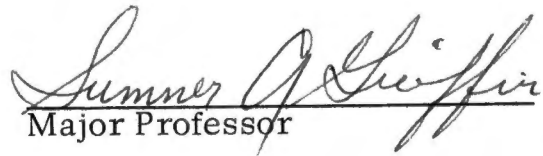


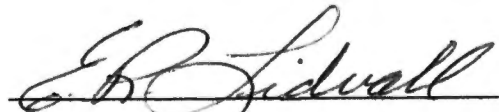
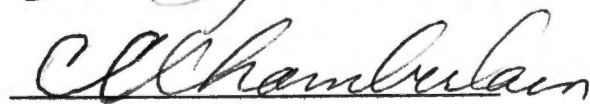
August 1, 1969

To the Graduate Council:

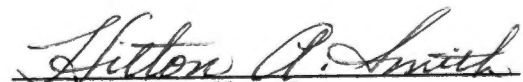
I am submitting herewith a thesis written by David William Porter, entitled "Hair As An Indicator of the Mineral Nutrition of the Pig." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Animal Husbandry.


Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:


Vice Chancellor for
Graduate Studies and Research

HAIR AS AN INDICATOR OF THE MINERAL
NUTRITION OF THE PIG

A Thesis
Presented to
the Graduate Council of
The University of Tennessee

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by
David William Porter

August 1969

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ABSTRACT

This study was conducted to determine if mineral content of hair is of value as an indicator of the mineral nutrition of the pig. Eleven Duroc sows and ten Duroc litters were used from farrow to weaning, and forty-eight Duroc and Hampshire pigs were allotted to four treatments from weaning to market weight--control, high and low calcium and phosphorus, and control less trace mineral premix rations. The hair samples were analyzed for calcium, inorganic phosphorus, magnesium, zinc, iron and copper.

Calcium and copper concentrations in sow hair decreased significantly from farrowing to weaning; and inorganic phosphorus, magnesium and iron concentrations increased significantly. The pig hair decreased significantly in zinc, iron, copper and inorganic phosphorus from farrowing to weaning, while calcium content increased significantly.

The following observations were made on the mineral concentrations of the hair from the experimentally-fed pigs:

1. The magnesium levels were significantly lower in the hair of pigs on the high calcium and phosphorus treatment.
2. Inorganic phosphorus concentrations were significantly higher in the hair from pigs on the high calcium and

phosphorus treatment in two of the three samples collected.

3. There was significantly less zinc in the red hair of pigs on the high calcium and phosphorus treatment in one of the three samples collected.
4. Calcium concentrations were the highest of the minerals studied in the hair.
5. Black hair contained a greater concentration of calcium and magnesium than did red hair.
6. As the pigs got heavier, there was a trend for all the mineral studied to decrease in concentration.

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CHAPTER I

INTRODUCTION

It is recognized that minerals perform essential functions in the animal body and must be present in the diet. The proof that certain elements are essential rests upon experiments with one or more species. In these experiments, symptoms produced by diets deficient in a particular mineral have been prevented or overcome by adding that element to the diet. However, in many cases the symptoms are vague and non-specific, causing confusion as to what the problem is. The fact that diet influences the hair coat of an animal has long been recognized, but progress toward understanding how nutrition affects hair growth has been slow.

This experiment was conducted to study certain minerals in pig hair from birth to market and to determine if mineral content of hair is of value as an indicator of dietary mineral levels.

CHAPTER II

REVIEW OF LITERATURE

During the last few years a considerable amount of research has been done concerning calcium and phosphorus requirements of swine. Likewise, some research has been conducted concerning mineral deficiencies in animals and the ability to detect such deficiencies in hair. However, most of the research that has been conducted on minerals in hair has been done with zinc or zinc and calcium interactions in cattle or rats. Only limited information is available on high or low calcium and phosphorus levels and their effects on mineral levels in swine hair.

Calcium and Phosphorus Requirements

A review of the research on calcium and phosphorus indicates that there is still a great deal to learn on this subject. Several reports have shown that pigs will do well on levels of calcium and phosphorus below those recommended by NRC (National Research Council). Some indicated a decrease in daily gains and/or feed efficiency when calcium levels above 0.6% in the ration were fed. On the other hand, some workers have fed calcium and/or phosphorus levels above NRC recommendations without a decrease in daily gains or feed efficiency.

The type of ration fed and the level of many other nutrients in the ration are related to calcium and phosphorus requirements; and until those are understood, a satisfactory answer will not be available.

Miller et al. (1964) found that pigs receiving 0.2% phosphorus had a depressed growth rate, feed intake and mineral retention. An increase in dietary phosphorus to 0.5% resulted in an increased percent phosphorus retention. Dietary phosphorus levels below 0.5% reduced calcium retention; whereas, increasing phosphorus levels above 0.5% did not affect calcium balance. The calcium level was maintained at 0.8%.

Chapman et al. (1962) used a partial 6 x 7 factorial arrangement of treatments in conducting four trials on calcium and phosphorus requirements of growing-finishing pigs. Dietary levels of calcium and phosphorus ranged from 0.2 through 0.8%, and 0.2 through 0.7%, respectively. The dietary requirements to assure maximum rate of gain and optimum skeletal development were found to be 0.8% calcium and 0.6% phosphorus for pigs up to 45.5 kilograms, and 0.7% calcium and 0.5% phosphorus for pigs up to 90.9 kilograms.

Hansard et al. (1961) studied the absorption, excretion and utilization of radiocalcium by 42 pigs at different ages. Calcium absorption and retention were greatest in pigs 15 days old; absorption

decreased rapidly to 5 months, then slowly decreased to 12 months and decreased drastically in the older animals (30 to 72 months). Daily endogenous fecal calcium losses and requirements for maintenance increased with age to 5 months, and was extremely high in the aged animals. Although endogenous fecal calcium was relatively constant from 5 months to 6 years of age, the lowest level was in the youngest pigs; and the highest level was in the oldest pigs, indicating an age effect. The decreased digestibility and increased endogenous losses of calcium, with increasing age, resulted in increased maintenance requirements for older animals.

Combs and Wallace (1962) conducted a study in which a total of 202 pigs weaned at 2 weeks of age were used in five experiments to study the influence of varying levels of dietary calcium. In the three experiments where calcium levels of 0.40 and 0.88% were compared, the higher level depressed average daily gain; as did the ration containing 0.7% calcium in the fourth experiment. When calcium was increased from 0.40 to 0.80%, by increments of 0.1%, feed efficiency was best with the low calcium level.

Combs et al. (1966), working with 72 pigs weighing approximately 4.5 kilograms at two weeks of age, investigated the vitamin D-calcium-phosphorus interrelationship. When the level of calcium was increased from 0.48% to 0.88%, and to 1.32% in the ration, daily gains and feed efficiency decreased significantly.

High dietary levels of calcium have been associated with parakeratosis in swine. Newland et al. (1958) observed that one of the first reactions of pigs fed a high calcium diet was a loss of appetite, followed by a return to normal when the diet was supplemented with zinc. In their study it was found that even though energy intake was the same for all treatments, supplemental zinc improved weight gains and feed efficiency and prevented dermatosis in pigs fed high calcium diets.

Zimmerman et al. (1963) conducted a study to determine the optimum levels of calcium and phosphorus for maximum daily gains, feed efficiency and metatarsal calcification of swine 2 to 7 weeks of age. Low phosphorus levels and high calcium levels in the ration slowed daily gains. Calcium:phosphorus ratios of 1.6:1.0 or wider, adversely affected gains. Feed efficiency appeared to be independently affected by calcium and phosphorus. The highest levels of calcium (1.0%) and phosphorus (0.7%) in the ration produced the maximum metatarsal calcification; however, the largest increments of response came between the lower levels, especially with phosphorus. Zimmerman et al. (1963) suggested a maximum calcium level of 0.8% and a minimum phosphorus level of 0.6%.

Minerals in Hair

In a review of the effect of diet on hair growth, Flesch (1954) stated that impaired growth or loss of hair is a common and early non-specific response to many nutritional deficiencies of animals. However, a deficiency of vitamins and/or minerals are two deficiencies which seem to have a specific effect on hair growth.

The National Research Council recommends that the following minerals be added to growing-finishing swine rations: calcium, phosphorus, cobalt, iodine, iron, copper, magnesium, manganese, potassium, selenium, sodium, chlorine and zinc. A deficiency of certain of these minerals has been shown to have a specific effect on hair growth.

Marston (1946) showed that a deficiency of copper, apart from causing loss of pigment in hair and wool, caused sheep to produce wool that lacked in waviness or crimp. With the addition of copper to the diet, the wool was restored to normal growth and crimp.

Only a limited amount of work has been conducted to study the value of hair as an indicator of mineral levels in the animal. Hidiroglou et al. (1963) conducted a study to compare the selenium content of cattle hair with the incidence of muscular dystrophy of calves. Calves sick or dead from the disease were born to cows with low selenium content of the hair (range 0.06 to 0.23 ppm).

White muscle disease was not observed in calves from cows having a selenium content of the hair above 0.25 ppm. Hidioglou et al. (1963) stated that "the selenium of the hair may be a helpful factor in diagnosing white muscle disease."

Lewis et al. (1957) reported that zinc content of swine hair is markedly affected by dietary zinc. They found that pigs fed 0.8% and 1.2% calcium developed severe parakeratosis, while supplementation of the 0.8% level with 100 ppm of zinc gave the pigs excellent protection. When the calcium content of the ration was decreased from 1.2% to 0.8% or 0.5%, there was a significant increase in the zinc content of the hair.

Reinhold et al. (1968) showed that hair from rats fed diets nearly depleted of zinc-- 2 ppm-- was substantially lowered in its zinc concentration as compared to the controls. The lowered zinc concentration occurred with greater frequency than decreased growth rates. Some rats with greatly decreased zinc in the hair maintained growth rates comparable to those of the paired-fed controls which received 20 ppm of zinc in the ration. It was also shown that when the controls were fed diets containing 30 ppm of zinc, the concentration of zinc in the hair rose substantially. They found that lowered zinc concentrations in the hair of zinc depleted rats were associated with higher calcium concentrations. It was postulated that a competition between zinc and calcium for certain chemical groupings in

hair may exist. Reinhold et al. (1968) concluded that the concentration of zinc in hair depends mainly on the quantity of zinc in the diet, but that it does not define the state of nutrition.

Miller et al. (1965) and Perry et al. (1968) found that the level of zinc in the hair of cattle was influenced by the level of zinc in their diets. Perry et al. (1968) found a significant relationship between increased levels of zinc in the diet and increased concentrations of zinc in hair. Level of zinc in the hair and rate of gain had no noticable relationship. By doubling the amount of calcium in the diet, the concentration of zinc in the hair was significantly lowered. Miller et al. (1965) found that hair from zinc-deficient calves contained less zinc than from those given adequate zinc. When the groups were fed an adequate diet, the differences disappeared.

Miller et al. (1965) found that in Holsteins the descending order of zinc content in hair was white tail, black body and white body. O'Mary et al. (1969) found that color did not significantly affect zinc content in Hereford cattle hair. Miller et al. (1965) stated that the distal and proximal ends of hair contained the same amounts of zinc. However, they found that hair from the neck and rib regions tended to have more zinc than hair from the leg regions. O'Mary et al. (1969), in comparing red hair from the face with red hair from the rump area in two Hereford calves, found no difference in the mineral content of the two locations. Zacherl and Weiser

(1963), in a study using four animals, showed that hair from the tail contained more magnesium than hair from other parts of the body; whereas, zinc was uniformly distributed.

Washburn et al. (1954) and O'Mary et al. (1969) found the percent ash was higher in red hair than in white hair. O'Mary et al. (1969) found that percent ash in Hereford's ranged from 1.15 to 1.32% and from 0.29 to 0.42% for red and white hair, respectively. Washburn et al. (1953) found that percent ash in Guernsey cattle hair to be 3.3 and 1.8% for red and white, respectively. The values for Guernsey's, while larger than those for Hereford's, are in the same direction with respect to color differences.

Miller et al. (1965) in studying the zinc content of hair reported that hair from five month old calves had more zinc than did hair from young or old cows which were not different. O'Mary et al. (1969) found that calves' hair had higher amounts of sodium, calcium, copper and potassium, but lower amounts of manganese and iron than the hair of older cattle. These data may have been influenced by differences in requirements.

O'Mary et al. (1969) in their study of nine minerals -- sodium, copper, zinc, calcium, phosphorus, magnesium, manganese, iron and potassium -- found the largest variation in mineral content was due to season. Red and white hair samples were taken from Hereford

cows and calves in August and March. Highly significant differences were found between seasons in seven of the nine minerals studied: In August, the hair contained larger amounts of sodium, copper, calcium, magnesium, manganese and potassium when compared to the samples collected in March; hair collected in March had a higher content of iron.

Red hair had a higher percent ash and a larger content of calcium, phosphorus, magnesium, manganese, iron and potassium; but less copper than white hair. Hair from cows and calves differed in that calves had more sodium, calcium, copper and potassium, but less manganese and iron.

CHAPTER III

EXPERIMENTAL PROCEDURE

Source of Data

The data used in this trial was collected from the purebred Duroc and Hampshire herds at the Tennessee Agricultural Experiment Station, Main Station, Knoxville. This study included eleven sows and litters during the nursing period, and forty-eight pigs during the growing-finishing period, from the June, 1968 farrowing.

Herd Management

During the gestation period, sows and gilts were kept on pasture and fed in individual stalls. Gilts were fed to gain approximately 45 kilograms and sows 27 to 32 kilograms. When the sows and gilts were brought to the farrowing barn -- approximately 3 days pre-farrowing -- they were washed and disinfected with organic iodine solution, wormed with piperazine, and then placed in farrowing stalls. For two to three days prior to farrowing, the sows and gilts were fed a ration high in fiber to aid in preventing udder problems and constipation. After farrowing, the sows were fed a ration of approximately 2.2 kilograms daily; the ration being gradually increased so that they received 2.6 to 4.4 kilograms daily.

Pig Management

Within twelve hours after birth, pigs were weighed, ear notched and the needle teeth were clipped. To prevent anemia, one milliliter of iron dextrin, containing 100 milligrams of iron, was injected intramuscularly four days after birth. All male pigs were castrated at three to five weeks of age.

Pretrial Treatment

During the nursing period sows and litters were placed on half-acre lots with access to portable type housing and automatic waterers; or were put on concrete in confinement pens also equipped with an automatic waterer.

Pigs were weaned between the 54th and 58th day of age. After an adjustment period of approximately seven days, the pigs were weighed and assigned to a treatment group.

The pigs assigned to the four treatments were placed on concrete platforms equipped with an automatic waterer, self feeder and portable housing for shelter. All pigs were wormed with piperazine in the feed at the start of the experiment and again three weeks later.

Assignment to Treatment

Forty-eight Duroc and Hampshire pigs were assigned to the experiment on the seventh day after weaning. The pigs were

individually weighed and assigned to a treatment on the basis of breed and weight.

Each of the four treatment groups consisting of four Duroc and two Hampshire pigs, were then randomly assigned to the following treatments:

- I. Control
- II. Control with high level of calcium and phosphorus
- III. Control with low level of calcium and phosphorus
- IV. Control minus trace mineral premix

Rations

The ration fed to sows during lactation is listed in Table I. The experimental rations for the four treatments are listed in Table II. The control ration with high calcium and phosphorus was calculated to be approximately twice NRC recommendations for calcium and phosphorus. The control with low calcium and phosphorus was calculated to be approximately one-half NRC recommendations. The control less trace mineral premix treatment, upon analysis, proved to contain trace minerals in amounts which met NRC recommendations (Table III). The 16% protein ration was fed until the pigs in each lot averaged 56.9 kilograms; then changed to the 14% protein ration which was fed until the end of the experiment.

TABLE I

RATION FED TO LACTATING SOWS

Ingredients	Amount in Pounds
Ground yellow corn, dent No. 2	730
Soybean oil meal (44%)	100
Dehydrated alfalfa meal (17%)	100
Tankage (50%)	50
Defluorinated rock phosphate ^a	14
Salt	5
Trace mineral premix ^b	1
Vitamin premix ^c	1

^a Guaranteed analysis of defluorinated rock phosphate:

Phosphorus	minimum	18.50%
Calcium	maximum	24.00%
Calcium	minimum	20.00%
Fluorine	maximum	0.185%

^b Guaranteed analysis of trace mineral premix:

Manganese	minimum	10.00%
Iron	minimum	10.00%
Calcium	maximum	11.00%
Calcium	minimum	9.00%
Copper	minimum	1.00%
Zinc	minimum	10.00%
Iodine	minimum	0.30%
Cobalt	minimum	0.10%

TABLE I (CONTINUED)

^cGuaranteed vitamin premix per pound:

Riboflavin	8,000 milligrams
d-Pantothenic acid	14,720 milligrams
(equivalent to 16,000 milligrams calcium pantothenate dextrorotatory)	
Niacin	36,000 milligrams
Choline chloride	40,000 milligrams

TABLE II

EXPERIMENTAL RATIONS

	Control	Control Less Trace Mineral Premix	Control With High Calcium and Phosphorus	Control with Low Calcium and Phosphorus
Ground yellow corn, dent No. 2	771	772	746	781
Soybean oil meal (44%)	200	200	195	203
Dicalcium phosphate ^a	10	10	40	7
Ground limestone ^b	10	10	10	---
Salt	5	5	5	5
Trace mineral premix ^c	1	---	1	1
Vitamin premix ^d	2	2	2	2
Antibiotic ^e	1	1	1	1
Approximate Protein	16%	16%	16%	16%
Approximate Calcium	0.70%	0.70%	1.34%	0.35%
Approximate Phosphorus	0.53%	0.53%	1.10%	0.35%

TABLE II (CONTINUED)

	Control	Control Less Trace Mineral Premix	Control with High Calcium and Phosphorus	Control with Low Calcium and Phosphorus
Ground yellow	821	822	796	831
Soybean oil meal (44%)	150	150	145	153
Dicalcium phosphate ^a	10	10	40	---
Ground limestone ^b	10	10	10	7
Salt	5	5	5	5
Trace mineral premix ^c	1	---	1	1
Vitamin premix ^d	2	2	2	2
Antibiotic ^e	1	1	1	1
Approximate Protein	14%	14%	14%	14%
Approximate Calcium	0.69%	0.69%	1.33%	0.34%
Approximate Phosphorus	0.51%	0.51%	1.05%	0.33%

TABLE II (CONTINUED)

^aGuaranteed analysis of dicalcium phosphate:

Calcium minimum 20.00%
 Calcium maximum 24.00%
 Phosphorus minimum 18.50%

^bGuaranteed analysis of ground limestone:

Calcium minimum 36.00%

^cGuaranteed analysis of trace mineral premix:

Manganese minimum 10.00%
 Iron minimum 10.00%
 Calcium maximum 11.00%
 Calcium minimum 1.00%
 Zinc minimum 10.00%
 Iodine minimum 0.30%
 Cobalt minimum 0.10%

^dGuaranteed vitamin premix per pound:

Riboflavin 8,000 milligrams
 d-Pantothenic acid 14,720 milligrams
 Niacin 36,000 milligrams
 Choline chloride 40,000 milligrams

^eGuaranteed antibiotic per pound:

Chlortetracycline 20 grams

TABLE III

MINERAL COMPOSITION OF THE EXPERIMENTAL RATIONS^a

	Control	Control Less Trace Mineral Premix	Control with High Calcium and Phosphorus	Control with Low Calcium and Phosphorus
Ash, %	4.64	4.64	7.10	3.55
Calcium, mg/100 g	641	641	1215	409
Inorganic phosphorus, mg/100 g	202	202	236	174
Magnesium, mg/100 g	170	155	192	166
Iron, ppm	434	300	550	344
Zinc, ppm	139	355	139	139
Copper, ppm	26	24	26	26

^aAverage of four samples, two each from a 16% and 14% batch of mixed feed.

The self feeders were checked daily and filled when necessary. Records were kept on the feed consumption of each pen.

Hair Collection

Hair samples were collected from sows and pigs within 24 hours after farrowing and at weaning (54-to-58 days of age). Samples were collected from the experimentally fed pigs at 45.5, 68.3 and 91.0 kilograms.

Hair samples from the pigs were collected on a litter basis at both the farrowing and weaning periods. Hair was obtained by clipping the entire body of new-born pigs with hand operated hair clippers and was stored in glass bottles at 40°F for mineral analysis. At weaning, a hair sample was collected on a litter basis from all pigs in a litter from an area bounded by approximately the third and tenth ribs. Hair samples from the sows were collected and both farrowing and weaning from approximately the same area.

Hair samples were collected from the experimentally fed pigs when each pig weighed 45.5, 68.3 and 91.0 kilograms $\pm$ 2.3 kilograms. Samples were taken from an area approximately between the third and tenth ribs. A red sample was collected from each Duroc pig, and a black sample from each Hampshire pig. Samples were stored in plastic storage bags under refrigeration (40°F) for mineral analysis.

Laboratory Analysis

The hair samples were washed and ashed using the procedure of O'Mary et al. (1969). The clipped sample was thoroughly washed using a non-mineral detergent, then rinsed in deionized-distilled water until the filter appeared clean.

The hair and feed samples were analyzed for calcium, copper, iron, zinc and magnesium by atomic absorption spectrophotometry using a Perkin-Elmer Model 303 with a standard burner head and air-acetylene flame. Absorption was measured at 2110, 3247, 2493, 2147 and 2856 angstroms for calcium, copper, iron, zinc and magnesium, respectively. Concentrations were determined by comparison with the appropriate standard readings.

Ash samples were dissolved in 5 milliliters of 6N hydrochloric acid. One milliliter of this solution was then diluted in precalibrated test tubes with deionized, distilled water. The final dilution of the hair and feed samples varied from 50-to-500 and 100-to-1,000 respectively, depending on the concentration of the elements and the detection limits for that element. A 5% lanthanum oxide (La_2O_3) solution was included to maintain the lanthanum concentration between 500 and 10,000 ppm in the final dilution. This was to prevent phosphate interference with calcium and magnesium. All other conditions were as described by Perkin-Elmer (1967).

Inorganic phosphorus was determined in all ashed samples by the colorimetric method of Boltz and Mellon (1948), and Fiske and Subbarow (1925), using a Beckman Spectronic 20.

Analysis of Data

Records were compiled on pig weights at allotting and every week thereafter until the pigs weighed 91.0 kilograms. Feed consumption records were maintained on a pen basis. Mineral concentrations of hair were recorded and summarized for pigs at farrowing and weaning and at 45.5, 68.3 and 91.0 kilograms. Analysis of variance as described by Snedecor (1956) were used to evaluate hair mineral concentrations of sows and pigs at farrowing and weaning, and treatment differences in rate of gain, feed efficiency and hair mineral concentrations of the experimental pigs at 45.5, 68.3 and 91.0 kilograms.

In the discussion of the results in this thesis, significant and highly significant refer to the 5% and 1% level of probability, respectively.

CHAPTER IV

RESULTS AND DISCUSSION

Sow Hair at Farrowing and Weaning

Hair samples were collected from eleven Duroc sows (1) at the time they farrowed (June), and (2) at 56 days $\pm$ 2 days post-farrowing -- at the time their pigs were weaned (August). The hair was analyzed for calcium, inorganic phosphorus, magnesium, zinc, iron and copper.

The results of this study are shown in Table IV. Calcium and copper content decreased rather drastically from farrowing to weaning, while phosphorus, magnesium and iron concentrations increased. Zinc content remained constant for the two collections.

The calcium content varied over a wide range at both the farrowing and weaning collection periods; varying from 491-to-2,485 ppm at farrowing, and from 451-to-1,093 at the 56 day post-farrowing collection. However, the means were highly significantly different: being 1,392 and 753 ppm at farrowing and weaning, respectively.

TABLE IV

CALCIUM, INOREANIC, PHOSPHORUS, MAGNESIUM, ZINC, IRON AND COPPER
CONCENTRATION IN PPM OF SOW HAIR AT FARROWING AND WEANING

Sow No.	Calcium		Inorganic Phosphorus		Magnesium		Zinc		Iron		Cooper	
	F.	W.	F.	W.	F.	W.	F.	W.	F.	W.	F.	W.
51-1	793	1109	36	138	86	1146	201	179	243	327	17	4
51-3	491	515	27	82	48	443	181	172	243	337	20	2
54-3	1282	891	26	73	148	627	162	158	294	310	18	2
42-3	1138	451	45	104	150	348	159	156	299	277	17	2
13-2	2485	635	36	65	302	363	258	243	394	901	17	2
57-9	1448	1093	45	105	187	901	199	191	299	500	17	2
49-5	1138	987	15	156	122	1046	158	183	248	495	14	3
49-4	1646	619	9	160	206	773	169	175	395	1010	14	2

TABLE IV (CONTINUED)

Sow No.	Calcium		Inorganic Phosphorus		Magnesium		Zinc		Iron		Cooper	
	F.	W.	F.	W.	F.	W.	F.	W.	F.	W.	F.	W.
8-4	2440	530	27	113	358	441	150	172	333	455	14	2
43-4	1060	702	45	74	143	660	189	188	311	337	8	3
X	1392*	753*	31*	107*	175*	675*	182	183	306*	495*	15.6*	2.4*

F. = Farrowing samples taken from Duroc sows in June, 1968, within 24 hours after farrowing.

W. = Weaning samples taken from Duroc sows in August, 1968, at 56 days ⁺ 2 days post-farrowing.

* Denotes samples - within minerals - differ at the 1% level of probability.

Copper content in hair was highly significantly decreased from an average of 15.6-to-2.4 ppm at farrowing and weaning, respectively. The variation within the collection periods was rather small, and the differences between periods were rather large.

The mean zinc content in hair was constant for both collection times. The phosphorus content increased significantly to weaning -- 31 versus 107 ppm -- as did the iron concentration -- 306 versus 495 ppm.

The magnesium concentration increased significantly from farrowing to weaning. The mean values were 175 and 675 ppm at farrowing and weaning, respectively. This is contrary to the report of Hennig (1966), who reported that magnesium content of sow hair decreased during lactation. The variations among samples were quite large; ranging from 48-to-358 ppm at farrowing, and from 348-to-1,146 ppm at weaning.

Pig Hair at Farrowing and Weaning

Hair samples from the pigs were collected on a litter basis at birth and weaning, which were June and August (54 to 58 days of age), respectively. The hair was analyzed for calcium, inorganic phosphorus, magnesium, zinc, iron and copper. The results of this study are shown in Table V. Calcium was the only mineral

TABLE V

CALCIUM, INORGANIC, MAGNESIUM, ZINC, IRON AND COPPER CONCENTRATION
IN PPM OF PIG HAIR AT BIRTH AND WEANING

Litter No.	Calcium		Inorganic Phosphorus		Magnesium		Zinc		Iron		Copper	
	B.	W.	B.	W.	B.	W.	B.	W.	B.	W.	B.	W.
22	198	1552	427	160	214	229	635	182	1458	366	48	3
23	507	1682	252	190	481	300	522	168	781	328	81	3
26	403	1682	263	120	33	231	557	194	729	796	75	2
28	312	1210	270	100	194	124	500	141	695	392	39	1
30	376	1244	177	240	222	127	314	158	542	150	56	1
31	351	1367	202	184	216	262	290	168	385	150	42	1
33	536	1025	203	160	363	165	234	160	307	150	34	1

TABLE V (CONTINUED)

Litter No.	Calcium		Inorganic Phosphorus		Magnesium		Zinc		Iron		Copper	
	B.	W.	B.	W.	B.	W.	B.	W.	B.	W.	B.	W.
38	373	1490	124	184	211	235	251	164	406	150	37	1
39	385	1210	174	140	396	218	334	176	638	150	51	1
40	135	1401	77	160	79	277	147	173	218	344	21	3
41	288	2283	160	160	279	300	231	167	242	984	27	3
X	351**	1468**	212*	163*	244	224	365**	168**	582**	360**	46.5**	1.8**

B = Birth samples taken from Duroc pigs in June, 1968, within 24 hours after birth.

W = Weaning samples taken from Duroc pigs in August, 1968, at 56 days⁺ - 2 days of age.

* Denotes samples - within minerals - differ at the 5% level of probability.

** Denotes samples - within minerals - differ at the 1% level of probability.

that increased in concentration from birth to weaning. The mean values were 351 and 1,468 ppm at birth and weaning, respectively, and were highly significantly different. Phosphorus and magnesium content decreased significantly between the two periods, while magnesium concentration was not significantly different. The zinc content decreased from 365-to-168 ppm, and the iron content decreased from 582-to-260 ppm, from birth to weaning, respectively. These differences were highly significant. However, copper showed the most drastic decrease, going from an average of 46.5-to-1.8 ppm at birth and weaning, respectively. There was a great deal of variation in copper concentration at birth -- varying from 21-to-81 ppm -- but practically no difference at weaning -- 1-to-3 ppm. This was similar to the results found in the hair of the sows; with the decrease in the sow's hair not being quite so drastic.

Sow Versus Pig Hair at Farrowing and Weaning

Mean mineral concentrations of sow and pig hair at farrowing and weaning are presented in Table VI. Mean values of inorganic phosphorus, magnesium and iron increased in sow hair, but decreased in pig hair. Inorganic phosphorus concentration increased from 31-to-107 ppm in sow hair, and decreased from 212-to-163 ppm in the pig hair. Magnesium increased from 175-to-675 ppm and decreased from 244-to-224 ppm in the sow and pig

TABLE VI

MEAN CALCIUM, INORGANIC PHOSPHORUS, MAGNESIUM,
ZINC, IRON AND COPPER CONCENTRATIONS IN PPM OF SOW
AND PIG HAIR AT FARROWING AND WEANING ^a

	Sows	Pigs
Calcium		
Farrowing	1392	351
Weaning	753	1468
Inorganic Phosphorus		
Farrowing	31	212
Weaning	107	163
Magnesium		
Farrowing	175	244
Weaning	675	224
Zinc		
Farrowing	182	365
Weaning	183	168
Iron		
Farrowing	306	582
Weaning	495	360
Copper		
Farrowing	15.6	46.5
Weaning	2.4	1.8

^a Hair samples were taken within 24 hours after farrowing and 56 days [±] 2 days post-farrowing.

hair, respectively. Iron increased from 306-to-495 ppm in the sow hair and decreased from 582-to-360 ppm in the pig hair at farrowing and weaning, respectively. Calcium concentration in the sow hair decreased from 1,392-to-753 ppm, while it increased in the pig hair from 351-to-1,468 ppm. Zinc content remained constant in the sow hair for the two periods, but decreased from 365-to-168 ppm in the pig hair. Copper concentration decreased rather drastically in both sow and pig hair from farrowing to weaning. It decreased from 15.6-to-2.4 and from 46.5-to-1.8 in the sow and pig hair, respectively.

Pig Hair from Birth to Market

Mean calcium, inorganic phosphorus, magnesium, zinc, iron and copper levels in the hair of Duroc pigs from birth to market are shown in Table VII. Hair samples were collected on a litter basis at birth and weaning (56 days $\pm$ 2 days); and on an individual basis from the pigs fed the control ration (Table II) at 45.5, 68.3 and 91.0 kilograms.

Calcium increased dramatically from birth to weaning (351-to-1,468 ppm), remained rather constant to 45.5 kilograms, and then decreased to market weight. Inorganic phosphorus and magnesium decreased from birth to weaning -- 212-to-163 ppm

TABLE VII

MEAN CALCIUM, INORGANIC PHOSPHORUS, MAGNESIUM, ZINC,
IRON AND COPPER CONCENTRATION IN PPM OF PIG HAIR FROM BIRTH TO MARKET

Hair Collections	Birth ^a	Weaning ^b	45.5 kg ^c	68.3 kg ^c	91.0 kg ^c
Calcium	351	1468	1432	918	535
Inorganic Phosphorus	212	163	161	151	104
Magnesium	244	224	229	152	105
Zinc	265	168	183	164	158
Iron	582	360	121	101	98
Copper	46.5	1.8	17	12	12

^aSamples taken on a litter basis within 24 hours after birth.

^bSamples taken on a litter basis 56 days $\pm$ 2 days of age.

^cSamples taken at the respective weight from Duroc pigs fed the control ration listed in Table II.

and 244-to-224 ppm, respectively -- remained constant between weaning and 45.5 kilograms, then decreased to market weight. Zinc concentration decreased from birth to weaning (365-to-168 ppm), slightly increased at 45.5 kilograms, and then decreased slowly to market weight. Iron content decreased markedly from birth to weaning and from weaning to 45.5 kilograms (582, 360 and 121 ppm, respectively), and then decreased slowly to market weight. Copper values decreased drastically from birth to weaning (46.5-to-1.8 ppm), then increased greatly at 45.5 kilograms and remained constant between 68.3 and 91.0 kilograms.

Hair from Experimental Pigs

Hair samples were collected from pigs at 45.5 kilograms (sample I), 68.3 kilograms (sample II) and 91.0 kilograms (sample III); and were analyzed for copper, iron, zinc, magnesium, inorganic phosphorus and calcium. Individual readings were pooled within color, and within treatment for statistical analysis. Duncan's multiple range as described by Steel and Torrie (1960) was used to evaluate treatment differences in mineral content of hair.

Copper

Treatment differences in copper concentration of hair were not significant in the red or black samples at any of the three collection periods (Table VIII). Both red and black samples tended to have a higher concentration of copper at period I than at either of the other two periods. Anke (1967) indicated a mean value of 7.8 ppm of copper in 671 samples of black hair from dairy cattle; while O'Mary et al. (1969) reported a mean value of 10-14 ppm of copper in red hair samples from Hereford cattle. The values reported here were higher than those reported by Anke (1967), and higher than those reported by O'Mary (1969) for sample I (taken at 45.5 kg). However, samples II (taken at 68.3 kg) and III (taken at 91.0 kg) were within the range reported by O'Mary (1969).

Iron

No definite pattern was observed in iron concentrations of hair between the various treatments (Table IX). The red hair collected as sample I from the high calcium and phosphorus fed pigs was significantly lower in iron than that of the various other treatments. However, in sample II the hair from the pigs on high calcium and phosphorus treatment was significantly higher in iron content than the other treatments. Sample I of the black hair was

TABLE VIII

TREATMENT EFFECT IN PPM ON COPPER CONCENTRATIONS
OF RED AND BLACK HAIR

Treatment	Control	High Ca-P	Low Ca-P	Control Less Trace Mineral Premix
No. of Animals	12	12	12	12
No. of Duroc Pigs (Red Samples)	8	8	8	8
No. of Hampshire Pigs (Black Samples)	4	4	4	4
<u>Copper Concentration, ppm</u>				
Red Hair ^a				
Sample I	17	19	19	17
Sample II	12	13	14	11
Sample III	12	14	13	14

TABLE VIII (CONTINUED)

Treatment	Control	High Ca-P	Low Ca-P	Control Less Trace Mineral Premix
<u>Copper Concentration, ppm</u>				
Black Hair ^a				
Sample I	19	20	15	22
Sample II	12	13	14	12
Sample III	12	12	10	14

^aHair samples were taken when the pigs weighed 45.5 kg (Sample I), 68.3 kg (Sample II) and 91.0 kg (Sample III).

TABLE IX

TREATMENT EFFECT IN PPM ON IRON CONCENTRATION
OF RED AND BLACK HAIR

Treatment	Control	High Ca-P	Low Ca-P	Control Less Trace Mineral Premix
No. of Animals	12	12	12	12
No. of Duroc Pigs (Red Samples)	8	8	8	8
No. of Hampshire Pigs (Black Samples)	4	4	4	4
<u>Iron Concentration, ppm</u>				
Red Hair ^c				
Sample I	121 ^a	91 ^b	134 ^a	139 ^a
Sample II	101 ^a	148 ^b	117 ^a	111 ^a
Sample III	98	78	100	98

TABLE IX (CONTINUED)

Treatment	Control	High Ca-P	Low Ca-P	Control Less Trace Mineral Premix
<u>Iron Concentration, ppm</u>				
Black Hair ^c				
Sample I	151 ^a	148 ^a	145 ^a	198 ^b
Sample II	143	162	130	193
Sample III	125	88	102	110

a, b Means on the same line, with the same superscript, do not differ significantly.
All others with different superscripts differ at the 5% level of probability.

^c Hair samples were taken when the pigs weighed 45.5 kg (Sample I), 68.3 kg (Sample II) and 91.0 kg (Sample III).

significantly higher in iron than the hair from pigs fed the other three experimental rations. The second sample of red hair and the second and third samples of black hair showed no significant differences between treatments. Generally, there was a trend to decreased iron concentrations as the pigs got heavier. The exception was in the high calcium and phosphorus treatment in which the red and black hair increased in iron content between the first and second periods.

Zinc

There were no significant differences in zinc concentration in red or black hair for samples I and II (Table X). However, in sample III there was significantly less zinc in the red hair of pigs fed the high level of calcium and phosphorus than for the controls and those fed a low level of calcium and phosphorus. This agrees with the reports of Lewis et al. (1957), Miller et al. (1965), Hennig (1966), Perry et al. (1968) and Reinhold et al. (1968). They found that zinc concentrations in hair was markedly reduced by high levels of calcium. However, no significant difference was found in zinc concentration of black hair for the various treatments in sample III.

TABLE X

TREATMENT EFFECT IN PPM ON ZINC CONCENTRATION
OF RED AND BLACK HAIR

Treatment	Control	High Ca-P	Low Ca-P	Control Less Trace Mineral Premix
No. of Animals	12	12	12	12
No. of Duroc Pigs (Red Samples)	8	8	8	8
No. of Hampshire Pigs (Black Samples)	4	4	4	4
<u>Zinc Concentration, ppm</u>				
Red Hair ^c				
Sample I	183	185	198	194
Sample II	164	173	162	144
Sample III	158 ^a	139 ^b	158 ^a	150 ^{a, b}

TABLE X (CONTINUED)

Treatment	Control	High Ca-P	Low Ca-P	Control Less Trace Mineral Premix
<u>Zinc Concentration, ppm</u>				
Black Hair ^c				
Sample I	189	184	189	204
Sample II	159	168	161	143
Sample III	132	141	124	143

a, b Means on the same line, with the same superscript, do not differ significantly. All others with different superscripts differ at the 5% level of probability.

^c Hair samples were taken when the pigs weighed 45.5 kg (Sample I), 68.3 kg (Sample II) and 91.0 kg (Sample III).

O'Mary et al. (1969) reported a mean zinc concentration of 131-to-139 ppm in the red hair of Hereford cattle. This study indicated that the zinc concentration of red hair from pigs-144-to-198 ppm-is much higher than that reported for cattle by O'Mary et al. (1969).

Even though zinc content of the ration was lower in the control less trace mineral premix treatment -- 55 ppm versus 139 ppm for the other three treatments -- zinc content was not reduced in the hair. This is contrary to the reports of Miller et al. (1965), Perry et al. (1968) and Reinhold et al. (1968), who found that the level of zinc in the hair was influenced by the level of zinc in the diet. It should be pointed out, however, that even though the zinc content of the control less trace mineral premix treatment was markedly lower than that of the other treatments, it met NRC recommendations.

Magnesium

In these trials high levels of calcium and phosphorus in the diet reduced the magnesium content of the hair markedly (Table XI). The magnesium concentration of the red hair for all three samples was significantly lower for the pigs fed the high calcium and phosphorus ration than for any other treatment. Also, in red hair the magnesium concentrations of the controls

TABLE XI

TREATMENT EFFECT IN PPM ON MAGNESIUM CONCENTRATION
OF RED AND BLACK HAIR

Treatment	Control	High Ca-P	Low Ca-P	Control Less Trace Mineral Premix
No. of Animals	12	12	12	12
No. of Duroc Pigs (Red Samples)	8	8	8	8
No. of Hampshire Pigs (Black Samples)	4	4	4	4
<u>Magnesium Concentration, ppm</u>				
Red Hair ^d				
Sample I	229 ^a	94 ^c	279 ^a	170 ^b
Sample II	152 ^a	69 ^c	140 ^a	107 ^b
Sample III	105 ^a	47 ^b	101 ^a	98 ^a

TABLE XI (CONTINUED)

Treatment	Control	High Ca-P	Low Ca-P	Control Less Trace Mineral Premix
<u>Magnesium Concentration, ppm</u>				
Black Hair ^d				
Sample I	580	440	631	579
Sample II	494	384	468	490
Sample III	340 ^b	268 ^c	345 ^b	414 ^a

a, b, c Means on the same line, with the same superscript, do not differ significantly.
All others with different superscripts differ at the 5% level of probability.

d Hair samples were taken when the pigs weighed 45.5 kg (Sample I), 68.3 kg (Sample II) and 91.0 kg (Sample III).

and the low calcium and phosphorus treatments were significantly higher than that of the control less trace mineral premix in samples I and II.

There were no significant differences due to treatment for sample I or II in magnesium content of black hair. However, for sample III, the magnesium content was significantly lower in the hair from pigs fed the high calcium and phosphorus ration when compared to the treatments. The hair from the control and low calcium and phosphorus treatments were significantly lower than the control less trace mineral treatment in magnesium concentration. This is contrary to the findings of Hennig (1965), who reported that by supplementing the ration with calcium, magnesium content of sow hair was increased. There was a definite trend in both red and black hair and in all the treatments, for the magnesium level of decrease as the pigs got heavier.

The data indicates that there is considerably more magnesium in black hair than there is in red hair. This agrees with the report of Anke (1967), who reported a larger mean value of magnesium in the black hair of dairy cattle than the mean values on white and red hair.

Inorganic Phosphorus

The phosphorus content of red and black hair was significantly greater in the pigs fed a high level of calcium and phosphorus than for the other three treatments in sample I (Table XII). Sample II showed a significantly higher level of phosphorus in the red and black hair of pigs receiving the high calcium and phosphorus ration as compared to the pigs receiving the control and low calcium and phosphorus diet. The red hair samples of the high calcium and phosphorus fed pigs had a significantly higher amount of phosphorus than did the control less trace mineral premix fed pigs at sample II. However, this was not the case in the black samples. As the pigs got heavier, the variation in phosphorus content of the various treatments was progressively smaller. In sample III, there was no significant difference in phosphorus content of black hair from the pigs on any treatment. In the red hair, however, the pigs fed the control less trace mineral premix ration and the low calcium and phosphorus ration had a significantly higher concentration of phosphorus in the hair than did the controls.

Anke (1967) reported mean values for phosphorus in black hair from dairy cattle to range between 190-and-222 ppm. O'Mary et al. (1969) reported mean values of red hair from Hereford

TABLE XII

TREATMENT EFFECT IN PPM ON INORGANIC PHOSPHORUS CONCENTRATION
OF RED AND BLACK HAIR

Treatment	Control	High Ca-P	Low Ca-P	Control Less Trace Mineral Premix
No. of Animals	12	12	12	12
No. of Duroc Pigs (Red Samples)	8	8	8	8
No. of Hampshire Pigs (Black Samples)	4	4	4	4
<u>Inorganic Phosphorus, ppm</u>				
Red Hair ^c				
Sample I	161 ^a	229 ^b	168 ^a	162 ^a
Sample II	151 ^a	184 ^b	138 ^a	147 ^a
Sample III	104 ^a	122 ^b	130 ^{a, b}	142 ^b

TABLE XII (CONTINUED)

Treatment	Control	High Ca-P	Low Ca-P	Control Less Trace Mineral Premix
<u>Inorganic Phosphorus, ppm</u>				
Black Hair ^c				
Sample I	243 ^a	453 ^b	183 ^a	234 ^a
Sample II	227 ^a	318 ^b	186 ^a	266 ^{a, b}
Sample III	162	225	150	223

a, b Means on the same line, with the same superscript, do not differ significantly. All others with different superscripts differ at the 5% level of probability

^c Hair samples were taken when the pigs weighed 45.5 kg (Sample I), 68.3 kg (Sample II) and 91.0 kg (Sample III).

cattle to range between 145-to-165 ppm. The values presented in Table XII are somewhat higher or lower depending on treatment and sample number.

Calcium

There was a great deal of variation in calcium concentration of hair within treatments between treatments and between samples collected at the various weights (Table XIII). The data from this study indicate no apparent relationship between the ration and hair concentration of calcium. The data do show, however, that there is a much higher concentration of calcium in black hair as compared to red hair. As was the case with most of the other minerals studied; the calcium content of hair decreased markedly as the pigs got heavier.

O'Mary et al. (1969) found that the calcium content of Hereford hair was affected by the time of collection, color and age of the animal, with the differences being highly significant. Calcium values were higher in hair that was collected in March as compared to those collected in August, and were much higher in red hair than in white hair. Hair from calves had a higher concentration of calcium than that from cows.

TABLE XIII

TREATMENT EFFECT IN PPM ON CALCIUM CONCENTRATION
OF RED AND BLACK HAIR

Treatment	Control	High Ca-P	Low Ca-P	Control Less Trace Mineral Premix
No. of Animals	12	12	12	12
No. of Duroc Pigs (Red Samples)	8	8	8	8
No. of Hampshire Pigs (Black Samples)	4	4	4	4
<u>Calcium Concentration, ppm</u>				
Red Hair ^c				
Sample I	1432 ^a	1007 ^{a, b}	1290 ^{a, b}	924 ^b
Sample II	918	1217	985	882
Sample III	535	467	457	587

TABLE XIII (CONTINUED)

Treatment	Control	High Ca-P	Low Ca-P	Control Less Trace Mineral Premix
<u>Calcium Concentration, ppm</u>				
^c Black Hair				
Sample I	3674	3363	2190	1914
Sample II	2112	3049	2594	2865
Sample III	1524 ^a	1420 ^a	1456 ^a	1774 ^b

a, b Means on the same line, with the same superscript, do not differ significantly.

All others with different superscripts differ at the 5% level of probability.

^c Hair samples were taken when the pigs weighed 45.5 kg (Sample I), 68.3 kg (Sample II) and 91.0 kg (Sample III).

Performance of the Experimental Pigs

Between the pigs on the various treatment, there were no significant differences in either average daily gain or feed efficiency up to 45.5 kilograms, or between 45.5 and 91.0 kilograms. However, the pigs receiving the control less trace mineral premix ration had a significantly higher average daily gain as compared to the high and low calcium and phosphorus groups (Table XIV).

Feeding levels of calcium and phosphorus in excess of NRC recommendation (approximately twice the recommended level) or lower (approximately one-half the recommended level) tended to give lower daily gains and poorer feed efficiencies. The addition of trace minerals was not beneficial in these trials; as levels in the diet met NRC recommendations without the addition of the trace mineral premix.

TABLE XIV

EFFECT OF DIFFERENT LEVELS OF CALCIUM, PHOSPHORUS AND TRACE MINERALS
IN THE RATION ON THE PERFORMANCE OF GROWING-FINISHING PIGS

	Control	High Ca-P	Low Ca-P	Control Less Trace Mineral Premix
No. lots/treatment	2	2	2	2
No. pigs/lot	6	6	6	6
Average wt., kg.				
Initial	20.2	20.1	20.2	20.1
Final	92.2	91.4	90.6	91.8
Performance Start to 45.5 K kilograms				
Avg. daily gain, kg.	0.57	0.56	0.53	0.60
Feed/kg. gain	1.26	1.28	1.33	1.25
Performance Start to 91.0 K kilograms				
Avg. daily gain, kg.	0.67 ^{a, b}	0.64 ^a	0.65 ^a	0.72 ^b
Feed/kg. gain	1.48	1.59	1.54	1.50

TABLE XIV (CONTINUED)

	Control	High Ca-P	Low Ca-P	Control Less Trace Mineral Premix
	Performance Between 45.5 and 91.0 Kilograms			
Avg. daily gain, kg.	0.75	0.67	0.72	0.82
Feed/kg. gain	1.55	1.73	1.70	1.65

a, b Means on the same line with the same superscript do not differ significantly. All others with different superscripts differ at the 5% level of probability.

CHAPTER V

SUMMARY

This study was conducted to determine if mineral content in hair is of value as an indicator of the mineral nutrition of the pig. Eleven Duroc sows and ten Duroc litters were used from farrowing to weaning. Forty-eight Duroc and Hampshire pigs were allotted to the following treatments from weaning to market weight: (1) Control; (2) Control with a high level of calcium and phosphorus; (3) Control with a low level of calcium and phosphorus and (4) Control less trace mineral premix.

Hair samples were taken at farrowing and weaning (56 days $\pm$ 2 days post-farrowing) from the sows and litters; and were taken at 45.5 (sample I), 68.3 (sample II) and 91.0 kilograms (sample III) from the experimentally-fed pigs. The samples were analyzed for calcium, inorganic phosphorus, magnesium, zinc, iron and copper.

In this study calcium and copper concentrations in sow hair decreased significantly from farrowing to weaning, and inorganic phosphorus, magnesium and iron concentrations increased significantly, while zinc content did not change significantly.

The pig hair from farrowing to weaning decreased significantly in zinc, iron, copper and inorganic phosphorus concentrations. Calcium content increased significantly, while magnesium concentration was not significantly different between the two samples.

The following observations were made on the mineral concentrations of the hair from the experimentally-fed pigs:

1. In the hair from pigs fed the high calcium and phosphorus ration, magnesium levels were significantly lower as compared to the other treatments.
2. In the hair from pigs fed high levels of calcium and phosphorus, inorganic phosphorus concentration was significantly higher for samples I and II.
3. In the red hair of pigs fed the high calcium and phosphorus ration, there was significantly less zinc as compared to the other treatment in sample III.
4. Calcium concentrations in the hair were the highest the minerals studied. However, the data show no apparent connection between the ration and the hair concentration of calcium.
5. At any of the collection times, there were no significant differences in copper concentration between treatments in red or black hair.

6. There was no definite pattern in iron concentration between the various treatments.
7. Black hair contained a markedly higher concentration of calcium and magnesium than did the red hair.
8. As the pigs got heavier, there was a trend for all minerals studied to decreased in concentration in the hair.

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LITERATURE CITED

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