Macro-Minerals for Swine Diets

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Introduction

Minerals constitute a small percentage of swine diets, but their importance to growth, health, and productivity of the pig cannot be over-emphasized. Swine require 15 minerals in their diet and macro-minerals are the minerals that swine need in larger quantities, usually described for inclusion in percent of the diet. The macro-minerals are: calcium, phosphorus, sodium, chlorine, potassium, magnesium, and sulfur. About 5 percent of the total body weight of swine consists of minerals. Although these minerals are indigenous in most feed grains, some are at low concentrations in feedstuffs commonly used in swine diets. Consequently, it is essential that the diet be balanced using supplemental mineral sources. Minerals are essential for most of the basic metabolic reactions in the body and are an important factor in growth, reproduction, and resistance to diseases. They have a role in digestion; metabolism of protein, fats, and carbohydrates; and the structure of chromosomes, enzymes, nerves, blood, skeleton, hair and milk.

The efficiency of mineral absorption depends on concentration of that mineral in the diet, the mineral source and its availability, mineral to mineral interactions in the diet, and the mineral status of the animal. Most swine are housed in confinement today, so they depend primarily on their daily feed to supply needed mineral requirements. However, minerals should not be added to the diet haphazardly. Overuse can lead to serious consequences, including antagonistic interactions between minerals leading to potential deficiencies and impaired growth of the pig.

Objectives:

1. Provide background on the biological importance of macro-minerals for swine
2. Discuss the differences in dietary phosphorus recommendations
3. Present common sources of macro-minerals for swine diets

Calcium and Phosphorus

Calcium and phosphorus play an important role in the development and maintenance of the skeletal system, blood clotting, muscle contraction and many other regulatory functions. Calcium and phosphorus are the two most abundant minerals in the pig. In the pig 96-99% of the calcium and 60-80% of the body phosphorus is found in the skeletal system. These two minerals must be considered together when formulating diets based on the pig's requirements, as their ratio to each other can greatly affect their absorption and utilization in the body. The accumulation of calcium and phosphorus in bone is interdependent and one will not accumulate without the other. In bone, calcium and phosphorus are deposited in a 2.2:1 ratio [1,2].

A deficiency in calcium can result in improper bone formation, reduced bone strength, lameness, and under extreme deficiency, poor growth. In young pigs this deficiency can be observed as rickets. However, in mature swine, pigs will remove calcium from their bones when fed a deficient diet, weakening their bones. This is the most common cause of "downer" sows post-weaning. The sow depleted her bone reserves to meet milk production demands and consequently created bones that are brittle and break easy during the moving, mixing and fighting post-weaning [1,2].

The calcium content of corn, small grains and soybean meal is very low and requires swine diets to be supplemented with calcium in all phases of swine production. In the U.S., most of the pig's calcium requirement (50-75%) is typically met by feeding calcium carbonate (ground limestone). The remainder is typically met by supplemental phosphorus sources like mono- or di-calcium phosphate which contain a substantial amount of calcium (Table 1).

Phosphorus is required in the diet of pigs for proper skeletal growth and mineralization, as well as cellular functions. In the pig, approximately 75% of the phosphorus in the body is in the skeleton while 25% is in soft tissues. Phosphorus is found in every cell in the body serving in the energy system (ATP), cell structural components like phospholipids, phosphorylation sites for enzyme activation, and an initiation factor for protein synthesis [2]. The amount of phosphorus required for growth is less than the amount required for maximum bone development [1]. A dietary phosphorus deficiency has an immediate depressing effect on appetite, growth rate, and feed efficiency of swine [1,2].

In swine nutrition, phosphorus can be expressed in three different ways: total, bio-available, or digestible phosphorus. Total dietary phosphorus is the chemically analyzed amount of phosphorus in the diet, but does not provide any indication of the amount of phosphorus that is available to the pig for maintenance and growth. Many of the feedstuffs used in swine diets are of plant origin and the phosphorus in these ingredients is poorly digested by the pig. This is because the majority of phosphorus (60-90%) is bound in a phytic acid ring called phytate [3]. Pigs do not have the digestive enzyme, phytase, to remove the phosphorus from this structure and therefore this phytate phosphorus is unavailable to the pig. Commercial phytase is available for use in swine diets and is discussed in more detail in PIG Factsheet # 07-03-04 (Feed Additives for Swine – Enzymes and Phytase).

This effect of phytic acid phosphorus is best demonstrated by evaluating corn and soybean meal which have only 28 and 32% of the total phosphorus being digestible by the pig; the rest is bound as phytate phosphorus and is unavailable to the pig (PIG factsheet #07-07-09, Composition and Usage Rate of Feed Ingredients for Swine Diets). This is why total phosphorus should not be the only value to consider when evaluating whether the pig's phosphorus requirement is met. As a result of the poor digestibility of plant phosphorus, pork producers have traditionally had to add phosphorus-rich ingredients to the diet to ensure that the pig's phosphorus requirement is met. This approach is necessary, but costly and has potential consequences for the environment as undigested phosphorus passes through the pig and enriches manure with phosphorus. If manure is applied to crop land at excessive rates, phosphorus will accumulate in the soil and potentially lead to environmental issues (See factsheet 07-05-02; Managing nutrient excretion and odor in pork production through nutrition).

Digestible phosphorus is the value frequently utilized for diet formulation in the European pork industry. Digestible phosphorus is determined similar to other nutrients through a collection of feces or ileal digesta when a specific ingredient is fed. This allows for the determination of digestible phosphorus of a specific feed ingredient by difference between phosphorus intake and excretion in the feces. The use of digestible phosphorus in diet formulation will allow the industry to feed closer to the pig's phosphorus requirement. Relative bio-available phosphorus (also known as available phosphorus) values for feed ingredients and requirement estimates are more commonly used by most swine nutritionists in the United States. Relative bio-available phosphorus is determined based on a relative relationship to building bone ash or bone strength compared to an inorganic standard that was fed in that same experiment. Most relative bio-available phosphorus studies use monocalcium phosphate, dicalcium phosphate, or monosodium phosphate as the reference standard to which the feed ingredient's relative bio-availability is compared to. One challenge with the relative bio-available phosphorus system is that the phosphorus reference standard is assumed to be 100% digestible, but in reality these standards have between 76 and 92% digestible phosphorus in the pig (PIG factsheet #07-07-09, Composition and Usage Rate of Feed Ingredients for Swine Diets). Variability in the digestibility of the standards used to compare feed ingredients to for relative bio-availability means the actual bio-available phosphorus values can have considerable variation. The NSNG

Table 1. Mineral concentrations in macro mineral sources for swine (as-fed basis)[a]. Percent bio-availability and apparent total tract digestibility of phosphorus for swine shown in parenthesis, respectively[a]
(From Factsheet 07-07-09; Composition and Usage Rate of Feed Ingredients for Swine Diets)

Mineral element	Source	Dry Matter (%)	Calcium (%)[b]	Phosphorus (%)[c]	Sodium (%)	Chloride (%)	Iron (ppm)	Manganese (ppm)	Zinc (ppm)	Magnesium (%)	Potassium (%)	Sulfur (%)
Calcium	Calcium chloride, dihydrate	---	27	---	---	---	---	---	---	---	---	---
	Limestone (minimum 95% calcium carbonate)	99	38.0	0.02 (---, ---)	0.08	0.02	600	200	18	1.61	0.08	0.08
	Oyster shell	99	37.6	---	0.21	0.01	2840	133	---	0.30	0.10	---
Calcium and Phosphorus	Bone meal, steamed	97	29.8	12.5 (82, ---)	0.04	---	850	300	126	0.30	0.20	2.40
	Dicalcium phosphate	96	20 to 24	18.50 (100, 81)	0.18	0.47	7900	1400	92	0.80	0.15	0.80
	Monocalcium phosphate	100	17.00	21.10 (100, 81)	0.20	---	7500	100	220	0.90	0.16	0.80
	Calcium sulfate, dehydrate	85	21.85	---	---	---	---	---	---	0.48	---	16.19
	Defluorinated rock phosphate	100	32.00	18.00 (87, ---)	3.27	---	8400[d]	500	43	0.29	0.10	0.13
	Monoammonium phosphate	97	0.35	24.20 (100, ---)	0.20	---	4100	100	300	0.75	0.16	1.50
	Curaco phosphate	100	35.09	14.23 (50, ---)	0.20	---	3500	---	---	0.80	---	---
	Soft rock phosphate	100	16.09	9.05 (40, ---)	0.10	---	19200	1000	---	0.38	---	---
Magnesium	Magnesium carbonate	81	0.02	---	---	---	---	100	---	30.20	---	---
	Magnesium oxide	100	1.69	---	---	---	10600	---	---	55.00	0.02	0.10
	Magnesium sulfate, heptahydrate	49	0.02	---	---	0.01	---	---	---	9.60	---	13.04
Potassium	***Potassium chloride***	100	0.05	---	1.00	46.93	600	10	---	0.23	51.37	0.32
	Potassium sulfate	---	0.15	---	0.09	1.50	700	10	---	0.60	43.04	17.64
Sodium	Sodium carbonate	---	---	---	43.30	---	---	---	---	---	---	---
	Sodium bicarbonate	---	0.01	---	27.00	---	---	---	---	---	0.01	---
Sodium and chloride	Sodium chloride	---	0.30	---	39.50	59.00	100	---	---	0.005	---	0.20
Sodiumand phosphorus	Disodium phosphate	100	---	21.15 (100, ---)	31.04	---	---	`---	---	---	---	---
	Monosodium phosphate	87	0.09	24.94 (100, 92)	18.65	0.02	10	---	---	0.01	0.01	---
Sodium and sulfur	Sodium sulfate, decahydrate	---	---	---	13.80	---	---	---	---	---	---	9.70

[a]These mineral supplements are not chemically pure compounds, and the composition may vary substantially among sources. The supplier's analysis should be used if it is available. For example, feed-grade dicalcium phosphate contains some monocalcium phosphate and feed-grade monocalcium phosphate contains some dicalcium phosphate. Dashes indicate that no data were available. Most common sources are in bold-italic.
[b]Estimates indicate 90 to 100% relative bioavailability of calcium in most sources of monocalcium phosphate, dicalcium phosphate, tricalcium phosphate, defluorinated phosphate, calcium carbonate, calcium sulfate, and calcitic limestone. The calcium in high-magnesium limestone or dolomtic limestone is less bioavailable (50 to 80%).
[c]Bioavailability estimates are generally expressed as a percentage of monosodium phosphate or monocalcium phosphate.
[d]Iron in defluorinated phosphate is about 65% as available as the iron in ferrous sulfate.

provides recommendations for both relative bio-available phosphorus and digestible phosphorus as concentration in the diet and related to dietary energy content for various classes of swine. We recognize that most of the U.S. pork industry uses the bio-available phosphorus system [4], but we are providing digestible phosphorus recommendations in an effort to guide the industry toward use of more accurate and reliable phosphorus recommendations. Additionally, we utilized lean accretion rates of grow-finish pigs to estimate our recommendations for digestible phosphorus [5,6]. We believe this approach provides further refinement of our digestible phosphorus recommendations for the growing-finishing pig, because it is more reflective of its true requirement. The next step in phosphorus recommendations to progress to determining true or standardized ileal digestible phosphorus requirements for swine, similar to the progress we have made in amino acids.

The calcium to phosphorus ratio is important in swine nutrition. A wide calcium to phosphorus ratio will decrease the absorption of phosphorus, especially when phosphorus is fed near the requirement level [1]. A narrower calcium to phosphorus ratio will result in more efficient phosphorus absorption and is more critical in the young pig [1]. The suggested calcium to total phosphorus ratios in the National Swine Nutrition Guide is 1-1.2:1 across production phases. In general, the recommended calcium to bio-available phosphorus ratio is 1.4-2.4:1 and the ratio is from 1.6-3.0:1 for calcium to digestible phosphorus, both increasing as the pig matures from the nursery period to grow-finish and sow production phases.

Phytase inclusion in swine diets will reduce total dietary phosphorus by approximately 0.05 to 0.10 percentage units, depending on the amount of phytase enzyme added. This will increase the calcium to total phosphorus ratio to about 1.5:1, which is near the upper recommended limit for this ratio. However, the ratio of calcium to available phosphorus or digestible phosphorus will remain unchanged as the diets will still be formulated to the same available or digestible phosphorus content; it will just now require less total phosphorus to meet the pig's needs because more of the total phosphorus is available to pig due to the phytase in the diet. The reduction in dietary phosphorus when using phytase is usually accomplished by reducing supplemental mono- or di-calcium phosphate.

Plant based feedstuffs are usually inadequate sources of phosphorus for swine because of their low concentration and availability of phosphorus, therefore phosphorus must be supplemented in swine diets. The primary sources of supplemental phosphorus in pig diets are mono- or di-calcium phosphate. Mono- or di-calcium phosphate also supply a significant amount of calcium to the average pig diet. Other calcium and phosphorus sources are listed in Table 1 (from PIG Factsheet 07-07-09; Composition and Usage Rate of Feed Ingredients for Swine Diets).

Sodium and Chloride

Sodium and chloride are all involved in nutrient transfer across cell membranes, body pH regulation, water balance, and digestion. Sodium chloride (NaCl), or salt, provides the principal extracellular cation (Na^+) and anion (Cl^-) in the body. Sodium and chloride cannot be stored in the body to any great extent, so consumption above daily needs must be excreted. Salt deficiency results in a reduction in rate and efficiency of growth. Salt toxicity can be caused by dehydration if access to fresh water is unavailable or restricted. Signs of salt toxicity include nervousness, weakness, staggering, epileptic seizures, paralysis and death. Sodium and chloride are commonly deficient in swine rations. The standard recommendation of 0.2-0.3% inclusion of salt will meet the dietary Na and Cl requirements of nursery, growing, and finishing pigs fed a grain-soybean meal diet while sows will require higher salt inclusions (0.50%). If milk by-products such as dried skim milk or whey, or blood products are used, dietary supplemental salt concentrations should be reduced because these ingredients are high in sodium and/or chloride. See PIG Factsheet 07-07-09, (Composition and Usage Rate of Feed Ingredients for Swine Diets) for sodium and chloride composition of feedstuffs used in swine diets.

Potassium

Potassium is involved in nerve-muscle function, electrolyte balance and is part of the sodium-potassium pump in many cells [5]. Therefore, dietary potassium and sodium are interrelated. Potassium is also involved in ammonium ion excretion by the kidney [1], regulation of heart rate, and preventing tetany in skeletal muscle [5]. The potassium content in typical corn-soybean meal swine diets is more than adequate to meet the potassium needs of pigs; therefore, it is rarely supplemented.

Magnesium

Magnesium is part of the mineral make-up of bone and is a co-factor in several enzymes. Several of the key enzymes that require magnesium are involved in glucose and energy metabolism and protein synthesis [5]. The pig requires magnesium in the parts per million concentrations in the diet and a typical corn-soybean meal diet will provide magnesium at 30 times the requirement [1]. Magnesium deficiency has rarely been seen due to these high concentrations in grain and oilseed protein sources commonly used in swine diets.

Sulfur

Sulfur is an essential element that is part of several compounds in the body; glutathione, chondroitin sulfate, di-sulfate linkages in proteins. The sulfur containing amino acids (methionine and cysteine) seem to be adequate for providing the sulfur needs of swine. Therefore, sulfur generally is not added to swine diets and no sulfur requirement for swine has been defined [1,5]. With the increased use of dried distillers grains with solubles (DDGS) in swine diets, excess sulfur may need monitoring. The DDGS products contain about 0.4% sulfur due to sulfuric acid used in the ethanol plants. This high level of sulfur will increase hydrogen sulfide emissions from swine operations and could limit the use of high sulfur ingredients based on air quality concerns (See factsheet 07-05-02; Managing nutrient excretion and odor in pork production through nutrition). Also if water sources are high in sulfur a laxative effect can be observed in pigs [5].

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Frequently asked questions:

Is there a risk of feeding excess macro minerals?
Some macro minerals, particularly calcium, if added in excess, will interfere with adsorption of other minerals. For instance, excess calcium can interfere with zinc and results in a skin disorder called parakeratosis. So minerals should not be added beyond normal margins of safety. If minerals are added without reason, more harm than good can occur.

Should I adjust my mineral supplementation based on my water?
There are several parts of the U.S. that have water quality issues related to high total dissolved solids content. Often these water sources are high in calcium and/or sulfur. These hard water situations can affect the gut pH, provide excess minerals that may interfere with feed minerals, and can often decrease water consumption which can make excreting the excess minerals difficult for the swine. Typically nutritionists have not taken into count the minerals coming from the water source. However, it can be necessary if the water sources are extremely high in minerals.