

PROTEIN UTILIZATION AND AMINO ACID AVAILABILITY  
IN EARLY WEANED PIGS

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ACID AVAILABILITY IN  
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## CHAPTER I

### INTRODUCTION

Weaning pigs as early as three weeks of age is considered essential in order to shorten the breeding cycle and maximize the reproductive efficiency of the sow herd. One of the major problems with early weaning is "postweaning lag" in the early weaned pig which lasts from five to ten days, and is characterized by very low feed intake, little or no gain and frequently by diarrhea. Growth rate and efficiency of feed utilization of early weaned pigs have been shown to be superior when starter diets contain high levels of milk based protein, minimizing the effect of the postweaning lag period. Milk proteins are expensive relative to soybean meal and from an economic standpoint, the utilization of milk protein in starter diets may not be practical. The reasons for the unfavorable response to soybean protein have not been determined. Delineation of the factors responsible for the poor performance of young pigs fed soybean protein is essential before maximum performance can be attained with less expensive soybean proteins.

Different treatments of soybean meal (alkali or acid treatment) as well as supplementation with essential amino

acids and digestive enzymes have been tested in attempts to improve the utilization of soybean meal protein by the early weaned pig.

These studies have met with limited success. Ethanol extraction of soybean flour prevented intestinal disorders of calves fed milk replacers containing heated soybean flour, however, ethanol extraction of soybean meal has not been tested with early weaned pigs.

Swine diets are routinely formulated to exactly supply the most limiting amino acid. The accuracy of such formulation can be affected by the amino acid availability of the feedstuffs used. The availability of essential amino acids from milk or plant protein for the three to seven week old pig is unknown. In addition, when diets are formulated to meet the need for the most limiting amino acid, excesses of all other amino acids are provided. Such excesses of essential or non essential amino acids have been shown to depress rate and efficiency of gain in chicks by precipitating an amino acid imbalance. More work is necessary with early weaned pigs to determine if amino acid excesses in standard grain-soybean diets adversely effect performance.

Three possible explanations for the poor performance of young pigs fed soybean proteins are as follows: 1) a detrimental intestinally active substance present in soybean meal; 2) availability of the most limiting amino acids from soybean are lower than from milk protein and 3) amino acid

excesses provided by a corn-soybean protein diet are more detrimental to growth of young pigs than excesses in a corn-milk protein diet.

This study was conducted to assess the effect of protein source on performance and nutrient availability in the young pig. Soybean proteins differing in the composition of both protein and nonprotein components were utilized. Specific objectives were to: 1) Re-evaluate the effect of diets containing milk or plant protein sources on gain and efficiency of gain in early weaned pigs; 2) Determine the effect of ethanol extraction of soybean meal on the performance of young pigs; 3) Develop a cannula and surgical technique suitable for ileal cannulation and sample collection in three week old pigs; 4) Determine apparent availability of dry matter, starch, nitrogen and individual amino acids in milk and soybean proteins using ileally cannulated early weaned and ileally cannulated finishing pigs; 5) Estimate true amino acid availability for both early weaned and finishing pigs; 6) Compare estimates of apparent and true availability between early weaned and finishing pigs; 7) Relate nutrient availability of early weaned pigs to performance estimates obtained in the growth study (objective number 1).



## CHAPTER II

### REVIEW OF LITERATURE

#### Performance and Digestive Characteristics of Early Weaned Pigs Fed Various Protein Sources

Pigs have been successfully raised when weaned as early as 1 d after farrowing with growth rates equal to or exceeding those of pigs raised on the sow. Average daily gains (ADG) of suckling pigs from birth to 2 wk of age have been reported to range from 165 - 226 g (Young and Smith, 1973; Aherne and Speer, 1974). Several workers have reported an ADG in excess of 180 g during the first 2 wk of artificial feeding of pigs when the dietary protein source was entirely of milk origin (Sewell et al., 1953; Schneider and Sarrett, 1969; Coalson and Lecce, 1973; Pettigrew et al., 1977a). Braude et al. (1970) reported ADG of up to 250 g in pigs fed liquid milk protein diets from 2 to 28 d of age while gains ranging from 250 to 280 g per day were reported by Wilson and Leibholz (1981) for pigs fed dry, milk protein diets from 7 to 28 d of age. Dried skim milk (DSM), as a protein source for neonatal pigs, has been shown to be superior to skim milk hydrolysate (Pettigrew et al., 1977b) and casein plus whey (Pettigrew et al., 1977a).

Comparisons of Pigs Fed Milk or Soybean  
Proteins as the Sole Source of  
Supplemental Protein

Several studies have been conducted directly comparing performance of early weaned pigs fed diets containing either milk or soybean protein sources. For convenience these data have been summarized in Table 1. These studies indicate a reduction in ADG associated with the replacement of dietary milk proteins with various sources of soybean protein. The range in reduced gain was from 0 to .18 kg per day with a weighted mean of .08 kg (weighted by number of pigs in each study) for pigs weaned between 0 to 14 d of age. The weighted mean reduction in average daily feed intake (ADFI) resulting from the replacement of milk protein with soybean proteins was .06 kg and ranged from .03 to .15 kg. In addition, the kilograms of feed required to produce 1 kg of gain (F:G) was increased by a weighted average of .65 kg and ranged between .20 and 1.04 kg. For 12 of the 13 studies with pigs weaned between 0 and 14 days of age comparing performance, between pigs fed milk proteins or soybean proteins, ADG, ADFI or F:G was improved ( $p < .05$ ) when milk proteins were fed.

For pigs weaned between 15 and 28 days of age, those fed milk proteins had an improved ADG ranging from 0 to .17 kg with a weighted mean ADG of .06 kg greater than pigs fed a source of soybean protein. In addition, there was an increase in ADFI ranging from .03 to .20 kg with a weighted

TABLE 1  
Performance Comparison of Early Weaned Pigs Fed  
Either Milk or Soybean Protein Diets<sup>a</sup>

Reference	Total Pigs	Initial Age (d)	Initial Weight (kg)	Trial Length (d)	Type of Diet	Type of Milk Protein	Type of Soy Protein	Trait	Response Difference from Milk Protein	p <sup>b</sup>
Bayley and Holmes, 1972	16	10	----	21	Liquid	DSM	SF	ADG	- .02kg	*
Coalson et al., 1972	—	21	----	21	Liquid	MS	SF	ADG F:G	- .01kg .47kg	*
Combs et al., 1963	12	15	2.13	42	Dry	DSM	SBM	ADG ADFI F:G	- .17kg - .20kg .43kg	** ** *
Hays et al., 1959	36	10	3.04	35	Dry	DSM	SBM	ADG F:G	- .18kg .82kg	* *
							SBM + Met	ADG F:G	- .09kg .27kg	* *
Jones et al., 1977	22	21	----	21	Liquid	DSM	SF	ADG F:G	.00kg .25kg	
Kellogg et al., 1964	24	20	5.10	28	Dry	DSM	SBM	ADG F:G	- .06kg .24kg	
	18	16	6.30	28	Dry	Casein	ISP	ADG F:G	- .09kg .48kg	

Table 1 Continued

Reference	Total Pigs	Initial Age (d)	Initial Weight (kg)	Trial Length (d)	Type of Diet	Type of Milk Protein	Type of Soy Protein	Trait	Response Difference from Milk Protein	P
							ISP + Met	ADG F:G	- .10kg .43kg	
Lecce et al., 1979	37	14	4.00	16	Liquid	DSM	SF	ADG ADFI F:G	- .13kg -.15kg 1.04kg	*
Leibholz 1982	32	7	2.00	21	Dry	Casein	ISP	ADG ADFI F:G	- .03kg .03kg .32kg	* * *
							SBM	ADG ADFI F:G	- .02kg .03kg .26kg	* * *
Maner et al. 1961	25	3	1.51	21	Liquid	Casein	ISP	ADG F:G	- .04kg .55kg	** **
							ISP + Met	ADG F:G	- .03kg .48kg	** **
Mateo and Veum, 1980	45	1	1.24	14	Liquid and Dry	DSM	ISP	ADG G:F	- .08kg - .35kg	* *
						Casein	ISP	ADG G:F	- .06kg - .26kg	* *

Table 1 Continued

Reference	Total Pigs.	Initial Age (d)	Initial Weight (kg)	Trial Length (d)	Type of Diet	Type of Milk Protein	Type of Soy Protein	Trait	Response Difference from Milk Protein	P
		14	2.92	14	Dry	DSM	ISP	ADG G:F	- .03kg - .03kg	
						Casein	ISP	ADG G:F	.00kg - .01kg	
Partridge, 1981	36	28	6.17	35	Dry	DSM	SBM	ADG ADFI F:G	- .03kg - .03kg .02kg	
Pond et al., 1971	24	2	----	21	Liquid	Casein	ISP	ADG G:F G:Prot	- .02kg - .14kg - .50kg	* * *
Puchal et al., 1962	40	22	5.18	28	Dry	DSM	SBM	ADG F:G	- .08kg .16kg	
Schmidt et al., 1973	32	3	1.50	21	Dry	DSM	SBM	ADG G:F	- .06kg - .30kg	* *
Schneider and Sarett, 1969	15	0	1.10	31	Liquid	WH	ISP	ADG G:Mcal G:Prot ADFI	- .08kg - .01kg - .50kg - .07kg	*

Table 1 Continued

Reference	Total Pigs	Initial Age (d)	Initial Weight (kg)	Trial Length (d)	Type of Diet	Type of Milk Protein	Type of Soy Protein	Trait	Response Difference from Milk Protein	P
Sherry et al. 1978	32	2	1.50	21	Liquid and Dry	DSM	ISP	ADG G:F	- .06kg - .26kg	* *
Wilson and Leibholz, 1980	36	7	2.05	21	Dry	DSM + Casein	ISP	ADG ADFI F:G	- .16kg - .07kg .61kg	** ** **
							SBM	ADG ADFI F:G	- .16kg - .05kg .53kg	** ** **
	10	7	2.43	28	Dry	DSM + Casein	ISP	ADG ADFI F:G	- .11kg - .05kg .20kg	** * **

<sup>a</sup>Abbreviations for feedstuffs and units not outlined in the style and form of the J. Anim. Sci. (1981).  
 DSM - dried skim milk; ISP - isolated soybean protein; SBM soybean meal; SF - soybean flour; MS - milk solids; WH - whole milk; Met - methionine; ADG - average daily gain; F:G - feed per unit of gain; G:F - gain per unit of feed; G:Mcal - gain per megacalorie of diet; G:Prot - gain per unit of dietary protein.

<sup>b</sup>Probability level: \* -  $P < .05$ ; \*\* -  $P < .01$ .

average of .07 kg and the F:G was decreased by a weighted average of .21 kg with a range of .02 to .48 kg.

Significant differences occurred, for ADG, ADFI or F:G, in 2 of the 4 studies in which probabilities were reported for this age of pig.

These studies also indicate that replacement of milk protein in the diets of early weaned pigs with either soybean flour (SF), soybean meal (SBM) or isolated soybean protein (ISP) results in a reduction (weighted average) in ADG of .07, .09 and .06 kg, in ADFI of .15, .05 and .04 kg and an increase in F:G of .75, .34 and .47 kg for SF, SBM and ISP, respectively. It is evident from these studies that early weaned pigs fed diets with the supplemental protein source solely from soybeans do not perform as well as pigs fed diets with the supplemental protein source solely from milk proteins. In addition, pigs fed diets with SF as the sole supplemental protein source showed a larger reduction in performance than those fed either SBM or ISP.

In addition to the pronounced performance differences noted between young pigs fed either milk or soybean protein sources, metabolic differences have also been observed including differences in gastric pH, rate of passage, apparent nutrient digestibility and plasma urea concentrations. Hays et al. (1959) reported that the apparent digestibility of both dry matter and protein were reduced at 2 wk of age for pigs fed SBM diets when compared to those fed DSM diets. Apparent digestibility increased

from 88 to 92% and 78 to 82% for dry matter and protein, respectively, for pigs fed SBM diets between 2 and 5 wk of age while digestibility remained constant at about 96% for both dry matter and protein in pigs fed DSM diets. Nitrogen retention was higher for pigs fed the DSM diets (76%) compared to those fed a SBM diet (51%) at 2 wk of age but was similar for both diets at 5 wk of age (50 and 58% for SBM and DSM diets, respectively). Similar results were reported by Wilson and Liebholz (1981) in which higher apparent dry matter and nitrogen digestibility was reported for pigs fed DSM and casein diets compared to those fed either SBM or ISP during two 5 d collection periods at 2 and either 5 or 6 wk of age. Apparent digestibility increased with age for pigs fed diets with either of the two soybean protein sources as the source of supplemental protein but was similar for both periods in pigs fed diets with either of the milk proteins as the source of supplemental protein. Apparent digestibility estimates were higher for pigs fed ISP than for pigs fed SBM. Nitrogen retention as a proportion of nitrogen intake was greater and plasma urea concentration was lower for pigs fed the milk protein diets than for pigs fed the soybean protein diets. This supports the contention of Eggum (1970) that the level of blood urea is inversely proportional to the efficiency of nitrogen utilization. Mateo and Veum (1980) also reported higher apparent digestibilities for dry matter, crude protein, energy, ash and fat and higher serum levels of protein in



two week old pigs fed casein diets compared to those fed ISP diets. However, diets fed from 1 to 29 d of age had no effect on subsequent nursery performance from 29 to 64 d of age when all pigs were fed the same diet.

In a unique study, involving pigs equipped with gastric fistulas, Maner et al. (1962) found that the stomach pH of 4 wk old pigs fed liquid casein diets dropped from 5.6 at 5 min after feeding to 1.7 2 h after feeding whereas 4 h were required for pH to return to prefeeding levels (about 1.8) in pigs fed soybean protein diets. However, in 8 wk old pigs the pH of stomach contents returned to prefeeding levels within 2 h with both casein and soybean protein diets. Rate of passage through the gastrointestinal tract of 4 wk old pigs was established to be 14 to 24 h for pigs fed semi-purified soybean protein diets compared to 36 to 48 h in those fed casein diets. Rate of passage was similar for both diets in 8 wk old pigs and ranged from 40 to 50 h.

Other studies have been conducted in which soybean proteins have been used to replace portions of the milk protein in the diets of early weaned pigs. Lecce et al. (1979) fed a slurry diet in which either 50 or 100% of the milk protein was replaced by soybean protein or 36% of the milk protein was replaced by corn and soybean protein to pigs from 14 to 30 d of age. Rate of gain decreased as the level of milk protein in the diet decreased, however, these differences were significant only for the period from 14 to 22 d of age. Post-treatment performance was similar when

all pigs were fed the same commercial starter ration for an additional 12 d period.

In a similar study Sherry et al. (1978) conducted three trials in which pigs were fed isocaloric and isonitrogenous diets from 2 to 23 d of age. Protein sources in these diets included corn, whey, DSM and SBM with varying ratios of SBM and DSM protein. ADG and G:F decreased as the percentage of milk in the diet decreased and the performance of pigs receiving less than 25% milk protein was severely depressed compared to pigs receiving 45% or more of the supplemental protein from milk proteins. Apparent digestibility coefficients for carbohydrate, nitrogen and ash increased as the percentage of milk protein in the diet increased while serum urea nitrogen levels were greatest for diets containing 52% or more supplemental protein from corn and soybean protein. In addition, during the post-treatment period of 23 to 65 d of age when pigs were group fed the same diet, performance was severely depressed in pigs fed neonatal diets containing less than 25% milk protein. The reduction in performance seen in this study is consistent with results reported by Schmidt et al. (1973) who observed a reduction in performance associated with decreasing milk protein in the diet of early weaned pigs fed corn, soybean and milk protein diets.

Wilson and Leibholz (1981) also substituted SBM for various portions of DSM and casein in the diets of pigs from 7 to 35 d of age. When SBM was substituted for milk

proteins, at levels up to 75% of the total dietary protein, ADG and F:G was reduced by as much as 85% between 7 and 14 d of age and by as much as 31% between 21 and 28 d of age. Apparent digestibility of both dry matter and nitrogen decreased as the level of SBM in the diet increased.

Two studies have been reported involving a total of over 600 pigs weaned between 15 and 23 d of age in which various portions of whey protein were added to a basal milo-SBM diet. Clarkson and Allee (1982) and Pope and Allee (1982) reported that pigs fed 20% milk protein, in the form of whole dried whey, gained faster ( $P < .05$ ) during the first two weeks postweaning and during the entire 35 day trial than did pigs fed the basal diet with no added whey. In addition, Pope and Allee (1982) reported that feeding the 20% whey protein diet only during the first two weeks postweaning was as effective as feeding the 20% whey protein diet for five weeks postweaning.

In contrast to the previous studies, Decuyper et al. (1981b) reported that ADG and F:G of pigs fed milk based diets in which 40% of the milk protein was replaced by an ISP that was totally soluble in water or an ISP that was easily dispersed in water, was superior to that of pigs fed an all milk protein diet. Performance of pigs fed the all milk protein diet was superior to the performance of pigs fed a diet in which 40% of the milk protein was replaced with an ISP that was totally insoluble in water. However, significant differences in performance in this study were

only apparent during the fourth week on trial when pigs were fed from 12 to 40 d of age. Performance over the entire trial was very good for this age of pig with gains averaging over 350 g per day on an average of 1.1 g of feed per g of gain. In addition, the apparent nitrogen digestibility was relatively high for all diets averaging 93.0, 95.3, 89.9 and 86.4% at 2 wk of age and 95.5, 95.3, 91.9 and 94.6% at 6 wk of age for pigs fed the milk protein, soluble ISP, dispersible ISP and insoluble ISP diets, respectively. This high level of performance for all treatments was probably due to the high level of milk protein in all of the experimental diets. It has also been reported (Decuyper et al., 1981a) that the improved performance demonstrated by pigs fed the soluble ISP may be due in part to partial hydrolysis of this protein during the extraction procedure and enhanced proteolysis due to the soluble nature of this protein.

The performance of early weaned pigs fed milk protein diets has clearly been shown to be superior to that of pigs fed soybean protein diets. In general, as the level of milk protein in the diet decreases the nutrient utilization and digestibility of the diet also decreases.

#### Comparisons of Young Pigs Fed

#### Other Protein Sources

As previously indicated, feeding milk protein diets to pigs weaned as early as one day after birth can result in

excellent performance. However, under commercial conditions this practice may not be economically feasible; therefore less expensive sources of dietary protein are desirable. Many studies have been conducted comparing the performance of early weaned pigs fed various protein sources to the performance of early weaned pigs fed diets with either milk or soybean protein as the supplemental protein source. Blair (1961) compared the use of whitefish meal to SBM fed to pigs growing from 4.5 to 11 kg and found that pigs fed either an 18 or 23 percent protein SBM diet performed similarly to pigs fed an 18% protein fish meal (FM) diet. Growth rate was further improved by 11% and feed efficiency by 14% when the protein was increased to 23% in the FM ration. Increasing the protein content of the SBM ration to 28% resulted in very poor growth and gastric ulceration. Performance was similar when these same diets were fed to pigs growing from 11 to 18 kg. Source of dietary protein prior to 18 kg had no effect on post-treatment performance of these pigs from 18 kg to market weight when all were fed the same diet.

Inclusion of three percent FM in an 18% protein diet with SBM as the major source of dietary protein resulted in no significant effect on weight gain for pigs with an initial weight of 6.1 kg fed for a 9 wk period (Meade et al., 1965). This 3% inclusion of FM did result, however, in a significant improvement in F:G that was equal to that obtained by the inclusion of 10% DSM. Including 3% tankage

with the addition of 3% FM negated the positive effect of FM on F:G. The improvement in F:G resulting from the inclusion of FM may have been due to the higher lysine and methionine levels in this diet compared to the basal SBM diet.

Leibholz (1982) reported that ADG and F:G for pigs that were fed 27% protein FM diets from 7 to 28 d of age were better than for pigs fed similar diets of either ISP or SBM. However, performance of pigs fed the FM diet was inferior to that of pigs fed a casein diet. Apparent digestibility of both dry matter and nitrogen in the soybean and fish protein diets were lower than those in the milk protein diets. Apparent digestibility of all diets increased between 2 and 4 wk of age which is contrary to studies reporting no increase in apparent digestibility, for pigs fed milk protein diets, with increasing age (Hays et al., 1959; Wilson and Leibholz, 1980). Apparent digestibility of both dry matter and nitrogen for pigs fed the FM diet was intermediate to that of pigs fed the ISP and SBM diets.

Reduced gain and F:G for pigs fed FM diets compared to those fed either SBM or DSM diets have been reported in three studies in which pigs were weaned between 15 and 22 d of age and fed either 20% crude protein diets for a 28 d period (Puchal et al., 1962; Kellogg et al., 1964) or 17.5% crude protein diets for a 42 d period (Combs et al., 1963). In addition, Newport and Keal (1983b) reported no difference in F:G for pigs fed 19% crude protein SBM based diets supplemented with either DSM, FM or a combination of both.

Differences in gain were also not significant when feed intake was held constant across all diets. Combs et al. (1963) reported apparent digestibility of dry matter, protein, fat and energy for pigs fed DSM, SBM or FM diets at 4, 6 and 8 wk of age. At 4 and 6 wk of age the apparent digestibility of dry matter, protein and energy were higher for pigs fed DSM than for pigs fed either SBM or FM diets. Digestibility of fat at both 4 and 6 wk of age was similar for pigs fed either milk protein or FM diets. Fat digestibility in pigs fed both of these diets was higher than in pigs fed the SBM diet. No significant differences in nutrient digestibility were observed at 8 wk of age at which time digestibilities were maximized for all treatments.

Fish protein concentrate (FPC), from dried fish offal, has been tested by a few workers as a source of supplemental protein for early weaned pigs. As is the case with FM diets, the results of these studies have been inconsistent. Pond et al. (1971) found FPC to be equal to casein and superior to ISP in promoting growth and total serum protein concentration after 21 d of feeding isonitrogenous diets to pigs from 2 to 23 d of age. In contrast, Bayley and Holmes (1972) reported that growth over a 3 wk period, for pigs weaned at 10 d of age and fed FPC diets, was equal to or below that of pigs fed SF and inferior to that of pigs fed DSM. Growth of pigs fed a FPC-whey diet was intermediate to growth of those fed either SF or DSM diets. Newport (1979)

reported that replacement of DSM, in the diets of pigs from 2 to 28 d of age, with a FPC-dried whey mixture resulted in improved gain and efficiency when 50% of the DSM was replaced but resulted in a reduction in both gain and efficiency when 100% of the DSM was replaced. In addition, Newport and Keal (1983a) showed a significant linear decrease in both gain and efficiency as increasing amounts of DSM was replaced with a FPC-dried whey mixture in the diets of pigs weaned at 2 d of age and fed for 26 d.

A limited number of studies have been conducted to compare the performance of early weaned pigs fed either cottonseed meal feather meal or meat meal to that of early weaned pigs fed more traditional protein sources. Puchal et al. (1962) and Kellogg et al. (1964) both reported inferior growth and efficiency for pigs weaned at 20 to 22 d of age and fed 20% crude protein diets of either cottonseed or meat meal when compared to pigs fed similar diets of FM, SBM or DSM. Performance of pigs fed meat meal diets was inferior to that of pigs fed cottonseed meal diets. Combs et al. (1963) reported that for pigs weaned at 15 d of age and fed a 20% crude protein corn-peanut meal diet for a 6 wk period, performance was inferior to that of pigs fed a corn-SBM diet of similar protein content. Apparent digestibility of dry matter, protein, fat and energy in pigs fed peanut meal diets remained relatively constant as pigs increased in age from 4 to 8 wk. In general, nutrient digestibility for pigs fed peanut meal diets was lower than for pigs fed SBM diets



and digestibility of each diet component tested increased with increasing age for pigs fed SBM diets. Similarly, Lloyd et al. (1957) reported increased digestibility of dry matter, nitrogen, energy and fat at 7 wk of age compared to 3 wk of age in pigs fed complex diets containing DSM, SBM and FM.

Performance of early weaned pigs fed diets containing fish protein sources is similar to that of pigs fed soybean protein diets and in general, is superior to that observed in pigs fed other non milk protein diets.

#### Soybean Protein Treatments for Improved Utilization in Other Species

Poor utilization of plant protein sources by young animals has also been documented in studies with the preruminant calf, in which calves fed milk replacers containing only vegetable sources of protein showed inferior performance to calves fed milk protein sources or a combination of milk and vegetable protein sources (Stein and Knodt, 1954; Noller et al., 1956a; Noller et al., 1956b; Fries et al., 1958). Colvin and Ramsey (1968) reported that calves fed milk replacers containing fully cooked SF, that had been exposed to an acid environment (pH 4.0) for five hours at 37 C prior to inclusion in the milk replacer, grew at nearly twice the rate of calves fed milk replacers containing untreated SF. In addition, Colvin and Ramsey (1969) reported that calves fed milk replacer containing

fully cooked SF, that had been exposed to an alkaline environment (pH 10.6) for five hours at 37 C prior to inclusion in the milk replacer, grew at rates equal to that of calves fed milk replacers containing acid treated SF and more rapidly than calves receiving milk replacer containing untreated SF. Additionally, weanling rats fed the diets containing either acid or alkali treated SF grew as rapidly as rats fed casein diets and had higher ADG than rats fed untreated SF diets.

Gorrill et al. (1967) observed a decrease in pancreatic secretion as well as protein and enzyme concentration and activity of pancreatic secretion in calves fed high levels of soybean protein in liquid diets when compared to those fed all milk protein diets. Nitsan et al. (1972) reported inferior growth for calves fed soybean milk replacers that was partially overcome by heating the soybean protein to 120 C for 25 minutes prior to incorporation into milk replacers. However, growth and digestion trials by Gorrill and Thomas (1967) and Ramsey and Willard (1975) showed that heated SF is unsuitable as the major source of protein for preruminant calves. In addition, Smith and Sissons (1975) reported inhibition of flow out of the abomasum in calves which were previously sensitized to soybean protein and subsequently fed SF or ISP milk replacers when compared to those receiving all milk protein milk replacers. This appeared to be associated with high titers of serum antibodies to an antigen present in SF in calves fed SF or ISP diets. In

addition increased rates of ileal flow and decreased nitrogen absorption was observed in calves fed heated SF diets compared to those receiving cows milk or casein diets (Sissons and Smith, 1976). Kilshaw and Smith (1979) reported IgG and IgE antibodies specific for soybean protein appearing within 2 wk in the serum of calves fed SF as a constituent of a milk based diet. Extraction of SBM protein with hot aqueous ethanol, prior to incorporation into milk replacers, was reported (Sissons et al., 1979) to alleviate the allergenic response associated with feeding soybean proteins to young calves and resulted in performance similar to that obtained with feeding all milk diets. Barratt et al. (1979) noted that although commercial extraction of SBM with hot aqueous ethanol is beneficial in reducing the apparent antigenic nature of the product, some cases have been reported which suggest that the harmful antigen clearly survives the extraction process. Therefore, precautions must be taken to insure proper extraction procedures. In a review entailing the effects of soybean products on the digestive processes within the gastrointestinal tract of calves, Sissons (1982) suggested that a factor in some soybean products survives digestion in the abomasum and small intestine and, to varying degrees in different calves, causes abnormalities in the digestive process for which associated immunological reactions are probably provoked by antigenically active soybean proteins, glycinin and beta-conglycinin, and that there is evidence for similar reactions

occurring in man. Evidence also exists for similar reactions occurring in the young pig, however, the occurrence of an antigenic response to soybean protein in the pig has not been adequately tested.

Improvement in utilization of soybean proteins for young pigs could result from ethanol extraction of soybean protein, if indeed an antigenic response exists in the pig as it appears to in the young calf. This concept has not yet been adequately tested in the young pig.

#### Comparisons of Pigs Fed Supplemented or Treated Soybean Protein Sources

Many attempts have been made to identify the factors responsible for the inferior performance of young pigs fed soybean protein diets in an effort to improve soybean protein utilization by the early weaned pig. Fuller and Crofts (1977) reported that carbohydrate in the diet of growing pigs has a protein sparing effect even on zero protein diets. Hudman et al. (1955) reported that fractionation of a 40% level DSM diet indicated that both the protein and carbohydrate fraction of the skim milk were responsible for superior performance over purified soybean protein-cornstarch diets. In contrast, no difference in pig performance due to carbohydrate source was reported when pigs between 1 and 29 d of age were fed diets containing either lactose or wheat starch (Wilson and Leibholz, 1979) or diets containing either lactose or glucose (Mateo and

Veum, 1980). Veum and Mateo (1981) reported lower ADG and lower ADFI in pigs fed diets containing cornstarch from 15 to 36 d of age than for pigs fed diets containing glucose or sucrose, both of which produced similar results. However, gain adjusted for equal feed intake was similar for all three carbohydrate sources.

Lewis et al. (1957) attributed the poor utilization of soybean protein to a proteolytic enzyme deficiency and insufficiently developed enzyme system in the young pig. Previously discussed differences in the apparent digestibility of diet components and reported high blood urea levels and low nitrogen retention for pigs fed soybean protein diets as well as improved ration digestibility with increasing age of the pig also suggest inadequately developed enzyme systems in very young pigs. Efird et al. (1982) studied the digestive capacity development in pigs from 1 to 22 d of age and found that proteolytic enzyme activity in the stomach decreased from 1 to 22 d of age at which time an increase in activity occurred. Intestinal trypsin activity increased from 1 to 8 d of age, after which there was very little change, while intestinal chymotrypsin activity tended to continue to increase with increasing age. Pigs weaned to dry milk protein diets at 16 d of age had higher intestinal enzyme activities, higher pancreas weight and higher stomach pH at 22 d of age than sow reared pigs. Intestinal length decreased with increasing age but weight per unit of length increased with age of the pig.

Several attempts have been made to improve soybean protein utilization by early weaned pigs by supplementing soybean diets with proteolytic enzymes. To date, these attempts have met with very little success. Lewis et al. (1955) reported improvement of up to 29 and 23% for ADG and F:G, respectively, when pepsin, pancreatin or a combination of both were added to soybean protein diets. However, performance was still inferior to that of pigs fed either casein or DSM diets when weaned between 6 and 10 d of age. In contrast, no consistent improvement in performance was observed for pigs weaned between 0 and 11 d of age and fed soybean protein diets supplemented with pepsin and pancreatin (Cunningham and Brisson, 1957), pepsin, pancreatin, diastase, ethomid C/15, sucrase or various combinations of these enzymes (Alsmeyer et al., 1957; Combs et al., 1960), pepsin and alpha-amylase (Calder et al., 1959) or pepsin, trypsin or pepsin and trypsin (Maner et al., 1961). Calder et al. (1959) reported an increased incidence of scours in addition to decreased gain and F:G with pepsin supplementation of soybean protein diets. Cunningham and Brisson (1957) fed pigs weaned at 2 d of age a soybean protein diet in which the soybean protein had been predigested with pepsin and found that these pigs developed diarrhea within 24 h and died within 7 d. In addition, young pigs fed FM diets supplemented with pepsin also failed to show an improvement in performance.

Other attempts to improve the utilization of soybean protein diets by the young pig by supplementation of these diets with normally limiting essential amino acids have shown a varied response and have also met with only limited success. Hays et al. (1959) reported improved gains and efficiency for pigs weaned at 10 d of age and fed .05% supplemental DL-methionine in SBM diets compared to those fed unsupplemented SBM diets. Adjusting the gains achieved in this study to equal digestibility resulted in equal gain estimates for pigs fed methionine supplemented SBM diets and pigs fed DSM diets. Supplementing arginine in SBM diets resulted in no improvement in pig performance. Similarly, Maner et al. (1961) reported that methionine supplementation of soybean protein diets fed to pigs weaned at 3 d of age improved gain, efficiency and nitrogen retention over that achieved by pigs fed unsupplemented soybean protein diets but was inferior to that of pigs fed casein diets. Kellogg et al. (1964) reported no effect of methionine supplementation when 15 d old pigs were fed ISP rations supplemented with .1% DL-methionine for 28 d. Pigs fed supplemented and unsupplemented ISP diets showed similar performance that was inferior to that of pigs fed casein diets. Meade et al. (1965) also reported that methionine supplementation of soybean diets had no significant effect on pig performance but .15 to .20% supplemental L-lysine added to either 16 or 16.7% crude protein corn-SBM-FM-whey diets fed to pigs weaned at 21 d of age did result in an

improvement in both gain and efficiency over that of pigs fed unsupplemented diets. An absence of improvement in performance due to methionine or lysine supplementation of soybean protein diets for young pigs was reported by Lennon et al. (1971) and Wilson and Leibholz (1981). Wilson and Leibholz (1981) reported toxic effects of methionine supplementation that provided methionine-cysteine levels equal to that found in whole egg.

Studies have been conducted to determine if the improvement in performance seen in calves fed acid or alkali treated soybean proteins would also be evident in young pigs. Lennon et al. (1971) observed an improved performance in pigs weaned at 17 d of age and fed an alkali treated SF liquid diet for 28 d when compared to those receiving diets containing an untreated SF. In addition, pigs fed diets containing alkali treated SBM showed improved performance over those fed untreated SBM diets. In contrast, Wilson and Leibholz (1981) observed similar ADG and F:G ratio in pigs fed an alkali treated or untreated SF from 7 to 35 d of age. In the same study pigs fed alkaline treated SBM performed significantly better than pigs fed either alkali treated or untreated SF, however, performance was still significantly below that of pigs fed a DSM-casein diet. Similarly, Coalson et al. (1972) fed 26% crude protein liquid diets containing either casein, acid treated SF or untreated SF to pigs from 3 to 6 wk of age and found no difference in gain or efficiency of gain between dietary treatments.



Comparisons of SF diets at varying protein levels indicated that SF diets of 12 percent crude protein were sufficient for pigs weaned at 3 wk of age. This is consistent with the results of Jones et al. (1977) who showed that pigs weaned at 3 wk of age and fed liquid SF diets containing 11% of the total calories from untreated SF performed similarly to pigs fed diets containing 25 percent of the calories from either acid treated SF or casein when pigs were fed from an automatic feeding machine.

Supplementation of soybean diets with digestive enzymes or essential amino acids or the treating of soybean proteins with acid or alkali in an effort to improve diet digestibility and pig performance has led to inconsistent results and for the most part has been disappointing.

#### Amino Acid Balance and Availability

Amino acid availability estimates for supplemental protein sources in the young pig is essentially devoid. Improved availability estimates of the essential amino acids in soybean proteins for young pigs may lead to more precise diet formulations which helps to avoid the possibility of amino acid excesses and interactions that have been shown to be detrimental to other animal species and may exist in young pigs. The balance of amino acids supplied to the pig is of concern as the availability of nutrients including amino acids varies widely among feedstuffs. The importance of

balanced patterns of amino acids has been thoroughly documented with broilers (Lewis, 1968; Allen et al., 1970; D'Mello and Lewis, 1970a,b,c; D'Mello and Lewis, 1971). D'Mello and Lewis (1970a) reported the existence of a specific lysine-arginine interaction in broiler chicks fed diets deficient in methionine, tryptophan, histidine and threonine with arginine at marginally adequate levels and lysine added to excess in graded levels. Growth inhibition induced by excess lysine was overcome only by the addition of arginine to the diet. In a similar trial, interactions were also noted for leucine and isoleucine and for leucine and valine in broiler chicks in which the adverse effects of leucine were overcome by additions of isoleucine and valine (D'Mello and Lewis, 1970b). The formulation of diets, as is commonly done, to exactly meet the requirement of the most limiting amino acid will automatically provide an excess of all other amino acids in the diet. Diets formulated to minimize these excess amino acids have been shown to improve efficiency of growth when lower concentrations of protein are fed (Waldrup et al., 1976; Young et al., 1978). The leucine-isoleucine interrelationship is the only amino acid relationship to have been extensively investigated in the young pig. Pigs that averaged 5.9 kg initially were fed diets with graded levels of leucine and isoleucine, in a factorial arrangement of treatments (Ostermer et al. 1973). Leucine level in the diet exerted a significant quadratic effect on both gain to feed (G:F) and gain to protein ratio.

Isoleucine level in the diet did not effect gain, G:F or gain to protein ratio and no leucine by isoleucine interactions were observed. Similarly, Henry et al. (1976) reported that no leucine-isoleucine interaction was apparent when the leucine to isoleucine ratio in the diet ranged from 1.7 to 3.0 in a trial with 24 young gilts averaging 19.8 kg.

In typical grain-soybean diets fed to growing-finishing pigs the arginine in the ration is well above the recommended level (NRC, 1979). In light of the reports of the lysine-arginine interactions found in broilers (D'Mello and Lewis, 1970a) and the fact that lysine and arginine are both basic amino acids and share a common pathway for absorption from the gut, there has recently been concern that these high arginine levels may have a negative effect upon the utilization of lysine by the pig. Hagemeyer et al. (1983) conducted studies in which growing pigs were fed graded levels of lysine and arginine and concluded that excess arginine affects pig performance only when combined with a lysine deficiency. In a similar study, Anderson et al. (1984) reported that additions of crystalline arginine from 0 to 1.6 percent to a conventional starter diet resulted in decreased feed intake and gain in a 28 d growth trial. Addition of l-lysine.HCL to these diets failed to alleviate the adverse effects of excess arginine suggesting the absence of a specific interference with lysine utilization and hence the absence of a classical arginine-lysine antagonism in the growing pig.

If diets are to be formulated only with balanced amino acid patterns in an attempt to improve animal performance it is imperative that we have a thorough knowledge of the bio-availability of essential amino acids and nitrogen in commonly used feeds. The common methods of determining amino acid availability in feedstuffs, including chemical, enzymatic, microbial and animal assays, are discussed in a review by McLaughlin and Campbell (1969). The most commonly used procedure for the determination of amino acid availability for pigs has been the fecal index method of Kuiken and Lyman (1948). This method considers the amount of specific amino acids consumed compared to the amount voided in the feces without accounting for microbial modification in the hindgut. Several more recent studies have shown both disappearance and synthesis of amino acids in the hindgut resulting in considerable differences in amino acid availabilities determined in the feces compared to those determined from digesta obtained from the distal ileum of the small intestine (Holmes et al., 1974; Ivan and Farrell, 1976; Sauer et al., 1977; Tanksley et al., 1980; Taverner and Farrell, 1981; Jorgenson et al., 1984). Misir and Sauer (1982) reported that the availability of energy substrates in the diet may affect the results of fecal availability determinations. When starch was infused into the hindgut of cannulated pigs fed cornstarch based diets fecal amino acid excretion increased and the apparent amino acid availability of essential amino acids (fecal

determination) decreased when compared to determinations made when water was infused into the hindgut instead of starch. In association with microbial fermentation in the hindgut, Hodgson et al. (1977) and Just et al. (1981) showed that proteins or amino acids that disappear from the large intestine of the pig do so as ammonia or amines that are excreted in the urine and are therefore of no value to the pig. For these reasons determination of amino acid availability by analysis of digesta obtained from the terminal ileum of the small intestine appears to be the method of preference at this time.

With the increased costs of pork production it would be extremely beneficial if expensive milk proteins, that are currently used in complex diets for early weaned pigs to maximize performance, could be replaced with less expensive SBM without the corresponding postweaning lag and reduced performance. This can only be accomplished by determination of the factor(s) associated with this inferior performance and taking steps to eliminate its effect. Continued research in determining the effect of ethanol extraction of soybean protein on the performance of young pigs as well as determining amino acid availability of soybean protein in the diets of young pigs may ultimately accomplish this goal.

#### LITERATURE CITED

- Aherne, F. X. and V. C. Speer. 1974. Energy and nitrogen metabolism and performance responses of lactating sows fed Thyroprotein. *J. Anim. Sci.* 38:310.
- Allen, W.R., D. H. Baker and H.M. Scott. 1970. Quantitative impairment of argine utilization by graded levels of dietary lysine. *Poul. Sci.* 49:1363.
- Alsmeyer, W. L., G. E. Combs, Jr., and H. D. Wallace. 1957. Enzyme supplementation of baby pig rations containing various carbohydrate and proteinaceous feedsstuffs. *J. Anim. Sci.* 16:1040.
- Anderson, L. C., A. J. Lewis, E. R. Peo, Jr., and J. D. Crenshaw. 1984. Effects of excess arginine with and without supplemental lysine on performance, plasma amino acid concentrations and nitrogen balance of young swine. *J. Anim. Sci.* 58:369.
- Barratt, M. E. J., P.J. Strachan and P. Porter. 1979. Immunologically mediated nutritional disturbances associated with soya-protein antigens. *Proc. Nutr. Soc.* 38:143.
- Bayley, H. S. and J.H.G. Holmes. 1972. Protein sources for early weaned pigs. *J. Anim. Sci.* 35:1101. (Abstr.).
- Blair, R. 1961. The early weaning of pigs VII. The effect of level and source of protein in the diet of pigs weaned at 10 lb. live weight on subsequent performance and carcass quality. *J. Agr. Sci. (Camb.)* 57:373.
- Braude, R., K. G. Mitchell, M. J. Newport and J. W. G. Porter. 1970. Artificial rearing of pigs. 1. Effect of frequency and level of feeding on performance and digestion of milk proteins. *Brit. J. Nutr.* 24:501
- Calder, A. F. C., G. A. Lodge and R. Blair. 1959. The early weaning of pigs. V. The inclusion of digestive enzymes and antibiotics in diets for pigs weaned at 6-7 lb. live weight. *J. Agr. Sci.* 53:130.
- Clarkson, J. R. and G. L. Allee. 1982. Effect of diet and method of feeding on performance of pigs weaned at three weeks. *J. Anim. Sci.* 55(suppl. 1):80.

- Coalson, J. A. , E. E. Jones and J. G. Lecce. 1972. Diets using soy flour for pigs 3 weeks of age. J. Anim. Sci. 35:214.
- Coalson, J. A. and J. G. Leece. 1973. Herd differences in the expression of fetal diarrhea in artificially reared piglets weaned after 12 hr. vs 36 hr of nursing. J. Anim. Sci. 36:1114.
- Colvin, B. M. and H. A. Ramsey. 1968. Soy flour in milk replacers for young calves. J. Dairy Sci. 51:898.
- Colvin, B. M. and H. A. Ramsey. 1969. Growth of young calves and rats fed soy flour treated with acid or alkali. J. Dairy Sci. 52:270.
- Combs, G. E., W. L. Alsmeyer, H. D. Wallace and M. Koger. 1960. Enzyme supplementation of baby pig rations containing different sources of carbohydrate and protein. J. Anim. Sci. 19:932.
- Combs, G. E., F. L. Osegueda, H. D. Wallace and C. B. Ammerman. 1963. Digestibility of rations containing different sources of supplementary protein by young pigs. J. Anim. Sci. 22:396.
- Cunningham, H. M. and G. J. Brisson. 1957. The effect of proteolytic enzymes on the utilization of animal and plant proteins by newborn pigs and the response to predigested protein. J. Anim. Sci. 16:568.
- D'Mello, J. P. F. and D. Lewis. 1970a. Amino acid interactions in chick nutrition. 1. The interrelationship between lysine and arginine. Brit. Poul. Sci. 11:299.
- D'Mello, J. P. F. and D. Lewis. 1970b. Amino acid interactions in chick nutrition. 2. Interrelationship between leucine, isoleucine and valine. Brit. Poul. Sci. 11:313.
- D'Mello, J. P. F. and D. Lewis. 1970c. Amino acid interactions in chick nutrition. 3. Interdependence in amino acid requirements. Brit. Poul. Sci. 11:367.
- D'Mello, J. P. F. and D. Lewis. 1971. Amino acid interactions in chick nutrition. 4. Growth, food intake and plasma amino acid patterns. Brit. Poul. Sci. 12:345.
- Ducuyperre, J. A., P. Knockaert and H. K. Henderickx. 1981a. In vitro and in vivo protein digestion in pigs fed diets containing soybean protein isolates with different physical properties. J. Anim. Sci. 53:1297.

- Ducuyperre, J. A., A. Meeusen and H.K. Henderickx. 1981b. Influence of the partial replacement of milk protein by soybean protein isolates with different physical properties on the performance and nitrogen digestibility of early weaned pigs. *J. Anim. Sci.* 53:1011.
- Efird, R. C., W. D. Armstrong and D. L. Herman. 1982. The development of digestive capacity in young pigs: Effects of age and weaning system. *J. Anim. Sci.* 55:1380
- Eggum, B.D. 1970. Blood urea measurement as a technique for assessing protein quality. *Brit. J. Nutr.* 24:983.
- Fries, G. F., C. A. Lassiter and C. F. Huffman. 1958. Effects of enzyme supplementation of milk replacers on growth of calves. *J. Dairy Sci.* 41:1081.
- Fuller, M. F. and R. M. J. Crofts. 1977. The protein-sparing effect of carbohydrate. 1. Nitrogen retention of growing pigs in relation to diet. *Brit. J. Nutr.* 38:419.
- Gorrill, A. D. L. and J. W. Thomas. 1967. Body weight changes, pancreatic size and enzyme activity, and proteolytic enzyme activity and protein digestion in intestinal contents from calves fed soybean and milk protein diets. *J. Nutr.* 92:215.
- Gorrill, A. D. L., J. W. Thomas, W. E. Stewart and J. L. Morrill. 1967. Exocrine pancreatic secretion by calves fed soybean and milk protein diets. *J. Nutr.* 92:86.
- Hagemeyer, D. L., G. W. Libal and R. C. Wahlstrom. 1983. Effects of excess arginine on some growth and plasma amino acid levels. *J. Anim. Sci.* 57:99.
- Hays, V. W., V.C. Speer, P. A. Hartman and D. V. Catron. 1959. The effect age and supplemental amino acids on the utilization of milk and soya protein by the young pig. *J. Nutr.* 69:179.
- Henry, Y., P. H. Duee and A. Rerat. 1976. Isoleucine requirement of the growing pig and leucine-isoleucine interrelationship. *J. Anim. Sci.* 42:357.
- Hodgon, E. S., F. D. Horney and H. S. Bayley. 1977. Nitrogen metabolism in pigs receiving soybean and rapeseed meal. *Can. J. Anim. Sci.* 57:832 (Abstr.).



- Holmes, J. H. G., H. S. Bayley, P. A. Leadbeater and F. D. Horney. 1974. Digestion of protein in small and large intestine of the pig. *Brit. J. Nutr.* 32:479.
- Hudman, D. B., V. C. Speer, G. C. Ashton and D. V. Catron. 1955. Comparison of sources of carbohydrate for the baby pig. *J. Anim. Sci.* 14:1209 (Abstr.).
- Ivan, M. and D. J. Farrell. 1976. Nutritional evaluation of wheat straw. 5. Disappearance of components in digesta of pigs prepared with two re-entrant cannulae. *Anim. Prod.* 23:111.
- Jones, E. E., J. A. Coalson and J. G. Lecce. 1977. Soy flour as a source of protein for baby pigs. *J. Anim. Sci.* 45:1073.
- Jorgensen, H., W. C. Sauer and P. A. Thacker. 1984. Amino acid availabilities in soybean meal, sunflower meal, fishmeal and meat and bone meal fed to growing pigs. *J. Anim. Sci.* 58:926.
- J. Anim. Sci.* 1981. Editorial policy and procedures style and form information for contributors. *J. Anim. Sci.* 53:845.
- Just, A., H. Jorgensen and J. A. Fernandez. 1981. The digestive capacity of the caecum-colon and the value of the nitrogen absorbed from the hindgut for protein synthesis in pigs. *Brit. J. Nutr.* 46:209.
- Kellogg, T. F., V. W. Hays, D. V. Catron, L. Y. Quinn and V. C. Speer. 1964. Effect of level and source of dietary protein on performance and fecal flora of pigs. *J. Anim. Sci.* 23:1089.
- Kilshaw, P. J. and J. W. Sissons. 1979. Gastrointestinal allergy to soybean protein in preruminant calves. Antibody production and digestive disturbances in calves fed heated soybean flour. *Res. Vet. Sci.* 27:361.
- Kuiken, K. A. and C. M. Lyman. 1948. Availability of amino acids in some foods. *J. Nutr.* 36:359.
- Lecce, J. G., W. D. Armstrong, P. C. Crawford and G. A. Ducharme. 1979. Nutrition and management of early weaned piglets: Liquid vs. dry feeding. *J. Anim. Sci.* 48:1007.
- Leibholz, J. 1982. Utilization of casein, fishmeal and soybean proteins in dry diets for pigs between 7 and 28 days of age. *Anim. Prod.* 34:9.

- Lennon, A. M., H. A. Ramsey, W. L. Alsmeyer, A. J. Clawson and E. R. Barrick. 1971. Soy flour as a protein source for early-weaned pigs. *J. Anim. Sci.* 33:514.
- Lewis, C. J., D. V. Catron, C. H. Liu, V. C. Speer and G. C. Ashton. 1955. Enzyme supplementation of baby pig diets. *J. Agr. Food Chem.* 3:1047.
- Lewis, C. J., P. A. Hartman, C. H. Liu, R. O. Baker and D. V. Catron. 1957. Digestive enzymes of the baby pig. Pepsin and trypsin. *J. Agr. Food Chem.* 5:687.
- Lewis, D. 1968. Amino acid interactions in nutrition, especially between arginine and lysine. *Biological Interrelationships in nutr.* 15:157.
- Lloyd, L. E., E. W. Crampton and V. G. Mackey. 1957. The digestibility of ration nutrients by three- vs. seven-week old pigs. *J. Anim. Sci.* 16:383.
- Maner, J. H., W. G. Pond, J. K. Loosli. 1961. Utilization of soybean protein by baby pigs and by rats. *J. Anim. Sci.* 20:614.
- Maner, J. H., W. G. Pond, J. K. Loosli and R. S. Lowrey. 1962. Effect of isolated soybean protein and casein on the gastric pH and rate of passage of food residues in baby pigs. *J. Anim. Sci.* 21:49.
- Mateo, J. P. and T. L. Veum. 1980. Utilization of casein or isolated soybean protein supplemented with amino acids and glucose or lactose by neonatal piglets reared artificially. *J. Anim. Sci.* 50:689.
- McLaughlan, J. M. and J. A. Campbell. 1969. Methodology of protein evaluation. In: H. N. Munro (Ed.) *Mammalian Protein Metabolism*. pp406-409. Academic Press, New York and London.
- Meade, R. J., J. T. Typpo, M. E. Tumbleson, J. H. Goihl and Helmut von der Mehden. 1965. Effects of protein source and level, and lysine and methionine supplementation on rate and efficiency of gain of pigs weaned at an early age. *J. Anim. Sci.* 24:626.
- Misir, R. and W. C. Sauer. 1982. Effect of starch infusion at the terminal ileum on nitrogen balance and apparent digestibilities of nitrogen and amino acids in pigs fed meat and bone and soybean meal diets. *J. Anim. Sci.* 55:599.

- Newport, M. J. 1979. Artificial rearing of pigs 9. Effect of replacement of dried skim-milk by fish-protein concentrate on performance and digestion of protein. Br. J. Nutr. 41:103.
- Newport, M. J. and H. D. Keal. 1983a. Artificial rearing of pigs 13. Effect of replacement of dried skim milk by a functional fish-protein concentrate on the performance of pigs and digestion of protein. Br. J. Nutr. 49:43.
- Newport, M. J. and H. D. Keal. 1983b. Effect of protein source on performance and nitrogen metabolism of pigs weaned at 21 days of age. Anim. Prod. 37:395.
- Nitsan, Z., R. Volcani, S. Gordin and A. Hasdai. 1972. Growth and nutrient utilization by calves fed milk replacers containing milk or soybean protein concentrate heated to various degrees. J. Dairy Sci. 54:1294.
- Noller, C. H., C. F. Huffman, G. M. Ward and C. W. Duncan. 1956a. Dried whey and lactose as supplements to a vegetable milk replacer. J. Dairy Sci. 39:992.
- Noller, C. H., G. M. Ward, A. D. McGilliard, C. F. Huffman and C. W. Duncan. 1956b. The effects of age of the calf on the availability of nutrients in vegetable milk replacer rations. J. Dairy Sci. 39:1288.
- NRC. 1979. Nutrient Requirements of Domestic Animals, No. 2. Nutrient Requirements of Swine. Eighth Revised Ed. National Academy of Sciences-National Research Council, Washington, DC.
- Ostemer, G. A., L. E. Hanson and R. J. Meade. 1973. Leucine-isoleucine interrelationship in the young pig. J. Anim. Sci. 36:674.
- Partridge, I. G. 1981. A comparison of defluorinated rock phosphate and dicalcium phosphate, in diets containing either skim milk powder or soya bean meal as the main protein supplement, for early weaned pigs. Anim. Prod. 32:76.
- Pettigrew, J. E., B. G. Harmon, S. E. Curtis, S. G. Cornelius, H.W. Norton and A.H. Jensen. 1977a. Milk proteins for artificially reared piglets. III. Efficacy of sodium caseinate and sweet dried whey. J. Anim. Sci. 45:261.

- Pettigrew, J. E., B. G. Harmon, J. Simon and D. H. Baker. 1977b. Milk proteins for artificially reared piglets. II. Comparison to a skim milk hydrolysate. J. Anim. Sci. 44:383.
- Pond, W. G., W. Snyder, E. F. Walker, Jr, B. R. Stillings and V. Stidwell. 1971. Comparative utilization of casein, fish protein concentrate and isolated soybean protein in liquid diets for growth of baby pigs. J. Anim. Sci. 33:587.
- Pope, S. and G. L. Allee. 1982. Use of whey in diets for pigs weaned at three weeks. J. Anim. Sci. 55(suppl. 1):291.
- Puchal, F., V. W. Hays, V. C. Speer, J. D. Jones and D. V. Catron. 1962. The free blood plasma amino acids of swine as related to the source of dietary proteins. J. Nutr. 76:11.
- Ramsey, H. A. and T. R. Willard. 1975. Symposium: Recent advances in calf rearing. Soy protein for milk replacers. J. Dairy Sci. 58:436.
- Sauer, W. C., S. C. Strothers and G. D. Phillips. 1977. Apparent availabilities of amino acids in corn, wheat and barley for growing pigs. Can. J. Anim. Sci. 57:585.
- Schmidt, M. K., M. P. Sherry and T. L. Veum. 1973. Amino acid sources for neonatal piglets. J. Anim. Sci. 37:290. (Abstr.)
- Schneider, D. L. and H. P. Sarett. 1969. Growth of baby pigs fed infant soybean formulas. J. Nutr. 98:279.
- Sewell, R. F., B. E. Sheffy, R. G. Eggert and J. K. Loosli. 1953. Studies on the protein requirement of suckling pigs. J. Anim. Sci. 12:597.
- Sherry, M. P., M. K. Schmidt and T. L. Veum. 1978. Performance of neonatal piglets mechanically fed diets containing corn, soybean meal and milk protein. J. Anim. Sci. 46:1250.
- Sissons, J. W. 1982. Effects of soya-bean products on the digestive processes in the gastrointestinal tract of preruminant calves. Proc. Nutr. soc. 41:53.
- Sissons, J. W. and R. H. Smith. 1976. The effect of different diets including those containing soya-bean products, on digesta movement and water and nitrogen absorption in the small intestine of the pre-ruminant calf. Brit. J. Nutr. 36:421.

- Sissons, J. W., R. H. Smith and D. Hewitt. 1979. The effect of giving feeds containing soya-bean meal treated or extracted with ethanol on digestive processes in the preruminant calf. *Brit. J. Nutr.* 42:477.
- Smith, R. H. and J. W. Sissons. 1975. The effect of different feeds, including those containing soya-bean products, on the passage of digesta from the abomasum of the preruminant calf. *Brit. J. Nutr.* 33:329.
- Stein, J. F. and C. B. Knodt. 1954. Further studies on the use of soybean flour and whey solubles in milk replacement formulas for young dairy calves. *J. Dairy Sci.* 37:655.
- Tanksley, T. D., Jr. and D. Knabe. 1980. Availability of amino acids for swine. *Proc. 1980 Arkansas Nutr. Conf., Dept. Anim. Sci. Univ. of Arkansas, Fayetteville.*
- Taverner, M. R. and D. J. Farrell. 1981. Availability to pigs of amino acids in cereal grains. 3. A comparison of ileal availability values with fecal, chemical and enzymatic estimates. *Brit. J. Nutr.* 46:173.
- Veum, T. L. and J. P. Mateo. 1981. Utilization of glucose, sucrose or cornstarch with casein or isolated soybean protein supplemented with amino acids by 8-day-old pigs reared artificially. *J. Anim. Sci.* 53:1027.
- Waldroup, P. W., R. J. Mitchell, J. R. Payne and K. R. Hazen. 1976. Performance of chicks fed diets formulated to minimize excess levels of essential amino acids. *Poul. Sci.* 55:243.
- Wilson, R. H., J. Leibholz. 1979. Protein, fat and carbohydrate in the diets of pigs between 7 and 28 days of age. *Anim. Prod.* 28:391.
- Wilson, R. H., J. Leibholz. 1981. Digestion in the pig between 7 and 35d of age 1. The performance of pigs given milk and soybean proteins. *Brit. J. Nutr.* 45:301.
- Young, L. G. and G. C. Smith. 1973. Processing soybeans with sodium hydroxide and copper sulfate for pigs. *Can. J. Anim. Sci.* 53:587.
- Young, R. J., Axuan Ngo and A. H. Cantor. 1978. Balancing amino acids for poultry to reduce total dietary protein. *Cornell Nutr. Conf., Dept of Anim. Sci Cornell Univ., Ithica.*

## CHAPTER III

### EFFECT OF PROTEIN SOURCE ON THE PERFORMANCE OF EARLY WEANED PIGS

#### Summary

Growth rate, efficiency of feed utilization and the apparent fecal amino acid (AA) availability was determined in 72 Yorkshire boar pigs weaned at 21 d and fed practical diets with either calcium caseinate (CAS), isolated soybean protein (ISP), ethanol extracted soybean protein (ESoy) or soybean meal (SBM) as the primary source of supplemental protein. Diets were formulated to provide .95% lysine on an as fed basis. Estimates of feed intake, gain and efficiency of feed utilization were obtained weekly while the apparent availability of dry matter (DM), starch, nitrogen (N) and amino acids (AA) was estimated from fresh fecal samples collected at the end of the 3rd wk on trial. No difference ( $P > .1$ )<sup>74</sup> was observed among dietary treatments for average daily feed intake (ADFI), however, average daily gain (ADG) was higher ( $P < .05$ ) in pigs fed the CAS diets compared to those fed the ESoy or SBM diets. Averaged over the entire 5 wk trial the ADFI was 630, 650, 590 and 640 g and the ADG was 340, 320, 290 and 300 g for pigs fed the CAS, ISP, ESoy and SBM diets, respectively. A week by diet interaction

was observed ( $P < .01$ ) for G:F with pigs fed the CAS diet being more efficient ( $P < .01$ ) than those fed any of the soybean protein diets during the 1st wk on trial and more efficient ( $P < .05$ ) than pigs fed the SBM diet during the 2nd wk on trial. The G:F was similar among pigs fed all dietary treatments after the 2nd wk on trial. Higher apparent fecal availability of DM ( $P < .05$ ), lysine ( $P < .05$ ), valine ( $P < .05$ ), methionine ( $P < .01$ ) and proline ( $P < .01$ ) was observed for pigs fed the CAS diet than for pigs fed any of the soybean protein diets. Treatment effects among dietary protein sources were also evident ( $P < .1$ ) for the availability of N, isoleucine, leucine and tyrosine. The average apparent fecal availability for the EAA was 86.8, 82.4, 84.1 and 80.2% for the CAS, ISP, ESOY and SBM diets, respectively. These differences in availability may account for the differences observed among dietary treatments for ADG and G:F, however, further studies are necessary in order to fully evaluate the effect differences in AA availability among dietary protein sources may have on the growth and performance of young pigs.

(Key words: Swine, Early Weaned Pig, Soybean Meal, Amino Acid Availability)

### Introduction

Superior performance in pigs weaned between 1 and 28 days of age has been reported when diets containing milk proteins were compared to those of either soybean meal (Hays

et al., 1959; Combs et al., 1963; Schmidt et al., 1973; Wilson and Leibholz, 1981), soy flour (Bayley and Holmes, 1972; Coalson et al., 1972; Lecce et al., 1979) or isolated soybean protein (Maner et al., 1961; Pond et al., 1971; Sherry et al., 1978; Mateo and Veum, 1980; Leibholz, 1982). These studies have not elucidated the etiology of the milk protein effect. In an attempt to improve the performance of young pigs fed soybean protein diets, Lewis et al. (1955) added pepsin and/or pancreatin to the diet and found improvements in both gain and efficiency of gain when compared to pigs fed unsupplemented diets. However, other workers (Cunningham and Brisson, 1957; Combs et al., 1960; Maner et al., 1961) have been unable to confirm these observations. Similarly, Lennon et al. (1971) reported improved gain and efficiency for pigs fed diets containing alkali treated soybean protein while Coalson et al. (1972), Jones et al. (1977) and Wilson and Leibholz (1981) reported no improvement in gain and efficiency of pigs fed diets containing soybean protein treated with either acid or alkali.

Growth and digestion trials have shown that heated soy flour is unsuitable as the major source of protein for preruminant calves (Gorrill and Thomas, 1967; Nitson et al., 1972; Ramsey and Willard, 1975) and that treating soy flour with acid (Colvin and Ramsey, 1968) or alkali (Colvin and Ramsey, 1969) resulted in improved performance. In addition, digestive disturbances and slow growth observed in



calves fed heated soy flour diets (Smith and Sissons, 1975) were prevented when the soy flour was extracted with hot aqueous ethanol prior to incorporation into milk replacer diets (Sissons and Smith, 1979). The effect of ethanol extraction of soybean protein has not been tested in pigs.

Differences observed in the gain and efficiency of early weaned pigs fed either milk or soybean protein diets may be explained by differences in the bioavailability of the essential AA contained in these protein sources. Several studies (Lewis et al, 1980; Zimmerman, 1980; Rozell and Zimmerman, 1984) have shown that the lysine (limiting AA in common grain-SBM diets) requirement for the 5-10 kg pig fed a grain-SBM diet is considerably higher than the .95% currently recommended by NRC (1979). Therefore, diets formulated to meet the minimum requirements for lysine as recommended by NRC (1979) may be deficient in lysine and small differences in the availability of lysine (or other AA) could result in large differences in pig performance. At this time AA availability data for this age of pig is extremely limiting.

This study was conducted to determine the effect of source of protein and method of processing of soybean protein upon performance and dry matter, nitrogen, amino acid and starch availability in pigs weaned at 21 d of age.

## Materials and Methods

Seventy-two Yorkshire boar pigs were used to study the effect of dietary protein source on the performance of early weaned pigs. Twelve pigs in each of 6 replicates were weaned at approximately 21 d of age and randomly allotted within litter to one of the four dietary treatments providing a total of 18 pigs per treatment. The average initial weight for all pigs on trial was 5.8 kg. One milk and 3 soybean protein sources were used in practical diets (Table 1) formulated to meet NRC (1979) requirements for the 5-10 kg pig. Protein sources were calcium caseinate (CAS), isolated soybean protein (ISP), ethanol extracted soybean protein (ESoy) and 44% crude protein solvent extracted soybean meal (SBM). Protein sources were substituted for corn on an equal lysine basis to provide .95% lysine. All other amino acids were above NRC (1979) requirements and crude protein ranged from 17 to 19% among diets. Pigs were housed in individual metal pens measuring .7 by 1.0 m in an environmentally controlled feeding room maintained at 27 - 32 C . Pigs had access to feed and water ad libitum throughout the trial. Pigs remained on trial for a 35 d period with pig weight and feed intake recorded weekly. Feed waste was collected in pans placed under individual feeders and dried to provide a more accurate estimate of feed intake. During the third week of each replicate chromic oxide was added to each diet at the rate of .25% to provide an indigestible marker for determining nutrient

availability. A fresh fecal sample was collected from each pig on the last day of the 3rd wk of each replicate and stored at -20 C prior to lypholyzation and grinding for laboratory analysis.

Dry matter and nitrogen content of both feed and feces were determined according to AOAC (1975) methods. Starch content was determined by the method of Macrae and Armstrong (1968) and chromic oxide by the method of Stevenson and DeLangen (1960). Amino acid concentration, with the exception of tryptophan, was determined from acid hydrolysates by ion exchange chromatography using a Beckman model 121 automatic amino acid analyzer according to the methods outlined in the Beckman model 121 amino acid analyzer instruction manual 121-1M-1A April 1970, Palo Alto CA. Acid hydrolysis was conducted under nitrogen reflux in 6N HCl for 24 h.

Data for each response criteria were analyzed as a split plot design using least-squares analysis of variance procedures (SAS, 1979). The model for ADFI, ADG and G:F included the main effects of block, treatment and week and the appropriate interactions with weight and age on test as covariates. Treatment effects were tested with the block by treatment interaction as the appropriate error term. The model for availability estimates included block and treatment.

## Results and Discussion

The protein and amino acid composition of all diets is shown in table 2. Crude protein as well as the essential amino acids (EAA) arginine, phenylalanine and threonine were highest in the soybean protein diets while methionine and valine were highest in the CAS diet. The remainder of the EAA were similar among all diets.

The effect of dietary protein source on average daily feed intake (ADFI) and average daily gain (ADG) is presented in table 3. Average daily feed intake was similar ( $P>.1$ ) in pigs fed all dietary treatments over the 5 wk trial. This is consistent with other studies which reported similar ADFI among early weaned pigs when whole milk diets were compared with ISP diets (Schneider and Sarett, 1969) and when dried skim milk (DSM) diets were compared to soybean flour (SF) diets (Lecce et al., 1979) or SBM diets (Partridge, 1981). Pigs fed the CAS diet grew 6.3, 17.2 and 13.3% faster than pigs fed the ISP, ESOY ( $P<.05$ ) or SBM ( $P<.05$ ) diets, respectively, while pigs fed the ISP diets grew 10.3 and 6.7% faster than those fed either the ESOY ( $P<.05$ ) or SBM diets, respectively. ADG was similar among pigs fed the ESOY and SBM diets. Differences observed in ADG were primarily the result of differences that occurred during the first 2 wk on trial (table 4). During the first week on trial, pigs fed the CAS diet grew faster than pigs fed the ESOY or SBM diet ( $P<.05$ ). In fact, pigs fed the ESOY diet actually lost weight during the 1st wk on trial. This trend

was still evident in wk 2 of the trial although differences were significant only for pigs fed the ESOY diet. With the exception of pigs fed the ESOY diet during the third week ADG was similar among pigs on all treatments during the last 3 wk on trial. It should be noted that although significant differences were observed in ADG the first 3 wk of the trial and gain was similar during the last 2 wk, no treatment by week interaction ( $P > .6$ ) was observed.

The effect of dietary protein source on the efficiency of feed utilization was similar to that observed for ADG (table 5). Pigs fed the CAS diets had a higher ( $P < .01$ ) gain to feed ratio (G:F) during the first week on trial than pigs fed any of the soybean protein diets. Furthermore, during wk 1 pigs fed either the ISP or SBM diets were more efficient ( $P < .01$ ) than those fed the ESOY diet. During wk 2, pigs fed the CAS diet had a G:F ratio similar to that observed in pigs fed ISP or ESOY diets but had a greater ( $P < .05$ ) G:F ratio than pigs fed the SBM diet. The G:F ratio was similar for all pigs regardless of dietary treatment during the 3rd, 4th or 5th week on trial resulting in a treatment by week interaction ( $P < .01$ ). Averaged over the entire trial the G:F ratio of the pigs fed the CAS diet was higher ( $P < .01$ ) than the average G:F ratio of all pigs fed soybean protein diets (520 and 410 g gain per kg feed for CAS and soybean protein diets, respectively).

Several workers have reported higher ADG and improved efficiency of feed utilization for pigs fed CAS diets

compared to those fed ISP diets (Maner et al., 1961; Pond et al., 1971; Mateo and Veum, 1980; Wilson and Leibholz, 1981; Leibholz, 1982) or SBM diets (Wilson and Leibholz, 1981; Leibholz, 1982). In addition, in a 21 d study Wilson and Leibholz (1981) observed a greater magnitude of difference for ADG during the first week on trial than during the last week on trial between pigs fed milk or soybean protein diets.

The 340 g/d gain reported for pigs fed the CAS diet as well as the 300 g/d gain for the average of those fed the soybean protein diets in this study are similar to values reported by other workers for this age of pig (Puchal et al., 1962; Kellogg et al., 1964; Jones et al., 1977) which range from 325 to 370 and 250 to 390 g/d for pigs fed milk and soybean protein diets, respectively. However the G:F ratio reported in this study for all diets was below that reported by these same workers.

The apparent fecal availability of DM was highest in pigs fed the CAS diet averaging 2.7, 3.4 and 5.2 percentage units higher ( $P < .05$ ) than in pigs fed the ISP, ESOY and SBM diets, respectively (table 6). The apparent availability of DM in pigs fed the ISP diet was similar to that observed in pigs fed the ESOY diet but higher ( $P < .01$ ) than that observed in pigs fed the SBM diet. Dry matter availability was similar ( $P > .1$ ) in pigs fed the ESOY and SBM diets. The apparent fecal availability of DM reported for pigs fed the SBM diet (82.4%) was similar to that reported by Combs et

al. (1963) in which 5 to 6 wk old pigs were fed corn-SBM diets (81.5%). Similarly, differences in the apparent fecal availability of DM between the CAS and SBM diets and ISP and SBM diets reported in this study are consistent with differences reported by Leibholz (1982) for pigs fed diets with similar sources of dietary protein. Hays et al. (1959) and Wilson and Leibholz (1981) also reported higher apparent fecal DM availability for young pigs fed milk protein diets compared to those fed soybean protein diets. Differences in DM availability between pigs fed the CAS and ISP diets are primarily due to differences in N availability since the apparent availability of starch was similar among all dietary treatments ranging from a low of 98.3% in pigs fed the SBM diet to a high of 99.0% in pigs fed the CAS diet. Differences in DM availability among the soybean protein sources may be due to the removal of complex carbohydrates during the isolation and extraction procedures in ISP and ESOY.

Apparent fecal availability of N was highest ( $P < .1$ ) in pigs fed the CAS diet and lowest in pigs fed the SBM diet (table 7). The difference in N availability between pigs fed the CAS and ISP diets (3.1 percentage units) was similar to the difference in DM availability (2.7 percentage units) for these same protein sources. The N availability value reported for pigs fed the SBM diet (76.2%) in this study was similar to that reported by Combs et al. (1963) in 5 to 6 wk old pigs fed a corn-SBM diet (75.9%). Apparent fecal

availability was higher for methionine ( $P < .01$ ), lysine ( $P < .05$ ) and valine ( $P < .05$ ) in pigs fed the CAS diet than for pigs fed any of the soybean protein diets (table 7). The apparent availability of methionine and lysine was similar among pigs fed all of the soybean protein sources while availability of valine was higher ( $P < .05$ ) in pigs fed the ESOY diet than in pigs fed the SBM diet with the availability of valine in pigs fed the ISP diet being intermediate. Other EAA for which differences among dietary treatments were observed ( $P < .1$ ) were isoleucine and leucine. The apparent availability of these AA appeared to be higher in pigs fed the CAS diet than in pigs fed any of the soybean protein diets with the greatest differences in availability being between the CAS and SBM diets. Differences in apparent fecal availability were not observed ( $P > .1$ ) for the remaining EAA, however, with the exception of arginine, the actual availability of these AA was higher in pigs fed the CAS diet than in those fed any of the soybean protein diets. Differences in the fecal availability among dietary treatments for the nonessential AA were observed only for proline ( $P < .01$ ) and tyrosine ( $P < .1$ ). Availability in both instances was highest in pigs fed the CAS diet and lowest in pigs fed the SBM diet. The apparent fecal availability of the remaining nonessential AA was similar among all dietary treatments. Since apparent fecal availability data for the young pig fed diets similar to those in this study are not available in the literature, comparisons must be made with



values obtained from older growing-finishing pigs. Apparent fecal availability estimates ranging from 88 to 92% for the average availability of the EAA have been reported for growing-finishing pigs fed SBM diets (Tanksley et al., 1981; Sauer et al., 1982; Rudolph et al., 1983; Jorgensen et al., 1984). These values in growing-finishing pigs are higher than the value reported in our study (80.2%) for the average apparent availability of the EAA in the SBM diet. This could be due to increased nutrient availability with increasing age in young pigs (Hays et al., 1959; Combs et al., 1963; Wilson and Leibholz, 1981; Leibholz, 1982). Furthermore, the semipurified cornstarch based diets fed to the growing-finishing pigs (Tanksley et al., 1981; Sauer et al., 1982; Rudolph et al., 1983; Jorgensen et al., 1984) would be expected to have a higher nutrient availability than the practical diets fed to the early weaned pigs in our study. These diets formulated to meet the NRC (1979) requirement for lysine (.95%) for the 5-10 kg pig have been shown to be below the levels of lysine (1.15-1.20%) reported to provide maximum gain and efficiency for this age of pig fed grain-SBM diets (Lewis et al., 1980; Zimmerman, 1980; Rosell and Zimmerman, 1984). Therefore, since lysine availability is higher for CAS than for the soybean proteins, one would expect to see better performance in pigs fed CAS. The differences observed in fecal AA availability between dietary protein sources, especially between the CAS and SBM diets, were not as large as differences observed

among these same protein sources when availability was determined at the terminal end of the small intestine in pigs fed semipurified cornstarch based diets (Walker, 1984). For the practical diets in this study the percent of the total protein provided by corn in the CAS diet (43.6%) was higher than in the ISP (37.7%), ESOY (35.9%) or SBM diet (33.0%). These differences in the amount of corn protein may have resulted in the smaller differences observed between dietary protein sources in this study.

In general, the results of this study indicate that faster growth and a higher G:F ratio can be achieved during the first 2 wk postweaning when pigs weaned at 3 wk of age are fed casein in place of soybean protein and equal gain and efficiency can be achieved after the 2nd wk postweaning with either casein or soybean proteins. Feeding ISP to young pigs during the first 2 wk postweaning appears to provide some advantage over SBM, however, differences were relatively small. No improvement in ADG or G:F ratio was observed for pigs fed the ESOY diet compared to those fed either ISP or SBM diets, however, there appeared to be a slight trend for higher apparent AA availability for this diet when compared to the ISP diet. Both the ISP and the ESOY diets appeared to offer higher AA availability than the SBM diet.

TABLE 1  
COMPOSITION OF DIETS

Ingredient	Diets <sup>a,b</sup>			
	CAS	ISP	ESoy	SBM
	%			
Corn (IFN 4-02-935)	87.14	83.17	77.87	69.99
Calcium caseinate <sup>c</sup>	9.74			
Isolated soy protein <sup>d</sup>		13.39		
Ethanol extracted soy protein <sup>e</sup>			18.69	
Soybean meal (IFN 5-04-604)				26.67
Calcium carbonate (IFN 6-01-069)	0.87	1.21	1.15	1.19
Dicalcium phosphate (IFN 6-01-080)	1.35	1.33	1.39	1.25
Vitamin, TM premix <sup>f</sup>	.35	.35	.35	.35
Salt (IFN 6-14-013)	.30	.30	.30	.30
ASP-250	.25	.25	.25	.25
	100	100	100	100
Calculated Analysis (%)				
Crude protein	17.11	18.97	18.81	17.89
Lysine	.95	.95	.95	.95
Calcium	.80	.80	.80	.80
Phosphorus	.60	.60	.60	.60

<sup>a</sup>As fed basis.

<sup>b</sup>CAS: calcium caseinate diet; ISP: isolated soybean protein diet;  
ESoy: ethanol extracted soybean protein diet; SBM: soybean meal diet.

<sup>c</sup>Ultra supreme calcium caseinate, Erie Casein Co. Inc., Erie, IL.

<sup>d</sup>Soybean protein grade II, United States Biochemical Corp., Cleveland, OH.

<sup>e</sup>Promocaf, Central Soy, Fort Wayne, IN.

<sup>f</sup>Supplied 4,405 IU vitamin A, 3,304 IU vitamin D, 4.4 mg riboflavin, 22 mg pantothenic acid, 33 mg niacin, 880 mg choline chloride, .02 mg vitamin B<sub>12</sub>, 11 IU vitamin E, 2.2 mg menadione, .22 mg iodine, 99 mg iron, 22 mg manganese, 11 mg copper, 99 mg zinc and .11 mg selenium per kg of feed.

TABLE 2  
PROTEIN AND AMINO ACID  
COMPOSITION OF DIETS

Item	Diet <sup>a,b</sup>			
	CAS	ISP	ESoy	SBM
Crude protein, %	17.9	19.9	19.5	19.1
Amino acids, %				
Essential				
Arginine	.78	1.31	1.30	1.24
Histidine	.51	.52	.51	.50
Isoleucine	.78	.85	.82	.80
Leucine	1.87	1.90	1.85	1.77
Lysine	1.03	1.02	1.02	1.01
Methionine	.46	.37	.34	.36
Phenylalanine	.88	1.00	.97	.94
Threonine	.72	.75	.76	.76
Valine	1.01	.95	.92	.90
Nonessential				
Alanine	.87	1.07	1.05	1.02
Aspartic acid	1.28	1.96	1.94	1.91
Cystine	.23	.40	.42	.40
Glutamic acid	3.51	3.61	3.51	3.40
Glycine	.51	.81	.81	.81
Proline	1.73	1.28	1.27	1.21
Serine	.93	1.00	1.00	.97
Tyrosine	.87	.79	.77	.77

<sup>a</sup>Dry matter basis.

<sup>b</sup>For explanation of diet code names, see table 1, footnote b.

TABLE 3  
EFFECT OF PROTEIN SOURCE ON AVERAGE  
DAILY FEED INTAKE (ADFI) AND  
AVERAGE DAILY GAIN (ADG)

Item	Diet <sup>a</sup>			
	CAS	ISP	ESoy	SBM
Pigs per treatment, no. <sup>b</sup>	17.0	18.0	17.0	17.0
Initial age, d	20.9	20.9	21.1	20.9
Initial weight, kg	5.7	5.8	6.0	5.7
Final weight, kg	17.7	17.1	16.8	16.2
ADFI, g	630	650	590	640
ADG, g	340 <sup>c</sup>	320 <sup>cd</sup>	290 <sup>e</sup>	300 <sup>de</sup>

<sup>a</sup>For explanation of diet code names, see table 1, footnote b.

<sup>b</sup>One pig on the CAS diet died from causes unrelated to dietary treatment. One pig was removed from each of the ESoy and SBM diets for prolonged feed refusal.

<sup>cde</sup>Means in the same row with different superscripts differ  $P < .05$ .

TABLE 4  
EFFECT OF PROTEIN SOURCE AND TIME  
ON AVERAGE DAILY GAIN<sup>a</sup>

Item		Diet <sup>b</sup>			
		CAS	ISP	ESoy	SBM
		g			
Week	1	70 <sup>c</sup>	20 <sup>cd</sup>	- 30 <sup>d</sup>	10 <sup>d</sup>
	2	250 <sup>c</sup>	220 <sup>cd</sup>	180 <sup>d</sup>	200 <sup>cd</sup>
	3	340 <sup>cd</sup>	350 <sup>c</sup>	300 <sup>d</sup>	320 <sup>cd</sup>
	4	470	470	480	450
	5	570	550	530	540

<sup>a</sup>Adjusted for age and weight on trial.

<sup>b</sup>For explanation of diet code names, see table 1, footnote b.

<sup>cd</sup>Means in the same row with different superscripts differ P<.05.

TABLE 5  
EFFECT OF PROTEIN SOURCE AND TIME  
ON GAIN TO FEED RATIO<sup>a</sup>

Item	Diet <sup>b</sup>			
	CAS	ISP	ESoy	SBM
	g/1000 g feed			
Week 1	280 <sup>c</sup>	20 <sup>d</sup>	-290 <sup>e</sup>	- 10 <sup>d</sup>
2	670 <sup>f</sup>	620 <sup>fg</sup>	600 <sup>fg</sup>	500 <sup>g</sup>
3	570	600	560	540
4	550	540	580	510
5	530	470	480	480
Average	520	450	386	404

<sup>a</sup>Adjusted for age and weight on trial.

<sup>b</sup>For explanation of diet code names, see table 1, footnote b.

<sup>cde</sup>Means in the same row with different superscripts differ P<.01.

<sup>fg</sup>Means in the same row with different superscripts differ P<.05.

TABLE 6  
 APPARENT AVAILABILITY OF DRY MATTER AND STARCH  
 MEASURED OVER THE TOTAL DIGESTIVE  
 TRACT FOR EARLY WEANED PIGS

Item	Diet <sup>a</sup>				SE
	CAS	ISP	ESoy	SBM	
Pigs per treatment, no. <sup>b</sup>	17.0	18.0	17.0	17.0	
Initial age, d	20.9	20.9	21.1	20.9	
Initial weight, kg	5.7	5.8	6.0	5.7	
Dry matter, %	87.6 <sup>c</sup>	84.9 <sup>d</sup>	84.2 <sup>de</sup>	82.4 <sup>e</sup>	.8
Starch, %	99.0	98.5	98.6	98.3	.3

<sup>a</sup>For explanation of diet code names, see table 1, footnote b.

<sup>b</sup>One pig on the CAS diet died from causes unrelated to dietary treatment. One pig was removed from each of the ESoy and SBM diets for prolonged feed refusal.

<sup>cde</sup>Means in the same row with different superscripts differ  $P < .05$ .



TABLE 7  
 APPARENT AVAILABILITY OF NITROGEN AND AMINO  
 ACIDS MEASURED OVER THE TOTAL DIGESTIVE  
 TRACT FOR EARLY WEANED PIGS<sup>a</sup>

Item	Diet <sup>b</sup>				SE
	CAS	ISP	ESoy	SBM	
Pigs per treatment, no. <sup>b</sup>	17.0	18.0	17.0	17.0	
Initial age, d	20.9	20.9	21.1	20.9	
Initial weight, kg	5.7	5.8	6.0	5.7	
Nitrogen, % <sup>c</sup>	83.7	80.6	80.8	76.2	1.1
Amino acids, %					
Essential					
Arginine	88.4	90.6	91.1	88.1	.6
Histidine	89.7	86.8	88.4	86.0	.8
Isoleucine <sup>c</sup>	86.1	81.0	82.6	77.6	1.2
Leucine <sup>c</sup>	88.4	82.2	85.0	80.9	1.2
Lysine	86.3 <sup>d</sup>	82.8 <sup>e</sup>	83.8 <sup>e</sup>	80.1 <sup>e</sup>	.9
Methionine	87.7 <sup>g</sup>	79.6 <sup>h</sup>	81.0 <sup>h</sup>	78.9 <sup>h</sup>	1.2
Phenylalanine	86.5	82.6	83.8	78.5	1.1
Threonine	82.4 <sup>d</sup>	77.2	80.0	75.6 <sup>f</sup>	1.2
Valine	85.6 <sup>d</sup>	78.8 <sup>ef</sup>	81.1 <sup>e</sup>	75.7 <sup>f</sup>	1.2
Avg	86.8	82.4	84.1	80.2	
Nonessential					
Alanine	78.9	75.3	78.4	73.5	1.5
Aspartic acid	81.5	85.0	86.0	82.1	.9
Cystine	95.3	96.0	97.8	95.2	.8
Glutamic acid	90.4	87.7	89.1	86.0	.8
Glycine	75.0	78.6	80.4	75.3	1.2
Proline	93.2 <sup>g</sup>	87.7 <sup>h</sup>	88.2 <sup>h</sup>	84.2 <sup>i</sup>	.9
Serine	87.5	84.4	85.9	81.3	1.0
Tyrosine <sup>c</sup>	88.1	82.4	83.5	79.0	1.1
Avg	86.2	84.6	86.2	82.1	

<sup>a</sup>One pig on the CAS diet died from causes unrelated to dietary treatment. One pig was removed from each of the ESoy and SBM diets for prolonged feed refusal.

<sup>b</sup>For explanation of diet code names, see table 1, footnote b.

<sup>c</sup>Treatment effect  $P < .1$ .

<sup>d</sup>Means in the same row with different superscripts differ  $P < .05$ .

<sup>ghi</sup>Means in the same row with different superscripts differ  $P < .01$ .

## LITERATURE CITED

- AOAC. 1975. Official Methods of Analysis (12th Ed.). Association of Official Analytical Chemists, Washington, DC.
- Bayley, H. S. and J.H.G. Holmes. 1972. Protein sources for early weaned pigs. J. Anim. Sci. 35:1101. (Abstr.).
- Coalson, J. A. , E. E. Jones and J. G. Lecce. 1972. Diets using soy flour for pigs 3 weeks of age. J. Anim. Sci. 35:214.
- Colvin, B. M. and H. A. Ramsey. 1968. Soy flour in milk replacers for young calves. J. Dairy Sci. 51:898.
- Colvin, B. M. and H. A. Ramsey. 1969. Growth of young calves and rats fed soy flour treated with acid or alkali. J. Dairy Sci. 52:270.
- Combs, G. E., W. L. Alsmeyer, H. D. Wallace and M. Koger. 1960. Enzyme supplementation of baby pig rations containing different sources of carbohydrate and protein. J. Anim. Sci. 19:932.
- Combs, G. E., F. L. Osegueda, H. D. Wallace and C. B. Ammerman. 1963. Digestibility of rations containing different sources of supplementary protein by young pigs. J. Anim. Sci. 22:396.
- Cunningham, H. M. and G. J. Brisson. 1957. The effect of proteolytic enzymes on the utilization of animal and plant proteins by newborn pigs and the response to predigested protein. J. Anim. Sci. 16:568.
- Gorrill, A. D. L. and J. W. Thomas. 1967. Body weight changes, pancreatic size and enzyme activity, and proteolytic enzyme activity and protein digestion in intestinal contents from calves fed soybean and milk protein diets. J. Nutr. 92:215.
- Hays, V. W., V.C. Speer, P. A. Hartman and D. V. Catron. 1959. The effect age and supplemental amino acids on the utilization of milk and soya protein by the young pig. J. Nutr. 69:179.
- Jones, E. E., J. A. Coalson and J. G. Lecce. 1977. Soy flour as a source of protein for baby pigs. J. Anim. Sci. 45:1073.

- Jorgensen, H., W. C. Sauer and P. A. Thacker. 1984. Amino acid availabilities in soybean meal, sunflower meal, fishmeal and meat and bone meal fed to growing pigs. *J. Anim. Sci.* 58:926.
- Kellogg, T. F., V. W. Hays, D. V. Catron, L. Y. Quinn and V. C. Speer. 1964. Effect of level and source of dietary protein on performance and fecal flora of pigs. *J. Anim. Sci.* 23:1089.
- Lecce, J. G., W. D. Armstrong, P. C. Crawford and G. A. Ducharme. 1979. Nutrition and management of early weaned piglets: Liquid vs. dry feeding. *J. Anim. Sci.* 48:1007.
- Leibholz, J. 1982. Utilization of casein, fishmeal and soybean proteins in dry diets for pigs between 7 and 28 days of age. *Anim. Prod.* 34:9.
- Lennon, A. M., H. A. Ramsey, W. L. Alsmeyer, A. J. Clawson and E. R. Barrick. 1971. Soy flour as a protein source for early-weaned pigs. *J. Anim. Sci.* 33:514.
- Lewis, A. J., E. R. Peo, Jr., B. D. Moser and T. D. Crenshaw. 1980. Lysine requirement of pigs weighing 5 to 15 kg fed practical diets with and without added fat. *J. Anim. Sci.* 51:361.
- Lewis, C. J., D. V. Catron, C. H. Liu, V. C. Speer and G. C. Ashton. 1955. Enzyme supplementation of baby pig diets. *J. Agr. Food Chem.* 3:1047.
- Maner, J. H., W. G. Pond, J. K. Loosli. 1961. Utilization of soybean protein by baby pigs and by rats. *J. Anim. Sci.* 20:614.
- Mateo, J. P. and T. L. Veum. 1980. Utilization of casein or isolated soybean protein supplemented with amino acids and glucose or lactose by neonatal piglets reared artificially. *J. Anim. Sci.* 50:689.
- Macrae, J. C. and D. G. Armstrong. 1968. Enzyme method for determination of alpha-linked glucose polymers in biological materials. *J. Sci. Agr.* 19:578.
- Nitsan, Z., R. Volcani, S. Gordin and A. Hasdai. 1972. Growth and nutrient utilization by calves fed milk replacers containing milk or soybean protein concentrate heated to various degrees. *J. Dairy Sci.* 54:1294.

- NRC. 1979. Nutrient Requirements of Domestic Animals, No. 2. Nutrient Requirements of Swine. Eighth Revised Ed. National Academy of Sciences-National Research Council, Washington, DC.
- Partridge, I. G. 1981. A comparison of defluorinated rock phosphate and dicalcium phosphate, in diets containing either skim milk powder or soya bean meal as the main protein supplement, for early weaned pigs. *Anim. Prod.* 32:76.
- Pond, W. G., W. Snyder, E. F. Walker, Jr, B. R. Stillings and V. Stidwell. 1971. Comparative utilization of casein, fish protein concentrate and isolated soybean protein in liquid diets for growth of baby pigs. *J. Anim. Sci.* 33:587.
- Puchal, F., V. W. Hays, V. C. Speer, J. D. Jones and D. V. Catron. 1962. The free blood plasma amino acids of swine as related to the source of dietary proteins. *J. Nutr.* 76:11.
- Ramsey, H. A. and T. R. Willard. 1975. Symposium: Recent advances in calf rearing. Soy protein for milk replacers. *J. Dairy Sci.* 58:436.
- Rosell, V. L. and D. R. Zimmerman. 1984. Effects of graded levels of lysine and excess arginine and threonine on Young Pigs fed practical diets. *J. Anim. Sci.* 59:135.
- Rudolph, B. C., L. S. Boggs, D. A. Knabe, T.D. Tanksley, Jr. and S. A. Anderson. 1983. Digestibility of nitrogen and amino acids in soybean products for pigs. *J. Anim. Sci.* 57:373.
- SAS. 1979. SAS Users Guide. Statistical Analysis System Institute, Cary, NC.
- Sauer, W.C., R. Cichon and R. Misir. 1982. Amino acid availability and protein quality of rapeseed meal for pigs and rats. *J. Anim. Sci.* 54:292.
- Schmidt, M. K., M. P. Sherry and T. L. Veum. 1973. Amino acid sources for neonatal piglets. *J. Anim. Sci.* 37:290. (Abstr.)
- Schneider, D. L. and H. P. Sarett. 1969. Growth of baby pigs fed infant soybean formulas. *J. Nutr.* 98:279.
- Sherry, M. P., M. K. Schmidt and T. L. Veum. 1978. Performance of neonatal piglets mechanically fed diets containing corn, soybean meal and milk protein. *J. Anim. Sci.* 46:1250.

- Sissons, J. W., R. H. Smith and D. Hewitt. 1979. The effect of giving feeds containing soya-bean meal treated or extracted with ethanol on digestive processes in the preruminant calf. *Brit. J. Nutr.* 42:477.
- Smith, R. H. and J. W. Sissons. 1975. The effect of different feeds, including those containing soya-bean products, on the passage of digesta from the abomasum of the preruminant calf. *Brit. J. Nutr.* 33:329.
- Stevenson, A. E. and H. DeLangen. 1960. Measurement of feed intake by growing cattle and sheep. VII. Modified wet digestion method for determination of chromic oxide in faeces. *New Zealand J. AGR. Res.* 3:314.
- Tanksley, T. D., Jr, D. A. Knabe, K. Purser, T. Zebrowska and J. R. Corley. 1981. Apparent digestibility of amino acids and nitrogen in three cottonseed meals and one soybean meal. *J. Anim. Sci.* 52:769.
- Walker, W. R. 1984. Protein utilization and amino acid availability in early weaned pigs. Ph.D. Dissertation. OK. State Uni. Stillwater, OK.
- Wilson, R. H., J. Leibholz. 1981. Digestion in the pig between 7 and 35d of age 1. The performance of pigs given milk and soybean proteins. *Brit. J. Nutr.* 45:301.
- Zimmerman, D. R. 1980. Lysine requirement of the 5 to 10 kg pig. *J. Anim. Sci.* 51(suppl. 1):78.

## CHAPTER IV

### A SIMPLE T-CANNULA ILEAL CANNULATION PROCEDURE FOR NEONATAL PIGS

#### Summary

A suitable cannula and surgical procedure for ileal cannulation of pre-weaned pigs is described. A lightweight durable T-cannula that provides adequate sample flow in pigs fed either semi-purified or practical diets was developed and installed in pigs at 18 d of age to facilitate digestion studies immediately following weaning. These cannulas are easily maintained, and provide a means of repeated sample collection from pigs up to 60 kg at which time they can be nonsurgically removed from the conscious pig and replaced with larger cannulas for subsequent studies. A screw cap and collar provide a means of adjustment for growth and simplify maintenance and collection procedures.

#### Introduction

In order to maximize production efficiency it is essential to understand nutrient availability in pigs during all phases of production. A number of recent studies (Holmes et al., 1974; Ivan and Farrell, 1976; Sauer et al., 1977; Tanksley and Knabe, 1980; Jorgensen et al. 1984) have

suggested that estimation of ileal bioavailability is the method of choice in estimating availability of nutrients in the pig. The bioavailability of nitrogen and essential amino acids in pigs estimated by comparing nutrient composition of fecal material to that of feed does not account for modifications by microbial organisms in the cecum and small intestine (Holmes et al., 1974; Ivan and Farrell, 1976; Sauer et al., 1977; Tanksley and Knabe, 1980; Taverner and Farrell, 1981; Jorgensen et al., 1984). In addition, the determination of ileal AA availability may be more accurate since digestion and absorption of most nutrients is essentially complete in the small intestine and nitrogen and amino acids that disappear from the hindgut are of little or no value to the pig (Just et al., 1981).

The neonatal pig at weaning is subjected to extreme diet changes (Lecce et al., 1979) during a period when digestive capacity is undergoing rapid development (Lewis et al., 1957; Hartman et al., 1961; Efird et al., 1982). Studies to estimate ileal bioavailability in the pig immediately postweaning are essential to an understanding of dietary effects on performance. Although, several ileal cannulation techniques, with both re-entrant (Cunningham et al., 1962; Easter and Tanksley, 1973; Ivan, 1974) and T-cannulas (Horzczaruk et al., 1972; Sauer, 1976; Decuypere et al., 1977) have been described for collecting intestinal samples for estimation of nutrient bioavailability in growing-finishing pigs, no such techniques have been

developed for the neonatal pig. The extremely small intestinal diameter in the young pig prohibits the use of complicated re-entrant cannulas or T-cannulas normally constructed of thick-walled, flexible plastic tubing. A suitable cannula for the young pig must be small enough to fit within the lumen of the small intestine yet provide sufficient internal diameter to allow suitable digesta flow through the cannula. A further complication with the young pig is that the cannula must be designed with minimum protrusion beyond the body wall since it is very difficult to restrict the movement of young pigs within a metabolism crate.

The purpose of this paper is to describe a lightweight, T-cannula suitable for ileal cannulation which will allow repeated sample collection in early weaned pigs.

## Materials and Methods

### Cannula Design

Figure 1 illustrates the cannula designed for ileal cannulation of 18 d old pigs. The material used to make this single piece cannula was an acetal homopolymer resin (Delrin 600<sup>1</sup>) that provides a rigid lightweight yet extremely durable plastic. The cannula was constructed from a 4 cm diameter solid stock bar of Delrin measuring 3 cm in length. This bar was machined to a diameter of 2 cm

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<sup>1</sup>Dupont Chemical Corp., Willmington, Delaware



starting at one end and proceeding for a distance of 2.7 cm. This left .3 cm at the opposite end of the bar the original diameter. The bar was then threaded externally (10 threads/cm) starting at the small machined end and proceeding for a distance of 1.7 cm leaving an unthreaded section 1 cm long next to the large unmachined end of the bar. The 2 cm diameter section was then machine cut on two opposite sides (.5 cm from each side) leaving a 1 cm wide ovoid shaped body (figure 1A) with two flat smooth sides and threaded ends. The center of the bar was drilled out through the entire 3 cm length to provide an ovoid shaped barrel measuring .8 by 1.6 cm for digesta passage during collection. The large diameter end of the bar was hand tooled to provide a flanged end (figure 1B) designed with a concave inner surface to conform physically to the shape of the ileum (figure 2). The flange measured 3.7 cm long by 1.4 cm wide. Three holes (1 mm diameter) were drilled through each of the flat sides of the body of the cannula for sutures which were used to anchor the cannula and prevent rotation. All unthreaded areas on the cannula were hand finished to provide smooth surfaces and rounded edges in places where the cannula would likely come into contact with the pig.

To secure the cannula in place against the body of the pig, a lucite<sup>2</sup> collar (figure 1C) was made with a 2.5 cm

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<sup>2</sup>Dupont Chemical Corp., Willmington, Delaware

outer diameter and 2 cm inner diameter. This collar is threaded internally to match the threads on the body of the cannula. In addition to securing the cannula in place the collar allows adjustment to compensate for increasing body wall thickness with growth of the pig. A cap (figure 1D), also made of lucite, was designed in a similar fashion to provide a cap for the cannula to prevent leakage during periods between sample collection.

### Surgical Procedure

Yorkshire gilt pigs weighing 4.5 to 5.5 kg were removed from the litter approximately 1 h prior to surgery. Anesthesia was induced with halothane administered via face mask and maintained with an endotracheal tube. The pigs were placed in left lateral recumbency on padded cotton towels provided for warmth. The right flank was shaved with surgical clippers and prepped with a surgical scrub.

A laparotomy incision was performed in the right abdominal wall beginning 3 to 4 cm below the transverse process of the fourth lumbar vertebra and continuing ventrally for approximately 3 cm. The cecum was located and exteriorized and the ileo-cecal ligament identified. A section of ileum 3 to 4 cm proximal to the anterior attachment of the ileo-cecal ligament was isolated and packed off with saline saturated cotton gauze. A subserosal elliptical pursestring suture approximating the circumference of the body of the cannula was placed in the

anti-mesenteric surface of the ileum. The suture material used was number 3-0 polyglycolic acid (Dexon<sup>3</sup>). A longitudinal incision of minimal length to accommodate the flange of the cannula was made in the center of the purse-string. With gentle manipulation and the use of thumb forceps the cannula was inserted into the lumen of the ileum and the purse-string tightened around the base of the cannula body. Two simple interrupted sutures were placed transversely across the ileum at the anterior and posterior borders of the body of the cannula.

A stab incision was made through the right body wall dorsal and posterior to the original incision. The length of the stab incision was sufficient to barely accommodate the body of the cannula thus avoiding the necessity of skin sutures in this incision. The cannula was then brought up through the stab incision. It is essential that the cannula not be rotated and that the proximal end of the ileum remain ventral and the posterior end remain dorsal to allow gravity to facilitate sample collection. Nonabsorbable size 2-0 supramid<sup>4</sup> sutures were placed through the small holes in each side of the cannula and through the skin of the pig to prevent rotation of the cannula.

The original incision site was closed with number 2-0 Dexon sutures with a continuous interlocking pattern in the muscle layers and an interrupted pattern in the skin. After

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<sup>3,4</sup>Haver-Lockhart, Shawnee, Kansas

closing, a topical antibiotic spray was applied to the two incisions sites. The cannula collar was screwed down over the body of the cannula until the internal flange and ileum were pulled snugly against the internal peritoneal surface of the body wall. Care should be taken to avoid getting the collar so tight as to cause restriction of peripheral circulation in the area surrounding the cannula. The cap was then screwed tightly on to the top of the cannula to prevent leakage of intestinal contents. In the final step, cotton gauze was placed over the cannula and surgical area and an adhesive bandage wrapped over the gauze and around the abdomen of the pig. Care should be taken with male pigs to avoid enclosing the prepuce in the adhesive wrap. This wrap provides for protection of the incision site and cannula from trauma or foreign material and from other pigs in the litter during the recovery period.

#### Post Surgical Care

Immediately following surgery the pigs were returned to the litter and remained with the dam for a 7 d convalescent period. To avoid injury, from the sow or other pigs in the litter, the cannulated pigs were closely observed for 2 to 3 h after surgery or until the effects of the anesthesia were no longer evident. Following surgery, procaine penicillin was administered twice daily for 5 d at a dose of 20,000 IU/kg body weight.

In addition to the milk provided by the dam, the pigs were allowed continuous access to an 18% crude protein starter diet in creep feeders with water available at all times from nipple waters. The adhesive wrap was changed when necessary. In general, this was necessary only when the wrap was loosened by other pigs in the litter. The convalescent period was relatively uneventful and skin sutures were removed approximately 10 d postsurgery. Pigs were weaned and moved to individual metabolism crates 7 d postsurgery and started on digestibility studies following a 2 d adjustment period.

#### Results and Discussion

This cannula has been installed in 6 pigs at 18 d of age weighing between 4.5 and 5.5 kg. All pigs demonstrated complete recovery within 7 to 10 d postsurgery as evidenced by a lack of inflammation around the surgical area, and normal appetite and growth. Following weaning at 25 d of age, the adhesive wrap was removed and the cannula was left unprotected. Pigs were housed in smooth sided metabolism crates to minimize trauma caused by catching the cannulas on the sides of the crate. Crates were located in an environmentally controlled feeding room. Five of the 6 pigs were involved in a 5 wk digestion study (Walker, 1984) starting when pigs were 27 d of age. During this time all pigs were fed semi-purified cornstarch based diets. Samples were collected from the cannulas by removing the cap and

unscrewing the collar until the outside edge was flush with the end of the body of the cannula. A small plastic bag was then attached over the collar and around the body of the cannula. This provided a simple procedure that could normally be performed within the metabolism crate with the unrestrained pig. At the completion of the 5 wk trial all 6 pigs had ad libitum access to an 18% crude protein corn-soybean meal starter diet until they reached about 25 kg at which time they were fed a 16% crude protein growing diet until the cannulas were removed. Samples were collected from all pigs periodically during this time to insure that proper function of the cannula was maintained. When pigs reached approximately 35 kg live weight, the cannulas were removed from 3 of the pigs by hand manipulation of the cannula in the unanesthetized pig until the cannula was dislodged. A larger, flexible cannula (Horzczaruk et al., 1972) was inserted into the fistula immediately following removal of the small rigid cannula. This provided a means of nonsurgical removal of the small cannula followed by replacement with a larger T-cannula that could be maintained for subsequent trials as the pigs grew larger. The remaining 3 pigs with rigid cannulas as well as the 3 with flexible cannulas were maintained with periodic collections until they reached a weight of about 60 kg at which time all cannulas were nonsurgically removed.

This cannula provides a small, lightweight but sturdy cannula suitable for use in digestibility studies with

neonatal pigs. This cannula does not protrude excessively from the body of the pig; therefore minimizing problems encountered such as loss of cannula, ruptured intestine and intestinal blockage that have previously been observed when using other types of cannulas (flexible tygon tubing or stainless steel) in neonatal pigs (personal observations). Collections can be accomplished by one person on unrestrained pigs. This cannula is large enough to provide sufficient sample flow for routine analysis from pigs fed either semi-purified or practical diets. The screw on cap and collar allow adjustment for changes in body wall thickness that accompanies pig growth and provides a method for easily attaching bags for sample collection.

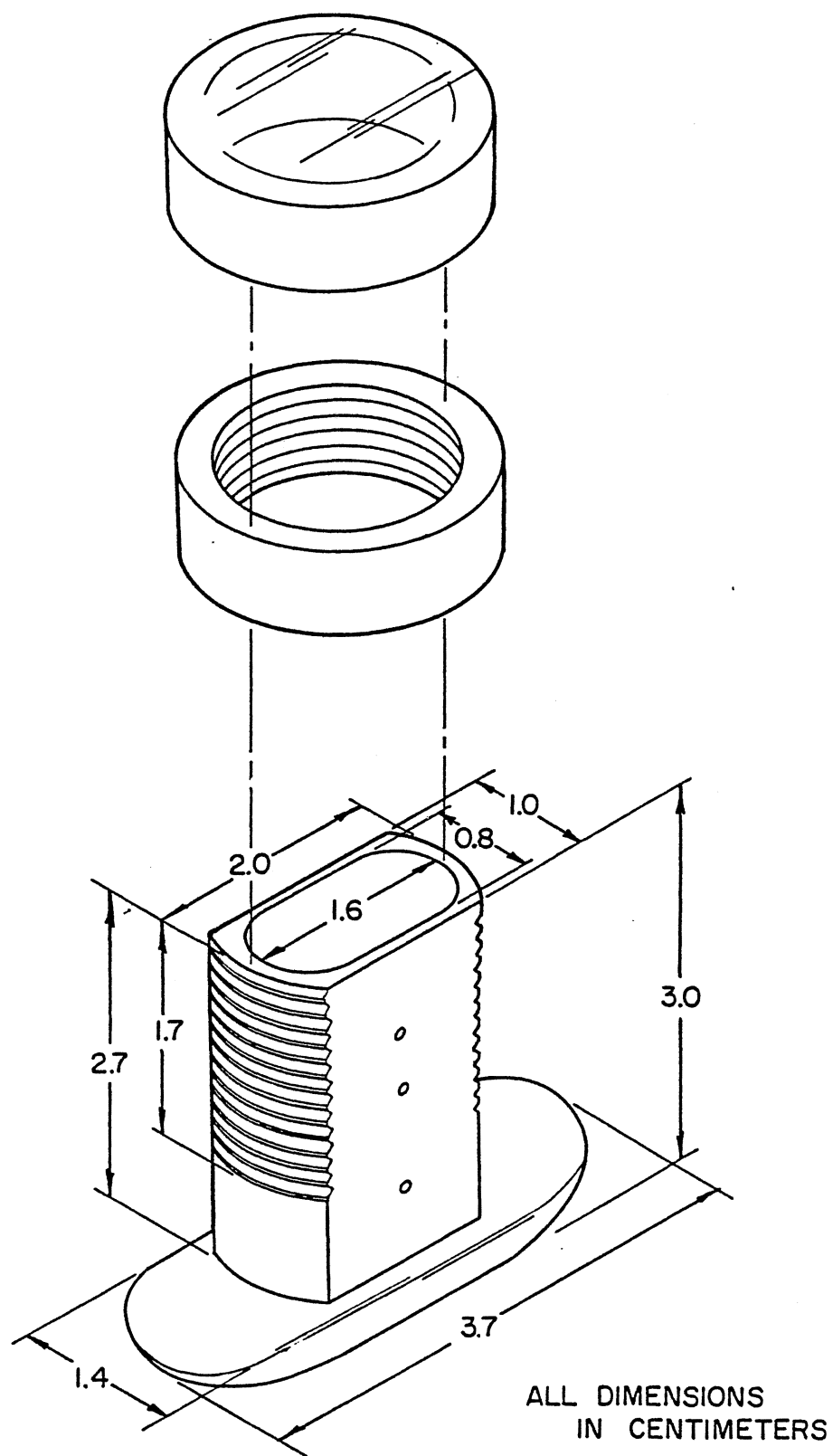


Figure 1. Design of the intestinal cannula for early weaned pigs. (A) body; (B) flange; (C) collar; (D) cap.



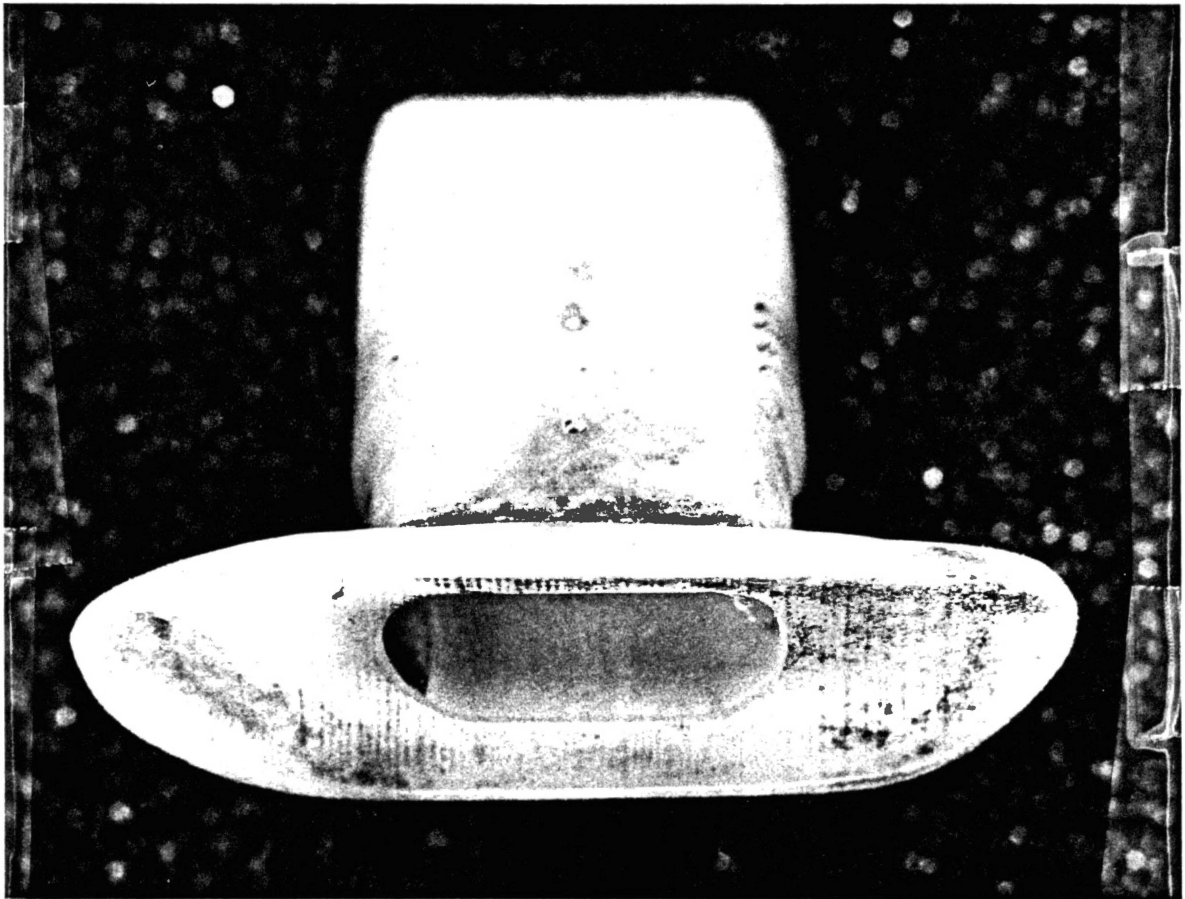


Figure 2. Ileal cannula showing flange shaped to conform to the lumen of the small intestine.

## LITERATURE CITED

- Cunningham, H. M., D. W. Friend and J. W. G. Nicholson. 1962. Note on a re-entrant fistula for digestion studies with pigs. *Can. J. Anim. Sci.* 42:112.
- Decuypere, J. A., I. J. Vervaeke, H. K. Hendrickx and N. A. Dierick. 1977. Gastro-intestinal cannulation of pigs: A simple technique allowing multiple replacements. *J. Anim. Sci.* 46:463.
- Easter, R. A. and T. D. Tanksley. 1973. A technique for re-entrant ileocecal cannulation of swine. *J. Anim. Sci.* 36:1099.
- Efird, R. C., W. D. Armstrong and D. L. Herman. 1982. The development of digestive capacity in young pigs: Effects of age and weaning system. *J. Anim. Sci.* 55:1380.
- Hartman, P. A., V. W. Hays, R. O. Baker, L. H. Neagle and D. V. Catron. 1961. Digestive enzyme development in the young pig. *J. Anim. Sci.* 20:114.
- Holmes, J. H. G., H. S. Bayley, P. A. Leadbeater and F. D. Horney. 1974. Digestion of protein in small and large intestine of the pig. *Brit. J. Nutr.* 32:479.
- Horszczaruk, f., T. Zebrowska and W. Dobowolski. 1972. Permanent intestine fistulae for the study of digesta in pigs. II. Establishment of simple fistulae of small intestine. *Rocz. Nauk. Rol. B.* 94:99.
- Ivan, M. 1974. A new type of re-entrant cannula designed for use in the small intestine of the pig. *Australian Vet. J.* 50:547.
- Ivan, M. and D. J. Farrell. 1976. Nutritional evaluation of wheat straw. 5. Disappearance of components in digesta of pigs prepared with two re-entrant cannulae. *Anim. Prod.* 23:111.
- Jorgensen, H., W. C. Sauer and P. A. Thacker. 1984. Amino acid availabilities in soybean meal, sunflower meal, fishmeal and meat and bone meal fed to growing pigs. *J. Anim. Sci.* 58:926.
- Just, A., H. Jorgensen and J. A. Fernandez. 1981. The digestive capacity of the caecum-colon and the value of the nitrogen absorbed from the hindgut for protein synthesis in pigs. *Brit. J. Nutr.* 46:209.

- Lecce, J. G., W. D. Armstrong, P. C. Crawford and G. A. Ducharme. 1979. Nutrition and management of early weaned piglets: Liquid vs. dry feeding. J. Anim. Sci. 48:1007.
- Lewis, C. J., P. A. Hartman, C. H. Liu, R. O. Baker and D. V. Catron. 1957. Digestive enzymes of the baby pig. Pepsin and trypsin. J. Agr. Food Chem. 5:687.
- Sauer, W. C. 1976. Factors affecting amino acid availabilities for cereal grains and their components for growing monogastric animals. Ph.D. Dissertation. Univ. of Manitoba, Winnipeg, Manitoba, Canada.
- Sauer, W. C., S. C. Strothers and G. D. Phillips. 1977. Apparent availabilities of amino acids in corn, wheat and barley for growing pigs. Can. J. Anim. Sci. 57:585.
- Tanksley, T. D., Jr. and D. Knabe. 1980. Availability of amino acids for swine. Proc. 1980 Arkansas Nutr. Conf., Dept. Anim. Sci. Univ. of Arkansas, Fayetteville.
- Taverner, M. R. and D. J. Farrell. 1981. Availability to pigs of amino acids in cereal grains. 3. A comparison of ileal availability values with fecal, chemical and enzymatic estimates. Brit. J. Nutr. 46:173.
- Walker, W. R. 1984. Protein utilization and amino acid availability in early weaned pigs. Ph.D. Dissertation. OK. State Uni. Stillwater, OK.

## CHAPTER V

### AMINO ACID AVAILABILITY OF VARIOUS PROTEIN SOURCES IN EARLY WEANED AND FINISHING PIGS

#### Summary

Two 5 X 5 Latin square designed trials were conducted using either five 4 wk old gilts or five 90 kg barrows fitted with simple ileal T-cannulas to determine the effect of protein source and age of pig upon protein and amino acid availability. The apparent availability of nitrogen (N) and amino acids (AA) in pigs fed hydrolyzed casein (HCAS), calcium caseinate (CAS), isolated soybean protein (ISP), ethanol extracted soybean protein (ESoy) and soybean meal (SBM) were determined at the ileum of 4 to 9 wk old pigs and at both the ileum and over the total digestive tract in finishing pigs. The pigs were fed semi-purified diets formulated to contain 22% protein. True availabilities were calculated from values obtained from pigs fed the HCAS diets. The apparent availability of N and essential amino acids (EAA) at the terminal ileum in both early weaned and finishing pigs and over the total digestive tract of finishing pigs was higher ( $P < .01$ ) in pigs fed HCAS, CAS, ISP and ESoy than in those fed SBM. For the early weaned pig,

the apparent availability of N and AA was generally higher for the casein protein sources than for the soybean protein sources. In addition, the apparent availability of N and all AA except cystine and glycine significantly increased with increasing age of the young pigs. The apparent ileal availability of lysine, threonine and methionine for early weaned pigs fed SBM was 69.3, 69.3 and 59.3%, respectively. The apparent ileal availability was higher in the older pigs with an average availability for the EAA of 93.3, 89.5, 85.8, 85.2 and 70.5% and 95.3, 93.1, 93.4, 92.7 and 80.6% in pigs fed HCAS, CAS, ISP, ESOY and SBM in early weaned and finishing pigs, respectively. Apparent availability values over the total digestive tract were higher than values estimated at the ileum in the finishing pigs indicating a net disappearance of N and AA in the hindgut. The true AA availability estimates were higher than expected for both early weaned and finishing pigs on all dietary treatments suggesting the possibility of error in the estimation procedure.

(Key words: Swine, Early Weaned Pig, Soybean Meal, Amino Acid Availability, Ileal Cannulation)

### Introduction

Although weaning as early as 18 d can be an economic advantage, many swine producers experience postweaning problems with this management practice. The reduced performance accompanying early weaning has been well

documented (Bayley and Carlson, 1970; Kornegay et al., 1974; Campbell, 1976; Okai et al., 1981) and is associated with a reduced feed intake and little or no weight gain. Early weaned pigs experience a longer postweaning growth depression and higher mortality rate (Leibbrandt et al., 1975; Lecce et al., 1979) than those weaned later.

Several studies have reported inferior performance in early weaned pigs fed soybean protein diets compared to those fed milk protein diets (Hays et al., 1959; Maner et al., 1961; Combs et al., 1963; Pond et al., 1971; Mateo and Veum, 1980; Leibholz, 1982). Our studies (Walker, 1984) have demonstrated that the effect of protein source on performance is more evident during the first 2 wk postweaning than during the subsequent 3 wk period when pigs were weaned at 3 wk of age. The fact that the neonatal pig is subjected to extreme diet changes (Lecce et al., 1979) during a period when digestive capacity is undergoing rapid development (Lewis et al., 1957; Hartman et al., 1961; Efird et al., 1982) may account for the higher sensitivity to dietary protein sources observed in early weaned pigs compared to that normally seen in older pigs.

Several studies have shown that protein sources vary not only in AA content but also in availability when measured at either the ileum or in fecal samples of growing-finishing pigs (Holmes et al., 1974; Ivan and Farrell, 1976; Sauer et al., 1977; Tanksley and Knabe, 1980; Taverner and Farrell, 1981; Jorgensen et al., 1984),

however, studies in the early weaned pig where the effect of protein source may be even greater have not been conducted. Furthermore, it is common practice to formulate diets to barely meet the requirement for the most limiting AA and recent studies have shown that the requirement for lysine, the first limiting AA for maximum growth in typical grain-soybean diets, may be much higher than the current NRC (Lewis et al, 1980; Zimmerman, 1980; Rozell and Zimmerman, 1984) recommendation for lysine in diets for early weaned pigs weighing from 5 to 10 kg. Pigs fed diets containing lysine levels below the requirement for maximum gain and efficiency of gain would be responsive to small decreases in amino acid availability.

This study was conducted to determine the apparent biological availability and to estimate the true biological availability of dry matter, starch, N and individual AA in milk and soybean proteins fed to ileally cannulated early weaned pigs and to compare these values to those of finishing pigs fed the same diets.

#### Materials and Methods

Five Yorkshire gilt pigs were surgically fitted with simple T-cannulas located in the distal ileum approximately 5 cm from the ileocecal junction. Pigs were removed from the sow at 18 d of age at which time the cannulas were surgically installed. Cannula design and surgical techniques have been described previously (Walker, 1984).

Immediately following surgery pigs were returned to the sow where they remained with the rest of the litter for a 7 d convalescence period. Creep feed and water were available to pigs at all times during the convalescent period. After recovery the pigs were moved to an environmentally controlled feeding room where they were housed in individual elevated metal pens measuring .7 by 1.0 m. Temperature in the feeding room was maintained between 27 and 32 C for the duration of the trial. After a 2 d adjustment period the pigs were started on a 5 X 5 Latin square design trial at 27 d of age.

Dietary treatments consisted of two milk and three soybean protein sources in semi-purified cornstarch-cerelose based diets (Table 1). Protein sources included hydrolyzed casein (HCAS), calcium caseinate (CAS), isolated soybean protein (ISP), ethanol extracted soybean protein (ESoy) and 44% crude protein solvent extracted soybean meal (SBM). Twenty-two percent crude protein diets were formulated to exceed the NRC (1979) requirement for crude protein for the 5 - 10 kg pig by 10% such that no single AA would be limiting. Diets were supplemented with vitamins and minerals to provide complete balanced diets for this age and weight of pig. Chromic oxide was added as an indigestible marker for availability determinations. Each pig was fed a measured quantity of feed twice daily at 0800 and 2000 h and allowed continuous access to the feed for a 1 h period after which all uneaten feed was removed. To increase intake, dry



diets were mixed with an equal portion of water and fed as a gruel. All uneaten and wasted feed was collected, dried and weighed so daily feed intake for each pig could be monitored. Water was available from cup waters at all times.

Each of the five 7-d experimental periods consisted of a 4-d adjustment period followed by a 3-d collection period. Ileal samples were collected continuously on each collection day, beginning one hour after the morning feeding and continuing until either 50 g of wet sample was collected for each pig or until feeding time of the evening meal. Samples were collected in plastic bags suspended from the cannula. Bags containing sample were changed at a maximum of 1 h intervals. After removal from the pig all samples were immediately frozen and stored at -20 C. Ileal samples collected over the 3 collection days of each period were composited by treatment prior to lypholization and grinding for laboratory analysis.

Dry matter and N content of both feed and ileal samples were determined according to AOAC (1975) methods. Starch content was determined by the method of Macrae and Armstrong (1968) and chromic oxide by the method of Stevenson and DeLangen (1960). Amino acid concentration was determined from acid hydrolysates by ion exchange chromatography using a Beckman model 121 automatic AA analyzer according to the methods outlined in the Beckman model 121 amino acid analyzer instruction manual 121-1M-1A April 1970, Palo Alto

CA. Acid hydrolysis was conducted under nitrogen reflux in 6N HCl for 24 h. True AA availability was estimated based on the assumption that AA contained in HCAS are completely digested and absorbed and, therefore 100% available to the pig and that N and AA contained in samples collected from pigs fed the HCAS diets would be solely of endogenous origin. Therefore, true availability estimates were calculated by subtracting the mean values from samples obtained from pigs fed the HCAS diets from those values obtained from pigs fed the other dietary protein sources.

A second study was conducted using five Yorkshire barrows averaging 90 kg liveweight with simple T-cannulas constructed of pliable tygon tubing (15mm id) surgically installed in the ileum. The experiment consisted of a 5 X 5 Latin square arrangement of treatments using the same diets (table 1) as those fed the neonatal pigs, with the exception of a .1% reduction in the amount of vitamin trace mineral premix. Each pig was fed 1 kg of unwetted feed twice daily at 0800 and 2000 h with water available from nipple waters at all times. These pigs were housed in an environmentally controlled feeding room in individual slatted crates measuring .7 by 1.6 m for the duration of the trial. Each of the five 7-d experimental periods consisted of a 4-d adjustment period followed by ileal collections on the 5th and 7th d of each period. Ileal samples were collected continuously, on each collection day, beginning 1 h after the morning feeding and continuing until either 200 g of wet

sample was collected for each pig or until feeding of the evening meal. In addition, a fresh fecal grab sample was collected from each pig on both the 5th and 7th d of each period for fecal availability determination. All samples were collected, stored and subjected to laboratory analysis using the same procedures described for the early weaned pig study. Fifth and 7th d ileal samples within each period were composited by treatment prior to laboratory analysis while 5th and 7th d fecal samples were analyzed separately.

The data for each response criteria were analyzed as a 5 X 5 Latin square design using least-squares analysis of variance procedures (SAS, 1979). The model included the main effects of pig, period and treatment.

## Results and Discussion

Early weaned pigs. Protein and AA composition of the dietary protein sources and the complete diets are shown in tables 2 and 3. The two casein protein sources were slightly higher in lysine content but similar in threonine and sulfur containing AA content to the 3 soybean protein sources. These are the AA that tend to be most limiting in diets that are commonly fed to early weaned pigs and, therefore, are of the most interest.

The apparent ileal availability of dry matter (DM) and starch in the various protein sources is shown in table 4. The apparent ileal DM availability in pigs fed HCAS, CAS, ISP and ESOY was higher ( $P < .01$ ) than those fed SBM while DM

availability in pigs fed CAS and ISP was higher ( $P < .05$ ) than those fed ESOY. These differences, at least to some extent, reflect differences in dietary crude fiber content. The DM availability estimates reported in this study were much lower than those reported for young pigs fed semi-purified SBM diets (Hays et al., 1959; Wilson and Leibholz, 1981; Leibholz, 1982) or for young pigs fed CAS or ISP diets (Leibholz, 1982). This was not unexpected since these literature values are based on total tract determination of availability and hence would be expected to be higher when pigs are fed diets with highly available energy sources (Misir and Sauer, 1982). The availability of starch exceeded 95% and was similar for all protein sources except in pigs fed HCAS when starch availability was slightly reduced.

The apparent ileal availability of N, the EAA and the nonessential AA (NEAA), with the exception of cystine and glycine, was lower ( $P < .01$ ) in pigs fed SBM than in those fed all other protein sources (table 5). The average apparent ileal availability of the EAA in pigs fed SBM was 70.5% compared to 91.3, 89.5, 85.8, and 85.2% for those fed HCAS, CAS, ISP and ESOY, respectively. The apparent ileal availability of both lysine and threonine was higher ( $P < .05$ ) in pigs fed HCAS than in those fed ISP or ESOY while the availability of these AA was intermediate in pigs fed CAS. The apparent ileal availability of methionine was similar ( $P < .1$ ) in pigs fed HCAS, CAS, ISP or ESOY. For the remainder of the EAA, effects similar to those reported for

lysine and threonine were evident for histidine, isoleucine, leucine and valine while effects similar to those reported for methionine were evident for arginine and phenylalanine. Although differences were not always significant there was a trend for higher apparent availabilities in the casein protein sources when compared to the soybean protein sources. In addition, when CAS was compared to the average of the soybean proteins the apparent ileal availability was higher ( $P < .05$ ) for CAS in each of the EAA with the exception of arginine. The literature is essentially devoid of ileal AA availability estimates for early weaned pigs and, therefore, comparisons must be made with estimates reported for older growing-finishing pigs. Estimates ranging from 79.7 to 84.9% have been reported for the average apparent ileal availability of the EAA in SBM for growing-finishing pigs (Tanksley et al., 1981; Sauer et al., 1982; Jorgensen et al., 1984). The lower value reported in this study for the average apparent ileal availability of the EAA in SBM (70.5%) is not surprising since the digestive capacity of the neonatal pig is undergoing rapid development (Lewis et al., 1957; Hartman et al., 1961; Efird et al., 1982). In addition, the presence of proteolytic enzyme inhibitors in SBM is likely to have a greater effect in young pigs than in older growing-finishing pigs.

A linear increase over time ( $P < .05$ ) was observed for the apparent ileal availability of N, all of the EAA and the NEAA with the exception of cystine and glutamic acid (table

6). Several studies have been reported in which an increase in nutrient availability has been observed with increasing age in young growing pigs (Hays et al., 1959; Combs et al., 1963; Wilson and Leibholz, 1981; Leibholz, 1982).

Pigs fed diets limiting in EAA would be responsive to small differences in AA availability. Recent studies have shown that the lysine requirement for the 5 to 10 kg pig is higher than the .95% currently recommended by NRC (Lewis et al, 1980; Zimmerman, 1980; Rozell and Zimmerman, 1984). Therefore, the differences in availability observed in this study may account for reduced growth and efficiency observed in pigs fed soybean protein diets compared to those fed CAS diets during the first 2 wk postweaning in pigs weaned at 3 wk of age and fed these same protein sources in practical diets formulated to meet minimum NRC requirements for lysine (Walker, 1984).

The true availability estimates for the EAA averaged 96.4, 94.3, 96.5 and 90.5 in pigs fed CAS, ISP, ESOY and SBM, respectively (table 7). There was no difference ( $P < .1$ ) in the true availability of lysine, threonine, the sulfur containing AA or histidine among pigs fed any of the dietary treatments. For the remaining EAA, the true ileal availability of isoleucine, leucine and arginine was similar in pigs fed CAS, ISP or ESOY but was higher ( $P < .05$ ) in these protein sources than in SBM. The true ileal availability of phenylalanine was higher ( $P < .05$ ) in pigs fed ESOY and CAS than in pigs fed SBM while true availability in pigs fed ISP

was intermediate. Similarly, the true availability of valine was higher ( $P < .05$ ) in pigs fed CAS than in pigs fed SBM and the true availability in pigs fed ISP and ESOY was intermediate. Trends were similar for the NEAA with the true ileal availability being lowest in pigs fed SBM. In addition, the average difference between the apparent and the true availability estimates (table 8) was greatest for pigs fed SBM (19.1%) followed by pigs fed ESOY (11.1%), ISP (8.5%) and CAS (7.1%). The average true ileal availability for the EAA in SBM for growing-finishing pigs was reported by Sauer et al. (1982) to be 87.3% while the same estimate reported in this study for early weaned pigs was 90.5%. In addition, the true ileal availability estimates for histidine (97.5%), lysine (94.9%), threonine (92.2%) and valine (88.9%) reported for the early weaned pig were all considerably higher than the corresponding values (85.8, 88.3, 81.1 and 78.1% for histidine, lysine, threonine and valine, respectively) reported for the older growing-finishing pig (Sauer et al., 1982). True ileal availability estimates of this magnitude were surprising since the apparent ileal availability estimates for the EAA averaged nearly 11% lower for the early weaned pig compared to similar estimates in the older growing-finishing pig.

Finishing pigs. Significant differences were not observed between values obtained from fecal samples collected on either the 5th or 7th d of each period and, therefore, these values were averaged and analyzed as a

single sample. The apparent availability of dry matter and starch at both the terminal ileum and over the total digestive tract is shown in table 9. The apparent dry matter availability at the terminal ileum was similar in pigs fed HCAS, CAS and ISP and over the total digestive tract in pigs fed HCAS, CAS, ISP and ESOY. The apparent dry matter availability was lower ( $P<.01$ ) in pigs fed SBM than in pigs fed all other protein sources at both sites and was lower at the terminal ileum ( $P<.01$ ) in pigs fed ESOY than for those fed HCAS, CAS and ISP. Dry matter disappearance from the hindgut ranged from 21.8% for SBM to 3.2% for HCAS which may be a reflection of the higher crude fiber content of SBM and the high digestibility of nutrients in HCAS. The apparent dry matter availability estimate obtained at the terminal ileum for pigs fed SBM (61%) in this study was lower than for previously reported values (Tanksley et al., 1981; Sauer et al., 1982; Rudolph et al., 1983; Jorgensen et al., 1984) that ranged from 74.9 to 83.6%. The reason for this apparently low ileal dry matter availability is unknown since the apparent availability of dry matter in SBM determined over the total digestive tract is similar to values reported by these same authors. Starch availability was similar for all protein sources and approached 100% when estimated at both the terminal ileum and over the total digestive tract.

The apparent ileal availability of N and all EAA was lower ( $P<.01$ ) in pigs fed SBM than for those fed HCAS, CAS,



ISP and ESOY (table 10). The apparent ileal availability of lysine and threonine was similar for pigs fed HCAS, CAS, ISP and ESOY while that of methionine was higher ( $P < .05$ ) in pigs fed HCAS than those fed either ISP or ESOY with those fed CAS being intermediate. Similar trends were evident for the remainder of the EAA and the NEAA. The average apparent ileal availability was 95.3, 93.1, 93.4, 92.7 and 80.6% for the EAA and 93.2, 88.4, 88.8, 91.0 and 75%, for the NEAA in pigs fed HCAS, CAS, ISP, ESOY and SBM, respectively. These values are all higher than those observed in the early weaned pig. The ileal availability values reported for SBM compare favorably with values previously reported by Tanksley et al. (1981), Sauer et al. (1982), Rudolph et al. (1983) and Jorgensen et al. (1984).

The true ileal availability of N exceeded 100% in pigs fed both SBM and ESOY which was higher ( $P < .05$ ) than values observed in pigs fed ISP or CAS (table 11). The average true ileal AA availability estimate for the EAA was 98.2%, 98.9%, 101.7% and 100.2% in pigs fed CAS, ISP, ESOY and SBM, respectively (table 10). True AA availability estimates for lysine were over 100% for all protein sources while estimates for threonine and methionine were over 100% in pigs fed ESOY and SBM and approaching 100% for those fed ISP. These values for lysine, threonine and methionine as well as those for arginine and phenylalanine were similar among all dietary protein sources. The true ileal AA availability values reported for SBM are all considerably

higher than those reported for SBM by Sauer et al. (1982), and with the exceptions of serine, alanine and threonine in CAS and cystine in ISP the true ileal availability estimates for all of the essential and nonessential AA for all protein sources was over 95%. Unexpectedly high estimates for true ileal availability in both the early weaned and finishing pig studies as well as several estimates for true availability that exceed 100% suggest over estimation of endogenous N and AA secretion leading to unusually high true availability estimates. This would result if the N and AA in HCAS were not completely digested and absorbed as was previously assumed and suggests that HCAS may not be a good source of AA for estimating endogenous secretions and true availability.

The apparent availability of the EAA measured over the entire digestive tract (fecal availability) averaged 97.3%, 96.8%, 95.3%, 95.4% and 85.9% in pigs fed HCAS, CAS, ISP, ESOY and SBM, respectively (table 12). The apparent fecal availability of the EAA and N was higher ( $P < .01$ ) in pigs fed HCAS, CAS, ISP and ESOY than in those fed SBM. In addition, the fecal availability of lysine was higher ( $P < .05$ ) in pigs fed CAS (97.7%) than in those fed ISP (96.2%) or ESOY (95.7%) and higher ( $P < .05$ ) in pigs fed HCAS (97.2%) than in those fed ESOY. Similarly, the fecal availability of threonine was higher ( $P < .05$ ) in pigs fed CAS (95.4%) than in those fed ISP (93.8%) or ESOY (93.7%) while availability in pigs fed HCAS (95.0%) was similar. The fecal availability

of methionine was higher ( $P < .05$ ) in pigs fed CAS (97.7%) and HCAS (97.6%) than in those fed ISP (93.1%) or ESOY (94.7%). Similar patterns were observed for the remainder of the EAA and the NEAA. Apparent fecal availability estimates reported in this study for pigs fed SBM are slightly lower than those reported for SBM by Tanksley et al. (1981), Sauer et al. (1982), Rudolph et al. (1983) and Jorgensen et al. (1984). This may have resulted from the low apparent availability of dry matter determined at the terminal ileum (61%), as was previously noted for SBM, providing more energy substrate to the hindgut than would normally be expected to occur with this type diet which in turn would result in an increase of microbial AA in the feces (Misir and Sauer, 1982) and lower fecal availability estimates.

The difference between apparent fecal and ileal availability determined by subtracting ileal availabilities from fecal availabilities is shown in table 13. Positive values indicate a net disappearance of AA from the hindgut while negative values indicate a net synthesis. With the exception of methionine and alanine in pigs fed HCAS, methionine and tyrosine in pigs fed ISP and tyrosine in pigs fed ESOY there was net disappearance of N and AA in the lower tract. Both disappearance (Holmes et al., 1974; Sauer et al., 1977; Tanksley et al., 1981) and synthesis (Holmes et al., 1974; Tanksley et al., 1981) of AA in the hindgut have been reported previously. Since these pigs were fed cornstarch based diets that were all highly available

(greater than 99% starch availability at the terminal ileum) a net disappearance of N and AA in the hindgut would be expected (Misir and Sauer, 1982). Disappearance of dry matter, N and AA from the hindgut was highest in pigs fed SBM and lowest in pigs fed HCAS as expected since Sauer et al. (1977) reported an inverse relationship between availability at the terminal ileum and degradation of AA in the large intestine.

The true fecal availability of N and AA are shown in table 14. With the exception of methionine the true fecal availability of the EAA and N were higher ( $P < .01$ ) in pigs fed CAS, ISP and ESOY than for those fed SBM. True fecal availability was similar among pigs fed CAS, ISP and ESOY for N and all of the EAA except phenylalanine. The true fecal availability estimates reported for pigs fed SBM in this study are slightly higher than those reported by Sauer et al. (1982) and may be a result of over estimation of endogenous secretions in pigs fed HCAS, however, these differences were small.

In general, the availability of N and AA in pigs fed SBM was lower than for those fed the other dietary protein sources. This may reflect differences in proteolytic enzyme inhibitors or carbohydrate complexes within the dietary protein source and may account for the inferior growth and efficiency observed for early weaned pigs fed SBM diets compared to those fed milk protein diets (Hays et al., 1959; Combs et al., 1963; Leibholz, 1982). The apparent ileal

availability of N and AA was higher for the older finishing pigs than for the early weaned pigs and for N and the EAA averaged 4.2, 3.6, 7.7, 7.4 and 10.2 percentage units higher availability for pigs fed HCAS, CAS, ISP, ESOY and SBM, respectively. These differences in availability should be considered when formulating diets for young pigs especially when using SBM as a supplemental protein source and formulating diets to meet minimum NRC requirements for lysine.

The use of HCAS as a source of AA for the purpose of estimating true availability values may lead to over estimation of endogenous N and AA secretion in the gut if HCAS is not completely available and consequently to over estimation of the true availability values. This may be especially true when estimating true ileal availability values. Although expensive the use of purified AA diets may provide a better estimate of endogenous secretions.

TABLE 1  
COMPOSITION OF DIETS

Ingredient	Diet (% DM basis) <sup>a</sup>				
	HCAS	CAS	ISP	ESoy	SBM
Corn starch (IFN 4-02-889)	30.82	31.35	30.48	25.93	18.91
Cerelose	30.82	31.35	30.48	25.93	18.91
Acid hydrolysed casein <sup>b</sup>	25.43				
Calcium caseinate <sup>c</sup>		25.43			
Isolated soy protein <sup>d</sup>			26.11		
Ethanol extracted soy protein <sup>e</sup>				35.25	
Soybean meal (IFN 5-04-604)					49.64
Solka floc	5.00	5.00	5.00	5.00	5.00
Corn oil	4.00	4.00	4.00	4.00	4.00
Calcium carbonate (IFN 6-01-069)	.70		.79	.78	.90
Dicalcium phosphate <sup>f</sup> (IFN 6-01-080)	1.73	1.73	2.00	1.97	1.50
Vitamin, TM premix <sup>f</sup>	.35	.35	.35	.35	.35
Salt (IFN 6-14-013)	.30	.30	.30	.30	.30
ASP 250	.25	.25	.25	.25	.25
Chromic oxide	.25	.25	.25	.25	.25
DL-tryptophan	.35				
	100	100	100	100	100
Calculated analysis (%)					
Crude protein	22.00	22.00	22.00	22.00	22.00
Lysine	1.97	1.89	1.43	1.41	1.38
Calcium	.80	.80	.80	.80	.80
Phosphorus	.60	.60	.60	.60	.60

<sup>a</sup>HCAS: acid hydrolyzed casein diet; CAS: calcium caseinate diet; ISP: isolated soybean protein diet; ESoy: ethanol extracted soybean protein diet; SBM: soybean meal diet.

<sup>b</sup>Acid hydrolyzed casein, type 1, Sigma Chemical Co. St. Louis, MO.

<sup>c</sup>Ultra supreme calcium caseinate, Erie Casein Co. Inc., Erie, IL.

<sup>d</sup>Soybean protein grade II, United States Biochemical Corp., Cleveland, OH.

<sup>e</sup>Promocaf, Central Soy, Fort Wayne, IN.

<sup>f</sup>Supplied 4,405 IU vitamin A, 3304 IU vitamin D, 4.4 mg riboflavin, 22 mg pantothenic acid, 33 mg niacin, 880 mg choline chloride, .02 mg vitamin B<sub>12</sub>, 11 IU vitamin E, 2.2 mg menadione, .22 mg iodine, 99 mg iron, 22 mg manganese, 11 mg copper, 99 mg zinc and .11 mg selenium per kg of feed.

TABLE 2  
PROTEIN AND AMINO ACID COMPOSITION  
OF DIETARY PROTEIN SOURCES

Item	Diet <sup>a</sup>				
	HCAS	CAS	ISP	ESoy	SBM
Crude protein, %	89.97	94.89	90.23	70.55	47.33
Amino acids, g/16 g N					
Essential					
Arginine	4.33	3.43	7.20	7.23	7.11
Histidine	3.32	2.81	2.53	2.62	2.66
Isoleucine	5.16	4.81	4.68	4.59	4.55
Leucine	7.66	8.82	7.97	7.83	7.78
Lysine	10.04	7.72	6.29	6.21	6.29
Methionine	2.66	2.80	1.44	1.41	1.54
Phenylalanine	3.13	4.83	5.17	4.94	4.98
Threonine	4.81	3.91	3.73	3.98	4.02
Valine	7.23	6.10	4.84	4.84	4.81
Nonessential					
Alanine	4.30	2.88	4.28	4.31	4.35
Aspartic acid	5.98	6.51	11.41	11.62	11.61
Cystine			1.07	1.20	1.23
Glutamic acid	21.92	21.13	19.42	18.90	18.73
Glycine	2.46	1.67	4.10	4.23	4.36
Proline	12.70	10.03	5.04	5.00	5.02
Serine	6.09	5.32	5.15	5.27	5.28
Tyrosine	2.97	5.35	3.73	3.70	3.75

<sup>a</sup>For explanation of diet code names, see table 1, footnote a.

TABLE 3  
 PROTEIN AND AMINO ACID  
 COMPOSITION OF DIETS<sup>a</sup>

Item	Diet <sup>b</sup>				
	HCAS	CAS	ISP	ESoy	SBM
Crude protein, %	22.88	24.13	23.56	24.87	23.50
Amino acids, %					
Essential					
Arginine	1.11	.90	1.88	1.94	1.63
Histidine	.85	.70	.65	.70	.61
Isoleucine	1.32	1.34	1.23	1.22	1.06
Leucine	1.96	2.39	2.04	2.04	1.76
Lysine	2.57	2.00	1.58	1.64	1.45
Methionine	.68	.72	.41	.38	.36
Phenylalanine	.80	1.35	1.34	1.32	1.18
Threonine	1.23	1.09	.94	1.04	.94
Valine	1.85	1.67	1.23	1.25	1.12
Nonessential					
Alanine	1.10	.79	1.08	1.12	1.01
Aspartic acid	1.53	1.83	2.93	3.07	2.78
Cystine			.14	.16	.14
Glutamic acid	5.61	5.73	4.85	4.89	4.24
Glycine	.63	.48	1.05	1.10	1.02
Proline	3.25	2.70	1.19	1.28	1.15
Serine	1.56	1.46	1.31	1.37	1.29
Tyrosine	.76	1.42	.96	.97	.89

<sup>a</sup>Dry matter basis.

<sup>b</sup>For explanation of diet code names, see table 1, footnote a.



TABLE 4  
 APPARENT ILEAL AVAILABILITY OF DRY MATTER AND  
 STARCH IN MILK AND SOYBEAN PROTEINS  
 IN EARLY WEANED PIGS<sup>a</sup>

Item	Diet <sup>b</sup>					SE
	HCAS	CAS	ISP	ESoy	SBM	
Dry matter, % <sup>c</sup>	80.7 <sup>de</sup>	85.4 <sup>d</sup>	83.0 <sup>d</sup>	77.0 <sup>e</sup>	65.0	1.6
Starch, %	94.5 <sup>e</sup>	98.7 <sup>d</sup>	98.5 <sup>d</sup>	98.8 <sup>d</sup>	97.3 <sup>de</sup>	.9

<sup>a</sup>Values are means of five observations.

<sup>b</sup>For explanation of diet code names, see table 1, footnote a.

<sup>c</sup>SBM differs from other diets  $P < .01$ .

<sup>de</sup>Means in the same row with different superscripts differ  $P < .05$ .

TABLE 5  
 APPARENT ILEAL AVAILABILITIES OF NITROGEN AND  
 AMINO ACIDS IN MILK AND SOYBEAN PROTEIN  
 SOURCES IN EARLY WEANED PIGS<sup>a</sup>

Item	Diet <sup>b</sup>					SE
	HCAS	CAS	ISP	ESoy	SBM	
Nitrogen, % <sup>c</sup>	86.0	84.5	81.8	83.4	68.4	2.1
Amino acids, %						
Essential						
Arginine <sup>c</sup>	88.8	86.7	90.9	90.5	77.8	1.6
Histidine <sup>c</sup>	89.5 <sup>d</sup>	89.2 <sup>de</sup>	84.4 <sup>de</sup>	83.9 <sup>e</sup>	70.3	1.8
Isoleucine <sup>c</sup>	93.6 <sup>d</sup>	89.6 <sup>de</sup>	87.7 <sup>de</sup>	87.2 <sup>e</sup>	73.3	2.1
Leucine <sup>c</sup>	93.3 <sup>d</sup>	92.8 <sup>de</sup>	86.9 <sup>de</sup>	86.0 <sup>e</sup>	72.2	2.3
Lysine <sup>c</sup>	92.0 <sup>d</sup>	89.6 <sup>de</sup>	84.1 <sup>e</sup>	85.0 <sup>e</sup>	69.3	2.2
Methionine <sup>c</sup>	93.8	92.8	85.9	82.6	59.3	4.8
Phenylalanine <sup>c</sup>	86.4 <sup>d</sup>	89.3 <sup>de</sup>	86.5 <sup>e</sup>	86.2 <sup>e</sup>	71.8	2.2
Threonine <sup>c</sup>	90.5 <sup>d</sup>	85.3 <sup>de</sup>	80.4 <sup>e</sup>	81.2 <sup>e</sup>	69.3	2.0
Valine <sup>c</sup>	94.1	90.4 <sup>de</sup>	85.0 <sup>e</sup>	84.1 <sup>e</sup>	71.2	2.2
Avg	91.3	89.5	85.8	85.2	70.5	
Nonessential						
Alanine <sup>c</sup>	90.9 <sup>d</sup>	82.9 <sup>e</sup>	83.1 <sup>e</sup>	83.2 <sup>e</sup>	68.5	1.9
Aspartic acid <sup>c</sup>	87.4	86.9	89.0 <sup>f</sup>	88.7	76.4 <sup>f</sup>	1.6
Cystine	100.0 <sup>d</sup>	100.0 <sup>d</sup>	70.0 <sup>f</sup>	77.5 <sup>e</sup>	64.0 <sup>f</sup>	2.4
Glutamic acid <sup>c</sup>	90.1 <sup>d</sup>	90.9 <sup>d</sup>	89.5 <sup>d</sup>	89.1 <sup>d</sup>	77.2 <sup>e</sup>	2.2
Glycine <sup>c</sup>	78.5 <sup>d</sup>	72.1 <sup>d</sup>	76.9 <sup>d</sup>	76.7 <sup>d</sup>	64.5 <sup>e</sup>	2.3
Proline <sup>c</sup>	96.5 <sup>d</sup>	94.3 <sup>d</sup>	85.7 <sup>e</sup>	85.8 <sup>e</sup>	73.5	1.9
Serine <sup>c</sup>	93.6 <sup>d</sup>	86.2 <sup>e</sup>	87.2 <sup>e</sup>	86.7 <sup>e</sup>	74.7	1.9
Tyrosine <sup>c</sup>	90.2	94.0	88.4	88.3	74.6	2.1
Avg	90.9	88.4	83.7	84.5	71.7	

<sup>a</sup>Values are means of five observations.

<sup>b</sup>For explanation of diet code names, see table 1, footnote a.

<sup>c</sup>SBM differs from other diets P<.01.

<sup>d</sup>Means in the same row with different superscripts differ P<.05.

TABLE 6  
EFFECT OF TIME ON APPARENT ILEAL AMINO ACID  
AVAILABILITY IN EARLY WEANED PIGS<sup>a</sup>

Item	WEEK					SE
	1	2	3	4	5	
DRY MATTER, %	77.7	75.5	79.9	79.4	78.6	1.6
Nitrogen, % <sup>c</sup>	78.9	75.9	81.5	85.8	81.8	2.1
Amino acids, %						
Essential						
Arginine <sup>b</sup>	81.8	84.2	87.7	91.7	89.4	1.6
Histidine <sup>c</sup>	81.1	79.2	83.8	88.2	85.1	1.8
Isoleucine <sup>b</sup>	83.0	81.6	86.4	92.0	88.3	2.1
Leucine <sup>c</sup>	82.7	82.1	86.2	91.6	88.6	2.3
Lysine <sup>b</sup>	81.3	77.4	84.6	89.8	87.0	2.2
Methionine <sup>c</sup>	78.2	74.6	83.7	91.6	87.0	4.8
Phenylalanine <sup>b</sup>	80.5	79.7	84.3	88.7	86.9	2.2
Threonine <sup>b</sup>	78.1	75.8	82.1	86.8	83.9	2.0
Valine <sup>c</sup>	82.2	79.7	85.0	90.7	87.2	2.2
Nonessential						
Alanine <sup>b</sup>	78.5	76.2	81.5	87.9	84.4	1.9
Aspartic acid <sup>b</sup>	82.5	82.3	86.7	89.7	87.3	1.6
Cystine	83.3	78.9	77.7	89.2	82.3	2.4
Glutamic acid	85.1	84.4	87.8	92.0	87.5	2.2
Glycine <sup>b</sup>	69.1	68.4	76.3	81.0	73.9	2.3
Proline <sup>c</sup>	85.0	83.0	87.3	91.8	88.9	1.8
Serine <sup>c</sup>	83.3	80.5	86.8	90.8	87.0	1.9
Tyrosine <sup>c</sup>	84.8	83.0	87.2	91.2	89.3	2.1

<sup>a</sup>Values are means of five observations.

<sup>b</sup>Linear effect  $P < .01$ .

<sup>c</sup>Linear effect  $P < .05$ .

TABLE 7  
TRUE ILEAL AMINO ACID AVAILABILITY ESTIMATES  
FOR MILK AND SOYBEAN PROTEIN SOURCES  
IN EARLY WEANED PIGS<sup>a</sup>

Item	Diet <sup>b</sup>				SE
	CAS	ISP	ESoy	SBM	
Nitrogen, %	94.8 <sup>cd</sup>	93.6 <sup>d</sup>	98.8 <sup>c</sup>	93.6 <sup>d</sup>	1.7
Amino acids, %					
Essential					
Arginine	97.4 <sup>c</sup>	96.9 <sup>cd</sup>	98.3 <sup>c</sup>	92.0 <sup>d</sup>	1.7
Histidine	99.3	97.0	99.6	97.5 <sup>d</sup>	1.6
Isoleucine	94.4 <sup>c</sup>	93.8 <sup>c</sup>	95.6 <sup>c</sup>	87.9 <sup>d</sup>	1.9
Leucine	97.1 <sup>c</sup>	92.6 <sup>cd</sup>	93.8 <sup>c</sup>	85.9 <sup>d</sup>	2.2
Lysine	97.4	95.5	99.9	94.9	1.6
Methionine	97.3	95.0	95.9	86.5 <sup>d</sup>	4.2
Phenylalanine	95.6 <sup>c</sup>	93.8 <sup>cd</sup>	96.2 <sup>c</sup>	88.8 <sup>d</sup>	2.1
Threonine	93.5	91.5	94.9	92.2	1.7
Valine	95.4 <sup>c</sup>	92.9 <sup>cd</sup>	94.5 <sup>cd</sup>	88.9 <sup>d</sup>	2.0
Avg	96.4	94.3	96.5	90.5	
Nonessential					
Alanine	92.3 <sup>c</sup>	91.2 <sup>cd</sup>	93.7 <sup>c</sup>	86.4 <sup>d</sup>	1.7
Aspartic acid	94.7 <sup>c</sup>	94.7 <sup>c</sup>	96.0 <sup>c</sup>	88.8 <sup>d</sup>	1.2
Cystine	100.0 <sup>c</sup>	80.4 <sup>e</sup>	90.0 <sup>d</sup>	85.4 <sup>de</sup>	2.2
Glutamic acid	97.9	99.1	101.9	99.8	1.5
Glycine	93.3	88.1	91.2	87.2	1.8
Proline	97.5 <sup>c</sup>	94.1 <sup>cd</sup>	96.4 <sup>c</sup>	91.4 <sup>d</sup>	1.5
Serine	91.5 <sup>cd</sup>	94.0 <sup>cd</sup>	95.5 <sup>c</sup>	89.0 <sup>d</sup>	1.7
Tyrosine	98.0 <sup>c</sup>	95.3 <sup>cd</sup>	97.5 <sup>c</sup>	90.0 <sup>d</sup>	2.0
Avg	95.7	92.1	95.3	89.9	

<sup>a</sup> Values are means of five observations.

<sup>b</sup> For explanation of diet code names, see table 1, footnote a.

<sup>cde</sup> Means in the same row with different superscripts differ P<.05.

TABLE 8  
DIFFERENCE BETWEEN APPARENT AND TRUE AVAILABILITY  
ESTIMATES DETERMINED AT THE END OF  
THE SMALL INTESTINE<sup>a</sup>

Item	Diet <sup>b</sup>			
	CAS	ISP	ESoy	SBM
Nitrogen, %	10.3	11.8	15.4	25.8
Amino acids, %				
Essential				
Arginine	10.7	6.0	7.8	14.2
Histidine	10.1	12.6	15.7	17.2
Isoleucine	4.8	6.1	8.4	14.6
Leucine	4.3	5.7	7.8	13.7
Lysine	7.8	11.4	14.9	25.6
Methionine	4.5	9.1	13.3	27.2
Phenylalanine	6.3	7.3	10.0	17.0
Threonine	8.2	11.1	13.7	22.9
Valine	5.0	7.9	10.4	17.7
Avg	6.9	8.5	11.3	20.0
Nonessential				
Alanine	9.4	8.1	10.6	17.9
Aspartic acid	7.8	5.7	7.3	19.4
Cystine		10.4	12.5	21.4
Glutamic acid	7.0	9.6	12.8	22.6
Glycine	21.2	11.2	14.5	23.7
Proline	3.2	8.4	10.6	17.9
Serine	5.3	6.8	8.8	14.3
Tyrosine	4.0	6.9	9.2	15.4
Avg	7.3	8.4	10.8	18.2

<sup>a</sup>Differences obtained by subtraction of apparent availability estimate from true availability estimate.

<sup>b</sup>For explanation of diet code names, see table 1, footnote a.

TABLE 9

APPARENT AVAILABILITIES OF DRY MATTER AND STARCH  
AT THE END OF THE SMALL INTESTINE AND OVER  
THE TOTAL TRACT OF FINISHING PIGS<sup>a</sup>

Item	Diet <sup>b</sup>					SE
	HCAS	CAS	ISP	ESoy	SBM	
Dry matter, %						
Terminal ileum <sup>d</sup>	88.5 <sup>e</sup>	85.6 <sup>e</sup>	85.7 <sup>e</sup>	76.1 <sup>f</sup>	61.0	1.1
Total tract <sup>c</sup>	91.7	91.3	90.3	90.5	82.8	.5
Difference <sup>c</sup>	3.2	5.7	4.6	14.4	21.8	
Starch, %						
Terminal ileum	99.8	99.8	99.9	99.9	99.6	.1
Total tract <sup>c</sup>	99.9	99.9	99.8	100.0	99.6	.1
Difference <sup>c</sup>	.1	-.1	.1	.1		

<sup>a</sup>Values are means of five observations.

<sup>b</sup>For explanation of diet code names, see table 1, footnote a.

<sup>c</sup>Differences obtained by subtraction of ileal availabilities from total tract availabilities.

<sup>d</sup>SBM differs from other diets  $P < .01$ .

<sup>e,f</sup>Means in the same row with different superscripts differ  $P < .01$ .

TABLE 10  
 APPARENT ILEAL AVAILABILITY OF NITROGEN AND  
 AMINO ACIDS IN MILK AND SOYBEAN PROTEIN  
 SOURCES IN FINISHING PIGS<sup>a</sup>

Item	Diet <sup>b</sup>					SE
	HCAS	CAS	ISP	ESoy	SBM	
Nitrogen, % <sup>c</sup>	92.3 <sup>d</sup>	88.1 <sup>e</sup>	90.6 <sup>de</sup>	89.7 <sup>de</sup>	79.5	1.2
Amino acids, %						
Essential						
Arginine <sup>c</sup>	94.7 <sup>de</sup>	93.1 <sup>e</sup>	97.0 <sup>d</sup>	96.1 <sup>d</sup>	87.3	.8
Histidine <sup>c</sup>	92.3 <sup>d</sup>	95.1 <sup>e</sup>	94.4 <sup>e</sup>	92.8 <sup>de</sup>	79.8	1.1
Isoleucine <sup>c</sup>	96.3 <sup>d</sup>	91.3 <sup>e</sup>	93.1 <sup>e</sup>	93.8 <sup>de</sup>	82.4	.9
Leucine <sup>c</sup>	96.7 <sup>d</sup>	95.4 <sup>de</sup>	93.3 <sup>e</sup>	93.3 <sup>e</sup>	81.8	1.0
Lysine <sup>c</sup>	96.7 <sup>d</sup>	96.3 <sup>de</sup>	95.4 <sup>e</sup>	94.3 <sup>e</sup>	81.8	1.2
Methionine <sup>c</sup>	97.7 <sup>d</sup>	95.8 <sup>de</sup>	93.8 <sup>e</sup>	94.2 <sup>e</sup>	86.1	1.0
Phenylalanine <sup>c</sup>	94.3	95.4	94.7	93.4	82.6	.9
Threonine <sup>c</sup>	92.4 <sup>d</sup>	84.9	87.4 <sup>de</sup>	85.8 <sup>e</sup>	67.5	2.7
Valine <sup>c</sup>	96.4 <sup>d</sup>	90.5 <sup>e</sup>	91.7 <sup>de</sup>	90.7 <sup>e</sup>	76.1	1.5
Avg	95.3	93.1	93.4	92.7	80.6	
Nonessential						
Alanine <sup>c</sup>	94.6 <sup>d</sup>	85.0 <sup>e</sup>	90.5 <sup>d</sup>	90.1 <sup>de</sup>	75.2	1.8
Aspartic acid <sup>c</sup>	92.2 <sup>d</sup>	90.2 <sup>d</sup>	93.4 <sup>e</sup>	93.4 <sup>e</sup>	79.8	1.2
Cystine	100.0 <sup>d</sup>	100.0 <sup>d</sup>	84.5 <sup>e</sup>	86.4 <sup>e</sup>	78.8 <sup>e</sup>	8.5
Glutamic acid <sup>c</sup>	89.6 <sup>e</sup>	91.9 <sup>de</sup>	95.5 <sup>d</sup>	95.2 <sup>d</sup>	80.6	1.6
Glycine	82.5 <sup>d</sup>	75.5 <sup>de</sup>	87.0 <sup>d</sup>	85.3 <sup>d</sup>	64.1 <sup>e</sup>	4.5
Proline <sup>c</sup>	97.1 <sup>d</sup>	93.1 <sup>e</sup>	93.2 <sup>d</sup>	91.0 <sup>d</sup>	76.3	2.4
Serine	94.9 <sup>d</sup>	81.0 <sup>e</sup>	92.9 <sup>d</sup>	91.2 <sup>d</sup>	75.7 <sup>e</sup>	1.8
Tyrosine <sup>c</sup>	96.5	97.0	96.7	95.7	84.4	.8
Avg	93.2	88.4	88.8	91.0	75.0	

<sup>a</sup>Values are means of five observations.

<sup>b</sup>For explanation of diet code names, see table 1, footnote a.

<sup>c</sup>SBM differs from other diets P<.01.

<sup>de</sup>Means in the same row with different superscripts differ P<.05.

TABLE 11  
TRUE ILEAL AMINO ACID AVAILABILITY ESTIMATES  
FOR MILK AND SOYBEAN PROTEIN SOURCES<sup>a</sup>  
IN FINISHING PIGS

Item	Diet <sup>b</sup>				SE
	CAS	ISP	ESoy	SBM	
Nitrogen, %	97.3 <sup>d</sup>	99.9 <sup>d</sup>	104.5 <sup>c</sup>	105.1 <sup>c</sup>	1.1
Amino acids, %					
Essential					
Arginine	99.8	100.0	101.6	99.6	.8
Histidine	102.3 <sup>d</sup>	101.8 <sup>d</sup>	105.3 <sup>cd</sup>	108.0 <sup>c</sup>	1.2
Isoleucine	95.4 <sup>e</sup>	97.6 <sup>de</sup>	101.8 <sup>c</sup>	100.3 <sup>cd</sup>	1.1
Leucine	98.5	97.0	99.8	96.6	1.1
Lysine	100.3	100.2	102.7	101.1	1.3
Methionine	98.6	99.7	102.4	100.1	1.1
Phenylalanine	99.0	98.3	99.9	97.3	1.0
Threonine	92.9	96.1	100.8	101.1	2.7
Valine	95.0	97.8	101.5	100.4	1.7
Avg	98.0	98.0	101.8	100.5	
Nonessential					
Alanine	93.1	96.4	100.2	97.5	1.9
Aspartic acid	97.4	97.8	101.0	97.2	1.3
Cystine	100.0	92.0	97.5	99.3	3.5
Glutamic acid	102.8 <sup>e</sup>	107.9 <sup>e</sup>	117.3 <sup>d</sup>	132.3 <sup>c</sup>	2.0
Glycine	98.0	97.1	102.8	101.5	4.5
Proline	96.7	100.7	105.0	107.2	250
Serine	86.0 <sup>d</sup>	98.2 <sup>c</sup>	100.7 <sup>c</sup>	96.7 <sup>c</sup>	1.8
Tyrosine	99.8	100.7	102.9	99.8	.9
Avg	96.7	98.9	103.4	103.9	

<sup>a</sup>Values are means of five observations.

<sup>b</sup>For explanation of diet code names, see table 1, footnote a.

<sup>cde</sup>Means in the same row with different superscripts differ P<.05.



TABLE 12  
 APPARENT FECAL AVAILABILITIES OF NITROGEN AND  
 AMINO ACIDS IN MILK AND SOYBEAN PROTEIN  
 SOURCES IN FINISHING PIGS<sup>a</sup>

Item	Diet <sup>b</sup>					SE
	HCAS	CAS	ISP	ESoy	SBM	
Nitrogen, % <sup>c</sup>	95.5	95.4	94.4	94.8	87.5	.4
Amino acids, %						
Essential						
Arginine <sup>c</sup>	96.2 <sup>e</sup>	96.5 <sup>e</sup>	97.9 <sup>d</sup>	97.8 <sup>d</sup>	91.3	.3
Histidine <sup>c</sup>	96.6	97.6	96.6	96.7	88.7	.4
Isoleucine <sup>c</sup>	96.6 <sup>d</sup>	95.4 <sup>d</sup>	95.1	95.0 <sup>e</sup>	84.4	.5
Leucine <sup>c</sup>	96.8 <sup>d</sup>	97.0 <sup>d</sup>	94.9 <sup>e</sup>	95.4 <sup>f</sup>	84.8	.3
Lysine <sup>c</sup>	97.2 <sup>de</sup>	97.7 <sup>d</sup>	96.2 <sup>ef</sup>	95.7 <sup>f</sup>	85.5	.4
Methionine <sup>c</sup>	97.6 <sup>d</sup>	97.7 <sup>d</sup>	93.1 <sup>e</sup>	94.7 <sup>e</sup>	88.1	.7
Phenylalanine <sup>c</sup>	94.8 <sup>d</sup>	97.3 <sup>e</sup>	95.6 <sup>e</sup>	95.7 <sup>e</sup>	85.6	.4
Threonine <sup>c</sup>	95.0 <sup>de</sup>	95.4 <sup>d</sup>	93.8 <sup>e</sup>	93.7 <sup>e</sup>	81.4	.5
Valine <sup>c</sup>	97.3 <sup>d</sup>	96.4 <sup>d</sup>	94.6 <sup>e</sup>	94.6 <sup>e</sup>	83.5	.5
Avg	97.3	96.8	95.3	95.4	85.9	
Nonessential						
Alanine <sup>c</sup>	94.5	93.0 <sup>de</sup>	93.4 <sup>d</sup>	92.9 <sup>d</sup>	79.9	.6
Aspartic acid <sup>c</sup>	94.0 <sup>e</sup>	95.5 <sup>d</sup>	97.1 <sup>d</sup>	96.7 <sup>d</sup>	87.4	.5
Cystine <sup>c</sup>	100.0 <sup>d</sup>	100.0 <sup>d</sup>	94.1 <sup>e</sup>	95.3 <sup>e</sup>	89.9	1.2
Glutamic acid <sup>c</sup>	97.9	97.5 <sup>f</sup>	98.0 <sup>d</sup>	97.7	90.7	.4
Glycine <sup>c</sup>	91.6 <sup>ef</sup>	90.8 <sup>d</sup>	94.6 <sup>d</sup>	94.2 <sup>e</sup>	82.5	.9
Proline <sup>c</sup>	98.8 <sup>d</sup>	98.5 <sup>d</sup>	96.9 <sup>e</sup>	96.8 <sup>e</sup>	89.0	.3
Serine <sup>c</sup>	96.2	94.2 <sup>d</sup>	96.1	95.9	86.9	.7
Tyrosine <sup>c</sup>	96.7 <sup>e</sup>	98.1 <sup>d</sup>	96.1 <sup>e</sup>	95.6 <sup>e</sup>	86.3	.4
Avg	96.1	96.0	95.8	95.6	86.6	

<sup>a</sup>Values are means of five observations.

<sup>b</sup>For explanation of diet code names, see table 1, footnote a.

<sup>c</sup>SBM differs from other diets  $P < .01$ .

<sup>d</sup>Means in the same row with different superscripts differ  $P < .05$ .

TABLE 13

DIFFERENCE BETWEEN APPARENT FECAL AVAILABILITY ESTIMATES  
AND THOSE DETERMINED AT THE END OF THE SMALL  
INTESTINE IN FINISHING PIGS<sup>a</sup>

Item	Diet <sup>b</sup>				
	HCAS	CAS	ISP	ESoy	SBM
Dry matter, %	3.2	5.7	4.6	14.4	21.8
Nitrogen, %	3.2	7.3	3.8	5.1	8.0
Amino acids, %					
Essential					
Arginine	1.5	3.4	.9	1.7	4.0
Histidine	4.3	2.5	2.5	3.9	8.9
Isoleucine	.3	4.1	2.0	.2	2.0
Leucine	.1	1.6	1.6	2.1	3.0
Lysine	.5	1.4	.8	1.4	3.7
Methionine	-.1	1.9	-.7	.5	2.0
Phenylalanine	.5	1.9	.9	2.3	3.0
Threonine	2.6	10.5	6.4	7.9	13.9
Valine	.9	5.9	2.9	3.9	7.4
Avg	1.2	3.7	1.9	2.7	5.3
Nonessential					
Alanine	-.1	8.0	2.9	2.8	4.7
Aspartic acid	1.8	5.3	3.7	3.3	7.6
Cystine	1.3		9.6	8.9	11.1
Glutamic acid	8.3	5.6	2.5	2.5	10.1
Glycine	9.1	15.3	7.6	8.9	18.4
Proline	1.7	5.4	3.7	5.8	12.7
Serine	1.3	13.2	3.2	4.7	11.2
Tyrosine	.2	1.1	-.6	-.1	1.9
Avg	2.9	7.6	7.0	4.6	11.1

<sup>a</sup>Differences obtained by subtraction of the apparent ileal availability estimate from the apparent fecal availability estimate.

<sup>b</sup>For explanation of diet code names, see table 1, footnote a.

TABLE 14  
TRUE FECAL AMINO ACID AVAILABILITY ESTIMATES  
FOR MILK AND SOYBEAN PROTEIN SOURCES  
IN FINISHING PIGS<sup>a</sup>

Item	Diet <sup>b</sup>				SE
	CAS	ISP	ESoy	SBM	
Nitrogen, % <sup>c</sup>	99.9	99.5	99.6	96.6	.4
Amino acids, %					
Essential					
Arginine <sup>c</sup>	100.5	100.0	99.9	96.7	.3
Histidine <sup>c</sup>	100.3	99.8	99.8	96.4	.3
Isoleucine <sup>c</sup>	98.5	99.1	99.1	94.4	.5
Leucine <sup>c</sup>	99.5	98.3	98.9	93.5	.3
Lysine <sup>c</sup>	100.5 <sup>d</sup>	100.0 <sup>d</sup>	99.6 <sup>d</sup>	95.3	.3
Methionine	100.1 <sup>d</sup>	98.9 <sup>e</sup>	99.3 <sup>e</sup>	96.9 <sup>e</sup>	.6
Phenylalanine <sup>c</sup>	100.1 <sup>d</sup>	98.8 <sup>e</sup>	99.1 <sup>e</sup>	94.0	.4
Threonine <sup>c</sup>	99.7	99.2	99.1	93.9	.5
Valine <sup>c</sup>	99.2	99.0	99.1	94.7	.5
Avg	99.8	99.2	99.3	95.1	
Nonessential					
Alanine <sup>c</sup>	99.7	99.1	98.6	93.6	.7
Aspartic acid <sup>c</sup>	100.1	100.3	100.0	95.5	.5
Cystine	100.0	99.6	100.0	99.3	1.5
Glutamic acid <sup>c</sup>	99.3	100.4	100.2	97.0	.4
Glycine <sup>c</sup>	99.7	99.2	98.9	93.4	.9
Proline <sup>c</sup>	99.7	99.9 <sup>d</sup>	100.0 <sup>d</sup>	96.7	.3
Serine	97.4 <sup>e</sup>	100.0 <sup>d</sup>	99.8 <sup>d</sup>	96.5 <sup>e</sup>	.7
Tyrosine <sup>c</sup>	100.3 <sup>d</sup>	99.7 <sup>de</sup>	99.3 <sup>e</sup>	95.2	.3
Avg	99.5	99.8	99.6	95.9	

<sup>a</sup>Values are means of five observations.

<sup>b</sup>For explanation of diet code names, see table 1, footnote a.

<sup>c</sup>SBM differs from other diets  $P < .01$ .

<sup>d,e</sup>Means in the same row with different superscripts differ  $P < .05$ .

## LITERATURE CITED

- AOAC. 1975. Official Methods of Analysis (12th Ed.). Association of Official Analytical Chemists, Washington, DC.
- Bayley, H. S. and W. E. Carlson. 1970. Comparisons of simple and complex diets for baby pigs: Effect of form of feed and glucose addition. J. Anim. Sci. 30:394.
- Campbell, R. G. 1976. A note on the use of feed flavor to stimulate the feed intake of weaner pigs. Anim. Prod. 23:417.
- Combs, G. E., F. L. Osegueda, H. D. Wallace and C. B. Ammerman. 1963. Digestibility of rations containing different sources of supplementary protein by young pigs. J. Anim. Sci. 22:396.
- Efird, R. C., W. D. Armstrong and D. L. Herman. 1982. The development of digestive capacity in young pigs: Effects of age and weaning system. J. Anim. Sci. 55:1380.
- Hartman, P. A., V. W. Hays, R. O. Baker, L. H. Neagle and D. V. Catron. 1961. Digestive enzyme development in the young pig. J. Anim. Sci. 20:114.
- Hays, V. W., V. C. Speer, P. A. Hartman and D. V. Catron. 1959. The effect age and supplemental amino acids on the utilization of milk and soya protein by the young pig. J. Nutr. 69:179.
- Holmes, J. H. G., H. S. Bayley, P. A. Leadbeater and F. D. Horney. 1974. Digestion of protein in small and large intestine of the pig. Brit. J. Nutr. 32:479.
- Ivan, M. and D. J. Farrell. 1976. Nutritional evaluation of wheat straw. 5. Disappearance of components in digesta of pigs prepared with two re-entrant cannulae. Anim. Prod. 23:111.
- Jorgensen, H., W. C. Sauer and P. A. Thacker. 1984. Amino acid availabilities in soybean meal, sunflower meal, fishmeal and meat and bone meal fed to growing pigs. J. Anim. Sci. 58:926.
- Kornegay, E. T., H. R. Thomas and C. Y. Kramer. 1974. Evaluation of protein levels and milk products for starter diets. J. Anim. Sci. 39:527.

- Lecce, J. G., W. D. Armstrong, P. C. Crawford and G. A. Ducharme. 1979. Nutrition and management of early weaned piglets: Liquid vs. dry feeding. *J. Anim. Sci.* 48:1007.
- Leibbrandt, V. D., R. C. Ewan, V. C. Speer and Dean R. Zimmerman. 1975. Effect of weaning and age at weaning on baby pig performance. *J. Anim. Sci.* 40:1077.
- Leibholz, J. 1982. Utilization of casein, fishmeal and soybean proteins in dry diets for pigs between 7 and 28 days of age. *Anim. Prod.* 34:9.
- Lewis, A. J., E. R. Peo, Jr., B. D. Moser and T. D. Crenshaw. 1980. Lysine requirement of pigs weighing 5 to 15 kg fed practical diets with and without added fat. *J. Anim. Sci.* 51:361.
- Lewis, C. J., P. A. Hartman, C. H. Liu, R. O. Baker and D. V. Catron. 1957. Digestive enzymes of the baby pig. Pepsin and trypsin. *J. Agr. Food Chem.* 5:687.
- Macrae, J. C. and D. G. Armstrong. 1968. Enzyme method for determination of alpha-linked glucose polymers in biological materials. *J. Sci. Agr.* 19:578.
- Maner, J. H., W. G. Pond, J. K. Loosli. 1961. Utilization of soybean protein by baby pigs and by rats. *J. Anim. Sci.* 20:614.
- Mateo, J. P. and T. L. Veum. 1980. Utilization of casein or isolated soybean protein supplemented with amino acids and glucose or lactose by neonatal piglets reared artificially. *J. Anim. Sci.* 50:689.
- Misir, R. and W. C. Sauer. 1982. Effect of starch infusion at the terminal ileum on nitrogen balance and apparent digestibilities of nitrogen and amino acids in pigs fed meat and bone and soybean meal diets. *J. Anim. Sci.* 55:599.
- NRC. 1979. Nutrient Requirements of Domestic Animals, No. 2. Nutrient Requirements of Swine. Eighth Revised Ed. National Academy of Sciences-National Research Council, Washington, DC.
- Okai, D. b., F. X. Aherne and R. J. Hardin. 1981. Effects of creep and starter composition on feed intake and performance of young pigs. *Can. J. Anim. Sci.* 56:373.

- Pond, W. G., W. Snyder, E. F. Walker, Jr, B. R. Stillings and V. Stidwell. 1971. Comparative utilization of casein, fish protein concentrate and isolated soybean protein in liquid diets for growth of baby pigs. J. Anim. Sci. 33:587.
- Rosell, V. L. and D. R. Zimmerman. 1984. Effects of graded levels of lysine and excess arginine and threonine on Young Pigs fed practical diets. J. Anim. Sci. 59:135.
- Rudolph, B. C., L. S. Boogs, D. A. Knabe, T.D. Tanksley, Jr. and S. A. Anderson. 1983. Digestibility of nitrogen and amino acids in soybean products for pigs. J. Anim. Sci. 57:373.
- SAS. 1979. SAS Users Guide. Statistical Analysis System Institute, Cary, NC.
- Sauer, W. C., S. C. Strothers and R. J. Parker. 1977a. Apparent and true availability of amino acid in wheat and milling by-products for growing pigs. Can. J. Anim. Sci. 57:775.
- Sauer, W. C., S. C. Strothers and G. D. Phillips. 1977b. Apparent availabilities of amino acids in corn, wheat and barley for growing pigs. Can. J. Anim. Sci. 57:585.
- Sauer, W.C., R. Cichon and R. Misir. 1982. Amino acid availability and protein quality of rapeseed meal for pigs and rats. J. Anim. Sci. 54:292.
- Stevenson, A. E. and H. DeLangen. 1960. Measurement of feed intake by growing cattle and sheep. VII. Modified wet digestion method for determination of chromic oxide in faeces. New Zealand J. AGR. Res. 3:314.
- Tanksley, T. D., Jr. and D. Knabe. 1980. Availability of amino acids for swine. Proc. 1980 Arkansas Nutr. Conf., Dept. Anim. Sci. Univ. of Arkansas, Fayetteville.
- Tanksley, T. D., Jr, D. A. Knabe, K. Purser, T. Zebrowska and J. R. Corley. 1981. Apparent digestibility of amino acids and nitrogen in three cottonseed meals and one soybean meal. J. Anim. Sci. 52:769.
- Taverner, M. R. and D. J. Farrell. 1981. Availability to pigs of amino acids in cereal grains. 3. A comparison of ileal availability values with fecal, chemical and enzymatic estimates. Brit. J. Nutr. 46:173.

- Walker, W. R. 1984. Protein utilization and amino acid availability in early weaned pigs. Ph.D. Dissertation. OK. State Uni. Stillwater, OK.
- Wilson, R. H., J. Leibholz. 1981. Digestion in the pig between 7 and 35d of age 1. The performance of pigs given milk and soybean proteins. Brit. J. Nutr. 45:301.
- Zimmerman, D. R. 1980. Lysine requirement of the 5 to 10 kg pig. J. Anim. Sci. 51(suppl. 1):78.

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