestibility.

Effects of N and P Feeding Regimens on Excreta Composition

The effects of dietary N and P feeding regimens on the composition of fecal and urinary excretion are reported in Figures 1 and 2. The changes in urinary and fecal N concentrations largely mirrored those of daily urinary N and fecal N excretion.

Pigs consuming common diets containing amino acid contents at or above the pigs needs typically excrete 74% urea N as a percentage of total urinary N (Cai, 1992). Because urea N accounts for the majority of the nitrogenous compounds excreted into the urine, it is a good predictor of whether the composition of urine has been altered. Figure 3 depicts urea N as a percentage of total urinary N by collection period. As dietary N concentration was reduced, urea N as a percentage of total urinary N began to decline in collection period three (P=.06) and four (P=.09). It was not until period five that urea N as a percentage of total urinary N reached a minimum. For pigs consuming constant levels of N, urea N represented 69.4% of the total urinary N excretion, while for pigs consuming the lowest N intakes (period four), urea N represented 58.8 % of total urinary N excreted. Stahly *et al., (*1998) reported that urea N represented 70 to 80% of excreted N when pigs consumed excess levels of nitrogen and 30-35% when minimum excretion is achieved. According to Coma *et al.,* (1995), it takes 2 to 3 d to establish a new equilibrium of plasma urea N after changing the dietary lysine concentration. Since the urine was analyzed for urea N only 24 h after adjusting the diet, it is possible that a longer adjustment period was necessary in order to determine urea N. As dietary N concentration was again increased once minimum excretion was achieved (period five), urea N was further reduced to 38.8% of urinary N, which is indicative that a longer adjustment period is necessary. This value more closely agrees with the 30 to 35% of excreted N obtained by Stahly *et al.,* (1998). The amounts of other nitrogenous compounds (i.e., creatinine and allantoin) excreted in the urine are relatively constant in animals fed common ingredients (i.e., low nucleic acid ingredients). Therefore, as the total urinary N is decreased, the percentage of the non-urea N components would be expected to increase. As urinary N excretion declines (Table 8) and the proportion of this N present as urea is reduced, it is thought that volatilization of N as NH_3 and, therefore, odor would be reduced (Kerr and Easter, 1995).

Estimates of the Minimum Biological Capacity for N Excretion

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 $g{\cdot}kg^{-1}BW^{.75}{\cdot}d^{-1}$ (SE .107) (Figure 4, Table 6). When daily digestible nitrogen intakes were below the pigs estimated needs (3.66 $g{\cdot}kg^{-1}BW^{.75}{\cdot}d^{-1}$), the amount of digestible N excreted in the urine from body maintenance processes is estimated as .239 $g{\cdot}kg^{-1}BW^{.75}{\cdot}d^{-1}$ (SE .126) and the amount excreted in the urine as being unusable for body N accretion is .206 $g{\cdot}kg^{-1}BW^{.75}{\cdot}d^{-1}$ (SE .059) 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 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 mg/kg $BW^{.75}$ 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 mg/kg $BW^{.75}$ (Fuller *et al.,* 1989; Stahly, 1990). Above maintenance, pigs were 79.3% (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, determined that nitrogen intake was used with 80% gross efficiency for N retention. Based on these data, our amino acid profile provided close to the balance 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, above the requirement, essentially the dietary N consumed in excess of the requirement was largely (90%) excreted.

Because the composition of the N sources was constant in all feeding regimens, it was not expected that fecal N excretion would be altered by N intake. Two-slope breakpoint analysis was used to confirm this expectation. Since there was not a breakpoint (Figure 5), all observations were used in the regression analysis of fecal N excretion, $g \cdot kg^{-1} BW^{.75} \cdot d^{-1}$ vs total daily nitrogen intake, $g \cdot kg^{-1} BW^{.75} \cdot d^{-1}$. The regression for this analysis was: $y = .040$ (SE .014) + .033 (SE .004)x, where the intercept is the amount endogenous fecal N losses, $g \cdot kg^{-1} BW^{.75} \cdot d^{-1}$, and the slope is undigested fecal N in grams per gram of digested N consumed per kg^{75} per day. Since 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 .04 $g \cdot kg^{-1} BW^{.75} \cdot d^{-1}$. 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 these data, fecal endogenous losses total .042 $g/kg\ BW^{.75} \cdot d^{-1}$ (Table 8). Endogenous urinary N losses were estimated as .239 g digestible $N \cdot kg^{-1} BW^{.75} \cdot d^{-1}$ in the current study. The minimum biological capacity for N excretion is, therefore, estimated to be .287 $g \cdot kg^{-1} BW^{.75} \cdot d^{-1}$ in pigs at N maintenance and 1.11 $g \cdot kg^{-1} BW^{.75} \cdot d^{-1}$ in pigs at maximum body N accretion. A maintenance estimate of .268 $g \cdot kg^{-1} BW^{.75} \cdot d^{-1}$ 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).

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 9. 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 10) 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 excreta solids produced in pigs expressing minimal N accretion are reported in Table 10. These amounts are contrasted to those of the ASAE standards. Feeding the highly digestible ingredients and minimizing antinutritional factors reduced excreta solids production from 30.1 to 7.9 $g \cdot kg^{-1} BW^{.75}$/d.

In Table 10, 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. Pig excreta contained 2.57 g N/liter of excreta when pigs were expressing minimum N excretion and maximum N accretion. A comparison of this value to that of the Iowa Adopted Standard, concentrations in commercial finishing swine pigs (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, indicate that dietary regimens that allow the minimum biological capacity for N excretion to be achieved also results in a 74 to 82% reduction in the concentration of N in the fresh excreta produced.

Implications

The minimum biological capacity for N excretion in pigs is 12 to 44% of currently assumed N excretion standards. Nutritional regimens that allow the minimum capacity for N excretion to be achieved are capable of allowing maximum body N accretion (i.e., lean tissue growth) to be achieved.

Table 1. Energy mix composition (%)

Ingredient	% of Mix
Corn starch	83.50
Dextrin	5.27
Corn bran[a]	4.46
Corn oil	6.59
Calcium carbonate	0.16
Ethoxyquin	0.02

[a] 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[a]	43.12
Crystalline amino acids	3.25
Corn starch	16.29
Corn bran[b]	5.80
Corn oil	5.40
Calcium carbonate	1.67
Ethoxyquin	0.01

[a] Contained the following (%): 1.8 lipid, 56.6 neutral detergent fiber, 1.5 nitrogen, .03 calcium, .02 phosphorus.

[b] 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
Selenium premix (.06%)	1.25
Vitamin mix[a]	12.50
Choline chloride, 60%	6.00
Mineral mix[b]	3.75
Magnesium oxide	3.75
Potassium sulfate	30.00
Sodium chloride	3.13
Monosodium phosphate	4.32
Antibiotic[c]	12.50
Corn starch	22.81

[a] 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_{12} .09 mg, Vitamin B_6 8.8 mg.

[b] Provided the following per kg of diet: Iron 262.5 mg, zinc 225 mg, Manganese 90 mg, Copper 26.3 mg, Iodine .3 mg.

[c] Provided the following per kg of diet: chlortetracycline 110 mg, sulfamethazine 100 mg, penicillin 50 mg.

Table 5. Dietary concentration (%) of total N and available P during each collection period.

		Dietary N and P Regimen[a]			
Item	Collection Period	CN CP	CN AP	AN CP	AN AP
Total N, %	1	3.41	3.41	3.41	3.41
	2	3.41	3.41	2.97	2.97
	3	3.41	3.41	2.68	2.68
	4	3.74	3.74	2.42[b]	2.41[c]
	5	3.74	3.74	2.76	2.76
	6	3.74	3.74	3.04	3.04
	7	3.74	3.74	3.27	3.27
	8	3.74	3.74	3.50	3.50
	9	3.74	3.74	3.74	3.74
Available P, %	1	0.70	0.70	0.70	0.70
	2	0.70	0.68	0.70	0.67
	3	0.70	0.66	0.70	0.65
	4	0.77	0.65[d]	0.72[e]	0.64[f]
	5	0.77	0.68	0.77	0.67
	6	0.85	0.71	0.85	0.71
	7	0.85	0.75	0.85	0.75
	8	0.85	0.80	0.85	0.80
	9	.085	0.85	0.85	0.85

[a] Constant (C) and adjusted (A) dietary N and P regimens.

[b] Mean of dietary % of N from 6 pigs (2.45, 2.12, 2.45, 2.45, 2.54, 2.54).

[c] Mean of dietary % N from 6 pigs (2.12, 2.45, 2.45, 2.54, 2.45, 2.45).

[d] Mean of dietary % available P from 6 pigs (.66, .63, .65, .63, .66, .66).

[e] Mean of dietary % available P from 6 pigs (.75, .76, .70, .69, .70, .70).

[f] Mean of dietary % available P from 6 pigs (.63, .65, .65, .65, .61, .64).

Table 6. Effect of dietary N and P regimen on N utilization in pigs by collection period.

		Dietary N and P Regimens[a]					Prob[b]		
Item	Collection Period	CN CP	CN AP	AN CP	AN AP	SEM[c]	N	P	N*P
Nitrogen intake, g/d									
	1	35.69	39.26	37.73	38.91	3.63	.99	.69	.93
	2	35.38	34.54	31.69	30.57		.29	.79	.97
	3	31.05	35.85	25.88	27.64		.07	.37	.68
	4	27.08	31.00	16.37	21.08		.01	.24	.91
	5	32.86	30.76	21.41	24.28		.01	.91	.49
	6	42.45	40.45	32.64	34.11		.08	.63	.38
	7	43.70	46.57	37.79	39.45		.07	.61	.95
	8	51.10	48.21	41.50	41.87		.03	.73	.65
	9	52.11	45.41	42.36	43.70		.12	.46	.27
Urinary N, g/d									
	1	11.61	17.57	15.38	16.07	2.28	.85	.26	.41
	2	10.21	10.13	8.76	9.58		.66	.87	.84
	3	7.99	11.03	5.82	6.39		.14	.43	.59
	4	6.56	8.67	3.56	4.37		.11	.52	.78
	5	9.02	9.17	4.08	4.87		.04	.84	.89
	6	13.35	13.62	7.34	8.48		.05	.90	.55
	7	14.47	17.59	11.32	11.94		.05	.47	.65
	8	18.86	17.93	13.53	13.96		.04	.91	.77
	9	18.81	18.18	14.76	14.70		.10	.88	.90
Fecal N, g/d									
	1	1.73	1.95	1.55	1.83	.21	.49	.26	.91
	2	1.18	1.61	1.57	1.24		.96	.82	.07
	3	1.52	1.32	1.32	1.16		.39	.38	.92
	4	1.15	1.13	0.93	1.02		.43	.85	.79
	5	1.43	1.35	1.10	1.03		.13	.72	.99
	6	1.72	1.54	1.83	1.63		.52	.30	.89
	7	1.75	2.00	1.38	1.59		.07	.31	.95
	8	1.91	2.38	2.21	1.69		.36	.92	.02
	9	2.23	1.87	2.17	2.49		.19	.94	.11

Table 6 (continued)

Item	Collection Period	Dietary N and P Regimens[a] CN CP	CN AP	AN CP	AN AP	SEM[c]	Prob[b] N	P	N*P
Apparent N digestibility, %									
	1	95.18	94.85	95.92	95.19	.58	.46	.30	.87
	2	96.65	95.16	94.79	95.72		.27	.62	.04
	3	95.09	96.33	94.70	95.69		.37	.06	.83
	4	95.67	95.76	94.19	94.94		.05	.48	.57
	5	95.48	94.92	94.63	95.66		.92	.69	.18
	6	95.80	96.15	94.29	95.00		.04	.46	.68
	7	95.76	95.65	95.94	95.67		.89	.74	.92
	8	96.28	94.93	94.68	95.67		.46	.76	.05
	9	95.63	95.81	94.67	93.82		.01	.56	.38
N retained, g/d									
	1	22.35	19.74	20.80	21.01	1.93	.87	.48	.42
	2	23.99	22.80	21.35	19.75		.14	.47	.91
	3	21.54	23.51	18.74	20.10		.11	.39	.87
	4	19.37	21.20	11.89	15.69		.01	.15	.61
	5	22.41	20.25	16.22	18.38		.04	.99	.27
	6	27.38	25.28	23.46	23.99		.30	.52	.36
	7	27.48	26.99	25.09	25.93		.34	.99	.67
	8	30.33	27.90	25.76	26.22		.11	.61	.46
	9	31.04	25.35	25.43	26.50		.25	.23	.08
N retention, % of digestible N intake									
	1	33.04	26.64	29.01	27.70	2.00	.53	.05	.22
	2	35.77	35.24	35.57	34.13		.70	.52	.79
	3	36.94	34.77	38.19	38.23		.17	.53	.52
	4	37.07	35.64	38.62	39.15		.14	.79	.57
	5	35.95	34.65	40.13	39.92		.01	.66	.75
	6	34.23	33.24	38.48	37.64		.04	.78	.85
	7	33.02	30.78	34.95	34.53		.10	.47	.63
	8	31.96	30.82	33.13	33.23		.30	.76	.72
	9	32.01	29.41	31.96	32.10		.44	.47	.42

Table 6 (continued)

Item	Collection Period	Dietary N and P Regimens[a] CN CP	CN AP	AN CP	AN AP	SEM[c]	Prob[b] N	P	N*P
N retention, % of intake									
	1	31.34	25.27	27.88	26.41	2.00	.63	.05	.25
	2	34.62	33.55	33.77	32.68		.60	.52	.99
	3	35.18	33.52	36.22	36.61		.22	.71	.54
	4	35.54	34.17	36.41	37.23		.24	.87	.51
	5	34.38	32.92	38.05	38.22		.01	.70	.62
	6	33.01	31.99	36.32	35.79		.07	.86	.89
	7	31.67	29.49	33.63	33.09		.10	.44	.65
	8	30.81	29.29	31.44	31.81		.34	.73	.57
	9	30.64	28.21	30.38	30.13		.63	.44	.50
Daily N retention, g/kg BW$^{.75}$									
	1	2.75	2.38	2.54	2.57	.18	.99	.41	.30
	2	2.74	2.59	2.43	2.27		.08	.39	.99
	3	2.35	2.55	2.07	2.24		.10	.30	.92
	4	2.07	2.17	1.29	1.68		.01	.17	.42
	5	2.27	2.00	1.69	1.89		.05	.85	.18
	6	2.63	2.42	2.33	2.34		.30	.55	.51
	7	2.46	2.44	2.34	2.39		.53	.94	.72
	8	2.61	2.44	2.30	2.30		.21	.92	.61
	9	2.56	2.11	2.18	2.21		.43	.24	.19

[a] Constant (C) and adjustable (A) N and P regimens.

[b] Probability of effects of dietary N and P regimens.

[c] Standard error of the mean.

Table 7. Estimation of the apparent digestible N intake, $g \cdot kg^{-1} BW^{.75} \cdot d^{-1}$, needed to maximize body N retention ($g \cdot kg^{-1} BW^{.75} \cdot d^{-1}$) based on a two-slope regression analysis

Criteria	Symbol	Requirement	Standard Error
Dietary N, g/kgBW$^{.75}$/day			
At maximum retention	R	3.66	.107
Body N retention, g/kg BW$^{.75}$/day			
At maximum retention	L	2.58	.053
Body N retention, g/kg BW$^{.75}$ of digestible intake			
At N intake below R	U	0.62	.033
At N intake above R	V	0.10	.069

Table 8. Estimation of the minimum biological capacity for N excretion at body N maintenance and at maximum body N accretion[a]

	Minimum N Excretion	
Excreta source	At N maintenance	At Maximal N accretion
Urine		
Endogenous N, $g \cdot kg^{-1} BW^{.75}$/day	.239	.239
Unused digested feed N, $g \cdot kg^{-1} BW^{.75}$/day	.000	.705
Feces		
Endogenous N, $g \cdot kg^{-1} BW^{.75}$/day	.040	.040
Undigested feed N, $g \cdot kg^{-1} BW^{.75}$/day	.008	.120
Total Excretion, $g \cdot kg^{-1} BW^{.75}$/day	.287	1.111

[a] Daily digestible N intakes needed to achieve body N maintenance and maximal body N accretion were .239 and 3.66 $g \cdot kg^{-1} BW^{.75} \cdot d^{-1}$, respectively.

Table 9. Responses of pigs to dietary amino acid intakes that maximized body N accretion at the N requirement and above the N requirement.

	Dietary Amino Acid Intakes			
Item	At N Requirement[a]	Above N Requirement[a]	At N Requirement[b]	Above N Requirement[b]
Dietary regimen components				
N digestibility	High	High	Moderate	Moderate
Antinutritional factor	Low	Low	Moderate	Moderate
Amino acid balance	Good	Good	Moderate	Moderate
Mean pig weight, kg	22.0	22.3	21.6	21.5
BW gain and feed utilization				
Feed intake, g/d	1172[c]	1224[d]	1272	1215
BW gain, g/d	782[c]	775[d]	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, $g \cdot kg^{-1}$ 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

[a] 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.

[b] Pigs fed corn-soybean meal-whey based diets (Williams et al., 1997c).

[c] Daily feed intake and BW gains of pigs consuming 37 g digestible N per day.

[d] Daily feed intake and BW gains of pigs consuming 46g digestible N per day.

Table 10. Excreta production and composition

Item	Excreta Source Minimum capacity N excretion[a]	Iowa standard[b]	Commercial standard[c]	ASAE standard[d]
Excreta produced				
Total, $g \cdot kg^{-1} BW^{.75}/d$				
As sampled	432			234
Amount evaporated[e]				?
Total	432			?
Solids, $g \cdot kg^{-1} BW^{.75}/d$	7.9			30.1
Excreta composition				
Solids, g/liter	18.4			128.6
N, g/liter				
As sampled	2.57	6.00	6.97	10.30
Amount volatilized[f]	--	4.00	4.65	4.10
Total	2.57	10.00	11.62	14.40
Total N excreted, g/kg BW gain/day	14.3			61.10[g]

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

[b] The N concentration of excreta of finishing pigs assumed for fertilizer value and regulatory policies in Iowa (Lorimor, *et al.*, 1997).

[c] The N concentration in excreta from 37 commercial swine concrete finishing pigs (Lorimor, *et al.*, 1997).

[d] The N concentration assumed in standard swine excreta (ASAE D384.1).

[e] No evaporation assumed for excreta at minimum N excreta because urine collected twice daily and frozen.

[f] 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.

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

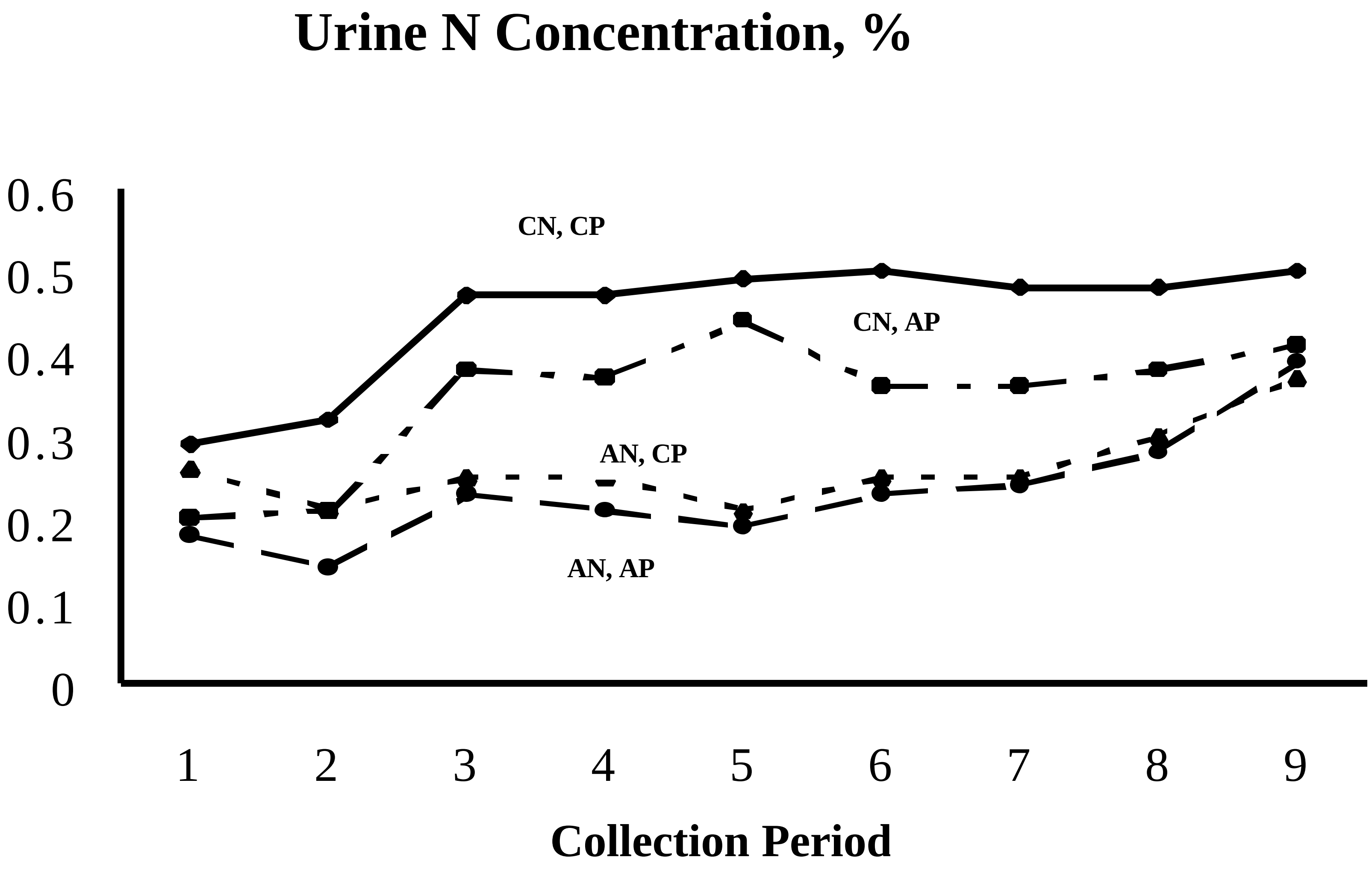

Figure 1. Effect of dietary N and P regimen during each of nine, 2-day collection periods on urinary N concentration, %. Dietary N and P regimens are constant N, constant P (CN, CP); constant N, adjusted P (CN, AP); adjusted N, constant P (AN, CP), adjusted N, adjusted P (AN, AP). SEM=.06.

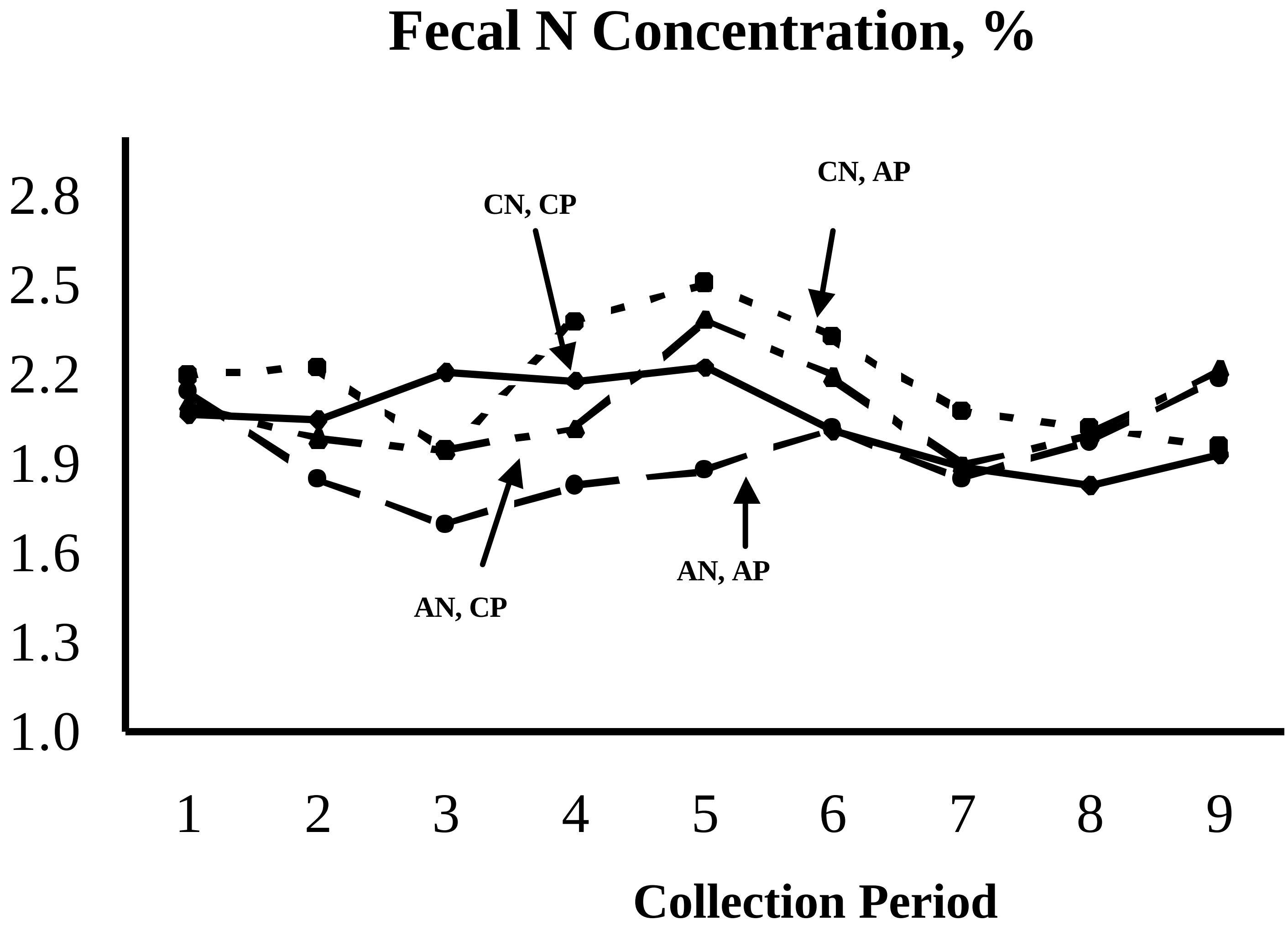

Figure 2. Effect of dietary N and P regimen during each of nine, 2-day collection periods on fecal N concentration, %. Dietary N and P regimens are constant N, constant P (CN, CP); constant N, adjusted P (CN, AP); adjusted N, constant P (AN, CP), adjusted N, adjusted P (AN, AP). SEM=.149.

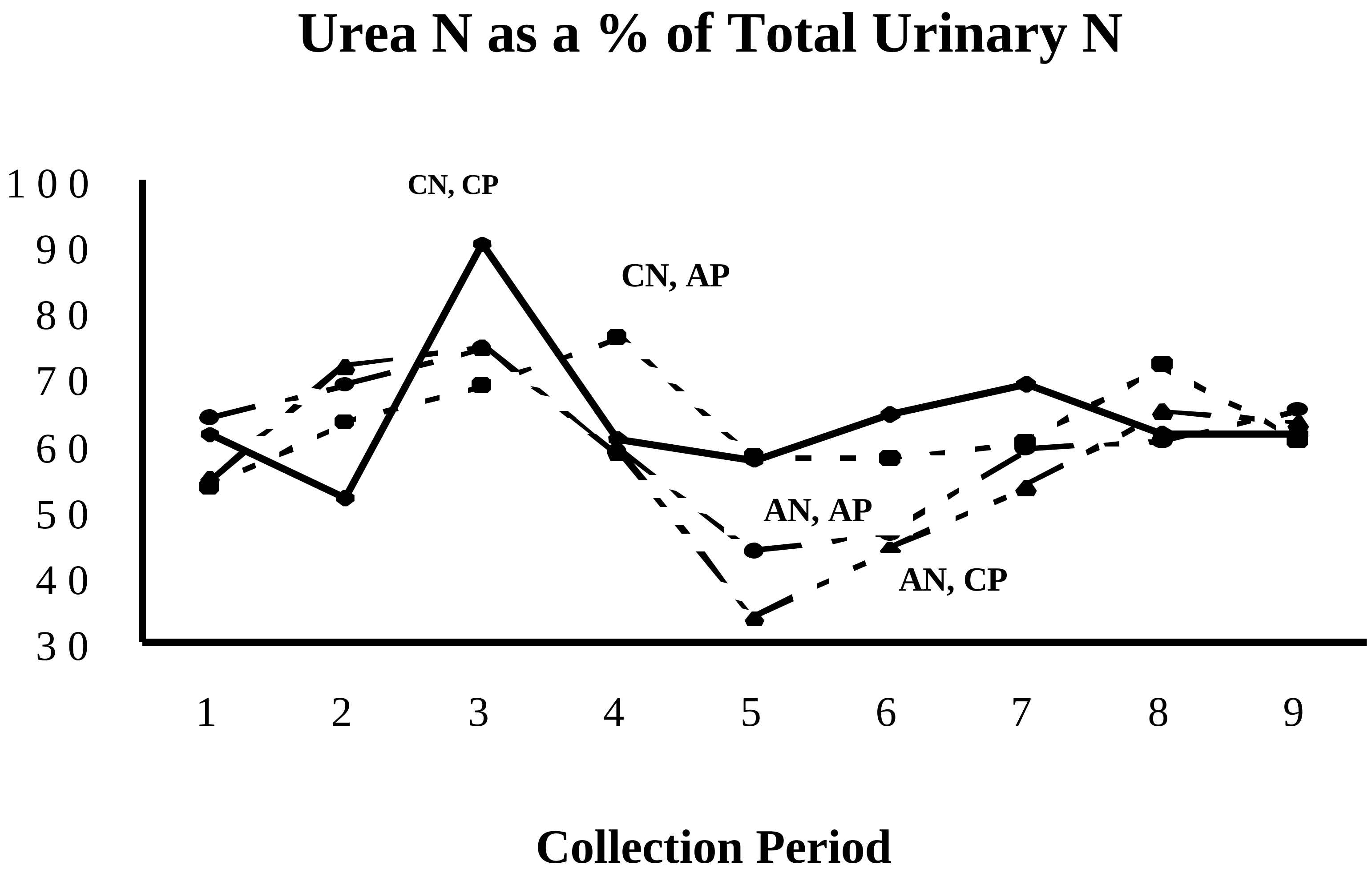

Figure 3. Effect of dietary N and P regimen during each of nine, 2-day collection periods on urea N as a percentage of total urinary N. Dietary N and P regimens are constant N, constant P (CN, CP); constant N, adjusted P (CN, AP); adjusted N, constant P (AN, CP); and adjusted N, adjusted P (AN, AP). SEM=5.73.

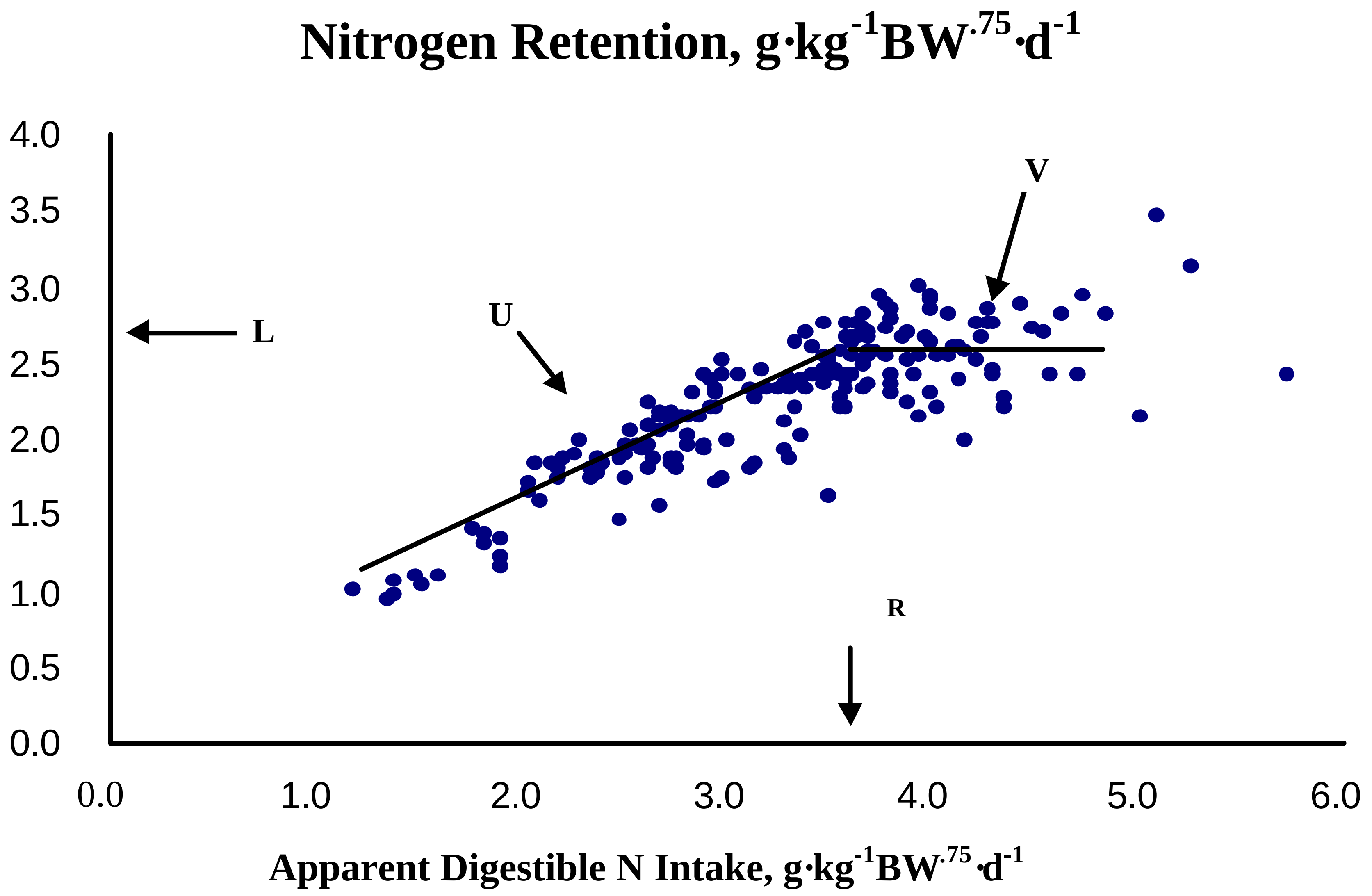

Figure 4. Estimation of the amount of apparent digestible N intake (R, g·kg^{-1}BW$^{.75}$·d^{-1}) needed to maximize N retention (L, g·kg^{-1}BW$^{.75}$·d^{-1}) and the relative efficiency (U, V) of utilization of digestible N for body N accretion at digestible N intakes below and above R, respectively. 190 observations.

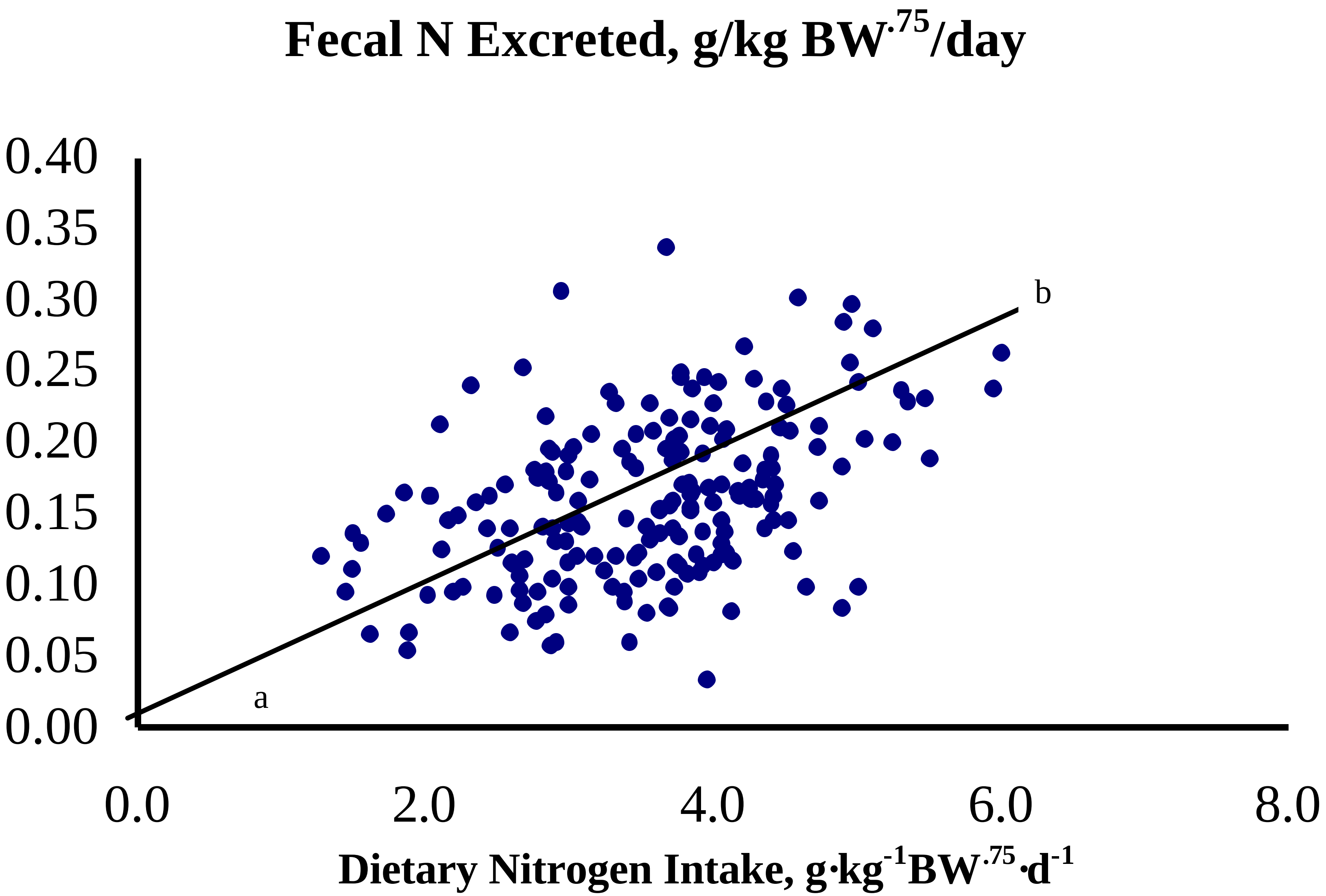

Figure 5. Estimation of the amount of endogenous fecal N excretion (a, g·kg^{-1}BW$^{.75}$·d^{-1}) and the amount (b) of undigested feed N excreted in the feces for each gram of dietary N intake, g·kg^{-1}BW$^{.75}$·d^{-1}. 190 Observations.