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Macro- and micromineral composition of pigs from birth to 145 kilograms of body weight

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Macro- and Micromineral Composition of Pigs from Birth to 145 Kilograms of Body Weight[1,2]

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ABSTRACT: Body mineral composition was determined in 81 pigs killed at birth, weaning (28 d), and at approximately 15-kg intervals to 145 kg of BW. Total body components, including internal tissue, whole blood, and hair, were wet-ashed and analyzed for their mineral contents with the inductive coupled plasma method, except for Se, which was determined by fluorometric analysis. The results demonstrated that the body protein:ash ratio increased from birth to 20 kg BW, remained constant to 125 kg, but then declined to 145 kg BW ($P < .01$). The K:Na ratio increased from birth to 105 kg BW and then reached a plateau ($P < .01$). The Ca:P ratio decreased from birth to 20 kg then remained relatively constant to 90 kg BW, whereupon it increased ($P < .01$). These ratios reflected the rate of development of muscle and bone tissue and the higher soft tissue requirement for P and K during early growth. When expressed on a fat-free tissue basis, body Na was higher than K at birth, but thereafter body K increased linearly ($P < .01$) and Na content declined ($P < .01$). When Mg, Mn, Mo, and Cr were expressed on a fat-free empty body weight basis, each increased from birth but they maintained the same relative concentrations from 20 to 145 kg BW ($P < .01$). Body Fe increased from birth to 20 kg BW but then gradually declined to 145 kg BW ($P < .01$), whereas Zn increased to 145 kg BW ($P < .01$). Selenium increased from birth to weaning and again after 105 kg BW ($P < .01$). The amount of Co in the fat-free empty body increased linearly ($P < .01$) with increasing pig weight, and body Cu decreased to 75 kg BW and then reached a plateau ($P < .01$). The nonessential elements Al, Sr, and Sn increased dramatically from birth to weaning with a low rate of increase from 8.5 to 145 kg BW ($P < .01$), but Sn decreased after weaning ($P < .01$). The nonessential elements generally had a more variable concentration than the dietary essential trace minerals. There was a quantitative increase ($P < .01$) in all macro- and microelements from birth to 145 kg BW.

Key Words: Elements, Minerals, Body Composition, Ash, Pigs

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Introduction

Previous studies evaluating the body composition of the pig have centered largely on the fat, protein, water, and ash components, with minimal information available on individual macro- and microelements. Body muscle and ash development is rapid in young animals, but after approximately 70 kg BW the rate of body protein accretion generally begins to decline, ash increases, albeit at a declining rate, and fat increases in a curvilinear manner (Shields et al., 1983). Our previous results demonstrated that the best fit line for total body protein from birth to 145 kg BW was quadratic, but the quadratic component was relatively small, reflecting an almost linear fit, with ash also increasing in a similar manner as muscle tissue (Shields et al., 1983). Consequently, body protein and ash quantitatively increased to 145 kg BW.

The results of Mahan and Newton (1995) evaluating individual mineral compositions of mature gilts demonstrated that total body macro- and most micromineral elements increased between 9 and 24 mo of age. However, when the animals had completed three reproductive cycles, most body mineral concentrations had a lower total body content than that of a nongravid group of a similar age. This suggests that

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mineral accretion occurred during the reproduction phase, but at a lower rate for reproducing sows. The need for mineral reservoir accumulation during earlier growth periods may therefore be important for future reproductive needs.

There is a limited amount of information regarding the individual mineral composition of swine. Our study examined the relative and quantitative macro- and micromineral concentrations of pigs at various intervals from birth to 145 kg BW.

Materials and Methods

Animals. A total of 81 (Hampshire × Yorkshire × Duroc) × Duroc pigs had been used to evaluate the major body contents (protein, water, fat, and ash) from birth to 145 kg BW (Shields et al., 1983). Samples from these animals were used to determine the pigs' macro- and micromineral compositions at various intervals. Nine pigs were killed at birth, and eight each at weaning (28 d), 20 kg BW, and thereafter at approximately 15-kg weight increments to a final body weight of 145 kg. Gilts and barrows were equally represented within each weight grouping, except for the neonates.

Neonatal pigs were removed before nursing the sow, electrically stunned, and killed by exsanguination. Pigs at weaning (28 d) were removed directly from the sow, whereas pigs from 20 to 145 kg BW were removed from a group of 12 pens containing a large pool of pigs (n = 8/pen). All pigs after being weaned were fed corn-soybean meal-based diets provided for ad libitum consumption until they were killed. The various diets provided to these pigs met or exceeded NRC (1988) nutrient standards. One diet was provided from weaning to 20 kg BW, a second from 20 to 55 kg BW, and while a third diet was fed from 55 to 145 kg BW. Diet compositions were reported earlier (Shields et al., 1983).

Pig selection at each weight grouping was restricted to an equalized number of barrows and gilts, with representative animals having a normal age at each respective weight. Although animals were of a similar genetic composition, each weight group was further restricted to a maximum of two pigs per litter. Pigs were stunned electrically and killed by exsanguination.

Processing Method and Mineral Analysis. Slaughter techniques, killing procedures, tissue collection processes, and grinding methods were previously reported (Shields et al., 1983). Digesta in the intestinal tract were removed, the tract was rinsed with water, and all body components (head, forelegs, and internal tissue) were combined but kept separate from the carcass. Hair was collected from three pigs at 20, 80, and 140 kg BW, pooled within weight group, washed with alcohol and ether, and dried before analysis. Blood was not collected at slaughter, but whole blood samples from six fed pigs of each weight group were collected from the vena cava. Whole blood samples were pooled within weight group, frozen, and later analyzed for their mineral contents. The carcass and body components were ground, subsampled, and then combined in the same relative proportion present at slaughter and mechanically mixed. Fat was extracted from the mixed subsample as previously described (Shields et al., 1983). The fat-free dried samples and whole blood samples were wet-ashed in perchloric and nitric acids and the individual mineral elements were determined using the inductively coupled plasma (**ICP**) spectroscopic (model 137, Applied Research Laboratories, Valencia, CA) method as outlined by AOAC (1995). Selenium was determined with the fluorometric method of AOAC (1995) using an ultraviolet detector (Turner Filter Fluorometer, Model 112, Unipath, Mountain View, CA).

The relative content of each individual mineral was calculated on a fat-free empty body weight (**FFEBW**) basis. Blood mineral concentrations were used to adjust their relative contribution into each weight group by assuming a linear decline in circulating blood content from 7 to 4% from birth to 145 kg, respectively, and total hair was considered to be .25% of body weight using the data of Kauffman et al. (1986). A quantitative assessment of total body minerals was calculated by multiplying the relative composition of each mineral/kilogram of FFEBW by the FFEBW of the animal.

Statistical Analysis. The relative and quantitative compositions of each mineral were analyzed from birth to 145 kg BW by regression analysis using the least squares GLM procedure of SAS (1985). Sex and animal weight groupings were included in the statistical model. There was no significant sex effect; thus, barrow and gilt data within each weight group were combined. The data are expressed as least squares means. The relative composition of each mineral on a FFEBW basis is provided in tabular form, and the total quantitative body content is graphically presented.

Results and Discussion

Empty body weight and FFEBW increased linearly ($P > .01$) from birth to 145 kg BW (Table 1). Even though, body protein and ash increased linearly ($P < .01$) to 145 kg, the rate of protein accretion was greater than the ash component (Figure 1). When these two body components were expressed as a ratio, the protein:ash ratio increased from birth to 20 kg BW, declined slightly from 20 to 35 kg, remained relatively constant to 125 kg, and then declined from 125 to 145 kg BW in a cubic manner ($P < .01$; Figure 2). The increasing ratio of these two body components from birth to 20 kg reflects the more rapid rate of muscle accretion compared with total mineral deposi-

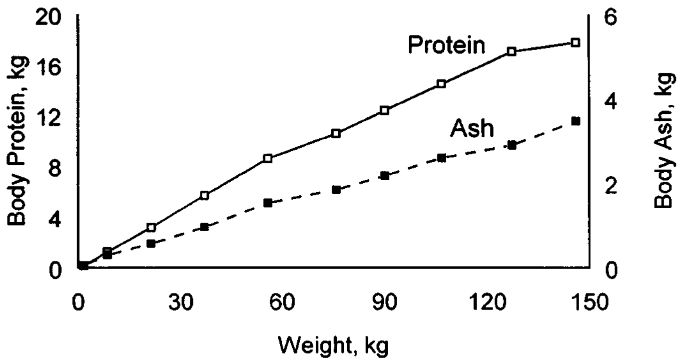

Figure 1. Quantitative increase in body protein and ash in pigs from birth to 145 kg BW.

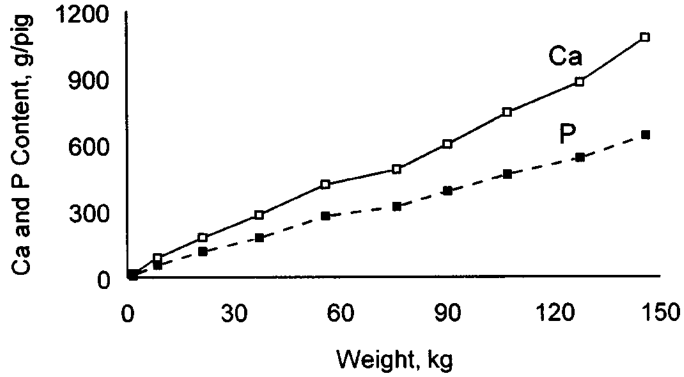

Figure 3. Quantitative changes of body Ca and P of pigs from birth to 145 kg BW.

tion, whereas from 20 to 125 kg the relative accretion rates of these two body components were similar. The subsequent decline in the protein:ash ratio from 125 to 145 kg BW suggests that muscle deposition was declining at a more rapid rate than the body ash component. Clawson et al. (1991), summarizing several studies, also demonstrated that this ratio changed depending on nutritional and nonnutritional factors.

Macrominerals

Calcium and Phosphorus. When the relative amounts of body Ca and P contents were expressed on a FFEBW basis from birth to 145 kg BW, a cubic response ($P < .01$) resulted (Table 1). Body Ca and P increased from birth to weaning (8.5 kg), remained constant from 20 to 75 kg BW, and then increased to 145 kg BW, whereupon Ca increased at a more rapid rate than P (Table 1). Spray and Widdowson (1950) had, however, reported that the concentration of Ca decreased from birth to 112 d of age and then increased, whereas P was constant to the 112-d period, whereupon it increased.

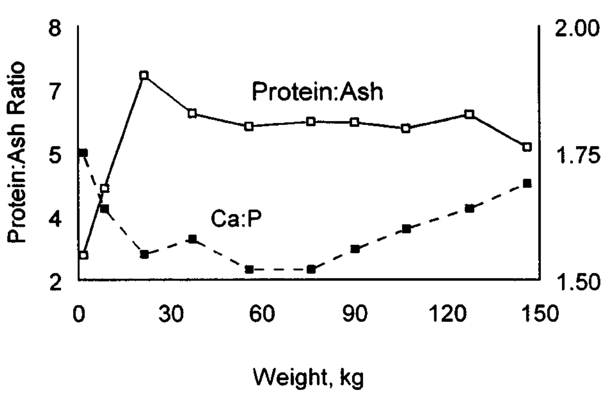

Figure 2. Body protein:ash and Ca:P ratio of pigs from birth to 145 kg BW.

Quantitatively, total body Ca and P increased linearly ($P < .01$) from birth to 145 kg BW (Figure 3). The rate of increase of total body P after 75 kg BW seemed to be at a lower magnitude than that of Ca. This response is attributed to differences in the relative accretion of muscle and skeletal tissue and the subsequent retention of individual minerals in these different tissues, conclusions consistent with the total body protein:ash ratio presented in Table 1 and Figure 2.

The ratio of body Ca to P changed from birth to 145 kg BW. From birth to 20 kg BW, body Ca:P ratio declined, remained low to 75 kg BW, but then increased to 145 kg BW, resulting in an overall cubic response ($P < .01$; Table 1). Most body Ca is present in bone tissue, and the body's Ca content largely reflects the amount of skeletal tissue development, whereas P is present in soft and hard tissues. During the early growth period when muscle accretion was increasing rapidly (birth to 75 kg), soft and hard tissue P retention increased. Total body P would be expected to increase at a faster rate relative to body Ca during the early growth period of the animal. This would result in a reduced Ca:P ratio during the period of rapid muscle formation. The increasing Ca:P ratio after 75 kg BW suggests that Ca and P deposition was occurring largely in skeletal tissue with a declining deposition of P in muscle (Table 1, Figure 2). The resulting ratio of total body Ca to P, therefore, reflects the incorporation of these two elements into both tissue compartments. Spray and Widdowson (1950) and Rymarz et al. (1982) demonstrated responses similar to our data.

Sodium and Potassium. Body Na and K contents presented in Table 1 demonstrated that the relative concentration of body Na was high at birth and then declined postnatally. Body Na remained constant to 105 kg BW, whereupon it increased to 145 kg BW, resulting in an overall cubic response ($P < .01$).

In contrast to the phasic changes of Na, the relative amount of K in the neonatal pig was low, increased dramatically by weaning, and then increased with

Table 1. Mineral composition of growing swine from birth to 145 kilograms body weight (expressed on a fat-free, empty body weight basis)

Item	Weight class											
	Neonate	Wean	20 kg	35 kg	60 kg	75 kg	90 kg	105 kg	125 kg	145 kg	Avg	SEM
Live weight, kg	1.55	8.5	21.3	37.1	55.8	75.8	90.1	106.8	127.4	146.0	67.0	16.0[a]
Empty body wt, kg	1.55	8.3	19.9	32.1	50.8	68.8	84.1	99.0	121.9	139.1	62.6	15.2[a]
Fat-free empty body wt, kg	1.52	7.3	17.5	29.6	41.4	53.1	60.9	69.0	72.6	81.7	43.5	9.0[a]
Protein:ash ratio	2.58	4.16	6.82	5.92	5.62	5.73	5.71	5.57	5.90	5.14	5.32	.37[b]
Ca:P ratio	1.75	1.64	1.55	1.58	1.52	1.52	1.56	1.60	1.64	1.69	1.61	.02[b]
K:Na ratio	.65	1.10	1.18	1.23	1.36	1.46	1.49	1.51	1.39	1.39	1.25	.02[d]
	% of FFEBW[c]											
Ash	4.08	4.08	2.65	3.24	3.69	3.47	3.56	3.76	3.98	4.23	3.67	.15[a]
Minerals												
Ca	1.00	1.21	1.02	.95	1.01	.91	.98	1.07	1.21	1.32	1.07	.04[b]
P	.58	.74	.66	.60	.66	.60	.63	.67	.74	.78	.67	.02[b]
	mg/kg FFEBW[c]											
Al	3.21	9.40	5.02	3.67	3.39	3.11	3.21	3.90	4.61	4.41	4.39	.59[b]
B	.56	.54	.54	.81	.44	.53	.58	.59	.59	.64	.58	.03[b]
Co	.04	.05	.07	.10	.11	.10	.11	.13	.14	.15	.10	.01[a]
Cr	.41	.94	.61	.62	.62	.51	.57	.60	.64	.88	.64	.05[b]
Cu	1.61	1.32	1.37	1.23	1.27	1.06	1.16	1.14	1.17	1.15	1.25	.05[b]
K	822.4	1,141.1	1,131.4	1,172.3	1,256.0	1,310.7	1,298.8	1,323.2	1,385.7	1,401.5	1,224.3	53.9[d]
Mg	171.0	256.2	222.9	243.2	248.8	239.2	250.0	252.2	275.5	279.4	243.8	9.6[d]
Fe	19.97	25.42	32.11	24.74	29.65	26.50	24.90	24.41	23.29	23.25	25.42	1.08[b]
Mo	.11	.13	.18	.18	.16	.14	.15	.14	.16	.18	.15	.01[d]
Mn	.43	.47	.85	.55	.42	.48	.45	.44	.44	.38	.49	.04[b]
Na	1,263.1	1,035.6	960.0	949.3	925.1	900.2	871.9	881.2	994.5	1,006.1	978.7	36.0[b]
Ni	.23	.15	.31	.22	.39	.44	.60	.60	.62	.51	.41	.05[b]
Se	.07	.09	.18	.17	.15	.19	.19	.27	.40	.41	.21	.04[d]
Sn	1.16	1.98	1.07	1.10	1.01	.95	.88	1.02	.77	.78	1.07	.11[b]
Sr	.35	1.44	1.38	1.97	1.83	1.84	1.93	1.83	2.03	1.86	1.65	.16[d]
Zn	10.93	15.28	15.16	16.25	17.37	18.29	19.57	19.45	22.67	21.37	17.63	1.08[d]

[a]Linear response ($P < .01$).
[b]Cubic response ($P < .01$).
[c]FFEBW = fat-free empty body weight.
[d]Quadratic response ($P < .01$).

increasing pig weight, resulting in an overall quadratic response ($P < .01$). The inverse relationship of body Na and K contents in newborn pigs compared with older animals had been previously demonstrated in rats, rabbits, cats, and pigs (Spray and Widdowson, 1950).

The sum of Na and K was fairly constant throughout the growth cycle (Table 1). Chuntananukoon et al. (1976) suggested that these osmotically active cations controlled the total amount of water in the body and that their sum reflected this phenomenon. In the present study, the concentration of these elements remained constant even when the water content declined in the fat-free empty body (Shields et al., 1983).

Potassium is largely an intracellular element (i.e., muscle), whereas Na is largely found in the circulatory fluid, which declines with increasing weight. Consequently, as muscle deposition increases, the amount of intracellular K would be expected to increase relative to Na. This response is generally consistent with findings of Rymarz et al. (1982), who reported an increase in the K:Na ratio from 11 to 30 wk of age.

When these two elements are expressed on a quantitative basis, both elements increased linearly ($P < .01$) from birth to 145 kg BW, but K increased at a faster rate than Na (Figure 4). This response is consistent with the increasing amount of muscle tissue and the subsequent retention of K in this tissue with increasing pig weight. Because the quantity of blood relative to total body mass declines, there was also a declining rate of total body Na.

Magnesium. Magnesium is an essential component of the body's enzyme system necessary for carbohydrate and protein metabolism, but there is also a small quantity of Mg adsorbed onto the bone hydroxyapatite crystal. Body Mg content at birth was lower relative to that in older and heavier pigs (Table 1). When Mg was expressed on a FFEBW basis, Mg concentration increased from birth to weaning, but then remained relatively constant to 145 kg BW, resulting in a quadratic response with weight ($P < .01$; Table 1). These data also support the conclusion that the combination of soft and hard tissue contained a relatively constant Mg content, particularly after 20 kg BW. When total body Mg was expressed on a quantitative basis from birth to 145 kg BW (Figure 4), it increased linearly ($P < .01$).

Dietary Essential Microminerals

Iron and Zinc. Iron and zinc are the two trace minerals in the largest concentration in the pig. These elements are not only vital for the body's enzyme systems, but Fe and Zn are also constituents of the heme compounds and epidermal tissue, respectively. When the elements are expressed on a FFEBW basis, Fe increased to 20 kg BW and then declined to 145 kg BW ($P < .01$; Table 1). Body Zn increased rapidly from birth to weaning, with a lower rate of increase to 90 kg followed by a decline to 145 kg BW. These results are in contrast to those of Spray and Widdowson (1950), who reported that Fe decreased from birth to weaning and then increased to 250 d of age. They also reported that Zn had a similar concentration from birth to 250 d of age. Differences in body Fe concentrations might be expected because of different management practices such as the use of injectable iron, access to creep feed, and whether animals are housed indoors or in dirt lots.

Quantitatively, Fe and Zn increased from birth to 145 kg BW, with a declining quadratic response ($P < .01$) demonstrated for Fe, whereas Zn increased linearly ($P < .01$; Figure 5). The quantity of body Fe probably reflected the quantity of heme and non-heme Fe compounds in body muscle mass relative to total body weight, whereas Zn reflected the increasing body surface area and the subsequent increasing Zn content in the epidermal tissue.

Copper, Manganese, and Selenium. When expressed on a FFEBW basis, body Cu declined dramatically from birth to weaning, continued to decline from 20 to 90 kg BW, whereupon it remained relatively constant

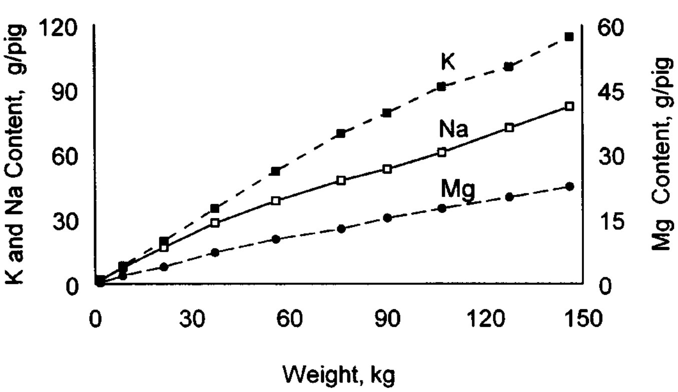

Figure 4. Qunatitative changes of Mg, Na, and K of pigs from birth to 145 kg BW.

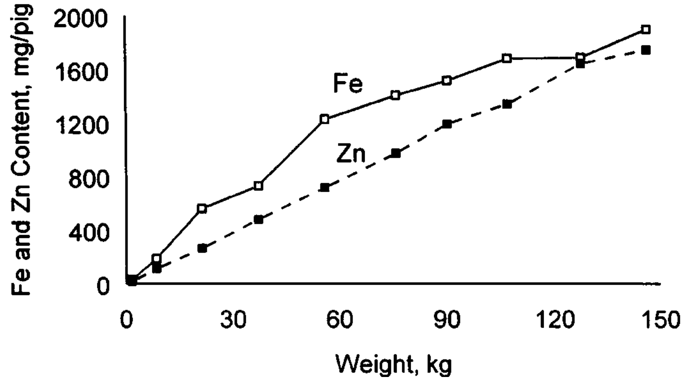

Figure 5. Quantitative changes of Fe and Zn of pigs from birth to 145 kg BW.

to 145 kg BW in a cubic response ($P < .01$, Table 1). These results are consistent with the low sow milk Cu content reported by Mahan and Newton (1995). Spray and Widdowson (1950) had demonstrated that Cu declined after pigs were weaned (21 d of age).

The relative amount of Mn increased from birth to 20 kg BW, declined rapidly from 20 to 60 kg BW, and then remained relatively constant to 145 kg BW ($P < .01$). Copper and Mn are components of tissue enzyme systems and would be expected to be relatively constant, particularly on a fat-free body mass basis, except for their higher intake from the diet relative to their tissue requirement and residual adsorption onto bone tissue.

Selenium, when expressed on a FFEBW basis, increased from birth to 20 kg BW, reached a plateau from 20 to 105 kg, and then increased to 145 kg BW ($P < .01$, Table 1). Pigs are born with low body Se concentrations, which increase dramatically upon the consumption of sow milk (Mahan, unpublished data). During the latter stages of growth, when sodium selenite is provided, most of the Se accumulates in liver tissue (Mahan, unpublished data).

Quantitatively, Cu, Mn, and Se increased linearly ($P < .01$) from birth to 145 kg BW, although Mn tended to reach a plateau, and Se seemed to increased in a quadratic manner, particularly after 90 kg BW (Figure 6).

Metabolically Essential Trace Minerals.

Cobalt, Chromium, and Molybdenum. Body Co content expressed on a FFEBW basis increased linearly ($P < .01$) from birth to 145 kg BW (Table 1). Chromium increased dramatically from birth to weaning, declined by 20 kg BW, and remained relatively constant to 125 kg, whereupon its concentration increased to 145 kg BW, resulting in an overall cubic response ($P < .01$).

Molybdenum concentration increased from birth to 20 kg BW but then was relatively constant to 145 kg

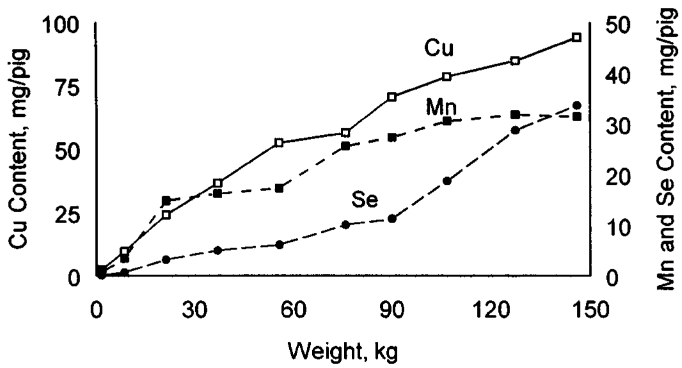

Figure 6. Quantitative changes of Cu, Mn, and Se of pigs from birth to 145 kg BW.

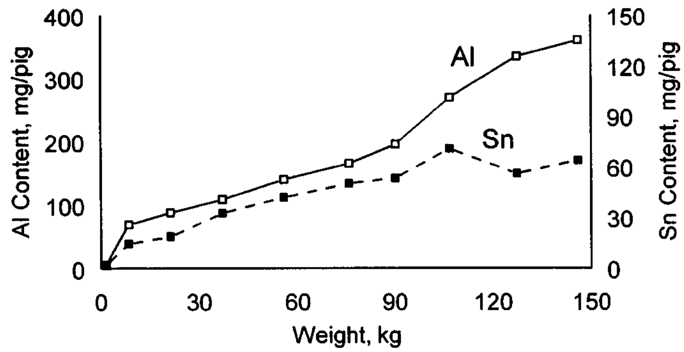

Figure 8. Quantitative changes of Al and Sn of pigs from birth to 145 kg BW.

BW, resulting in an overall quadratic ($P < .01$) response (Table 1).

Even though the current NRC (1988) publication does not identify Cr as a dietary essential trace mineral for pigs, evidence by Page et al. (1993) and Lindemann et al. (1995) suggests that Cr can increase lean muscle mass in the pig with a concurrent reduction of body fat. Cobalt, Cr, and Mo have recognized metabolic functions in animal tissue, Co as a constituent of vitamin B_{12}, Cr as a proposed component of the glucose tolerance factor, which has been postulated to interface between the cell and insulin, and Mo is a constituent of body enzyme systems. When these elements are expressed quantitatively, each increased linearly from birth to 145 kg BW ($P < .01$; Figure 7).

Nonessential Minerals

Aluminum and Tin. Body Al concentration expressed on a milligram/kilogram FFEBW basis was low in neonatal pigs, but it increased dramatically from birth to weaning. A marked decline in body Al content occurred from weaning to 35 kg BW then remained relatively constant to 90 kg BW, whereupon it increased by 145 kg BW in a cubic response ($P < .01$; Table 1). Mahan and Newton (1995) had previously demonstrated that sow milk had a high Al content, resulting in a large consumption of this element by the nursing pig. Quantitatively, Al accumulated in a cubic manner ($P < .01$), with the largest rate of increase between birth to weaning and from 90 to 145 kg BW (Figure 8). The increasing Al content in finisher pigs is attributed to Al in the macromineral supplements.

Tin increased sharply from birth to weaning, whereupon a rapid decline occurred to 20 kg BW, and it remained at a relatively constant concentration to 145 kg BW ($P < .01$; Table 1). Mahan and Newton (1995) had demonstrated that sow milk contained a relatively large quantity of Sn, which was the probable source of this element for the nursing pig. Total body Sn increased quadratically ($P < .01$) with a linear increase from 8.5 to 105 kg BW but did not increase further to 145 kg BW (Figure 8).

Strontium, Boron, and Nickel. When expressed on a mg/kg FFEBW basis, Sr increased dramatically from birth to 35 kg BW but then remained relatively constant to 145 kg BW ($P < .01$; Table 1). Quantitatively, Sr increased linearly ($P < .01$) from birth to 145 kg BW (Figure 9).

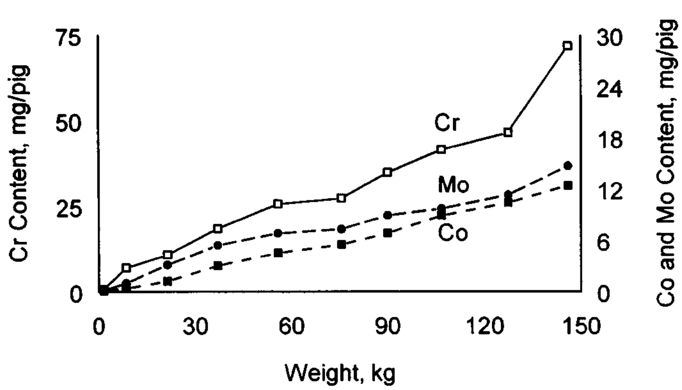

Figure 7. Quantitative changes of Cr, Co, and Mo of pigs from birth to 145 kg BW.

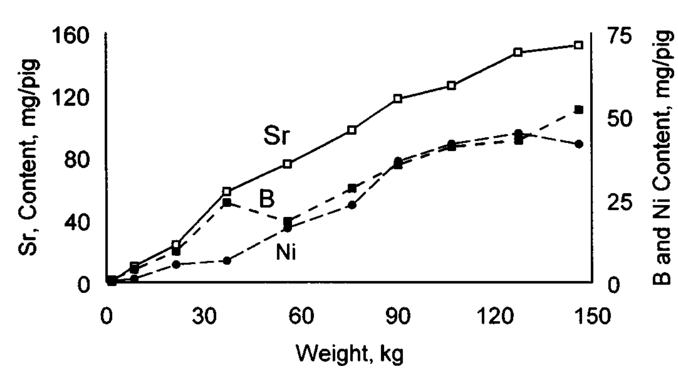

Figure 9. Quantitative changes of Sr, B, and Ni of pigs from birth to 145 kg BW.

Boron, when expressed on a mg/kg FFEBW basis, responded cubically ($P < .01$) as pig weight increased, resulting in the high and low values at 35 and 60 kg, respectively (Table 1). Quantitatively, B increased linearly ($P < .01$) from birth to 145 kg (Figure 9).

The body content of Ni was somewhat variable, but it increased linearly from birth to 90 kg, whereupon it reached a plateau to 145 kg BW, resulting in an overall cubic ($P < .01$) response (Table 1). When expressed on a quantitative basis, body Ni increased in a cubic manner ($P < .01$), with the largest increase occurring from 35 to 125 kg BW (Figure 9).

Implications

Body macromineral contents expressed as individual elements on a fat-free tissue basis, as a ratio to one another (Ca:P or K:Na), or to other body components (protein:ash) generally reflected the metabolic need for soft and(or) hard tissue development. Most trace minerals increased at a rapid rate during the nursing period, implying that the maternal mineral tissue stores were transferred to milk and then on to the tissue of the nursing pigs. Trace elements used for metabolic purposes generally maintained a relatively constant concentration from weaning to 145 kg BW. The concentration of Fe and Zn increased as pigs got heavier, reflecting the increased deposition of heme compounds and epidermal tissue, respectively. Nonessential minerals accumulated in body tissues, but their concentrations were generally more variable from birth to 145 kg body weight than concentrations of the essential trace elements.

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