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Effect of Nutritionally Controlled Growth Rate on Mineral Deposition Rates of Highly Selected Pigs

[1]Van Lunen, T. A., [2]D. J. A. Cole and [3]E. E. Falshaw
University of Nottingham, Sutton Bonington Campus, Loughborough, Leicestershire, LE12 5RD
Present Address:[1]Agriculture and AgriFood Canada, C/O Department of Health Management, Atlantic Veterinary College, University of Prince Edward Island, 550 University Avenue, Charlottetown, P.E., C1A 4P3, Canada; [2]Nottingham Nutrition International, 14 Potters Lane, East Leake, Lougborough, Leicestershire, LE12 6NQ, United Kingdom.; [3]Chest Wheel Barn, Rowlands Road, Walmersley Bury, Lancashire, BL9 5PB, United Kingdom

Abstract: An experiment was conducted to examine the effects of growth rate, as controlled by dietary lysine/DE ratio (g/MJ) on calcium, phosphorus and magnesium accretion rates of boars, gilts and barrows from 25 to 90 kg live weight. Twelve pigs (4 of each sex) were assigned to each dietary treatment consisting of lysine/DE ratios from 0.4 to 1.4, in 0.2 g/MJ increments. Feed was provided at 90% of ad libitum and at 90 kg all pigs were slaughtered and the body composition of 2 pigs per sex per treatment was determined. Growth responses to lysine/DE ratios were similar for all sexes with maximum growth rates occurring at the 0.8 and 1.0 g lysine/ MJ DE. Ash, P and Mg accretion rates increased linearly ($P<0.001$) in response to ADG except for P accretion in barrows. Ca accretion increased with increasing ADG, but not in a significant linear manner. The results of this study indicate that mineral accretion is closely related to growth rate in pigs. Based on the response of mineral accretion to growth rate, factorial estimates of Ca, P and Mg requirements were developed. Estimated net daily requirements for Ca, P and Mg for pigs from 25 to 90 kg live weight were of the order of 12.0, 4.8 and 0.32 g d^{-1}.

Key words: Ca, P, Mg, accretion, requirement, pigs

Introduction

Calcium, phosphorus and magnesium play a major role in the development and maintenance of the skeleton as well as in the performance of numerous physiological functions and lean tissue growth. They are also typically the elements which receive the greatest attention in feed formulation as cereal grains are low in these minerals or contain them in an unavailable form (i.e. phytate phosphorus). As mineral supplementation of diets can be costly, and attention is being placed on minimizing the mineral content of pig manure, increasing our understanding of the deposition of minerals in relation to growth rate is appropriate in order to provide adequate, but not excessive, dietary mineral levels to the growing pig.

According to Whittemore (1993), mineral content of the pig, as measured by ash content, is relatively uniform from one pig to another and is of the order of 3% of body weight. Despite this fact, it is known that the ash content of animals increases linearly with weight from birth to 145 kg live weight (Shields *et al.*, 1983). This is due to the intensive mineralization of the skeleton and the increase in its relative weight as the animal grows.

Despite differences in lean growth potential (Van Lunen and Cole, 1998), the sex of the pig appears to have little effect on the amount of bone or ash in the carcass (Shields *et al.*, 1983; Rook and Ellis, 1987). This suggests that in the growing pig, bone is relatively stable as a component of the body or carcass. Therefore, under nutritional adequacy, the mineral content and accretion rate in the pig is tied closely to its overall growth rate. In other words, faster growing animals will require a higher level of daily mineral consumption than slower growing pigs.

Work with porcine somatotropin highlights the importance of adequate mineral intake in relation to growth rate. Azain *et al.* (1991) and McNamara *et al.* (1991) reported that pST administration reduced feed intake to a point where daily P intake was below that recommended by NRC (1988). Carter and Cromwell (1998a,b) demonstrated that pST administration of finishing pigs only increased growth rate and lean deposition rate when dietary P was supplied at adequate levels. Carter and Cromwell (1998a) also reported that the fast growing pig appears to favour ash deposition in lean tissue and only increases ash deposition rate to bone when dietary P levels are in excess of lean tissue requirements. Pigs treated with pST required at least 15 g of P daily to maximize growth performance and 25 to 30 g d^{-1} P to maximize bone mineralization (Carter and Cromwell, 1998a).

ARC (1981) recommended using growth rate and daily intake as an attempt to define mineral requirements during growth. NRC (1988), on the other hand, used values based on body weight. ARC (1981) recommendations were higher than NRC (1988) at all weight ranges, especially for calcium requirements. The development of a computer model to estimate nutrient requirements of pigs (NRC (1998)) has greatly increased the accuracy and level of sophistication of estimating nutrient requirements, however, for calcium and phosphorus the approach is still based on body weight of the animal rather than its lean gain potential.

The approach of NRC (1998) towards mineral requirements of the pig is based on the work of Bertram *et al.* (1994) which showed that the genetic potential for lean growth has little effect on daily requirements for calcium and phosphorus. NRC (1998) also recognizes, however, that increased lean gain as a result of pST administration results in higher calcium and phosphorus requirements both as a percentage of the diet and as daily consumption. It appears logical that increasing lean gain by any means, such as by genetic manipulation or pST administration would have similar effects on dietary mineral requirements.

More work is required in this area to more fully understand the patterns of mineral accretion in the pig in relation to growth rate. A trial was conducted, using a fast growing pig genotype, where rate of gain was controlled nutritionally, to measure the relationship of Ca, P and Mg accretion to growth.

Materials and Methods

Thirty-six pigs from a genotype known for fast lean growth, made up of 12 litter mate groups of 1 boar, 1 gilt and 1 castrated male were assigned in a randomized block design to 6 dietary treatments. The dietary treatments were lysine/DE ratios of: 0.4, 0.6, 0.8, 1.0, 1.2, 1.4 g total lysine MJ DE^{-1}. All diets were similar in energy content (14.25 MJ kg^{-1} DE) and varied in protein content to provide the above ratios. The amino acid profile was based on the ideal protein of Van Lunen and Cole (1996). Tables 1 and 2 show the formulation and analysis of each of the diets. All diets contained Ca, P and Mg in excess of requirements (NRC (1998)) to avoid any nutritional constraints on the deposition of these minerals.

All pigs were housed in individual pens. Water was provided *ad libitum* via nipple drinkers while feed was provided twice daily (8.00 and 17.00 h) at 90% of *ad libitum* based on the intakes reported by Chadd *et al.* (1993) for hybrid pigs. This scale had been found in previous trials to match closely the *ad libitum* consumption patterns of the genotype used in this trial (Van Lunen and Cole 1995). The pigs started on experiment at a mean weight of 25.8 kg and were slaughtered at a mean of 90.6 kg live weight. The temperature of the building was maintained at 19°C. Live weight was measured weekly.

In addition to the 36 pigs described above, 9 pigs (3 of each sex) were slaughtered at the beginning of the trial at a mean live weight of 23.9 kg to provide baseline body composition data. When the pigs on test reached slaughter weight, feed was removed for 24 h, after which they were weighed and then slaughtered according to the methodology described in Van Lunen and Cole (1996).

Sample Collection and Chemical Analysis: The left side of the carcass and all of the offal from the pigs were stored at -25°C. After storage, the offal and carcass of each pig were ground and mixed separately in a Wolfking meat grinder (Model B 400, Wolfking A/S, 6 Industrivej, D.K. - 4200, Slagelse, Denmark). Samples of the ground and mixed material (150 g) were collected and lyophilized for 8 days. The lyophilized material was analysed for ash, Ca, P and Mg according to the methods described in Van Lunen and Cole (1996).

Total content of ash, Ca, P and Mg of each pig was calculated by multiplication of the ash, Ca, P and Mg contents by the dry matter (DM) weight of the offal and carcass (left side x 2). The offal and carcass values were then added together.

Proximate analysis of diets was performed according to methods outlined by the Association of Official Analytical Chemists (1990).

Statistical Analysis and Animal Care: Treatment and sex effects were assessed by analysis of variance using Genstat 5 (Genstat 5 Committee (1987)). Regression analysis was also employed using Genstat 5.

Animal Care: The trial was conducted under a specific project licence granted by the UK Home Office within the terms of the 'Animals (Scientific Procedures) Act' (1986) to ensure that Animal Welfare considerations were given highest priority.

Results

Table 3 shows the average daily gain (ADG), ash, Ca, P and Mg accretion rates of the pigs on test. The lysine/DE ratios of 0.8 and 1.0 g MJ^{-1} resulted in the fastest growth; of the order of 1000 g d^{-1}. There was no sex effect for ADG, ash, Ca, P and Mg accretion rates of the pigs used in this trial, and therefore, combined sex

Table 1: Feed Composition and analysis

Ingredient (g/kg) diet	0.4	0.6	0.8	1.0	1.2	1.4
Wheat		750	600	450	300	150
Barley	161	168	177	185	194	202
Wheat midlngs		35	70	105	140	175
Soybean meal	(48)	50	100	150	200	250
Peas		16	30.5	46	61	76.4
Dried skim milk		37	74	111	148	185
Rapeseed meal		16	32	48	64	80
Soya oil	45	37.8	30.1	23	15.3	7.9
Betamix 314[z]	12.5	12.5	12.5	12.5	12.5	12.5
Limestone		1	2	3	4	5.2
Dicalcium phosphate		20	16	12	8	4
Salt		3.3	2.5	1.9	1.2	0.6
Cellulose		5.1	4.0	3.0	2.0	1.0
Lysine monohydrochloride	3.2	3.2	3.1	3.1	3.0	3.0
Methionine			0.3	0.4	0.7	0.9
Threonine	0.8	1.0	1.6	1.8	1.9	2.1
Total	1000	1000	1000	1000	1000	1000
		Analysis (g/kg)				
Dry matter	915.2	92.23	92.38	91.65	91.59	91.73
Crude Protein	115.4	14.73	18.04	20.68	23.49	26.20
Lysine	5.7	0.84	1.18	1.50	1.71	1.90
Gross energy (MJ/kg)	16.55	16.65	16.80	16.73	16.79	16.57
Digestible energy (MJ/kg)[y]	14.3	14.3	14.2	14.1	14.0	13.9
Crude fibre	16.6	14.5	24.9	30.8	32.6	38.9
Neutral detergent fibre	52.5	67.9	83.4	91.2	106.7	118.5
Acid detergent fibre	18.8	33.6	46.9	51.4	59.8	58.4
Ash	46.9	52.0	49.6	54.5	58.4	59.9
Crude lipid	57.9	51.8	46.1	41.9	35.5	27.5
Ca	6.1	7.7	7.1	7.4	7.6	7.8
P	5.1	6.9	5.9	6.7	6.6	7.0

[z]mineral and vitamin supplement
[y]calculated value

Table 2: Dietary amino acid balance of experimental diets (lysine = 100)

Diet: (Lysine/DE)	0.4	0.6	0.8	1	1.2	1.4	Van Lunen and Cole (1996)
Lysine	100	100	100	100	100	100	100
Methionine + cyctine	86	73	68	67	67	59	50-55
Threonine	80	71	78	75	72	70	65-67
Tryptophan	20	21	18	18	20	20	18
Isoleucine	67	62	60	58	59	55	50
Leucine	151	138	129	129	128	124	100
Histidine	41	40	38	37	38	38	-
Phenylananine+tyrosine	160	134	122	115	115	108	100
Valine	79	76	74	71	72	66	70

Table 3: Growth and mineral accretion rates (g d^{-1}) of pigs fed diets containing graded lysine/DE ratios

Lysine/DE (g/MJ)	ADG	Ash gain	Ca gain	P gain	Mg gain
0.4	720	17.9	4.4	2.45	0.19
0.6	940	22.9	4.78	4.58	0.24
0.8	1070	27.3	9.99	4.21	0.3
1	1010	26.7	8.37	3.98	0.3
1.2	840	23.6	8.15	2.75	0.25
1.4	920	17.2	4.09	3.27	0.22
SeM	31.5	0.87	0.31	0.24	0.03
Contrasts					
Significance probability of contrast					
Diet	0.008	0.005	0.009	0.012	0.045
Lys/DE - linear	0.423	0.167	0.764	0.516	0.312
Lys/DE - quadratic	0.047	0.014	0.008	0.05	0.041

Table 4: Linear relationship of mineral accretion rates of pigs from 25 to 90kg live weight to daily gain (ADG)

Boars	Ash gain d^{-1} = 0.65 + 23.98 (ADG)	<0.001
Gilts	Ash gain d^{-1} = 1.82 + 23.89 (ADG)	<0.001
Barrows	Ash gain d^{-1} = - 0.79 + 24.54 (ADG)	<0.001
Boars	Ca gain d^{-1} = -8.60 + 14.71 (ADG)	>0.05
Gilts	Ca gain d^{-1} = -19.50 + 29.10 (ADG)	>0.05
Barrows	Ca gain d^{-1} = -11.15 + 19.50 (ADG)	>0.05
Boars	P gain d^{-1} = -0.78 + 4.55 (ADG)	<0.001
Gilts	P gain d^{-1} = 0.11 + 3.78 (ADG)	<0.001
Barrows	P gain d^{-1} = 1.48 + 2.29 (ADG)	>0.05
Boars	Mg gain d^{-1} = -0.109 + 0.366 (ADG)	<0.001
Gilts	Mg gain d^{-1} = -0.120 + 0.409 (ADG)	<0.001
Barrows	Mg gain d^{-1} = -0.019 + 0.285 (ADG)	<0.001

Table 5: Comparison of net (available) Ca and P requirements for growing pigs

Source	ARC (1981)	NRC (1988)	NRC (1998)	Proposed
Weight (kg)	45	50 - 110	57.5	57.5
Ca g d^{-1}	7.7	15.6 [z]	10.6 [z]	12
P g d^{-1}	4.6	4.7	3.9	4.8
Mg g d^{-1}	0.4	1.2	0.27	0.32

[z]NRC (1988 and 1998) only provide a total Ca requirement.

effects are shown in Table 3. Mineral accretion changed depending on ADG, as affected by the Lysine/DE ratio content of the diets. Despite the lack of sex effects in Table 3, linear regression analysis showed different responses of mineral accretion to growth rate for each sex. Table 4 describes the linear relationships of ash, Ca, P and Mg accretion to ADG. A highly significant ($P<0.001$) linear relationship was determined to exist between ADG and rate of ash, P (except for the barrows) and Mg accretion rate. Ca accretion did not respond linearly to ADG. As the ADG of the pigs increased, so did the accretion rates of ash, P and Mg accretion.

Discussion

There is little information in the literature describing the relationship of mineral accretion to growth rate. As the skeleton is the framework on which lean tissue is supported, it is reasonable to believe that faster growing pigs will have a greater rate of skeletal growth as well as muscle growth. As a result, it is also reasonable to assume that mineral accretion will be closely associated with general body growth as seen in this study.

From the responses seen here, one can estimate the mineral requirements of fast growing pigs.

The mineral requirements of modern genotypes can be estimated factorially by taking into account obligatory losses and retention. The availability of each mineral must also be considered and increased mineral availability is of utmost importance to meet the needs of the animal and to minimize the impact of pork production on the environment.

Although the linear relationship of Ca accretion to ADG was not significant, an estimate of the Ca requirements of fast growing pigs may still be justified as Ca accretion did increase with increasing ADG. The daily maintenance requirement of Ca was taken to be 35 mg kg^{-1} live weight (Guegeun and Perez, 1981; Henry *et al.*, 1984). The daily maintenance requirement for P was taken to be 10 mg/kg live weight (Beers and Jongbloed, 1992). As this experiment examined the growth and mineral accretion of pigs over an extended period (25 - 90 kg), the maintenance requirement must be based on the average live weight of 57.5 kg. The maintenance requirement for Ca, P and Mg are therefore:

Ca: $(35 \times 57.5) / 1000 = 2.01$ g d^{-1}

P: $(10 \times 57.5) / 1000 = 0.575$ g d^{-1}

Mg: $(0.4 \times 57.5)/ 1000 = 0.023$ g d^{-1}

Based on the maintenance requirements, as well as the mineral accretion rates and growth performance parameters of modern pigs from 25 to 90 kg live weight, it appears that modern pigs with ADG potentials of 1000 g d^{-1} have net Ca, P and Mg requirements of the order of 12.0 (2.01 + 9.99), 4.8 (0.575 + 4.21) g/d, and 0.323 (0.023 + 0.30), respectively. From the linear responses presented in Table 4, the Ca, P and Mg requirements for slower growing genotypes can also be estimated using similar equations to those above.

Table 5 gives a comparison of the net Ca, P and Mg requirements calculated above and those provided by ARC (1981), NRC (1988) and NRC (1998). From the table, it appears that Ca and P requirements of modern genotypes are similar to those of slower pigs. This is similar to the results of Bertram *et al.* (1994) which indicated that pigs with higher lean gain potentials did not have a higher dietary requirement for Ca or P as compared to pigs with a moderate lean gain potential. Our estimates for dietary Mg requirements of fast growing pigs is substantially lower than the values presented by NRC (1988, 1998).

Despite the similarity of the dietary Ca requirement and lower Mg requirement presented here, the comparison to NRC (1988, 1998) may be misleading as NRC presents Ca and Mg requirements as total rather than net values. Availability of minerals is an important factor when formulating pig diets. Whittemore *et al.* (1972) reported that Ca was only 41.5% available in grain-based diets when no organic supplementation took place, while the availability of Mg in natural ingredients is 50 to 60% available (Miller 1980, Nuoranne *et al.*, 1980).

If availability of Ca and Mg are taken into account, it appears that their dietary Ca requirement in modern pigs may be higher than in slower growing pigs, while P and Mg requirements are similar for all growing pigs.

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