animal

Determination of nutrient requirements for growth and maintenance of growing pigs under tropical condition

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Data from 27 feeding trials conducted on growing pigs from different research institutes across India were subjected to mixed model regression analysis to derive requirements of digestible energy (DE), crude protein (CP) and essential amino acids for maintenance and body weight gains. The ranges of maintenance requirements were determined to be: DE 516 to 702 kJ/kg $M^{0.75}$, CP 6.98 to 11.62, lysine 0.431 to 0.664, methionine 0.265 to 0.458, methionine + cystine 0.327 to 0.466, cystine 0.055 to 0.184, threonine 0.205 to 0.511, arginine 0.377 to 1.21, isoleucine 0.241 to 0.775, leucine 0.604 to 1.54, phenylalanine + tyrosine 0.496 to 1.33, tryptophan 0.078 to 0.213, and valine 0.330 to 0.892 g/kg $M^{0.75}$, respectively for different body weight ranges. The corresponding requirements for 1 g gain in body weight were: DE 28.6 to 38.6 kJ, CP 0.27 to 0.44 g, lysine 0.0071 to 0.0126 g, methionine 0.0047 to 0.0133 g, methionine + cystine 0.0151 to 0.0261 g, cystine 0.0043 to 0.0094 g, threonine 0.0052 to 0.0165 g, arginine 0.0045 to 0.0301 g, isoleucine 0.0023 to 0.0198 g, leucine 0.0150 to 0.0447 g, phenylalanine + tyrosine 0.0091 to 0.0382 g, tryptophan 0.0005 to 0.0044 g, and valine 0.0061 to 0.0222 g. Regression equations had high R^2 values (ranging from 0.50 to 0.99 for different estimates), low coefficients of variation, low variance of error estimates and the coefficients were highly significant (P < 0.001). Regressed values were used to develop feeding standards. As the new standards derived in the present study are based on a thorough analysis of a larger database than previous Indian standards, the new feeding standard seems to be more appropriate for India and other tropical countries.

Introduction

Pigs play a crucial role in the rural economy in many tropical countries. Pigs are recognised as one of the most effective livestock for promoting health and economy of poor people in the developing countries of the world. According to Food and Agricultural Organisation estimate (FAO, 2003), pigs contributed 630 thousand Mtonnes of meat amounting to 10.4% of total meat produced (6038 thousand Mtonnes) in India from different sources. The tropical developing countries with limited feed resources have to economise feeding of pigs by avoiding their wasteful feeding. Efficient utilisation of nutrients depends on adequate supplies of energy, protein and amino acids, which are of paramount importance in determining the productivity of pigs. Nutrient limitations prevent pigs from attaining their genetic potential. Thus an optimum growth rate and feed utilisation efficiency according to inherent genetic potentiality of a particular category of animal can be achieved

only through accurate evaluation of their nutrient requirements. Nutrient requirements not only provide a satisfactory guideline for formulation of rations for rearing the animal but are also used for planning of yearly purchase of feed when feed prices are minimum and also provide guideline in developing supplementary feeding strategies for pigs reared under semi-intensive systems. Nutrient requirements depend on body size and growth or production potentials of animals, environmental condition and quality of feed. Temperature, humidity, sunshine and wind velocity may increase or decrease nutrient needs depending upon region. The nutrient needs of pigs under tropical conditions probably differ from pigs found in temperate countries because of differences in genetic makeup, mature body size, growth rate, quality of feeds and climatic variations. The feeding standards for pigs, which are currently being followed (Indian Council of Agricultural Research, 1998; National Research Council (NRC), 1998) in tropical countries need to be updated and refined further to suit the requirements appropriate to the climate and other local

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factors (feedstuffs quality, breed type, growth rate, etc) as more data on nutrient intake and performance derived from feeding trials are available under different dietary and environmental situations. Several approaches are used for estimation of nutrient requirements. These include energy balance in calorimetric chamber studies, short-term nitrogen (N) and energy balance trials with metabolism trials and comparative slaughter on different feeding levels, factorial approaches from estimates of endogenous N losses in animals fed on low protein diet and analysis of intake *versus* performance data in feeding trials. Regression analysis of feeding trial data provides estimates of nutrient requirements of productive animals kept under normal farm feeding condition. This approach is less costly, more convenient and, most importantly, can generate nutrient requirement data for animals kept under a normal production setting, without requiring energy chambers or slaughtering of animals and hence such an approach has been widely used (Ash and Norton, 1987; Abate, 1989; Onwuka and Akinsoyinu, 1989; Yang *et al.*, 1997a and b; Zhang and Coon, 2000; Paul *et al.*, 2002, 2003a, b and 2004; Mandal *et al.*, 2005; Okagbare *et al.*, 2004). The present study was undertaken to determine energy, protein and amino acid requirements of growing pigs employing regression analysis models on combined nutrient intake and performance data of almost all of the experimental feeding trials conducted so far in India under diverse tropical feeding conditions.

Material and methods

Data collection

The data on digestible energy (DE) intake, crude protein (CP) intake, amino acid intake, body weight (BW), average daily weight gain (ADG) and ration composition, generated through experimental feeding trials conducted on growing pigs in different research institutes of India were collected from published reports. In some reports information was incomplete with respect to one or more of the essential variables like BW, BW change and nutrient intake. Such reports were excluded. Only those data were admitted that contained complete information with respect to BW, BW changes and nutrient intake. Finally, data from 27 studies (details presented in Table 1) representing 102 different dietary treatment groups and 652 animals were used in the present study. These studies were conducted across a wide range of locations and conditions in India. The ranges of values of different parameters are summarised in the result section. In most of the trials, energy intake was expressed in DE units and protein as CP units.

Animals and feeding management in the feeding trials

The types of pigs included exotic purebred, indigenous non-descript, indigenous purebred or crossbred (Table 1). In most of the feeding trials pigs were fed in groups of four to 16 pigs *ad libitum* from a weighed allowance of feed. Out of 27 feeding trials, data from one trial (Soren, 2002) were on 48 individual pigs and for the rest of the studies data were on performance of groups (mostly four to six animals per group). In all the experiments growing pigs (above 2 months of age) were used. In most of the studies the pigs were housed individually in pens which provided a covered area having separate arrangement for feeding and watering and an open enclosure for exercise. In a few studies pigs were housed in groups. The ration components and other details are presented in Table 1.

All animals were supplemented with a mineral mixture and vitamins in the concentrate components. The average composition of the mineral mixture was: calcium , 26%; phosphorus, 4.5%; copper 0.48%; cobalt, 0.009%; manganese 0.08%; iodine (as KI) 0.0125%; zinc, 0.8%, sodium chloride, 23.5%. The mineral mixture was included at the rate of 1.5 kg per 100 kg ration. The average composition (per g) of the vitamin mixture was retinol, 24.8 mg; riboflavin 50 mg cholecalciferol 0.3 mg. The vitamin mixture was added at the rate of 20 g per 100 kg feed. Feed intake was recorded daily in all the experiments. BW was recorded every 2 weeks. Digestion or metabolism trials were also conducted to ascertain the nutritive value of rations in all the trials. In some of the trials, animals were fed individually but only group means were reported. In all the trials digestibility or metabolism trials of 6 to 7 days duration were conducted on individual animals but only group means were reported. During digestion trials pigs were placed in metabolism cages individually for separate collection of faeces and urine. Representative samples of feed offered, residue left and faeces were collected daily, pooled, stored and analysed for proximate principles using standard (Association of Official Analytical Chemists, 1970) procedures. The amino acid composition of the ration was presented in some of the reports. For the rest of the studies, amino acid composition of the rations was calculated based on the amino acid content of different feed ingredients reported by different Indian workers and NRC (1998). Environmental parameters were not recorded in any of the studies. However, on the basis of the geographical locations of the experimental stations (experiment stations are between 13°N and 32°N latitude; details presented in Table 1), it can be inferred that the climate was tropical, with hot and humid weather for most of the year and yearly temperature ranges from a minimum of -2°C to a maximum of 48°C.

Estimation of nutrient requirements

In the present study combined data from crossbreds with improved exotic breeds, indigenous purebreeds and non-descripts were utilised. At present sufficient data on different pig breeds with different lean growth potential are not available to establish separate nutrient requirement for a different lean growth category of pigs, if any, on these animals.

During preliminary analysis, it was observed that regression analysis of whole data resulted in relatively lower overall predictability than when analysis was done

Table 1 *Description of the database used to develop prediction equations for energy, protein and amino acid requirements of Indian pigs*

Source	Study type	Experimental design and dietary treatments	No. of pigs†	Genotype	Live weight range (kg)	Sex	Diet source	Measured criterion
Agarwal et al., 1982	Growth cum feeding trial	Complete randomised design T1- standard diet T2–30% maize replaced by wheat bran (WB) T3–60% maize replaced by WB	48 (3)	Landrace	14–69	ns	Maize, GNC, fish meal, wheat bran, mineral, vitamin mix	Digestibility, proximate composition, CP, DE, feed intake, ADG
Yadav et al., 1993	Growth cum feeding trial	Experiment 1 Randomised block design T1-conventional CM *ad lib* + *Stylosanthes* 500 g T2–50% CM + radish *ad lib* T3–25% CM +radish *ad lib*.	12 (3)	Crossbred	16.9–29	M	Maize, wheat bran, rice polish, GNC, fish meal, mineral and vitamin mix, *Stylosanthes*, radish	Digestibility, proximate composition, CP, DE, feed intake, ADG
		Experiment 2 Fodder radish (*Raphanus sativus* L.) diet	6	Mini Naga	16.3–16.7	F	*Ad libitum* fodder radish	-ditto-
Reddy et al., 1982	Growth cum feeding trial	Experiment 1 Blocking and 3 × 3 factorial arrangement of three levels of protein (16, 18 and 20% CP) and energy (3.1, 3.3 and 3.5Mcal DE per kg).	54 (9)	Large White Yorkshire	20–35 kg	36 M; 18 F	Maize, wheat bran, GNC, fish meal, mineral and vitamin mix	Digestibility, proximate composition, AA composition, CP, DE, feed intake, ADG
		Experiment 2 Randomised-block design three dietary treatments consisted of three energy levels (3, 3.3 and 3.5 Mcal DE per kg) each with 18%CP	36 (3)	-ditto-	20–44	M	-ditto-	-ditto-
Reddy et al., 1981	Growth cum feeding trial	T1–18.73%CP, 3.1Mcal DE/kg T2–17.78%CP, 3.1McalDE per kg T3–16.69%CP, 3.0Mcal DE per kg	18 (3)	Large White Yorkshire	35–60	12 F + 6M	Maize, wheat bran, GNC, fish meal, de-oiled rice bran, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, ADG
Pathak and Ranjhan, 1973	Growth cum feeding trial	Randomised block design T1-control-maize based diet T2–50% maize replaced by sal (*Shorea robusta*) seed meal T3–100% maize replaced by sal seed meal	12 (3)	ns	39–90	F	Maize, wheat bran, GNC, fish meal, de-oiled sal seed meal, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, ADG
Hati et al., 2000	Growth cum feeding trial	Complete randomised design T1-standard CM; T2, T3 and T4–33.3, 66.6 and 100% of maize replaced by marua (*Eleusine caracana*), respectively	32 (4)	Large White Yorkshire	16–75	ns	Maize, wheat bran, GNC, fish meal, marua, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, ADG
Kumar et al., 2000	Growth cum feeding trial	Complete randomised design T1-standard CM with 6.5% fish meal; T2- fish meal replaced by cooked soybean meal; T3-similar to T2 except it was fortified with lys and met	27 (3)	Tamworth × indigenous	13.5–41	ns	Maize, wheat bran, GNC, fish meal, cooked soya-bean meal, mineral and vitamin mix, Lys, met	Digestibility, proximate composition, CP,DE, feed intake, ADG
Prasad et al., 1991	Growth cum feeding trial	T1- conventional CM with niger cake; T2, T3 and T4–20, 40 and 60% of niger cake replaced with kosum (*Schleichera oleosa*) cake	24 (4)	Landrace × Tamworth × indigenous	18–89	12 M + 12F	Maize, GNC, fish meal, niger cake, kosum cake, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, ADG
Bhakt et al., 1991	Growth cum feeding trial	T1- conventional CM; T2, T3 and T4 – 5, 10 and 15% of treated sal (*Shorea robusta*) seed meal	20 (4)	Tamworth × indigenous and Landrace × indigenous	22–65	F	Maize, GNC, fish meal, wheat bran, urea treated sal seed meal, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, ADG

Table 1 *Continued*

Source	Study type	Experimental design and dietary treatments	No. of pigs[†]	Genotype	Live weight range (kg)	Sex	Diet source	Measured criterion
Yadav et al., 1995	Growth cum feeding trial	Exp. 1:1-Conventional CM; T2-conventional CM 60% + 40% sweet potato tubers Exp. 2: 2 group, fed CM with or without maize	8 (2) 8 (2)	Crossbred	39–57	M	Wheat, maize, rice polish, GNC, fish meal, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, ADG
Yadav and Gupta, 1995	Growth cum feeding trial	T1- conventional CM; T2-rice polish based diet	8 (2)	Crossbred	66–86	M	Maize, rice polish, Wheat bran, GNC, fish meal, meat meal, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, ADG
Rao et al., 1997	Growth cum feeding trial	T1 – ad lib conventional CM; T2- ad lib Amaranthus forage +2 kg CM	18 (2)	ns	67–78	ns	Bajra, de-oiled rice bran, de-oiled sunflower cake, GNC, fish meal, Amaranthus forage, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, ADG
Yadav et al., 1990	Growth cum feeding trial	2 kg conventional CM + ad lib maize fodder	4 (1)	Crossbred	117–138	M	Maize, rice polish, Wheat bran, GNC, fish meal, maize fodder, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, ADG
Sharda and Sagar, 1986	Growth cum feeding trial	3 × 3 factorial arrangement of 9 treatments comprising different levels of energy and protein at different stages of growth	45 (9)	Middle White Yorkshire	10–75	ns	Maize, homini feed, broken rice, Wheat bran, GNC, molasses, lard, fish meal, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, ADG
Sharda et al., 1976	Growth cum feeding trial	T1- conventional CM diet; T2—10% damaged pulses +CM	12 (2)	Middle White Yorkshire	18–80	ns	Maize, GNC, damaged pulses, fish meal, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, ADG
Sharda et al., 1982b	Growth cum feeding trial	Four groups fed diets containing 16, 20, 22 and 24 per cent protein	28 (4)	Crossbred (Middle White Yorkshire × indigenous)	14–52	ns	Maize, GNC, fish meal, bone meal, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, ADG
Sharda and Yadav, 1977	Growth cum feeding trial	T1—16% CP in growing phase and 14% CP in finishing phase fed once a day; T2- same diet fed twice a day	10 (2)	Middle White Yorkshire	14–70	ns	Maize, GNC, fish meal, bone meal, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, ADG
Sharda et al., 1982a	Growth cum feeding trial	T1—18%—16% CP; T2—16%—14%; T3—14%—12% CP, respectively during growing and finishing period	18 (3)	Middle White Yorkshire	14–75	ns	Maize, GNC, fish meal, bone meal, mineral and vitamin mix	Digestibility, CP,DE, feed ntake, ADG, lys
Sharda et al., 1981	Growth cum feeding trial	One group comprised Middle White Yorkshire breed and the other indigenous pigs fed similar diet	10 (2)	Middle White Yorkshire and indigenous	15.5–80; 6.1–27	ns	Maize, rice polish, wheat bran, GNC, fish meal, maize fodder, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, ADG
Sharda et al., 1975	Growth cum feeding trial	T1- conventional CM; T2–5% Lucerne meal + CM; T3–10% Lucerne meal + CM	18 (3)	Middle White Yorkshire	14–50	ns	Maize, GNC, fish meal, lucerne meal, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, ADG
Yadav et al., 1982	Growth cum feeding trial	T1-diet containing 60% maize. 20 and 40% of maize were replaced by hominy feed in T2 and T3, respectively	12 (3)	Large White Yorkshire	13–62	ns	Maize, homini feed, wheat bran, GNC, fish meal, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, ADG
Sharda et al., 1979	Growth cum feeding trial	T1-fed CM containing 5% wheat bran; T2- Fed CM containing 25% wheat bran	10 (2)	Middle White Yorkshire	14–70	ns	Maize, wheat bran, GNC, fish meal, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, ADG

Table 1 *Continued*

Source	Study type	Experimental design and dietary treatments	No. of pigs†	Genotype	Live weight range (kg)	Sex	Diet source	Measured criterion
Sharda and Singh, 1981	Growth cum feeding trial	T1-conventional CM, T2-CM with 20% Lucerne meal, T3-CM + 5% molasses; T4-CM + 20%Lucerne meal + 5% molasses	20 (4)	Middle White Yorkshire	14–73	11 M, 9F	Maize, rice polish, wheat bran, GNC, fish meal, lucerne meal, molasses, bone meal, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, ADG
Sharda and Yadav, 1981	Growth cum feeding trial	T1–18 and 16% CP; T2–16 and 14% CP; T3–14 and 12% CP; T4–14%CP + Lysine and 12% CP + Lysine	20 (4)	Middle White Yorkshire	12–70	ns	Maize, GNC, fish meal, bone meal, mineral and vitamin mix, lysine	Digestibility, proximate composition, CP,DE, feed intake, ADG
Sharda and Yadav, 1982	Growth cum feeding trial	All the pigs were fed grower diet	18 (3)	6 Middle White Yorkshire, 6 indigenous and 6 crossbred of Indigenous × Middle White Yorkshire	9.9–59	ns	Maize, GNC, fish meal, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, ADG
Bhar, 1998	Growth cum feeding trial	Different groups were fed different plane of energy and protein nutrition	48 (6)	Landrace × indigenous crossbred	6–60	M/F	Wheat bran, maize, GNC, mineral and vitamin mix	Digestibility, proximate composition, CP, DE, feed intake, ADG, Amino acids
Soren, 2002	Growth cum feeding trial	Different groups were fed different plane of energy and protein nutrition	48 (3)	crossbred	25–60	F	Rice bran, maize, GNC, mineral and vitamin mix	Digestibility, proximate composition, CP,DE, feed intake, AA, ADG

Abbreviations used: CM, concentrate mixture; GNC, groundnut cake; DE digestible energy; CP crude protein; AA amino acids; ADG average daily gain; M, male; F, female; ns = not stated in the report.
† Values in parentheses indicate number of experimental groups.

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separately for lower and higher BWs and there were substantial differences in estimates obtained at high and low BWs. Homogeneity of regression coefficients for different BW groups were tested using an F test (Steele and Torrie, 1984), which indicated that coefficients were different for different BW ranges groups for one or more nutrients. Hence the experimental data were arranged in four sets, i.e. for 7 to 20, 20 to 35, 35 to 60 and 60 to 127 kg BW for analysis. The BW range classes were as per the existing feeding standards being followed in India for pigs recommended by ICAR (Indian Council of Agricultural Research). The experimental data were subjected to regression analysis using the following model: $Y = a + bX_1$, where, Y is intake of DE, CP or amino acids, kJ or g per kg metabolic body weight ($M^{0.75}$) per day; X_1 is the ADG (g) per kg $M^{0.75}$; the intercept, a, is an estimate of maintenance requirement; the regression coefficient, b is the estimate of requirements for BW gain (kJ or g per g gain). A similar model was also used by other workers (Ratray *et al.*, 1974; Abate, 1989; Walter and Mao, 1989; Solis *et al.*, 1991; Paul *et al.*, 2002, 2003a, b and 2004) for estimation of nutrient requirements from feeding trial data.

Statistical analyses

All regression analyses were performed using mixed liner model procedures (St-Pierre, 2001; Statistical Packages for the Social Sciences (SPSS), 2003). Mixed model analysis was chosen because the data were gathered from various published studies and therefore it was necessary to consider the study effect as a random effect in the context of a metanalytic review (because the studies represent a random sample of a larger population of studies). Mixed effects regression models were constructed with both fixed effects (slope and intercept) and random effects (slope and intercept) for the independent variable. The random effects allowed for the possibility that, in the relationship between dependent and independent variables, each study had its own slope and intercept that varied randomly from study to study. In this context, the slope and intercept from the fixed effects model represent a mean slope and a mean intercept averaged over all studies. In fitting these models, unstructured covariance was utilised. In cases where random covariances were non-significant, a reduced model without a covariance component was fitted. In instances in which the random effect of slope was not significant, slope was removed from the random model. In a mixed effects model, there is no standard definition of R^2 as in standard (fixed effects) regressions. To assess overall model fit, the general linear model procedure of SPSS (2003) was used to fit a fixed effects regression of the dependent variable on the independent variable. To reflect the presence of random effects in the mixed effects models, a term representing study was added to the model. In addition, in those cases in which a random slope effect was present in the mixed effects model, a term for the interaction of the study and dependent variable was included in the model. The resultant value of R^2 is reported here. A similar method was also utilised

by Broderick and Clayton (1997) for construction of R^2 for mixed models. The performance of derived prediction equations was evaluated using variance of error estimate (σ_2^{error}) and its standard error, coefficient of variation (CV) of the model (square root of variance of error as % of mean of dependent variable), BIC (Schwarz's Bayesian Information Criteria), significance level of the parameters estimated and R^2 values (as constructed from the generalised liner model). During preliminary analysis we observed that the use of weight statement for weighted regression analysis gave the same/similar estimates when weight statements were not used. This is probably because of similar variations across studies. Hence, in the final analysis we have not used weighted regression.

Presentation of results of mixed model regression in the form of a dependent *versus* predictor variable graph where the regression line is shown in conjunction with the observations need adjustment of observations for lost dimensions because observations come from a multidimensional space (multiple studies) to a two dimensional plane. Adjustment of DE intake in kJ per kg metabolic body size (DEIMBS) values were made by adding each mixed model derived residuals to its corresponding predicted DEIMBS values as suggested by St-Pierre (2001).

Feeding standards were derived for nutrient requirements of different nutrients for maintenance at different BWs and for gain in BW.

Results

General information about the feeding trials

In the database, average BW and ADG of experimental pigs ranged from 7.01 to 127.6 kg and 43 to 684 g/day, respectively (Table 2). The mean, s.e. and range of DE concentration (MJ/kg), CP% and CP digestibility in the database were 12.6 $\pm$ 0.09 (9.64 to 15.50 MJ/kg), 17.4 $\pm$ 0.16% (10.4 to 24.0%) and 73.9 $\pm$ 0.131% (52.4 to 86.7%), respectively. The range of each variable (Table 2) was sufficient for realistic regression analysis and is representative of diversities observed in animal and feeding situations in India.

Energy and protein requirements

The regression equations developed for the prediction of DE and CP requirements (Table 3) had high ($P < 0.001$) significance level and R^2 values. The models had low variance of error estimates (σ_2^{error}), standard errors, CV and BIC. Comparison of actual *versus* predicted data indicated that presently derived requirements from the whole data set accurately predicted requirements of individual as well as group of pigs under varied dietary composition.

The estimated maintenance requirement of DE was in the range of 516 to 702 kJ/kg $M^{0.75}$ for different BW ranges and the estimate from the whole database was 688 kJ/kg $M^{0.75}$. The estimated requirements were in the range of 28.6 to 38.6 kJ DE per g ADG for different BW ranges and the

Table 2 *Mean values and variances of some of the variables analysed[†]*

BW range (kg)	No.		Average BW (kg)	ADG (g)	DMI (g/day)	DE (kJ/kg)	CP (%)	Lys (%)	Met (%)	Cys (%)	Met + cys (%)	Thr (%)	Arg (%)	Tryp (%)	Leu (%)	Ile (%)	Phe + tyr (%)	Val (%)
																	Amino acid	
7−20	36	Min	7.01	43	280	10 284	12.1	0.37	0.08	0.12	0.49	0.38	0.41	0.12	0.66	0.35	0.65	0.48
		Max	19.5	591	2033	14 644	21.8	0.89	0.64	0.44	0.91	0.61	1.25	0.25	1.82	0.79	1.46	0.88
		Mean	13.8	185	755	12 146	19.7	0.76	0.37	0.26	0.63	0.54	0.92	0.17	1.50	0.64	1.20	0.74
		s.e.	0.65	22.9	72	212	0.39	0.03	0.03	0.01	0.03	0.02	0.08	0.01	0.12	0.04	0.08	0.04
20−35	83	Min	20.5	111	766	9636	12.8	0.49	0.21	0.16	0.44	0.38	0.57	0.12	0.98	0.46	0.93	0.59
		Max	34.7	548	3390	15 489	24.0	0.90	0.83	0.35	1.15	0.74	1.82	0.30	1.98	0.96	1.83	1.12
		Mean	30.0	331	1392	12 828	17.9	0.74	0.49	0.27	0.75	0.61	1.26	0.19	1.63	0.73	1.43	0.89
		s.e.	0.33	9.8	5419	170	0.25	0.01	0.02	0.01	0.03	0.01	0.04	0.01	0.03	0.01	0.03	0.02
35−60	101	Min	35.9	136	1090	9895	12.0	0.46	0.18	0.12	0.40	0.49	0.67	0.10	0.96	0.46	1.07	0.63
		Max	59.9	667	3190	15 464	21.1	0.89	0.82	0.37	1.20	0.77	1.87	0.25	1.88	0.91	1.58	1.03
		Mean	47.2	375	1892	12 485	16.9	0.76	0.42	0.24	0.66	0.62	1.24	0.17	1.62	0.71	1.34	0.84
		s.e.	0.66	10.2	44.7	156	0.22	0.01	0.02	0.01	0.03	0.01	0.05	0.01	0.03	0.02	0.03	0.02
60−128	35	Min	60.1	240	1668	11 045	10.4	0.47	0.27	0.19	0.47	0.49	0.69	0.10	0.96	0.47	0.92	0.65
		Max	127.6	684	3467	14 313	22.0	0.85	0.82	0.33	1.15	0.73	1.68	0.24	1.83	0.86	1.68	1.05
		Mean	66.9	468	2349	13 100	15.0	0.63	0.55	0.27	0.82	0.56	1.02	0.16	1.49	0.62	1.24	0.78
		s.e.	1.87	20.6	71.7	177	0.56	0.03	0.03	0.01	0.02	0.04	0.01	0.06	0.01	0.02	0.03	0.02
Overall	255	Min	7.01	43	280	9636	10.4	0.37	0.08	0.12	0.40	0.38	0.41	0.10	0.66	0.35	0.65	0.48
		Max	127.6	684	3467	15 489	24.0	0.90	0.83	0.44	1.20	0.77	1.87	0.30	1.98	0.96	1.83	1.12
		Mean	39.4	346	1628	12 631	17.4	0.74	0.45	0.26	0.71	0.59	1.18	0.18	1.58	0.69	1.34	0.84
		s.e.	1.05	8.64	40.7	92	0.16	0.01	0.013	0.004	0.01	0.007	0.027	0.04	0.02	0.01	0.018	0.01

[†] Abbreviations used: BW, body weight; ADG, average daily gain; DMI, dry matter intake; DE digestible energy; CP, crude protein.

estimate from the whole database was 33.2 kJ DE per g ADG. The prediction equations accounted for 76 to 95% of the variations in observed DE intake. The distribution of adjusted DEIMBS and ADGMBS (ADG in g/kg MBS) values in conjunction with mean regression line across studies has been depicted in Figure 1.Upon visual examination of Figure 1, there appeared a strong relationship between DEIMBS and ADGMBS ($R^2 = 0.76$), and observations within study were very predictable. The prediction errors (CV) were in the range of 9.34 to 12.20% of actual mean intake and the overall prediction error of DE intake was in the order of

9.61% of the actual mean intake, which indicated good accuracy of prediction across the database. The prediction equations were used for development of feeding standards for DE requirement (Table 5) based on average feed intake and growth rate observed in the database.

The maintenance requirements of CP ranged from 6.98 to 11.6 g per kg $M^{0.75}$ for different BW ranges, while the estimate from the whole database was 8.97 g CP per kg $M^{0.75}$. The estimated requirements were in the range of 0.27 to 0.44 g CP per g ADG for different BW ranges and the estimate from the whole database was 0.42 g

Table 3 *Parameter estimates obtained using regression model[†] for apportioning of energy (kJ) and protein (g) intake for maintenance (a) per kg $M^{0.75}$ and growth per g gain) (b)[‡]*

BW range (kg)	No. of observations	Nutrient	a	b	σ_2^{error}	BIC	$R^{2\S}$	CV (%)
7−20	36	DE (kJ)	532 ± 64	32 ± 4.81	23 195 ± 5121	375.3	0.944	11.89
		CP (g)	11.62 ± 2.22	0.39 ± 0.09	4.22 ± 1.15	179.9	0.861	11.49
20−35	83	DE (kJ)	516 ± 85	34 ± 6.86	25 655 ± 4358	709.3	0.954	9.34
		CP (g)	11.52 ± 2.0	0.31 ± 0.04	4.23 ± 0.72	445.2	0.926	10.76
35−60	101	DE (kJ)	702 ± 87	28.6 ± 3.9	25 620 ± 4229	866.2	0.823	12.20
		CP (g)	10.68 ± 4.58	0.27 ± 0.14	6.88 ± 1.07	531.6	0.670	14.89
60−128	35	DE (kJ)	564 ± 124	38.6 ± 6.52	21 360 ± 6259	364.9	0.811	11.11
		CP (g)	6.98 ± 3.16	0.44 ± 0.14	3.97 ± 1.20	187.2	0.896	13.03
Overall (7−128)	255	DE (kJ)	688 ± 40	33 ± 3.6	15 790 ± 1489	2712	0.760	9.61
		CP (g)	8.97 ± 1.37	0.42 ± 0.05	3.99 ± 0.39	1240.2	0.790	11.13

[†] Model: intake/MBW = $a + b$(ADG/MBW); analysed using mixed model method considering study effect and its interaction effects as random. (Each observation is mean of observations on at least four animals.)
[‡] Abbreviations used: BW, body weight; DE, digestible energy; CP, crude protein; BIC, Schwarz's Bayesian Information Criteria; σ_2^{error} = variance of error estimate.
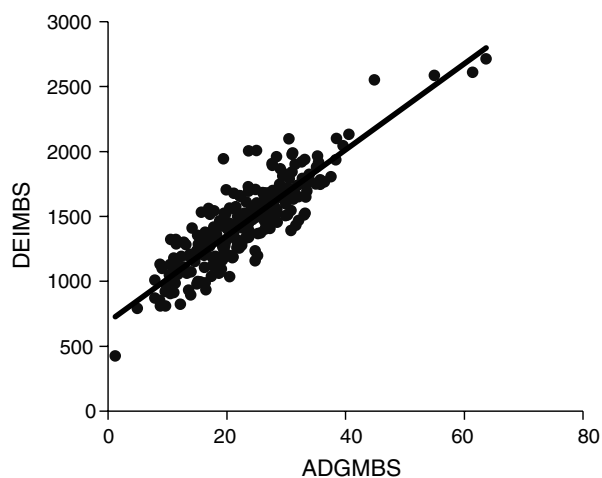[§] Coefficient of determination constructed for the mixed effects model.

Figure 1 Plot of adjusted digestible energy intake in kJ per kg metabolic body size (DEIMBS) on average daily gain in g per kg metabolic body size (ADGMBS) and the mean regression line across studies ($y = 33.144x + 688.07$; $R^2 = 0.7617$).
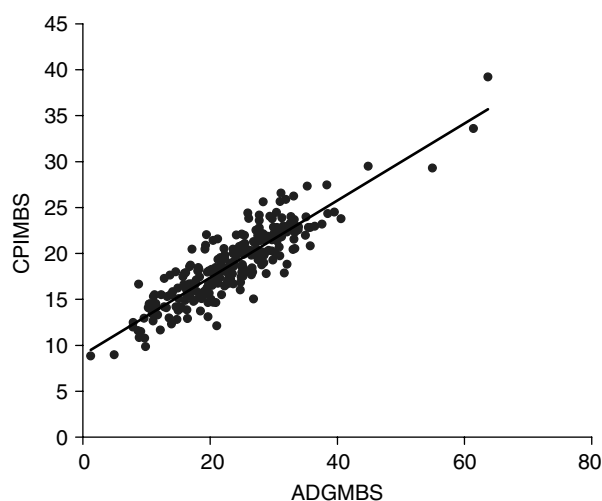

Figure 2 Plot of adjusted crude protein intake in g per kg metabolic body size (CPIMBS) on average daily gain in g per kg metabolic body size (ADGMBS) and the mean regression line across studies ($y = 0.42x + 8.9707$; $R^2 = 0.7902$).

CP per g ADG. The prediction equations accounted for 67 to 93% of the variations in observed CP intake. The distribution of adjusted DEIMBS and ADGMBS values in conjunction with mean regression line across studies has been depicted in Figure 2. A strong relationship existed (Figure 2) between CPIMBS and ADGMBS ($R^2 = 0.79$), and observations within study are highly predictable. The prediction errors (CV) were in the range of 10.76 to 14.89% of actual mean intake and the overall prediction error of CP intake were of the order of 11.13% of the actual mean intake, which indicated good accuracy of prediction across the database. The prediction equations were used for development of feeding standards for CP requirement (Table 5) based on average feed intake and growth rate observed in the database.

Amino acid requirements
The regression equations developed for the prediction of amino acid requirements (Table 4) had high ($P < 0.001$) significance level of the parameters estimated and high R^2 values. The models had low variance of error estimates (σ_2^{error}) and their standard errors, low CV and low BIC.

The estimated maintenance requirements of lysine were in the range of 0.431 to 0.664 g per kg $M^{0.75}$ for different BW ranges and the estimate from the whole database was 0.394 g per kg $M^{0.75}$. The estimated requirements for gains were in the range of 0.0071 to 0.0101 g per g ADG for different BW ranges and the estimate from the whole database was 0.01 257 g lysine per g ADG.

The estimated methionine requirements ranged from 0.265 to 0.458 g per kg $M^{0.75}$ for different BW ranges. The estimated values for gain were 0.0065 to 0.0124 g per g ADG for different BW ranges.

The estimated maintenance requirements of methionine + cystine were 0.327 to 0.466 g per kg $M^{0.75}$ for different BWs. The estimated requirements for live-weight gains were 0.0151 to 0.0261 g/g ADG for different BW ranges.

Cystine requirements were estimated for maintenance as 0.055 to 0.184 g per kg $M^{0.75}$ for different BW ranges. The requirements were in the range of 0.0043 to 0.0094 g per g ADG for different BW ranges.

Threonine requirements for maintenance were estimated as 0.205 to 0.511 g per kg $M^{0.75}$ for different BW ranges. The values of threonine requirements for live-weight gains were 0.0052 to 0.0165 g per g ADG for different BW ranges.

The estimated arginine requirements for maintenance ranged from 0.377 to 1.21 g per kg $M^{0.75}$ for different BW range. The estimated requirements for gain were in the range of 0.0045 to 0.0301 g arginine per g ADG for different BW ranges.

The estimated isoleucine requirements for maintenance were 0.241 to 0.775 g per kg $M^{0.75}$ for different BW ranges. The requirements for gains ranged from 0.0023 to 0.0198 g per g ADG for different BW ranges.

The estimated maintenance requirements of leucine were in the range of 0.604 to 1.54 g per kg $M^{0.75}$ for different BW ranges. The estimated requirements for live-weight gains were in the range of 0.0150 to 0.0447 g per g ADG for different BW ranges.

The phenylalanine + tyrosine requirements for maintenance were 0.496 to 1.33 g per kg $M^{0.75}$ for different BW ranges. For live-weight gains, the values emerged as 0.0091 to 0.0382 g per g ADG for different BW ranges.

The maintenance requirements of tryptophan were predicted as 0.078 to 0.213 g per kg $M^{0.75}$ for different BW ranges. Those for gains were 0.0005 to 0.0044 g per g ADG for different BW ranges.

Valine requirements were estimated 0.330 to 0.892 g per kg $M^{0.75}$ for different BW ranges. The values for gains were 0.0061 to 0.0222 g per g ADG for different BW ranges.

The prediction equations were used for development of feeding standards for amino acid requirements and

Table 4 *Parameter estimates obtained using regression model[†] for partitioning of amino acid intakes for maintenance (a, g per kg M[0.75]) and growth (b, g/g gain)[‡]*

BW range (kg)	Nutrient	a	b	σ^2_{error}	BIC	$R^{2§}$	CV (%)
7−20	Lysine	0.568 ± 0.057	0.0071 ± 0.0024	0.00 987 ± 0.00 312	− 16.80	0.829	13.52
	Methionine	0.265 ± 0.032	0.0124 ± 0.0047	0.00 359 ± 0.00 114	− 29.33	0.956	15.26
	Methionine + cystine	0.392 ± 0.037	0.0188 ± 0.0053	0.00 467 ± 0.00 148	− 22.76	0.969	10.31
	Cystine	0.128 ± 0.038	0.0066 ± 0.0010	0.00 350 ± 0.00 112	− 46.05	0.859	21.86
	Threonine	0.205 ± 0.065	0.0165 ± 0.0014	0.00 383 ± 0.00 267	2.95	0.992	8.14
	Arginine	0.377 ± 0.087	0.0301 ± 0.0047	0.08 632 ± 0.05 788	18.14	0.982	21.61
	Isoleucine	0.241 ± 0.081	0.0198 ± 0.0031	0.00 955 ± 0.00 600	10.82	0.972	10.78
	Leucine	0.862 ± 0.159	0.0366 ± 0.0106	0.01 614 ± 0.01 214	14.3	0.996	5.71
	Phenylalanine + tyrosine	0.496 ± 0.113	0.0382 ± 0.0029	0.03 261 ± 0.01 962	15.69	0.991	10.35
	Tryptophan	0.104 ± 0.041	0.0034 ± 0.0012	0.00 108 ± 0.00 063	− 2.07	0.857	15.12
	Valine	0.330 ± 0.072	0.0222 ± 0.0018	0.01 320 ± 0.00 769	11.26	0.990	10.87
20−35	Lysine	0.567 ± 0.055	0.0101 ± 0.0017	0.00 338 ± 0.00 083	− 69.81	0.808	7.47
	Methionine	0.327 ± 0.076	0.0077 ± 0.0023	0.00 251 ± 0.00 084	− 42.15	0.960	10.35
	Methionine + cystine	0.455 ± 0.082	0.0151 ± 0.0030	0.00 373 ± 0.00 104	− 50.1	0.952	8.11
	Cystine	0.184 ± 0.024	0.0043 ± 0.0007	0.00 058 ± 0.00 013	− 194.32	0.922	8.44
	Arginine	0.568 ± 0.211	0.0279 ± 0.0069	0.01 981 ± 0.00 706	6.99	0.863	10.91
	Threonine	0.302 ± 0.085	0.0132 ± 0.0029	0.00 349 ± 0.00 098	− 60.18	0.899	9.52
	Isoleucine	0.416 ± 0.123	0.0131 ± 0.0038	0.00 539 ± 0.00 166	− 26.9	0.829	9.72
	Leucine	0.929 ± 0.136	0.0299 ± 0.0054	0.01 577 ± 0.00 454	− .0175	0.870	5.64
	Phenylalanine + tyrosine	0.689 ± 0.170	0.0301 ± 0.0060	0.02 479 ± 0.00 662	1.997	0.811	10.77
	Tryptophan	0.078 ± 0.029	0.0044 ± 0.0010	0.00 052 ± 0.00 017	− 110.9	0.988	12.00
	Valine	0.368 ± 0.119	0.0205 ± 0.0040	0.01 037 ± 0.00 331	− 21.9	0.838	11.27
35−60	Lysine	0.664 ± 0.056	0.0075 ± 0.0021	0.00 637 ± 0.00 119	− 100.17	0.501	10.19
	Methionine	0.438 ± 0.089	0.0047 ± 0.0014	0.00 159 ± 0.00 033	− 141.49	0.501	10.19
	Methionine + cystine	0.466 ± 0.089	0.0161 ± 0.0027	0.00 541 ± 0.00 110	− 93.82	0.968	11.83
	Cystine	0.055 ± 0.023	0.0094 ± 0.0013	0.00 099 ± 0.00 017	− 228.82	0.953	11.28
	Threonine	0.511 ± 0.052	0.0052 ± 0.0018	0.00 232 ± 0.00 095	− 37.9	0.857	13.45
	Arginine	1.21 ± 0.129	0.0045 ± 0.0017	0.01 301 ± 0.00 550	− 4.18	0.589	8.55
	Isoleucine	0.775 ± 0.046	0.0023 ± 0.0017	0.00 435 ± 0.00 138	− 10.16	0.758	7.89
	Leucine	1.54 ± 0.240	0.0150 ± 0.0084	0.02 793 ± 0.00 974	10.79	0.758	8.50
	Phenylalanine + tyrosine	1.33 ± 0.243	0.0091 ± 0.0014	0.01 570 ± 0.0052	2.265	0.695	7.66
	Tryptophan	0.213 ± 0.017	0.0005 ± 0.00 006	0.00 048 ± 0.00 019	− 64.49	0.650	9.71
	Valine	0.892 ± 0.170	0.0061 ± 0.0039	0.00 734 ± 0.00 252	− 21.72	0.769	7.63
60−128	Lysine	0.431 ± 0.117	0.0096 ± 0.0053	0.00 799 ± 0.00 319	− 14.03	0.828	13.88
	Methionine	0.458 ± 0.089	0.0065 ± 0.0025	0.00 784 ± 0.00 460	− 11.87	0.836	14.66
	Methionine + cystine	0.327 ± 0.159	0.026 ± 0.0070	0.00 992 ± 0.00 373	− 4.27	0.928	11.88
	Cystine	0.148 ± 0.055	0.0065 ± 0.0025	0.00 075 ± 0.00 028	− 48.9	0.883	9.99
	Threonine	0.326 ± 0.088	0.0120 ± 0.0039	0.00 482 ± 0.00 201	− 23.38	0.845	11.94
	Arginine	0.896 ± 0.463	0.0065 ± 0.0174	0.00 443 ± 0.0.00 193	26.58	0.856	19.77
	Isoleucine	0.406 ± 0.090	0.0115 ± 0.0040	0.01 060 ± 0.0037	− 1.69	0.780	15.87
	Leucine	0.604 ± 0.154	0.0447 ± 0.0069	0.04 225 ± 0.014900	15.38	0.781	13.19
	Phenylalanine + tyrosine	0.496 ± 0.113	0.0382 ± 0.0028	0.03 261 ± 0.01 962	15.69	0.991	10.34
	Tryptophan	0.110 ± 0.033	0.0026 ± 0.0017	0.00 099 ± 0.00 032	− 39.7	0.837	19.26
	Valine	0.653 ± 0.245	0.0074 ± 0.0019	0.001158 ± 0.00 500	0.492	0.852	13.27
Overall (7−128)	Lysine	0.394 ± 0.0517	0.0126 ± 0.0013	0.00 647 ± 0.000783	− 285.7	0.703	10.67
	Methionine	0.266 ± 0.0277	0.0133 ± 0.00 173	0.00 239 ± 0.000339	− 295.0	0.947	11.69
	Methionine + cystine	0.366 ± 0.0244	0.02 244 ± 0.00 224	0.0058 ± 0.000721	− 234.7	0.926	10.68
	Cystine	0.129 ± 0.009	0.0067 ± 0.00 054	0.001526 ± 0.00 018	− 580.28	0.838	14.97
	Threonine	0.321 ± 0.0222	0.0126 ± 0.00 088	0.003389 ± 0.000505	− 100.05	0.915	13.15
	Arginine	0.531 ± 0.1032	0.0290 ± 0.0028	0.0286 ± 0.00 528	12.67	0.842	13.53
	Isoleucine	0.401 ± 0.0707	0.01 418 ± 0.0022	0.00 628 ± 0.001104	− 126.48	0.862	10.33
	Leucine	0.903 ± 0.0798	0.03 365 ± 0.00 376	0.02 797 ± 0.004987	7.32	0.913	9.32
	Phenylalanine + tyrosine	0.662 ± 0.0777	0.0345 ± 0.00 371	0.02 545 ± 0.00 409	− 0.329	0.874	10.59
	Tryptophan	0.117 ± 0.022	0.00 310 ± 0.00 074	0.000656 ± 0.00 012	− 280.25	0.831	9.71
	Valine	0.424 ± 0.062	0.0208 ± 0.0020	0.00 956 ± 0.00 001	− 88.01	0.881	10.44

[†] Model: intake/MBW = a + b(ADG/MBW); analysed using mixed model method considering study effect and its interaction effects as random. (Each observation is mean of observations on at least four animals.)
[‡] Abbreviations used: BW, body weight; BIC, Schwarz's Bayesian Information Criteria; σ^{error}_2 = variance of error estimate.
[§] Coefficient of determination constructed for the mixed effects model.

Table 5 *Daily nutrient requirements of growing pigs allowed feed ad libitum[†]*

	Body weight (kg)			
	7–20	20–35	35–60	60–127
Average weight in the range (kg)	13.8	30.0	47.2	66.9
ADG (g/day)	185	331	375	468
Average feed intake (DM, g/day)	755	1392	1892	2349
Estimated DE requirement (kJ/day)	2330	4296	5572	7475
Estimated CP requirement (g/day)	155	250	294	369
	Estimated amino acid (total basis) requirements						
	g/day	% of lys	g/day	% of lys	g/day	% of lys	g/day	% of lys
Lysine	5.37	100	10.61	100	14.76	100	14.57	100
Methionine	4.18	78	6.72	63	9.64	65	13.75	94
Methionine + cystine	6.28	117	8.63	81	14.43	98	19.82	136
Cystine	2.13	40	3.78	36	4.50	31	6.50	45
Threonine	4.52	84	8.24	78	11.15	76	13.24	91
Arginine	8.24	153	16.53	156	23.47	159	24.00	165
Isoleucine	5.38	100	9.66	91	14.82	100	14.87	102
Leucine	12.94	240	21.80	205	33.35	226	35.04	240
Phenylalanine + tyrosine	10.62	198	18.79	177	27.36	185	29.48	202
Tryptophan	1.36	25	2.45	23	4.03	27	3.78	26
Valine	6.46	120	11.50	108	18.35	124	18.73	60

[†] Abbreviations used: ADG, average daily gain; DM, dry matter; DE, digestible energy; CP, crude protein.

required dietary concentration of amino acids were worked out for growing pigs with expected BW, feed intake and growth rate similar to those of the average values observed in the database (Table 5).

Discussion

The estimated DE requirements for maintenance at different BWs (516 to 702 kJ/kg $M^{0.75}$) are higher than the value (460 kJ/kg $M^{0.75}$) adopted in the feeding standards of NRC (1998). The estimates of DE requirements for maintenance of pigs as reported in the literature across the world vary from 402 to 699 kJ/kg $M^{0.75}$ with most of the values falling between 435 to 544 kJ/kg $M^{0.75}$ (Whittemore, 1976; Bohme et al., 1980; Wenk et al., 1980; Agricultural Research Council, 1981; Noblet and Le Dividich, 1982; Campbell and Dunkin, 1983; Close and Stanier, 1984; McNutt and Ewan, 1984; Gadeken et al., 1985; Noblet et al., 1985). Hence, estimates of maintenance requirements obtained in the present study were in general agreement with previous reports. The estimated DE requirements for maintenance at 60 to 128 kg were lower than the values at 35 to 60 kg BW. This is probably because of the fact that at higher (> 50 kg) BWs inherited upper limit of protein retention of individual pig determines response of energy on growth rather than the amount of energy intake as observed in lower BWs (Schinchel and De Lange, 1996). Hence at higher BWs standard error of estimated parameter increases and predictability reduces. However, the estimate is within range of values reported for pigs of such weight range.

The energy requirements in the present study were estimated to be 32, 34.3, 28.6 and 38.6 kJ DE per g ADG for 7 to 20, 20 to 35, 35 to 60 and 60 to 128 kg BW, respectively (Table 3). No report on energy requirement of Indian pigs for growth could be traced hence direct comparison is not possible, however the values are slightly higher than the values reported for Indian sheep (Paul et al., 2003b) and goats (Mandal et al., 2005). Higher requirements of energy for gain at finishing stage is probably due to accumulation of more body fat over muscle tissue. NRC (1998) has also reported higher values for finishing period.

The estimates of requirement of CP for maintenance emanated from present database were 11.62, 11.52, 10.68 and 6.98 g/kg $M^{0.75}$ for the corresponding BWs. The CP requirements for 1 g ADG were estimated to be 0.39, 0.31, 0.27 and 0.44 g in the present study (Table 3).

Reports on partitioning of nutrient requirements for maintenance and growth of Indian pigs are scanty because most of the workers estimated requirements for maintenance and production together and expressed requirements in term of dietary concentration of nutrients. The existing Indian feeding standards (ICAR, 1998) do not give separate requirements for maintenance and gain but rather give total requirements. Most of the Indian workers fed pigs on a range of diets varying in energy and protein content, and the energy or protein level supporting highest growth rate and feed conversion efficiency was considered to be optimum requirements.

The estimates of dietary requirement of total energy for maintenance and growth emanated from present database

were 12.91, 12.91, 12.32 and 13.31 MJ DE per kg diet for 7 to 20, 20 to 35, 35 to 60 and 60 to 127 kg BW, respectively. The estimates are in agreement with the report of Dhudapker *et al.* (1971) who reported that growing Middle White Yorkshire pigs require 12.76 MJ DE per kg diet under Indian condition. Our estimates differ substantially from the values of energy requirement suggested by ICAR (1998): 13.81, 12.43, 11.04 and 11.04 MJ/kg DE for 10 to 20, 20 to 30, 35 to 60 and 60 to 90 kg BW, respectively. Our estimates also differ substantially from those of Sharda and Sagar (1986) who reported that Middle White Yorkshire pigs require 14.64 MJ DE per kg diet, 12.43 MJ DE per kg diet, 11.04 MJ DE per kg diet and 11.04 MJ DE/kg diet from 10 to 20 kg, 20 to 35 kg, 35 to 60 kg and 60 to 75 kg, respectively under Indian condition. Reddy *et al.* (1981) reported that Large White Yorkshire pigs weighing 20 to 35 kg under Indian conditions require 13.80 MJ DE per kg diet. Present estimates are lower than the requirement of 14.22 MJ DE per kg diet recommended by NRC (1998) for growing pigs irrespective of BWs.

The estimates of dietary requirement of total CP for maintenance and growth emanated from present database were 20.6, 18.0, 15.5 and 15.7% in diet for 7 to 20, 20 to 35, 35 to 60 and 60 to 127 kg BW, respectively. Our estima**t**es are higher than the values recommended by ICAR (1998) feeding standards: 18, 15, 13 and 12% CP for 10 to 20 kg, 20 to 35 kg, 35 to 60 kg and 60 to 75 kg, respectively. Earlier, Sharda and Sagar (1986) reported that Middle White Yorkshire pigs require 18.0, 14.4, 11.2 and 10.8% CP in diet for 10 to 20 kg, 20 to 35 kg, 35 to 60 kg and 60 to 75 kg, respectively. Dhudapker *et al.* (1971) reported that growing Middle White Yorkshire pigs require 18% CP in diet. Reddy *et al.* (1982) reported that Large White Yorkshire pigs weighing 20 to 35 kg under Indian conditions require 18% CP. Sharda *et al.* (1982a) reported that crossbred pigs (Middle White Yorkshire × Indian non-descript) between 14 and 52 kg BW require 16% CP in growing phase (14 to 25 kg BW) and 14% in finishing phase (25 to 71 kg BW) for optimum growth and feed efficiency but for producing leaner carcasses pigs needed 18% CP in growing phase and 16% CP in finishing phase. Present estimates are slightly higher than these reports. However, present estimates are comparable with the values recommended by NRC (1998) feeding standards: 20.9, 18, 15.5 and 13.2% CP for 10 to 20, 20 to 50, 50 to 80 and 80 to 120 kg BWs, respectively.

Information on amino acid requirements of Indian pigs is scanty. ICAR (1998) standards did not give requirements for amino acids. Sharda *et al.* (1982a) observed that ADG of pigs fed 18% CP (with 0.71% lysine) and 16% CP (with 0.63% lysine) was similar but higher than those fed 14% CP with 0.54% lysine indicating that lysine requirement during growth phase may be 0.63%. Present estimates of dietary lysine requirement if expressed as % in diet are slightly higher than this report. Apportioning of lysine requirement for maintenance and growth indicated that maintenance requirements range from 0.431 to 0.664 g/kg

$M^{0.75}$ and growth requirements range from 0.0071 to 0.0101 g/g ADG. Our estimate of Lys requirements for maintenance is higher than the value reported by Fuller *et al.* (1989) of 0.036 g per kg $M^{0.75}$. This difference can probably be attributed to following facts. Amino acid requirements are known to be dependent on genotype (e.g. animal's inherited upper limit to protein retention), environmental condition (stressors limit response to dietary nutrients), gastro-intestinal (GI) health (degree of sloughing of GI tract mucosa), and dietary situation (content of other amino acids, non-protein N, energy, interaction of energy and amino acids, fibre, digestibility of amino acids, etc.) and nutritional history of the animal. More importantly, methodological differences could be an important source of variance. Fuller *et al.* (1989) have estimated amino acid requirements based on N balance on metabolism trial employing graded amino acid levels and protein (at near or below maintenance level of N in the diet employing deletion method) in the synthetic (fibre-free) diet and N balance was used as response criteria. The amounts of amino acid needed to maintain the animal in N equilibrium were taken as maintenance requirement. The difficulty with this concept is that adult animals can adjust N output and reach equilibrium, particularly at lower levels of N/amino acid intake. Thus, N equilibrium as an indicator of adequate protein/amino acid intake is of questionable value (NRC, 1981). As endogenous secretions of amino acids rise with increase in dietary fibre and protein, measurements of maintenance requirements with synthetic or depleted diets are likely to be lower than those obtained with high fibrous or normal practical diets (Whittemore *et al.*, 2001). The estimate of Fuller *et al.* (1989) indicate theoretical minimum requirement for maintenance of N equilibrium under hypothetical situation i.e. when the animal is not gaining/loosing weight. Optimum nutrition of maintaining producing animals calls for a higher intake than the minimum required for maintaining N equilibrium as producing animals maintained under farm condition have more intense metabolism and protein turnover, than those under balance trial or under maintenance plane of nutrition (McDonald *et al.*, 1995). Thus, the maintenance requirements as estimated in our study by regression of growth *v.* BW and ADG data (using weight gain as response criteria instead of N balance) in producing animals maintained under farm condition (high environmental stress) and practical diet (high fibre/protein diet and diets containing unconventional feeds/agro industrial by products) is expected to be higher than the estimate derived by Fuller *et al.* (1989). Information on partitioning of lysine requirements of growing pigs for maintenance and growth are scanty. Most of the studies on nutrient requirements of growing pigs have studies combined requirements for maintenance and growth and studied optimum dietary level of lysine for optimum growth. Yang *et al.* (1997a) on regression analysis of intake *v.* growth in feeding trial, reported that growing pigs require upto 0.115 g lys per kg $M^{0.75}$ for maintenance which is also much higher than the

report of Fuller *et al.* (1989) but lower than our estimates. No report on lysine requirements for maintenance of growing pigs under Indian condition is available for comparison with our reports. Our estimates on total lysine requirements (for maintenance as well as gain) when expressed as % requirement in diet is comparable to most of the reports on growing pigs as reviewed by NRC (1998) for pigs of similar weight. The present estimates of growth requirements are lower than the estimates (0.018 to 0.01 943 g/g ADG) of Yang *et al.* (1997a). The lysine requirements for growing pigs suggested by NRC (1998) were 1.35, 1.15, 0.95, 0.75 and 0.60% for 5 to 10, 10 to 20, 20 to 50, 50 to 80 and 80 to 120 kg of live weight, respectively. Our estimates (when expressed as % of diet) for 35 to 60 and 60 to 120 kg BW were comparable to NRC (1998) values but estimates for 7 to 20 kg and 20 to 35 kg BW were slightly lower. The absolute lysine requirement values emanating from present study (Table 5) seem to be higher considering low lean growth rates. This can probably be attributed to the difference in genotype, diet and environment of the pigs causing less efficient absorption/utilisation of amino acids or by limiting response to nutrients leading to relatively higher maintenance requirements under tropical conditions

It has been shown that expression of amino acid requirements in terms of true digestible amino acid is better than in term of dietary total amino acid as digestibility of amino acid can vary with nature of ingredients. However, none of the reports analysed digestibility of amino acids probably because of difficulty in experimental methods required to estimate true amino acid digestibility. Hence, in the present study amino acid requirements have been derived and presented in term of total amino acid. Further, still today total amino acid values are used widely around the world including in India and good correlation was observed between dietary amino acid intake and performance of pigs across the database. This provides support to the fact that even if, requirement of dietary amino acid requirement is considered while formulating ration (until data are accrued on requirement of digestible amino acids), there will be increase in performance and improvement in economics of pig rearing.

The methionine + cystine requirements for growing pigs suggested by NRC (1998) were 0.76, 0.65, 0.54, 0.44 and 0.35% for 5 to 10, 10 to 20, 20 to 50, 50 to 80 and 80 to 120 kg of live weight, respectively. The present estimates of dietary methionine + cystine requirements (when expressed as % of diet) were comparable with NRC (1998) values at lower BWs but were higher than NRC (1998) at higher BWs.

For other amino acids also, our estimates were comparable with NRC values at lower BWs but higher at higher BWs. No Indian data are available for comparison.

Conclusion

The present study provides estimates of nutrient requirements of growing Indian pigs reared under normal farm feeding conditions based on regression analysis of intake *versus* performance values reported from different feeding trials conducted across India involving different breeds under wide dietary and climatic situations. Based on criteria of variance of error estimate (σ_2^{error}) and its standard error, CV of the model, BIC, significance level of the parameters estimated and R^2 values, prediction equations developed in the present study were valid and adequately accurate for predicting requirements under diverse conditions. These results suggest that the nutrient requirements derived in the present study can be used as a guide for feeding growing Indian pigs under diverse conditions prevailing in India. Utilisation of these requirements may result in the following benefits to the Indian pig industry: (1) increase in efficiency of nutrient utilization, (2) lowered feed costs, and (3) optimum weight gains with lowered stress on growing goats. However, the requirements presented here should be updated and refined further as more feeding trial data are generated on nutrient intake and production performance under different dietary and environmental situations.

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