INFLUENCE OF ENVIRONMENTAL TEMPERATURE ON NITROGEN RETENTION APPARENT DIGESTIBILITY OF PROTEIN AND AMINO ACIDS AND ENERGY BALANCE IN GROWING PIGS[1]

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ABSTRACT - Thirty crossbred, castrated male pigs weighing 32 kg were assigned to one of five experimental ambient temperatures (11°, 17°, 23°, 29° and 35°C). The pigs were housed randomly and individually in steel metabolism cages in temperature controlled rooms. The animals were fed according to their metabolic size and the methodology utilized was total feces and urine collection. The data were analyzed using regression analysis. The estimated values of apparent digestibility of dry matter and protein, nitrogen retention, net protein utilization and biological value increased as environmental temperature increased to 29°C, but decreased above this temperature. Both low (11° and 17°C) and high (35°C) temperatures decreased all of the parameters analyzed. Apparent digestibility of amino acids showed the same effect and was highest at 29°C and lowest at 11°C and 35°C. Digestible energy and metabolizable energy values showed that the efficiency of energy utilization increased as environmental temperature increased. It was determined that DE and ME were maximized at 26° and 27°C respectively. The results suggest that temperatures fall between 25° and 29°C are within the thermoneutral zone of 32 kg pigs kept in metabolism cages.

Index terms: metabolism assay, temperature, protein diet, corn-soybean meal, metabolism cage.

INFLUÊNCIA DA TEMPERATURA AMBIENTAL SOBRE A RETENÇÃO DE NITROGÊNIO, DIGESTIBILIDADE APARENTE DA PROTEÍNA BRUTA, AMINOÁCIDOS E BALANÇO DE ENERGIA, DE SUÍNOS EM CRESCIMENTO

RESUMO - Ensaios de metabolismo foram conduzidos objetivando verificar a influência das temperaturas (11°, 17°, 23°, 29° e 35°C) sobre o metabolismo da proteína, dos aminoácidos e da energia. Trinta suínos machos mestiços, castrados, pesando 32 kg foram distribuídos ao acaso e individualmente em gaiolas de metabolismo, seis em cada temperatura. Utilizou-se a metodologia de coleta total de fezes e o óxido férrico como marcador fecal. Os dados foram analisados usando análise de regressão. Os valores estimados para coeficiente de digestibilidade da proteína, retenção de nitrogênio, proteína metabolizável e valor biológico da proteína bruta aumentaram quando a temperatura ambiental aumentou até 29°C, decrescendo acima da mesma. Temperaturas de 11° e 17°C e de 35°C propiciaram decréscimos em todos os parâmetros analisados. A digestibilidade aparente dos aminoácidos foi melhor à temperatura de 29°C. A eficiência da utilização da energia digestível e metabolizável foi maximizada a 26° e 27°C, respectivamente. Os resultados sugerem que temperaturas entre 25° a 29°C constituem a Zona de Termoneutralidade de suínos em crescimento com 32.0 kg mantidos em gaiolas de metabolismo.

Termos para indexação: ensaios de metabolismo, temperatura, dieta, metabolismo da proteína, dieta de milho-soja, gaiolas de metabolismo.

INTRODUCTION

It is widely known that swine productivity is reduced by thermal stress imposed on the animal. The environment in which the pigs are exposed is considered the most important factor affecting their productivity. Today's modern swine structures are designed to maintain proper air movement and to provide

[1] Accepted for publication on February 14, 1991
Extracted from a Dissertation submitted by the senior author in partial fulfillment of the requirements for the Ph.D. degree to the faculty of Purdue University. West Lafayette, IN., U.S.A.

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controlled air temperature as well as necessary feed and water in order to maximize productivity. A complex pattern of thermoregulatory responses and adaptations allow swine to achieve and maintain a reasonably stable thermal balance while exposed to a wide range of thermal environments. Swine react to temperature extremes by adjustments in feed intake and heat exchange with their environments.

In terms of dietary energy utilization, production is the difference between metabolizable energy intake and heat production. Consequently, climatic factors that influence metabolizable energy intake will influence productivity and utilization of dietary energy (Young 1981).

The most important direct effect of climatic factors on the pig is on the exchange of heat between the pig and its environment. Environmental conditions which influence the heat transfer of the pig will influence the rate which energy and protein are utilized for productive purposes.

There is some evidence that increased environmental temperatures will increase the digestibility of energy in the diet (Fuller & Boyne 1972). Results in growing pigs exposed to a hot environmental temperature (34°C) have shown, an increase in the percentage of digested energy (Holmes 1974).

It appears that the thermal stress which alters energy availability, can also influence the effective utilization of protein (Payne & Jacob 1965). However, there is still a lack of complete agreement with regard to the effect of ambient temperature on apparent protein, nitrogen and energy digestibility.

The objective of these metabolism assays was to study the influence of environmental temperature on energy balance and nitrogen balance as well as apparent digestibility of protein and amino acids in growing pigs.

MATERIALS AND METHODS

This study consisted of five metabolism assays, involving a total of thirty crossbred (Landrace x Yorkshire), castrated male pigs, having an average initial weight of 23.9 + 0.8 kg.

The animals were assigned to one of five environmental temperature treatments. Two were below the lower critical temperature (11° and 17°C); two were close the thermoneutral zone (23° and 29°C) and one was above the upper critical temperature zone (35°C). The criteria of lower and upper critical temperatures and the thermoneutrality zone of pigs were the values cited by Close & Mount (1978).

Individual pigs were assigned to treatments from outcome groups based on litter and weight. Since only two temperature controlled rooms were available, special sequencing of treatment were made. Thus, the 11° and 29°C treatments were conducted in the 1st phase; treatments 17° and 35°C in the 2nd, and treatment 23°C in the 3rd phase. The temperature variation in each room is shown in Table 1. Each phase consisted of a total of twenty--seven consecutive days. The environment within the rooms was automatically controlled by microprocessor. Temperature was maintained within 0.2°C and relative humidity was held constant at approximately 60 percent.

During all trials, the pigs were kept individually in stainless steel metabolism cages (110 x 82 cm) equipped with nipple waterers to provide water *ad libitum*. The average initial pig weight at the beginning of the collection period was 32.0 + 2.5 kg. Feed was offered twice daily (0800 and 1700), and adjusted at the first day of the collection period, to an average of 98.9 -+ 2.0 g of feed/kg metabolic body weight (W 0.75). Average pigs weights and feed intake during the collection period are presented in Table 2. Feed intake was equalized within

TABLE 1. Mean values of temperatures in climatic rooms at each environmental temperature[a].

Treatment (°C)	Room	Mean	SD[b]	SE[c]
11	1	11.20	0.148	0.019
17	1	16.94	0.143	0.018
23	1	23.20	0.111	0.014
29	2	28.90	0.116	0.015
35	2	34.74	0.441	0.057

[a] Data from sixty observations per treatment. Relative humidity was held constant at 60%.
[b] Standard deviation of means.
[c] Standard error of means.

TABLE 2. Weights at beginning of adaptation and collection periods, metabolic body weight and feed intake, of growing pigs at each environmental temperature.

Treatment (°C)	Initial weight Adap. Per. (kg)	Weight at start Colec. Per (kg)	Metabolic body weight (MBW)	Feed by Metabolic body weight[a] (FMBW g/kg MBW)	Feed Intake g/day
11	24.80	33.20	13.83	96.45	1334
17	23.80	30.50	12.98	100.67	1306
23	23.00	31.20	13.20	100.38	1327
29	24.70	36.20	14.76	96.45	1423
35	23.00	28.90	12.46	100.67	1254
Mean	23.90	32.00	13.45	98.92	1329

[a] FMBW - Feed Intake/MBW ($W^{0,75}$).

replicate and provided with water in a 2.5:1.0 ratio (water:feed) in order to minimize wastage.

The same 18% protein, corn-soybean meal diet was utilized in all treatments and during both experimental periods (adaptation and collection period). The composition of the diet, calculated to provide vitamin and mineral levels to meet or exceed National Research Council (1979) recomendations, and proximate analysis values are presented in Table 3. The amino acid analysis of the diet is shown in Table 4.

The pigs were adapted for twenty-one days to their experimental temperatures before initiating the 5-day collection period. Total feed consumption and total excreta (feces and urine) were recorded on a daily basis. Ferric oxide (1%) was included in the diet as a visible marker to determine the onset and ending of fecal collection. During this period, feces were collected daily after each meal for individual pigs, accumulated in plastic bags and stored at -10°C. At the end of the period, samples were weighed mixed and sub-sampled for subsequent analysis.

Ten ml of concentrated sulfuric acid, diluted in deionized water (1:1 ratio), was added to the plastic urine containers initially, and at each collection to prevent mold growth and ammonia loss. Urine was collected daily (every morning) and was diluted to a constant volume (3.0 litter/day) with deionized water and a 5% aliquot was retained. Daily samples were pooled at the end of the collection period, filtered through glass wool and stored at -10°C for subsequent analysis.

Feces were dried at 50°C in a forced-air oven

TABLE 3. Composition and analysis of diet utilized in metabolism assays with growing pigs.

Item	Experimental Diet
Composition	------ % ------
Corn (ground)	73.40
Soybean Meal (48% CP)	23.40
Dicalcium Phosphate	1.40
Calcium Carbonate	1.10
Iodized Salt	0.25
Vitaminic Premix[a]	0.15
Mineral Premix[b]	0.05
Selenium Premix[c]	0.05
Total	100.00
Analysed levels (as fed)	
Dry Matter	88.18
Crude Protein	18.04
Ether Extract	2.84
Crude Fiber	3.22
Ash	1.40
Calcium	0.62
Phosphorus (Total)	0.55

[a] Composition per kg: vit. A, 2,328,00 IU; vit. D_3, 232,800 IU; vit. E, 8,800 IU; vit. K, 1,764 mg; Riboflavin, 2,328 mg; Ca-pantontenate, 9,312 mg; Niacin, 13,968 mg; vit. B_{12} 11,64 mg.

[b] Composition (%): Zn, 20; Fe, 10; Mn, 5.5; Cu, 1.1; I, 0.15.

[c] Composition per kg: Se, 220.5 m g.

TABLE 4. Amino acid composition of diet utilized in the metabolism assay in growing pigs. (as fed basis)[a].

Item	Percentage (%)
Amino Acid - Essential	
Arginine	1.02
Histidine	0.43
Isoleucine	0.69
Leucine	1.60
Lysine	0.77
Methionine	0.30
Phenylalanine	0.84
Treonine	0.63
Valine	0.88
Amino Acid - Nonessential	
Alanine	0.84
Aspartic Acid	1.64
Cystine	0.26
Glutamic Acid	3.07
Glycine	1.08
Proline	1.07
Serine	0.78
Tyrosine	0.66

[a] Free molecular weights were used in calculating amino acid percentages.

and frozen. Dried feces and feed were ground in a Wiley Mill to pass through 1 mm screen. In each replicate, feed and feces were analyzed for dry matter and nitrogen (Macro Kjeldahl) according to Association of Official Analytical Chemists (1984) methods. Protein content was estimated as 6.25 times the nitrogen content. A composite sample of the diet fed in each trial was analyzed for crude fiber (Van Soest & Wine 1967). Gross energy was measured using an Adiabatic Bomb Calorimeter (Parr Instrument 1984).

Urinary energy was determined after drying a 10 ml sample in polyethylene capsules (capacity 5 ml) in an air-forced oven at 50°C.

For amino acid analysis, diets were pooled (only one diet) and feces from three animals per each treatment were pooled and ground further in a Cyclone Mill (UD Corporation, Boulder, Colorado). Sample preparation for amino acid determination (diets and feces) was performed according to the method for unoxidized samples published by Elkin & Griffith (1985). The amino acids were quantitated with the use of Beckman 7300 High Performance Amino Acid Analyzer.

Nitrogen retention, apparent digestibility of dry matter, protein and amino acids, net protein utilization, biological protein values and digestible and metabolizable energy values were calculated from values based on the total collection of feces and urine.

The data for each response parameter were subjected to regression analysis (Steel & Torrie 1980), and were analyzed by using the General Linear Models Procedure of Statistical Analysis System Institute (1985). By statistical analysis, it was observed, that the variables weight and nitrogen intake were influenced by the treatments tested, thus those variables were not utilized as covariables in the model for regression analysis.

The nitrogen balance, apparent digestibility of protein and amino acids and energetic values were considered the dependent variable, and environmental temperatures were chosen as the independent variable in carring out a regression analysis. Treatment variation was partitioned into linear, quadratic and cubic components, using orthogonal polynomials, and F-tests were used to determine levels of significance.

RESULTS AND DISCUSSION

The effects of environmental temperature on weight at the start of the collection period (WSCP), daily ration intake (RI), daily dry matter intake (DMI), daily dry matter excreted (DME), dry matter of feces (DMF), apparent digestibility of dry matter (ADDM), daily nitrogen intake (NI), daily fecal nitrogen (FN), daily urinary nitrogen (UN), daily nitrogen retention (NR), apparent digestibility of protein (ADP), net protein utilization (NPU) and biological value (BV), are presented in Table 5. Polynomial regression equations relative to those variables derived from linear, quadratic and cubic models are presented in Table 6 and illustrated in Fig. 1, 2, 3, 4 and 5.

There was a significant cubic effect ($P < 0.01$) for the variables WSCP, RI, DMI, NI, FN, as well NR and ADP. There was a significant quadratic ($P < 0.01$) response for ADDM, UN, NPU and BV.

The cubic ($P < 0.01$) effect observed for

TABLE 5. Effect of environmental temperature on nitrogen balance, apparent digestibility of dry matter and protein and net protein utilization and biological value in growing pigs.

Item	Temperature (°C)					SE[a]
	11	17	23	29	35	
Sample Size	6	6	6	6	6	-
Initial Weight, (kg)	24.80	23.70	22.90	24.70	23.00	0.53
Weight Start Col. Per.[e], (kg)	33.10	30.50	31.30	36.20	28.50	0.75
Daily Ration Intake[e], (g)	1334	1306	1326	1420	1254	60.00
Daily Dry Matter Intake[e], (g)	1176	1151	1170	1252	1106	21.27
Daily Dry Matter excretion[c] (%)	168	150	152	147	140	4.08
App. Digestib. of Dry Matter[d] (%)	85.59	86.91	86.99	88.19	87.29	0.32
Daily Nitrogen Intake[b,e], (g)	36.98	36.20	36.80	39.37	34.77	0.67
Daily Fecal Nitrogen[b,f], (g)	5.28	5.40	5.01	4.29	5.24	0.11
Daily Urinary Nitrogen[d], (g)	12.12	8.37	8.43	8.70	9.32	0.24
Daily Nitrogen Retention[b,f], (g)	19.56	22.43	23.33	26.37	20.20	0.73
App. Digestibility Protein[b,f], (%)	85.68	85.07	86.38	89.07	84.91	0.35
Net Protein Utilization[b,d], (%)	53.07	61.92	63.45	66.89	58.08	1.67
Biological Value[b,d], (%)	62.00	72.79	73.46	75.10	68.39	1.99

[a] Standard error of the means (SE) for each item across all temperatures.
[b] Results expressed in dry-matter basis.
[c] Linear ($P < 0.01$) effects.
[d] Linear ($P < 0.01$) and quadratic ($P < 0.01$) effects.
[e] Quadratic ($P < 0.01$) and cubic ($P < 0.05$) effects.
[f] Linear ($P < 0.05$) quadratic ($P < 0.05$) and cubic ($P < 0.01$) effects.

NR and ADP is biologically difficult to explain. The apparent digestibility of protein (ADP) and nitrogen retention (NR) was higher for the animals kept at 11°C when compared with those housed at 17°C. No simple explanation for this is available. The most plausible explanation for the enhanced ADP and NR at 11°C as compared to 17°C, might be related to the manner in which the experiment was conducted, since animals with different initial weights were utilized. The pigs in the 11°C treatment were heavier than those at 17°C, and this difference was due to an increased rate of gain of the 11°C pigs during the 21-day adaptation period. This difference is also difficult to explain.

The weight at the start of the collection period may have an effect on RI and NI, since feed intake was provided as a function of metabolic body size. Also it is important to point out that the variables RI and NI show the cubic effect ($P < 0.01$) which may have influenced the subsequent results of NR and ADP. In addition to the cubic effects, the linear ($P < 0.05$) and quadratic ($P < 0.01$) effects for NR and ADP were significant. The values of those parameters increased as the environmental temperatures increased up to 29°C, and decreased after that. Both low (11° and 17°C) and high (35°C) temperatures decreased the apparent digestibility of protein as well as nitrogen retention in growing pigs in comparison to pigs housed at 23° and 29°C. These results show clearly that, environmental temperature alters the protein and nitrogen utilization in growing pigs.

At the lower temperatures (11° and 17°C), N retention was lower than at 23° and 29°C; this was probably due to the additional requirements for food energy to keep the pigs warm rather than for increased tissue protein

TABLE 6. Polynomial regression equations of dependent variable (Y) as function of environmental temperature (X) with the coefficient of determination (R^2). Nitrogen balance and digestibility of protein.

Y	Polynomial (X)	R^{2a}
Weight at Start Collec. Period	$86.242 - 8.6576X + 0.4190X^2 - 0.0062X^3$	0.62**
Daily Ration Intake (G/Day)	$2272.849 - 156.3128X + 7.798X^2 - 0.1188X^3$	0.44**
Dry Matter Feces %	$29.06 + 0.21X$	0.27**
Daily Dry Matter Intake (G/Day)	$2004.199 - 137.837X + 6.877X^2 - 0.105X^3$	0.44**
Daily Dry Matter Excreted (G/Day)	$175.014 - 0.9984X$	0.42**
App. Digestibility Dry Matter (%)	$82.209 + 0.3793X - 0.0065X^2$	0.49**
Daily Nitrogen Intake (G/Day)	$63.012 - 4.3335X + 0.2160X^2 - 0.0033X^3$	0.44**
Daily Fecal Nitrogen (G/Day)	$-1.0715 + 1.0784X - 0.0548X^2 + 0.0008X^3$	0.69**
Daily Urinary Nitrogen (G/Day)	$19.533 - 0.9051X + 0.0177X^2$	0.38**
Daily Nitrogen Retention (G/Day)	$32.007 - 2.5426X + 0.1607X^2 - 0.0028X^3$	0.61**
Apparent Digestibility Protein (%)	$111.698 - 4.3872X + 0.2218X^2 - 0.0034X^3$	0.73**
Net Protein Utilization (%)	$24.646 + 3.2993X - 0.0663X^2$	0.56**
Biological value (%)	$33.725 + 3.3561X - 0.0675X^2$	0.50**

[a] Coefficient of determination followed by *, ** are significant at $P < 0.05$ and $P < 0.01$ probability levels, respectively.

synthesis. Dietary protein was probably wasted.

Protein utilization is a function of available energy and when energy is limited, protein is then used as an energy source (Albanese 1959). Apparently at the low environment temperatures (11° and 17°C), protein was used for energy. When dietary protein is utilized for energetic purposes, the effective utilization of protein in a diet for protein accretion will be reduced with a subsequent decrease in protein or nitrogen retention in growing pigs (Fuller & Crofts 1977).

The decreased digestibility of protein and nitrogen retention agree with the results cited by Fuller & Boyne (1971, 1972). According to these authors, the heat production of individual pigs 20-90 kg live weight was increased at air temperatures of 5° and 13°C compared with 23°C; in association with these changes in energy metabolism, nitrogen retention was also reduced at the lower temperatures and was accompanied by an increase in urinary nitrogen. Similarly, Fuller (1965) observed that pigs exposed to cold environmental temperatures appeared to digest their dietary nitrogen less efficiently than those in the warm environment.

The decrease in NR at low temperatures, also was associated with an increase in urinary N excretion (Table 5 and Fig. 2). These data also show that UN increased ($P < 0.01$) as the

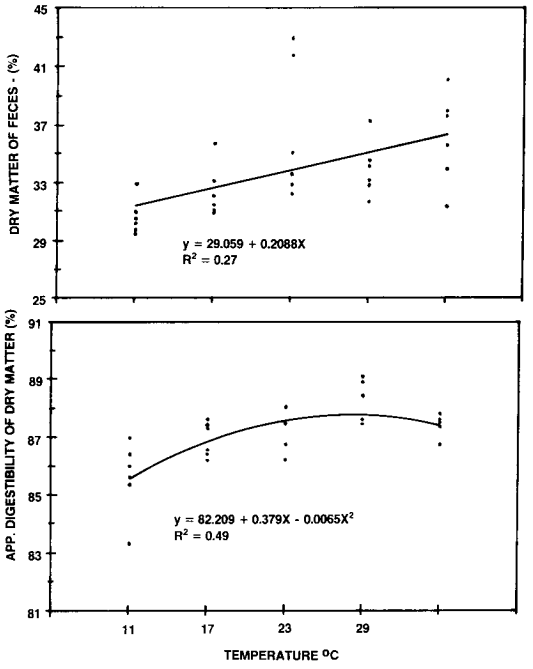

FIG. 1. Effect of environmental temperature on dry matter of feces (top display) and on apparent digestibility of dry matter (bottom display).

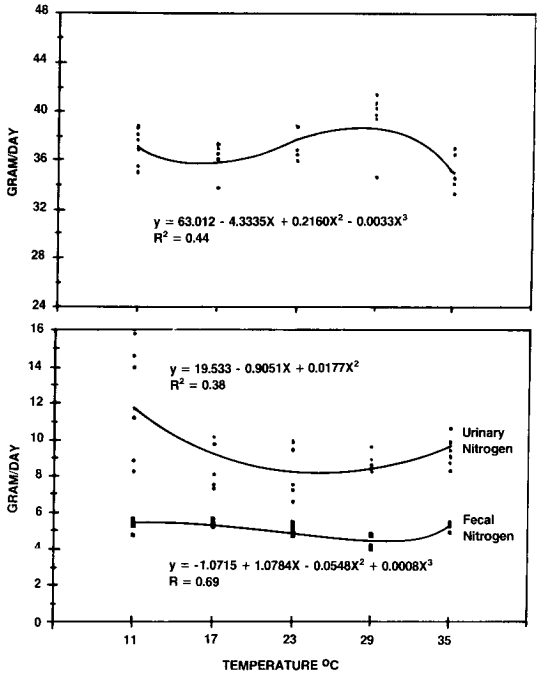

FIG. 2. Effect of environmental temperature on daily nitrogen intake (top display) and on daily urinary nitrogen, daily fecal nitrogen (bottom display).

environmental temperatures increased to 29°C, and then decreased (Table 5 and Fig. 2). Increased urinary N losses are indicative of high rates of dietary protein degradation and/or oxidation of muscle amino acids for thermoregulatory purposes for those animals exposed at low environmental conditions. The results relative to UN, are also in agreement with those reported by Fuller & Boyne (1971). A similar increase in urinary nitrogen excretion was shown to occur in sows exposed to 6° to 8°C (Holmes & MacClean 1974) associated with an increase in heat production.

As shown in Table 6 and Fig. 4, ADP and NR decreased at 35°C. These results agree with those reported by Gray & MacCraken (1973) and Holmes & Grace (1975), which also suggests that nitrogen retention may be decreased somewhat in heat stressed pigs.

The lower values of ADP at hot environmental temperature obtained here are in agreement with those reported by (Holmes 1973), who found that the apparent digestibility of protein was reduced at higher temperatures (33-35°C) compared with those kept at 25°C.

Over the total range of temperatures studied, ADDM, NPU and BV (Table 6 and Fig. 1 and 4) exhibited a quadratic effect ($P < 0.01$). They increased as the environmental temperature increased to 29°C, and then declined as the temperature increased. By taking the first derivative of the equations, it was determined that the maximum ADDM, NPU and BV were achieved at 29.1°, 24.9° and 24.8°C, respectively. These results indicate that the range of 25° to 29°C is within the thermalneutral zone (TNZ) for growing pigs housed in metabolism cages.

There was a linear ($P < 0.01$) response in the dry matter of feces (DMF) with increasing environmental temperature from 11° to 35°C

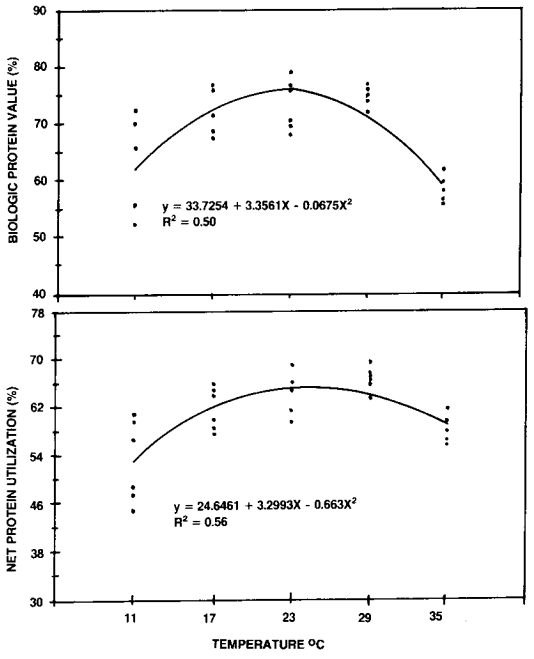

FIG. 3. Effect of environmental temperature on biological value (top display) and on net protein utilization (bottom display).

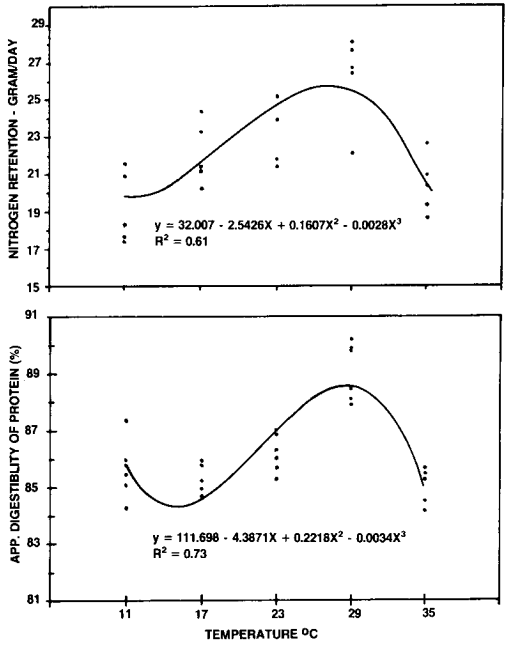

FIG. 4. Effect of environmental temperature on nitrogen retention (top display) and on apparent digestibility of protein (bottom display).

(Table 6 and Fig. 1). At low temperature, the DMF was lower, consequently more water was maintained in the feces in comparison with the feces of pigs kept at high environmental temperatures. These results are indicative that variations in water content of the feces might be related to the environmental temperature and this may have altered the rate of passage of digesta in the gut; this, in turn, possibly affected the absorption of nutrients. Reasons for this are not clear, but Kennedy et al. (1976) have indicated that there may be a reduction in retention time of digesta at low temperatures. Thus, the effectiveness of nutrient digestion and absorption might be diminished by reducing exposure time to digestive enzymes and absorption sites. Research conducted by Radomski & Orme (1971) indicated that thermogenesis induced by cold exposure is associated with higher enzymatic activity.

A part of the temperature effect on apparent digestibility of protein might also be attributed to the effect of thyroid activity. Although not measured in the present metabolism trials, thyroid hormone levels have been shown to influence gastrointestinal tract motility and rate of digesta passage as well as increasing metabolic rate in animals exposed to low environmental temperatures (Straw & Fregley 1967, Vybiral & Andrews 1979).

It is important to point out that under cold conditions, one would expect to find a decreased rate of nutrient utilization for growth since nutrients would be diverted from anabolic to oxidative metabolism (a proportion of nutrients would be catabolized) for thermogenesis. This has been found to be true for growing pigs housed under cold conditions (Jensen et al. 1969 and Fuller & Boyne 1971).

The influence of high environmental temperature on protein digestibility and nitrogen retention is less clear. Whereas Holmes (1973) and Gray & MacCraken (1973) suggested

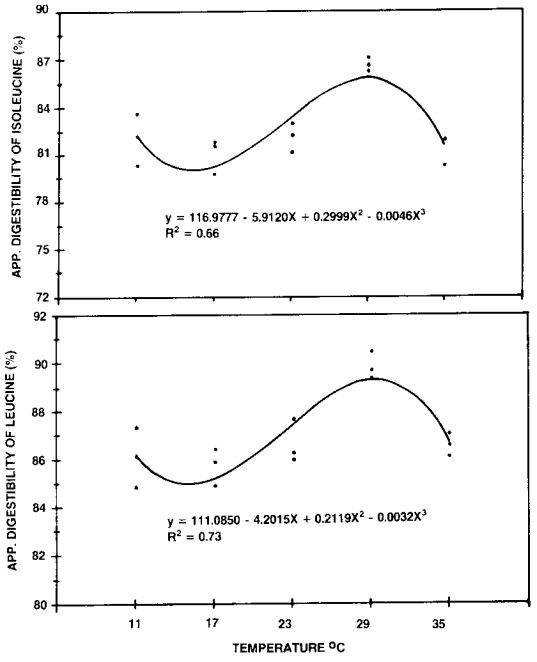

FIG. 5. Effect of environmental temperature on apparent digestibility of isoleucine (top display) and on apparent digestibility of leucine (bottom display).

decreases in these variables due to high temperatures, Fuller & Cadenhead (1969) reported increases. Verstegen et al. (1973), Le Dividich et al. (1980) and Berschaver et al. (1983) did not see any change in these variables when pigs were exposed to high environmental temperatures.

The results reported here show clearly that temperature above the upper critical temperature (35°C) decreased the apparent digestibility of protein and nitrogen in growing pigs. The discrepancy between these values and those reported by the literature is not easily explained.

Growth and other metabolic functions may be limited by availability of energy because of increased energy requirement for maintenance during thermal stress. When energy is limiting, protein may then be catabolized and used as an energy source. Because of the relationship between energy and protein requirements, the direct effect of high temperature on energy requirement may have a subsequent effect on protein required for growth or production in animals exposed to thermal stress (National Research Council 1981).

These results support the assumption that the higher nitrogen excretion and the lower NR and ADP at high environmental temperatures might be related to the utilization of dietary protein as an energy source by the growing pigs. The influence of high environmental temperatures on requirements in animal is complex. It may involve both protein synthesis and degradation. In the case of protein (amino acids), the increased use of protein for energy to maintain plasma glucose concentration (animal with low feed intake) indicates an increase in the requirements; this point needs further investigations (Klassing & Barnes 1988).

The polynomial regression equations of apparent digestibility of essential (Arginine, Histidine, Isoleucine, Leucine, Lysine, Methionine, Phenylalanine, Threonine, Valine) and nonessential (Alanine, Aspartic Acid, Cystine, Glycine, Proline, Serine, Tyrosine) amino acids derived from cubic models are presented in Table 7 and 8, and illustrated in Fig. 4, 5, and 6, respectively. It is important to point out that tryptophan was not analyzed, and it was also assumed that some loss, of the amino acids methionine and cystine might have occurred due to the acid hydrolysis procedure utilized. According to Elkin & Griffith (1985), the sulfur amino acids are destroyed to different degrees by acid hydrolysis when samples are not oxidized with performic acid before hydrolysis.

The apparent digestibility of essential and non-essential amino acids (ADAA) was significantly related to temperature in a cubic manner ($P < 0.01$). In addition to the cubic effect for ADAA, linear and quadratic effects ($P < 0.05$) were significant. In general, the ADAA values increased as the environmental temperature increased up to 29°C, and decreased after that. As previously discussed for ADP and NR, there is no obvious biological explanation for the cubic effect found in the

TABLE 7. Effect of environmental temperatures on apparent digestibility of amino acids in growing pigs. (dry matter basis).

Amino Acid	Temperature (°C)[a]					SE[b]
	11	17	23	29	35	
Essential						
Arginine[d]	92.75	91.67	92.69	94.69	91.66	0.12
Histidine[d]	91.20	89.92	90.81	93.15	89.79	0.15
Isoleucine[d]	82.05	81.05	83.50	86.67	81.44	0.32
Leucine[e]	86.10	85.75	86.68	89.88	86.06	0.23
Lysine[d]	79.80	78.24	81.35	85.33	79.07	0.24
Methionine[d]	82.87	79.97	82.88	87.35	81.66	0.41
Phenylalanine[e]	85.65	85.22	86.37	89.21	85.52	0.25
Threonine[e]	80.69	79.48	81.34	84.92	80.82	0.38
Valine[d]	80.53	79.63	81.88	85.22	79.83	0.27
Nonessential						
Alanine[e]	76.93	77.04	79.77	84.65	78.82	0.23
Aspartic acid[d]	85.66	84.52	86.21	89.34	84.79	0.24
Glutamic acid[e]	89.40	88.93	89.88	92.56	89.60	0.25
Cystine[c]	87.21	89.31	89.15	91.63	86.37	0.12
Glycine[e]	87.34	86.99	88.03	90.36	87.72	0.11
Proline[e]	90.39	90.17	90.56	92.47	90.19	0.31
Serine[e]	86.92	86.06	86.57	89.22	87.60	0.36
Tyrosine[e]	84.45	83.30	84.14	87.55	83.65	0.35

[a] Data for each temperature represent means of three observations.
[b] Standard error (SE) for each amino acid across temperatures.
[c] Quadratic ($P < 0.05$) effects.
[d] Quadratic ($P < 0.05$) and cubic ($P < 0.01$) effects.
[e] Linear ($P < 0.05$) and quadratic ($P < 0.05$) cubic ($P < 0.01$) effects.

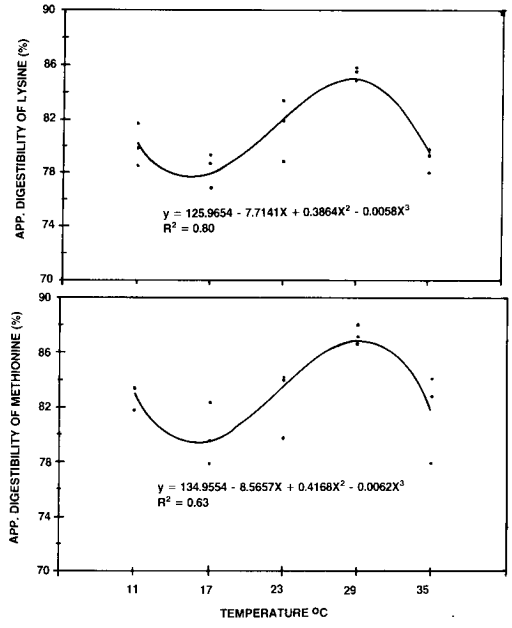

FIG. 6. Effect of environmental temperature on apparent digestibility of lysine (top display) and on apparent digestibility of methionine (bottom display).

present experiment. A tentative explanation utilized for ADP and NR might also be applied to the results of ADAA described here. According to these results both low (11°, 17°C) and high (35°C) temperatures, decreased the ADAA of essential and non-essential in growing pigs in comparison with those kept at 23° and 29°C. These results are similar with responses found in broilers by Wallis & Balnave (1984), which showed that the digestibilities of most amino acids decreased at higher temperatures in females broilers.

There is a lack of information about the effect of environmental temperature on amino acid metabolism in pigs; however, it is well known that factors such as feeding level, retention time of digesta in the small intestine (Ruckebuch & Bueno 1976) have an influence on the apparent digestibility of amino acids. The results of ADAA obtained here, showed a similar trend to those reported previously for the apparent digestibility of protein, which show that temperatures below or above the thermoneutral environmental temperature, decrease amino acid utilization in growing pigs. These results suggest that the temperature at 29°C was near optimal for the apparent digestibility of essential and non-essential amino acids in growing pigs.

The effects of environmental temperature on daily gross energy intake (GEI), daily fecal energy (FE), daily urinary energy (UE), digestible energy (DE) and metabolizable energy (ME) are presented in Table 9. Polynomial regression equations relative to these variables derived from linear, quadratic and cubic models are presented in Table 10.

There was a linear effect ($P < 0.05$) in FE and UE and there was a quadratic ($P < 0.05$) response in DE and ME. There was a cubic

TABLE 8. Polynomial regression equations of dependent variable (Y) as function of environmental temperature (X) with the coefficient of determination (R^2). Apparent digestibility of amino acids.

Y	Polinomial (X)	R^{2a}
Essential Amino Acid		
App. Dig. Arginine	$115.46 - 3.7505X + 0.1841X^2 - 0.0028X^3$	0.76**
App. Dig. Histidine	$116.77 - 4.1928X + 0.2041X^2 - 0.0030X^3$	0.80**
App. Dig. Isoleucine	$116.98 - 5.9120X + 0.2999X^2 - 0.0046X^3$	0.66**
App. Dig. Leucine	$111.08 - 4.2015X + 0.2119X^2 - 0.0032X^3$	0.73**
App. Dig. Lysine	$125.97 - 7.7114X + 0.3864X^2 - 0.0058X^3$	0.80**
App. Dig. Methionine	$134.96 - 8.5657X + 0.4168X^2 - 0.0062X^3$	0.63**
App. Dig. Phenylalanine	$109.80 - 4.0734X + 0.2060X^2 - 0.0031X^3$	0.74**
App. Dig. Treonine	$114.34 - 5.6059X + 0.2780X^2 - 0.0041X^3$	0.76**
App. Dig. Valine	$115.53 - 5.9258X + 0.3007X^2 - 0.0046X^3$	0.67**
Non essential Amino Acid		
App. Dig. Alanine	$114.31 - 6.4485X + 0.3353X^2 - 0.0051X^3$	0.86**
App. Dig. Asp. Acid	$117.94 - 5.3930X + 0.2690X^2 - 0.0041X^3$	0.72**
App. Dig. Cystine	$77.51 + 1.1150X - 0.0240X^2$	0.43**
App. Dig. Glut. Acid	$111.04 - 3.6224X + 0.1813X^2 - 0.0027X^3$	0.81**
App. Dig. Glycine	$106.49 - 3.2271X + 0.1629X^2 - 0.0024X^3$	0.75**
App. Dig. Proline	$104.96 - 2.4393X + 0.1224X^2 - 0.0018X^3$	0.69**
App. Dig. Serine	$106.47 - 3.1701X + 0.1514X^2 - 0.0022X^3$	0.51**
App. Dig. Tyrosine	$114.51 - 4.9457X + 0.2419X^2 - 0.0036X^3$	0.72**

[a] Coefficient of determination followed by *, ** are significant at $P < 0.05$ and $P < 0.01$ probability levels, respectively.

TABLE 9. Effect of environmental temperature on energy balance, digestible and metabolizable energy in growing pigs.

Item	Temperature (°C)					SE[a]
	11	17	23	29	35	
Sample Size	6	6	6	6	6	-
Daily Energy Intake[b,e], kcal	5300	5190	5272	5644	4984	95.90
Daily Fecal Energy[c], kcal	786	708	706	683	683	16.16
Daily Urinary Energy[c], kcal	625	586	481	513	512	35.56
Digestible Energy[b,d], kcal/kg	3838	3892	3903	3961	3889	14.90
Metabol. Energy[b,d], kcal/kg	3306	3383	3492	3550	3423	34.90

[a] Standard error of the means (SE) for each item across all temperatures.
[b] Values expressed in dry matter basis.
[c] Linear ($P < 0.01$) effects.
[d] Linear ($P < 0.01$) and quadratic ($P < 0.01$) effects.
[e] Quadratic ($P < 0.05$) and cubic ($P < 0.01$) effects.

($P < 0,01$) peso por dia do nascimento aos 182 dias (0,526 vs 0,444 kg), e do nascimento ao desmame (0,535 vs 0,462 kg). O melhor desempenho dos terneiros mestiços durante o período de aleitamento encontra suporte na literatura (Cundiff et al. 1974, Crockett et al. 1978, Reynolds et al. 1978, Chagas et al. 1980).

Os terneiros do grupo Charolês (C e NC) foram mais pesados ($P < 0,01$) do que os do grupo Aberdeen Angus (A e NA) aos 182 dias de idade (130,87 vs 109,46 kg), à desmama (162,20 vs 137,90 kg), bem como ganharam mais peso ($P < 0,01$) por dia do nascimento aos 182 dias de idade (0,536 vs 0,434 kg) e do nascimento ao desmame (0,544 vs 0,453 kg).

Nas Tabelas 1 e 2, pode-se observar os pesos e ganhos de pesos dos terneiros em relação ao sexo. Verifica-se que os machos foram sempre mais pesados ($P < 0,01$) do que as fêmeas, e tiveram maiores ($P < 0,05$) ganhos de peso médios diários. A maioria dos autores têm verificado que os terneiros machos são mais pesados ao nascimento do que as fêmeas. Dentre estes autores, Melton et al. (1967), Bond & Wiltbank (1970), Cundiff et al. (1974). Porém, outros autores não encontraram esta diferença (Restle 1975, Baker et al. 1982). Também, a maior parte dos trabalhos mostra que os machos ganham mais peso e têm maiores pesos à desmama (Melton et al. 1967, Bond & Wiltbank 1970, Rutledge et al. 1971, Cundiff et al. 1974, Restle 1975). Porém, Bellows & Short (1978) e Rocha & Ribeiro (1987) não encontraram diferença entre os sexos no peso à desmama.

TABELA 2. Médias estimadas e erros-padrão para os ganhos de peso médios diários (GMD-Kg) do nascimento aos 182 dias de idade, e até o desmame.

Efeitos	GMD Nasc.-182 dias	GMD Nasc.-desmame
Grupo genético do terneiro		
A. Angus (A)	0,394 ± 0,041 b	0,420 ± 0,035 b
Charolês (C)	0,495 ± 0,023 ab	0,504 ± 0,019 ab
Nelore x A	0,475 ± 0,021 b	0,487 ± 0,017 b
Nelore x C	0,578 ± 0,023 a	0,584 ± 0,019 a
Sexo		
Macho	0,512 ± 0,019 A	0,525 ± 0,015 A
Fêmea	0,459 ± 0,016 B	0,472 ± 0,013 B
Média	0,485 ± 0,012	0,498 ± 0,010

- Médias na mesma coluna, para o mesmo efeito, seguidas de letras iguais, não diferem entre si ao nível de 1% (a,b) ou 5% (A,B) de probabilidade (Teste de Scheffé).

Correlações entre os pesos, ganhos de peso dos terneiros e a produção de leite de suas mães

Como pode ser observado na diagonal da Tabela 3, as correlações entre ganhos de peso médios diários dos terneiros nos diversos períodos e as produções de leite de suas mães à data de término do período foram significativas ($P < 0,01$) até os 182 dias, o que está em concordância com Neville Junior (1962) e Klett et al. (1965), que encontraram correlações sempre altas até à desmama. Porém, outros autores observaram que as correlações tendiam a diminuir e deixavam de ser significativas a partir dos 120 dias de idade do terneiro (Drewry et al. 1959, Furr & Nelson 1964, Robison et al. 1978, Leal & Freitas 1982).

O ganho de peso médio diário dos terneiros, do nascimento ao desmame, teve uma correlação altamente significativa com a produção média diária de leite. A produção de leite explicou 56% do ganho de peso dos terneiros do nascimento ao desmame. Valores maiores do que este foram encontrados por Neville Junior (1962), Rutledge et al. (1971) e Totusek et al. (1973), porém, outros autores encontraram coeficientes de determinação menores do que 50% (Melton et al. 1967, Dickey et al. 1970, Robison et al. 1978).

Na Tabela 4, verifica-se que as percentagens médias dos componentes do leite tiveram correlações muito baixas e não-significativas, tanto com os pesos como com os ganhos de peso médios diários dos terneiros. Porém, as produções destes componentes tiveram corre-

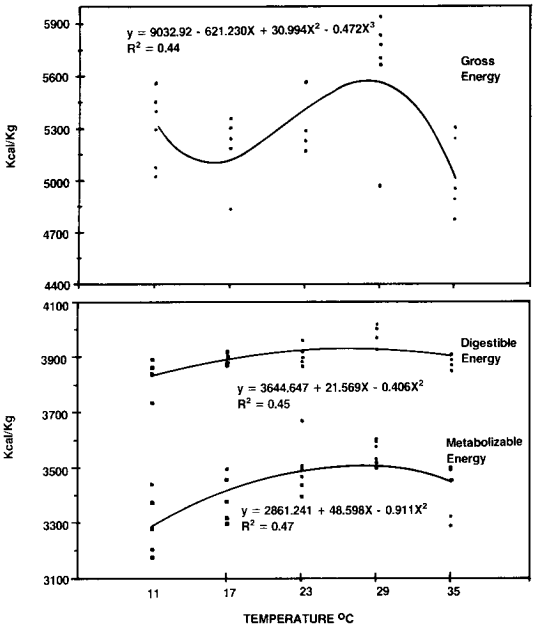

FIG. 7. Effect of environmental temperature on daily gross energy intake (top display) and on digestible energy, metabolizable energy (bottom display).

the treatments at conditions above the lower critical temperatures and this is consistent with the view that part of the heat production arising from the extra energy ingested would be used to offset the extrathermoregulatory heat production below the zone of thermoneutrality.

Phillips et al. (1982) found that pigs exposed to a low temperature (6°C) had an average DE significantly lower than those pigs exposed to 21°C. Studies which several species, including pigs, have reported reduced DE at low temperatures (Fuller & Boyne 1971, 1972, and Young et al. 1975). The findings reported here, support these studies, with the increase of environmental temperature until 29°C (thermoneutral temperature) was associated with the increase of energy utilization.

According to Verstegen et al. (1973) and Noblet & Le Dividich (1982), the interaction between environmental temperature and energy utilization is related to the amount of dietary heat increment, part of which is used for thermoregulation under cold conditions but must be dissipated under warm conditions. These data are consistent with this idea. The poor utilization of energy observed in pigs fed in the cold (11° and 17°C) compared with the 23°C and 29°C temperatures can be largely attributed to the increased energy expendure required for body heat production in pigs exposed in the cold environment. Consequently, pigs kept at low environmental temperature 4 to 7 degress below their lower critical temperature (Verstegen 1971, Close & Mount 1978) would be required to increase their dietary energy intake in order to meet their energy needs for body heat production and yet maintain a maximum rate of tissue synthesis. According to Kielanowski (1966), the energy requirement of a growing animal can be considered to be the sum of three components: the energy requirements for maintenance, protein accretion and fat deposition. Thus, the increase in energy for maintenance by the animals at low environmental temperature would be associated with an increase in heat production and energy requirement (Verstegen 1971; Fuller & Boyne 1972; Close & Mount 1978 and Noblet & Le Dividich 1982).

The present trials demonstrate that the effects of low environmental temperature on energy utilization are due primarily to variations in the level of energy expendure rather than to variations in energy intake. The increase of environmental temperature up to 29°C enhanced the estimated values of ME. These results are consistent with those reported by Webster (1981), Verstegen et al. (1973) and Blaxter (1977). This indicates that part of heat production that is dissipated at thermoneutrality is used for thermoregulatory requirement in the cold. Consequently, climatic factors that influence ME or heat production will influence the effective utilization of dietary energy. The ME from food is transformed into heat and net energy. The degree of heat production from all physiologic mechanisms influences total net energy produced. Thus as less heat is produced, more energy

becomes available for productive purposes.

As mentioned before, animals at low environmental temperatures had a decreased apparent digestibility of protein which might be related to the lower utilization of protein, since protein may be catabolized and used as a source of energy. This resulted in an increase in nitrogen excretion as urea. These results also support those reported by May & Bell (1971) who found that rate of protein catabolism was adversely related to the ME values in growing pigs. Pigs maintained in a range of temperatures from 11° to 35°C received an amount of food based on their metabolic body size, thus any differences between them could be attributed to a temperature effect. Higher metabolic rates due to increased heart rate, plasma glucose and free fatty acids has been found to occur in animals as a consequence of prolonged exposure to cold (Young 1975). Because of this, the efficiency of dietary energy utilization will be reduced. This probably explains the lowered energetic efficiency seen for pigs housed at 11° and 17°C compared with those at 29°C.

According to results presented in Table 10, the values of GEI, were cubically related with environmental temperature whereas the DE and ME were quadratically related. At temperatures above the upper critical temperature of 29°C, pigs were stressed by increased body temperature and the complexity of dissipating the excess heat, since metabolic processes require energy. The GEI decreased ($P < 0.01$) when the temperatures was above 29°C. These results demonstrate that pigs exposed to hot temperatures reduce their GEI in an attempt to lower the physiological burden of dissipating excess body heat. Although energy intake decreases in hot ambient temperatures, the adjustment of energy intake to temperatures above thermoneutrality is not sufficient to balance the reduced maintenance requirement at high environmental temperature according to Colemam & Evans (1982). This reduced level of energy intake was accompanied by reductions in energy utilization (DE and ME) by the animals exposed to high environmental conditions (35°C).

These findings are consistent with those reported by Bray & Atkinson (1977), Consolazio & Schnakenberg (1977) and Roberts & Coward (1985) who found that energy expendure was increased in pigs kept at ambient temperatures above thermoneutrality. These data also confirm the findings reported by Holmes (1974) who found a decrease in energy intake at high temperature. Fuller & Cadenhead (1969) found a decrease in the digestibility of energy, and Roberts & Coward (1985), reported an increase of energy expendure which was associated with reduced energetic efficiency in pigs exposed to a hot environmental temperature.

According to the first derivative of the quadratic equation for DE and ME it is indicated that a temperature range around 26° to 27°C represents the thermoneutral zone for pigs at 32 kg of live weight and housed in metabolism cages. These data confirm those of Gray & MacCraken (1973), who found that 29°C is very close to the zone of thermoneutrality for growing pigs housed in metabolism cages, since heat production was lower at 29°C than at 22°C. The data also support previous studies by Verstegen & Hel (1974), Holmes & Close (1976) and Close & Mount (1978) who estimated that the thermoneutral zone for individually-housed pigs weighing 20 to 50 kg was in the range of 24° to 30°C.

CONCLUSIONS

1. Both low (11° and 17°C) and high (35°C) temperatures decreased all of the parameters analyzed.

2. The apparent digestibility of amino acids was dependent on the ambient temperature in which the animals were housed, and was highest at 29°C and lowest at 11°C and 35°C.

3. Digestible (DE) and metabolizable energy (ME) values showed to be more efficiently utilized as environmental temperature increased and were maximized at 26° and 27°C respectively.

4. The results suggest that temperatures fall between 25° and 29°C are within the thermoneutral zone of 32 kg pigs kept in metabolism cages.

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