ADVANCES IN NUTRIENT ALLOWANCES FOR MAXIMUM LEAN GROWTH IN PIGS

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SUMMARY

Genetic selection for growth rate, feed efficiency, and lean meat content has resulted in the necessity of, and financial benefit from, feeding higher levels of better quality diets to genetically improved pigs. Independent of the presence of disease and inadequate management, productive rate can be limited below genetic and nutritional potential by environmental effects; especially ambient temperature and density of stocking. This paper attempts quantitative description of the relationships involved in these aspects of pig nutrition.

DESCRIPTION OF PROTEIN GROWTH

The potential daily rate of protein accretion ($\hat{Pr}$) may be described (Whittemore et al. 1988) as $B.Pt.\log_e(\hat{Pt}/Pt)$ where $\hat{Pt}$ is protein weight at maturity, Pt is current protein weight, and B is the growth rate parameter. Protein weight at time t (Pt) is $\hat{Pt}.\exp(-\exp(-B(t-t^*)))$. The point of inflection occurs at t^* days, and $(\hat{Pt}.B)/e$ is the maximum growth rate. Values for $\hat{Pt}$ appear to be 40-45kg for improved hybrid pigs, while B (the growth rate parameter) is in the region of 0.010, or possibly higher.

Selection for increased rates for $\hat{Pr}$ will increase $\hat{Pt}$ ($\hat{Pt} \triangleq 300\hat{Pr}$) and the sigmoid growth curve, when moving to the left consequent upon a steepening of the weight/time slope, will inevitably also increase in the ultimate value for weight. The value for time at maturity will not increase at the same rate as the value for weight at maturity. The use of a Gompertz function does not materially alter the view that over the usual range of nutrient unlimited growth in-slaughter pigs (30-90kg live weight) a single value for Pr can be an adequate working descriptor. Current estimates of $\hat{Pr}$ are probably in the ranges of 120-140, 140-160, and 160-180g respectively for castrated males, females and entire males of improved genotypes. Great grandparent stocks in nucleus breeding herds will have protein deposition rates in excess of these. The Gompertz function is, however, a better description than a single working value for it deals more effectively with

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protein deposition at higher live weights. This is especially important now that improved genotypes may have a greater mature size and therefore be used more efficiently at increasingly higher slaughter weights.

FEED INTAKE

Whittemore et al (1988), using the form, Maximum fresh feed intake (kg) = a + b x Age(days), suggest, for pigs between 21 and 140 days of age, respective b and a values of 0.033d and -0.486 for entire males, 0.029 and -0.263 for females, 0.035 and -0.396 for castrated males. Replacing Age by Live Weight (W,kg), for pigs growing between 5 and 85g live weight, respective b and a values were 0.046 and 0.347 for entire males, 0.043 and 0.411 for females, 0.048 and 0.416 for castrated males. It is usual for the feed intake of castrated males to be 10-15% greater than that for entire males and females. Subsequent to around about 90kg live weight and 150 days of age, the previous shown linear response appears to reach a plateau around which food intake oscillates. The average height of this plateau was reported as 4.0kg for entire males, 3.6kg for females, and 3.8kg for castrated males. During the linear phase of feed intake response to increase in age or live weight, achieved maximum feed intakes were rather higher than the $3.0W^{0.63}$MJ digestible energy (DE) proposed (amongst others) by ARC (1981); but rather similar to $0.14W^{0.75}$kg feed, although of different shape.

INFLUENCE OF TEMPERATURE ON FOOD INTAKE

A major factor limiting attained food intake is environmental temperature; or, more correctly, the extent to which the ambient temperature (T) is above the critical temperature (Tc). Critical temperature may be estimated as; Tc = 27 - 0.6H. This is proposed as appropriate for pigs of 10kg or more, where H measures the heat output (MJ) leaving the body in consequence of the total of the metabolic processes. With increasing growth rate, or maintenance requirement consequent upon greater body size, the value of H will rise and Tc consequently fall.

Newly weaned pigs of 5-8kg live weight have a particular demand for a warm environment. This is not only because they are small; after weaning young pigs grow slowly and heat output is restricted to being little over maintenance. As a rough approximation, for every 100g per day of extra growth the critical temperature of young growing pigs is reduced by about 1°C. A 5kg pig will lose into the environment around 2MJ of heat per day at zero growth, 3.5MJ per day when growing at 200g daily, and about

5MJ per day when growing at 400g daily. One 5kg pig growing at 400g per day will create more heat than two 5kg pigs growing at 50g per day. The ambient temperature of rooms for the reception of newly weaned 5-8kg pigs should be about 28-30°C. As growth rate picks up following the post-weaning trauma, the ambient temperature can be progressively reduced. Pigs weighing 20kg and growing rapidly at rates approaching 1kg per day are likely to be comfortable at around 18°c, and not above. The negative relationship between environmental temperature in excess of the critical temperature and feed intake will cause appetite reduction in young growing pigs, and consequent deterioration in feed conversion efficiency, growth rate, and ease of management.

In a study of North American pigs, Smith et al (1988) measured the daily feed intake of pigs between 26 and 108kg as, Daily feed intake (kg) = $0.404W^{0.46}$. Given prevailing ambient temperatures,ranging from 4-29°C under commercial conditions, these authors estimated the negative effect of temperature upon feed intake to be, Daily feed intake (kg/W(kg)) = 0.047 - 0.0007(T-Tc). In this study (T-Tc) ranged from -14°C to +16°C. The equation suggests that for each °c above the critical temperature food intake is reduced by about 0.7g per kg pig live weight. Equivalent values of 1.0g per kg live weight per °c above critical temperature can be interpolated from the data of Nichols et al (1980). These values are a little lower than the 2.5% reduction per °c proposed by Close and Mount (1978). A working value of 1g voluntary feed intake reduction per °c above critical temperature per kg of pig live weight appears to be reasonable (Hsia, personal communication).

The influence of excess environmental temperature upon voluntary feed intake and subsequent growth and efficiency in both young and growing and finishing pigs is considerable.

INFLUENCE OF STOCKING DENSITY UPON DAILY GAIN

Experience under commercial conditions consistently indicates a negative relationship between stocking density and growth rate in pigs. The relationship appears to be particularly strong in young and newly weaned pigs. Attempts to quantify this relationship under controlled conditions have often shown a weaker response than might have been expected from commercial experience. This is probably resultant from experimental conditions allowing the examination of stocking density alone, as a single factor; whereas under commercial conditions any stocking density effects would be likely to be exacerbated by associated factors such as incidence of disease.

Under research conditions the experiments of both Kornegay and Notter (1984), and of Edwards et al (1988), show a clear, positive relationship between space allowance in the fattening pen and pig growth rate. Space allowance may be satisfactorily expressed as a function of $Weight^{0.67}$. Where area (m^2) per pig equals $kW^{0.67}$, if k = 0.018 there is only sufficient space for the pig to lie on its sternum, if k = 0.025 there is sufficient space for the pig to lie in a normal recumbent position. Minimum space allowances for pigs housed on fully slatted floors usually approximate to the lying space plus 25%; in total giving k=0.031.

Edwards et al (1988) measured the growth rate of pigs on fully slatted floors from 25-85kg. From their data may be interpolated response to increasing space allowance in the form $M = ak^b$, where M is the multiple of the weight gain achieved in comparison to k = 0.025, and where a = 1.89 and b = 0.173. This relationship is likely to be effective over the range of k = 0.018 to k = 0.050. The stocking density that is consistent with optimum economic performance is unlikely to be that associated with maximum daily gain. Most authorities would estimate that for pigs housed on fully slatted floors optimum economic stocking density is likely to be within the range k = 0.027 to k = 0.035. But calculations of optima within this range may fail to take into account the additional benefits obtained from enhanced growth rates in newly weaned pigs in the weight range 5-20kg. Such benefits are the increased healthiness and vigour of rapidly growing newly weaned pigs kept at reduced stocking density, and more rapid throughput of pigs. The responses calculated from the work of Edwards et al (1988) are in accord with those from the review of Kornegay and Notter (1984).

GROWTH RESPONSES OF • GENETICALLY IMPROVED PIGS TO NUTRIENT SUPPLY

Genetic selection for lean tissue growth and against fatness has resulted in strains of improved hybrid slaughter-generation pigs with improved weight for age, a lower degree of maturity at slaughter, improved efficiency of feed use and enhanced lean meat content. Improved genotypes may be described in terms of their potential for the daily deposition of body protein ($\hat{Pr}$).

Dietary protein needs relate to the requirements for maintenance (m) and for protein retention (Pr). These are best expressed in terms of balanced amino acids or ideal protein (IP, ARC 1981). Total ideal protein (IP_t) may be calculated as; $IP_t(g/day) = D.CP.F.V.v$ where D is the ileal digestibility of CP, F is the feed intake, V is the biological value of the protein (i.e. the balance of the amino acids in dietary protein in comparison to the balance of amino acids in ideal protein) and v is the efficiency of transfer and retention into body tissue of ideal protein absorbed from the intestine. If $IP_m + IP_{Pr} = IP_t$, (IP_t can be estimated as 0.004Pt, where Pt is the total body protein mass), then $IP_{Pr} = IP_t - IP_m = Pr$, the daily rate of protein retention. This relationship will hold until $Pr = \hat{Pr}$, the plateau for genetic potential, when excess IP will be deaminated.

The concentration of dietary protein to be provided depends particularly upon the values D and V from the aspect of supply, and the value of $\hat{Pr}$ from the aspect of demand. The higher the value for $\hat{Pr}$ in consequence of the extent of genetic improvement, the higher will be the requirement for dietary IP.

Dietary DE concentration can be given from direct determination, or calculated from chemical components (as,for example, by use of the equation of Morgan et al (1987); DE (MJ/kg DM) = 17.5 - 0.015NDF + 0.016OIL + 0.008CP - 0.033ASH). DE supply (MJ/day) is n.DE.F, where n is the diet dry matter concentration.

Energy available to be metabolised (ME_t) may be partitioned to growth and retained in fat or lean tissues, or used for work. Energy for maintenance (E_m) is more likely to relate to the protein mass than the whole body, and $E_m = 1.85Pt^{0.78}$ has been proposed. Energy needed for protein deposition (E_{Pr}) comprises the energy retained in protein (23MJ/kg) and the work needed for protein accretion (estimates for which range from 10-45MJ, possibly dependent upon degree of maturity, total body protein mass, and rate of protein accretion, with an average value of about 21MJ/kg suggested by ARC).

Energy not being used for maintenance or protein growth will be partitioned to fatty tissue accretion (Lr). Energy retained in fat is around 39MJ/kg and the work required for fatty tissue accretion is about 14MJ/kg. Even when energy is inadequate for $E_m + E_{Pr}$ there is some minimum level of fatty tissue accretion essential to normal positive growth. This minimum, expressed as a proportion of the protein retention (Lr:Pr) seems to range between 1.2 and 0.4, depending upon sex and the extent of genetic improvement by selection against fatness. A further drain upon energy supply is that for cold thermogenesis; $0.12W^{0.75}(Tc-T)$, Tc being a function of heat output (H) as expressed -earlier.

At levels of amino acid (IP_t), and energy (ME_t) supply less than required for maintenance, maximum protein retention, essential fatty tissue growth and cold thermogenesis, lean growth potential will not be realised ($Pr<\hat{Pr}$) and efficiency of food use will be less than optimum. At levels of supply in excess of that required for these functions, the animal will fatten with detrimental consequences for carcass quality and efficiency of feed use. Animals of improved genotype with lower Lr:Pr ratios and higher values for $\hat{Pr}$ will require, and effectively utilise, enhanced levels of nutrient supply. Under ad libitum feeding conditions the rate of pig growth relative to the optimum will depend upon the balance between the genetic potential for lean tissue growth and the voluntary feed intake.

Guide diet specifications for genetically improved hybrid pigs are given in Table 1.

TABLE1 Guide diet specifications for genetically improved hybrid pigs*

	up to 15kg	up to 30kg	up to 100kg
Crude protein	220-270	220-250	180-220
Crude fat	50-120	50-100	20-70
Crude fibre	10-30	10-40	20-80
DE (MJ/kg)	15-17	14-16	13-15
Lysine**	14-18	13-16	10-13
Ca	11-15	11-10	8-10
P	9-11	9-10	6-8
Linoleic acid (approx)	20-50	10-50	6-20
Lysine (g/MJ DE)(approx)	1.0	1.0	0.80
DE:CP ratio (approx)	1:16	1:15	1:14

* Individual diets should vary according to the circumstances of the unit, the genetic quality of the pig, the number of different diets acceptable, and the economic cost/benefit. These diets are set to represent the higher levels of diet quality.

** Relative to lysine (1.00), the required proportions of essential amino acids are about: histidine 0.36; isoleucine 0.57; leucine 1.14; methionine + cystine 0.57; tyrosine + phenylalanine 1.00; threonine 0.64; tryptophan 0.14; valine 0.71.

ILEAL DIGESTIBLE (AVAILABLE) AMINO ACIDS

It is being suggested that diets should be compounded to ileal available amino acids rather than total amino acids. Compounding to ileal digestible amino acids can improve diet formulation accuracy and efficiency, but, as a general technique, it may be premature.

A diet made of known formulae of tried and trusted feed ingredients will, provided there is no unreasonable variation in nutrient content of an individual ingredient, result in a predictable and repeatable response in terms of growth rate and carcass quality for any given pig type. Such information is often sufficient knowledge for effective diet compounding. But analysis for crude protein (N x 6.25) allows freedom from fixed formula ingredients, while satisfying a given crude protein specification. Variable formulae may be used as relative prices of ingredients fluctuate; hence the development of least-cost diet formulation.

The growth and carcass quality responses of pigs to a wider range of feed ingredients show crude protein to be an unreliable predictor; the crude protein of some feed ingredients being more efficiently utilised than that of others. This is consequent upon differences; (i) in the digestibility of the crude protein, and (ii) in the amino acid composition of the crude protein. The digestibility of crude protein is a major determinant influencing variability in the response of pigs to diets of similar crude protein specification, and greatly added precision in feed formulation is achievable by specification on the basis of digestible crude protein (Table 2).

TABLE 2 Digestibility coefficients for crude protein in some pig feedstuffs.

	Crude protein (g/kg)	Digestibility of crude protein	Digestible crude protein (g/kg)
Fish meal	650	0.90-0.95	600
Ex soya bean meal	440	0.85-0.90	385
Barley meal	110	0.75-0.80	85
Rapeseed meal	360	0.50-0.70	216

Information on dietary essential amino acids increases the efficiency of diet formulation because account can be taken of feed ingredients of equal crude protein content having proteins of differing amino acid quality. For example, fish and soya protein have more lysine than barley or sunflower protein, while barley protein has more tryptophan than maize protein. Table 3 shows the lysine and threonine concentrations of some typical feed ingredients and exemplifies how, particularly in the case of lysine, protein qualities can differ.

TABLE 3 Total crude protein content of some pig feedstuffs, together with the concentrations of the essential dietary amino acids lysine and threonine in the protein.

	Crude protein in feed (g/kg feed)	Lysine in feed protein (g/kg protein)	Threonine in feed protein[1] (g/kg) protein)
Maize	90	27	38
Barley	110	32	35
Fish meal	650	74	46
Ex soya bean meal	440	62	42
Rapeseed meal	360	55	44
Ex groundnut	500	36	26

[1] The range of threonine concentrations in protein is narrower than the range of lysine concentrations.

That the pig industry should have managed for so long with diet specifications and feed ingredient analysis based on crude protein and total lysine alone is at first sight surprising until it is realised that protein supplements have tended to come from a highly conservative range; fish, soya and wheat by-products. Protein supplements with lower digestibility values, or with particularly poor amino acid balance, were simply considered as inappropriate for pig diets. With a conservative range of feed ingredients in the diet formulation, digestible crude protein in the diet is a constant proportion of the crude protein, and the amino acid balance of the final diet is satisfactory once any shortfall in lysine (the first limiting amino acid) has been made good.

The term "digestibility" as used in digestible crude protein refers to the crude protein disappearing between ingestion and faecal excretion. Values for digestibility of crude protein at the terminal ileum are usually about 8% lower than faecal digestibilities (over 43 feedstuffs, Ileal digestibility of crude protein = 0.92 (±0.08) Faecal digestibility of crude protein). If this relationship were to be constant, no greater precision would be achieved by using ileal rather than faecal digestibility values, but it is not constant and varies between feed ingredients (Tables 4 and 5).

TABLE 4 Ratio of ileal digestible. amino acid: ileal digestible crude protein (average of 43 feedstuffs)[1]

	Ileal digestible amino acid / Ileal digestible crude protein
Isoleucine	1.06
Lysine	1.02
Methionine	1.20
Threonine	0.95
Tryptophan	0.95

[1] Methionine is almost twice as variable for this character as the other amino acids. In the case of maize the ratios for lysine, threonine and tryptophan are 0.88, 0.94 and 0.92. For feather meal the ratio for lysine is 0.72.

TABLE 5 Ileal digestibility of some amino acids in some feedstuffs (values mostly from few measurements only)

	Protein[1]	Lysine	Methionine	Threonine	Tryptophan
Barley	70-80	70-80	75-85	65-75	70-80
Wheat	70-80	70-80	75-85	65-75	70-80
Maize	70-80	70-80	75-85	65-75	70-80
Wheat middlings	40-65	40-70	30-50	40-50	50-60
Maize gluten feed	40-60	50-60	57-70	40-55	30-40
Ex soya bean meal	75-85	80-90	80-90	75-80	75-80
Rapeseed meal	40-60	50-70	60-80	50-70	50-70
Meat & bone meal	40-70	50-70	60-80	50-65	40-60
Fish meal	80-90	85-95	85-95	75-85	70-75

[1] In general ileal digestibility of crude protein is about 8% lower than faecal digestibility of crude protein. Interesting exceptions are rapeseed meal (12% lower), corn gluten feed and corn gluten meal (16% lower), wheat middlings (17% lower), and meat and bone meal (14% lower).

The available amino acids system only increases the accuracy of precision of feeding if correct values exist for feed ingredients as used in each diet formulation at the time formulated. Where each of the factors in a reducing chain, from crude protein through to available amino acids, requires to be characterised by a fixed value, then no increase in precision can result from the reductionism. In such circumstances the available amino acid system merely represents a device with the (false) appearance of technological advance. Only if the links in the chain are variable, and only if the extent of the variation is known and only if dependable values are available to describe that variation, will reducing crude protein to available amino acids improve the precision of pig feeding.

There remain the twin problems: (i) difficulties in the identification of target nutrient demand for the daily supply of available amino acids, and thereby difficulties in the definition of a diet supply specification, and (ii) lack of accurate documented measurements of available amino acids for many feedstuffs, and variation between measurements made thus far for many feed ingredients. However, feed compounders are developing methodologies for estimating available amino acids for pigs from assays using other, more convenient, species. Whilst in vivo studies with live pigs cannulated at the terminal ileum will remain the datum for the measurement of available amino acids in feedstuffs, 'more rapid predictors for available amino acids, including chemical analysis, will come forward. It is also reasonable to assume that variation between batches of known feedstuffs in their available amino acid content will be predicted by simple linkages to readily analysable total crude protein and total amino acid content.

REFERENCES

ARC. (1981). "The Nutrient Requirements of Pigs? CAB, Farnham Royal, England.

CLOSE, W.M. and MOUNT, L.E. (1978). Br. J. Nutr. 40:413.

EDWARDS, S.A., ARMSBY, A.W. and SPECHTER, H.H. (1988). Anim, Prod. 46:453.

KORNEGAY, E.T. and NOTTER, D.R. (1984). Pig News and Information 5:23.

MORGAN, C.A., WHITTEMORE, C.T., PHILLIPS, P. and CROOKS, P. (1987). Anim. Feed Sci. Technol. 17:81.

NICHOLS, D.A., AMES, D.R. and HINES, R.M. (1980) Swine Day 1980 Kansas University.

SMITH, W.C., HINKS, C.E. and WHITTEMORE, C.T. (1988). Res. Dev. Agric. 5:47.

WHITTEMORE, C.T., TULLIS, J.B. and EMMANS, G.C. (1988). Anim. Prod. 46:437.

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