

## **The High Cost of Phosphorus for Pigs and Poultry: What are the Options?**

Nathan R. Augspurger, Ph.D., JBS United, Inc., Sheridan, IN  
David H. Baker, Ph.D., University of Illinois, Urbana, IL

The price of feed-grade phosphorus (P) supplements for animal nutrition has increased over four-fold in the last few years, and further price increases are expected in the future. The three dominant P supplements are dicalcium phosphate (22% Ca, 18.5% P), used prominently in swine and layer diets, defluorinated rock phosphate (33% Ca, 18% P), used prominently in broiler and turkey diets (for pellet quality), and mono-dicalcium phosphate (16% Ca, 21% P), used prominently in ruminant diets and in mineral and vitamin-mineral premixes. In the U.S., dical, defluor, and monocal have roughly a 40%, 30%, and 30% market share, respectively. Swine, and particularly poultry, are the biggest users of P supplements, with poultry accounting for over 50% of total usage.

The price of feed-grade phosphates closely follows the price of fertilizer phosphates, and the latter have experienced marked price increases, especially in the last year. Clearly, increased corn production (due importantly to ethanol demand) is a contributing factor on the demand side. Between 2008 and 2010, USDA predicts that corn prices will remain at around US\$5.00/bu. and soybean prices will be above US\$12.00/bu. Corn (also alfalfa) production requires twice the  $P_2O_5$  quantity per acre as soybean (also wheat) production. On the supply side, lack of economical  $H_2SO_4$  is an important factor in the price increase in both fertilizer phosphate and feed-grade phosphates for animals. Sulfuric acid is an indispensable ingredient in the manufacture of phosphate fertilizers, dical, and monocal, and its price has sky-rocketed 9-fold in the last year (Feedinfo News Service, 31/01/2008). Sulfur (later processed into  $H_2SO_4$ ) is a by-product of the oil and gas discovery and refining industries – and little new activity in these industries has occurred in recent years. Thus, the shortage of economical sulfur is a prime reason for the lack of supply and hence price increase of both feed-grade and fertilizer phosphates.

The significant increases in all dietary inputs—energy, protein, minerals, and vitamins—for livestock over the past several months have forced producers to evaluate any and all means of reducing feed costs, whilst maintaining adequate animal growth performance. Phosphorus is a noteworthy issue. Phosphorus (bioavailable) is required in amounts ranging from 0.60 to 0.25% in poultry diets (broiler chickens, turkeys, laying hens; NRC, 1994) and from 0.55 to 0.15% in pigs diets (NRC, 1998). Most commercial-type diets are formulated using cereals and oilseed

meals, in which the bioavailability of the P is poor, thus requiring additional P supplementation. Historically, inorganic phosphates (iP) have met that need cost-effectively. Recently, however, the cost of monocalcium phosphate, for example, has increased from approximately US\$200/ton just a few years ago to greater than US\$900/ton currently, forcing pig and poultry producers to evaluate other options for meeting P needs and reducing diet costs.

The major source of supplemental P is inorganic phosphates, i.e., monocalcium, dicalcium, defluorinated phosphates. Their high P concentration (18-21%) and bioavailability (85-100%) make them sound sources of P for pigs and poultry. But other than calcium and iron, these ingredients do not supply other nutrients that are required. By-product ingredients such as meat-and-bone meal (MBM), poultry meal, and dried distiller's grains with solubles (DDGS) contain higher amounts of bioavailable P along with protein/amino acids, minerals, vitamins, and energy. DDGS, however, has serious amino acid limitations and is also higher in fiber than either corn or soybean meal.

Supplemental P has been used in monogastric diets due the lack of endogenous phytase enzyme activity in the digestive tract of nonruminant animals. Much of the P contained in cereals and oilseed meals is bound in the form of phytic acid, a molecule that is largely indigestible by monogastric animals. Dietary supplementation of microbial phytase can increase the bioavailability of P from cereals and oilseed meals, thereby reducing the need for iP supplementation. Commercially-produced phytase has been used in monogastric nutrition for almost 15 years. The first commercially-available phytase was produced by the fungus *Aspergillus niger* (Natuphos, BASF). Research in pigs fed corn-soybean meal diets has shown that this phytase added to complete diets can release 0.06% P at inclusion rates of 500 phytase units (FTU) per kg of feed (Brana et al., 2006; Cromwell et al., 1995; Harper et al., 1997; Johnston et al., 2004) and up to 0.11% bioavailable P at 1,000 FTU/kg of feed (Cromwell et al., 1995; Pallauf et al., 1992; Simons et al, 1990). In broiler chickens fed corn-soybean meal diets, this fungal-derived phytase has been shown to release approximately 0.05-0.06% P at 500 FTU/kg (Adedokun et al., 2004; Denbow et al., 1998; Tamim et al., 2004) and 0.07% P at 1,000 FTU/kg (Augsburger et al., 2003; Denbow et al., 1995; Pillai et al., 2006).

A phytase derived from an *E. coli* strain isolated from the gut of pigs has been shown to release significantly greater amounts of P from diets for monogastric animals. Indeed, additions of 250 FTU/kg of one of these *E. coli*-derived phytases (OptiPhos®, JBS United, Inc.) to P-

deficient diets fed to pigs has resulted in calculated P-release values of approximately 0.13% P (Augspurger et al., 2007; Fent et al., 2004). At 1,000 FTU/kg, the total release from the diet was calculated to be 0.20% (Augspurger et al., 2004, 2007a; Fent et al., 2004). Work in broiler chickens has shown similar outcomes, with 250 FTU/kg releasing approximately 0.10% P (Augspurger and Webel, 2006; Augspurger et al., 2007b; Pillai et al., 2006), and 1,000 FTU/kg releasing approximately 0.20% P in both broilers and turkey poults (Applegate et al., 2003; Augspurger and Baker, 2004; Augspurger and Webel, 2006; Augspurger et al., 2003; Pillai et al., 2006). With second-cycle laying hens, OptiPhos® at 150 FTU/kg has been shown to totally eliminate the need for supplemental iP (Augspurger et al., 2007).

The amounts of other commercially-available phytases needed to release 0.20% P has not been researched in great detail. Augspurger and Baker (2004) compared OptiPhos to two fungal phytases (Natuphos and Ronozyme P [DSM]) in broiler chickens and found that 1,000 FTU/kg OptiPhos released 0.20% P, but greater than 5,000 FTU/kg of Natuphos was needed to release that amount of iP, and 10,000 FTU/kg Ronozyme P released only approximately 0.15% P. Research by Shirley et al. (2003) showed that in broiler chickens fed P-deficient diets, between 3,000 and 12,000 FTU/kg of Natuphos was required to release 0.20% P. Data reported from Kornegay and Qian (1996) showed that 1,000 to 1,400 FTU/kg Natuphos was able to replace approximately 0.11% P in pigs fed corn-soybean meal diets. The P-release value for Phyzyme XP (*E. coli*-derived phytase, Danisco) supplemented at 1,000 FTU/kg has been reported to be approximately 0.14% P in both broiler chickens (Adedokun et al., 2004; Dilger et al., 2004; Jendza et al., 2006; Olukosi et al., 2007; Ravindran et al., 2006) and pigs (Adeola et al., 2004; Jendza et al., 2005, 2006; Kadzere et al., 2007) fed corn-soybean meal-based diets.

The efficacy of 1,000 FTU/kg phytase from OptiPhos to replace approximately 20 lbs of monocalcium phosphate per ton of complete feed means that pig producers could eliminate dietary supplementation of inorganic phosphate (iP) to corn-soybean meal diets beginning in the early finishing period. Maximum replacement of inorganic phosphate by OptiPhos maintained growth rates and bone mineralization of growing-finishing pigs relative to those fed diets with supplemental inorganic phosphate (Augspurger et al., 2006; Fent et al., 2005). In fact, maximum replacement of iP with OptiPhos in the work of Augspurger et al. (2006) increased gain/feed ratios (3%) and reduced P excretion rates by a remarkable margin (69%) relative to iP-supplemented controls (Table 1). Replacement of 0.20% iP in broiler chickens (hatch to 6 or 7

wk) by 1,000 FTU/kg OptiPhos maintained both growth performance and bone mineralization compared to broilers fed diets supplemented with iP in multiple experiments (Pillai et al., 2006).

The option to replace up to 20 lbs of monocalcium phosphate per ton of complete broiler or pig feed offers significant flexibility in diet formulation. Replacing phosphate supplements with an efficacious phytase product in an early-finisher diet for pigs could add eight (8) kcal ME per lb of complete feed. Each scenario offers the opportunity to replace significant amounts of iP, thus reducing diet cost without negatively impacting animal performance and skeletal health. In most formulation schemes, the cost of phytase inclusion must be weighed against the value of iP removal, the latter including also the cost of phytase as well as more limestone and corn but less fat in each ton of feed.

### Conclusions

There are several strategies with which to reduce exposure to these historically high phosphate prices. Formulate and feed diets that meet the animals' requirement for P, but no higher. Large safety margins cannot be economically justified. Utilize phytase to its maximum economic advantage. In many situations, OptiPhos up to 1,000 FTU/kg complete diet can completely replace any need for inorganic phosphate. The high concentration of P in DDGS reduces the need for inorganic phosphate supplementation; indeed, the bioavailability of P in DDGS is six times greater than in corn and three times greater than in soybean meal. Keep in mind, also, that the P contained in the phospholipid fractions of fat and in the nucleic acids contained in yeast and other fermentation by-products is every bit as bioavailable as that in inorganic phosphates. And finally, when purchasing phosphate supplements, they should be valued on the basis of cost per unit of P, not cost per unit of product. For the most part, the relative bioavailability of P (i.e., relative to  $\text{KH}_2\text{PO}_4$ ) in dical, monocal, and defluor is about the same—and is quite high (90 to 95 %).

Appreciation is expressed to Steve Auman (Potash Corp.) and Jon Nelson (Southeastern Minerals Corp.) for advice on details of phosphate production.

## References

- Adedokun, S.A., J.S. Sands, and O. Adeola. 2004. Determining the equivalent phosphorus released by an *Escherichia coli*-derived phytase in broiler chicks. *Can. J. Anim. Sci.* 84:437-444.
- Adeola, O., J.S. Sands, P.H. Simmins, and H. Schulze. 2004. The efficacy of an *Escherichia coli*-derived phytase preparation. *J. Anim. Sci.* 82:2657-2666.
- Applegate, T.J., D.M. Webel, and X.G. Lei. 2003. Efficacy of a phytase derived from *Escherichia coli* and expressed in yeast on phosphorus utilization and bone mineralization in turkey poults. *Poult. Sci.* 82:1726-1732.
- Augspurger, N.R., and D.H. Baker. 2004. High dietary phytase levels maximize phosphorus utilization but do not improve protein utilization in chicks fed phosphorus or amino acid-deficient diets. *J. Anim. Sci.* 82:1100-1107.
- Augspurger, N.R., and D.M. Webel. 2006. Graded levels of an *E. coli* phytase expressed in yeast increase phosphorus bioavailability and retention in chicks. In: *Proc. Inter. Poult. Sci. Forum*, Atlanta, GA. p. 35.
- Augspurger, N.R., D.M. Webel, X.G. Lei, and D.H. Baker. 2003. Efficacy of an *E. coli* phytase expressed in yeast for releasing phytate-bound phosphorus in young chicks and pigs. *J. Anim. Sci.* 81:474-483.
- Augspurger, N.R., D.M. Webel, J.D. Spencer, and D.H. Baker. 2004. Pharmacologic levels of zinc reduce the efficacy of phytase in both young pigs and young chickens. *J. Anim. Sci.* 82:1732-1739.
- Augspurger, N., J. Spencer, D. Webel, T. Torrance, and B. Wolter. 2006. High levels of an *E. coli*-derived phytase can fully replace inorganic phosphorus in grow-finish pig diets. *J. Anim. Sci.* 84(Suppl. 2):76(Abstr.).
- Augspurger, N.R., A.M. Gaines, J.R. Danielson, and L.L. Southern. 2007a. The phosphorus-releasing efficacy of an *E. coli*-derived phytase in young pigs is dose-dependent and is not affected by the addition of a lipid-based coating added for pelleting stability. *J. Anim. Sci.* 85(Suppl. 1):310(Abstr.).
- Augspurger, N.R., S.D. Frankenbach, T.J. Applegate, J.S. Moritz, F. Ruch, and D.M.

- Webel. 2007b. Coating for pellet stability does not adversely affect the phosphorus-releasing efficacy of an *E. coli*-derived phytase in young chickens. In: Proc. Intl. Poult. Sci. Forum, Atlanta, GA, p. 35.
- Augspurger, N.R., D.M. Webel, and D.H. Baker. 2007c. An *Escherichia coli* phytase expressed in yeast effectively replaces inorganic phosphorus for finishing pigs and laying hens. J. Anim. Sci. 85:1192-1198.
- Brana, D.V., M. Ellis, E.O. Castaneda, J.S. Sands, and D.H. Baker. 2006. Effect of a novel phytase on growth performance, bone ash, and mineral digestibility in nursery and grower-finisher pigs. J. Anim. Sci. 84:1839-1849.
- Cromwell, G.L., R.D. Coffey, G.R. Parker, H.J. Monegue, and J.H. Randolph. 1995. Efficacy of a recombinant-derived phytase in improving the bioavailability of phosphorus in corn-soybean meal diets for pigs. J. Anim. Sci. 73:2000-2008.
- Denbow, D.M., V. Ravindran, E.T. Kornegay, Z. Yi, and R.M. Hulet. 1995. Improving phosphorus availability in soybean meal for broilers by supplemental phytase. Poult. Sci. 74:1831-1842.
- Denbow, D.M., E.A. Grabau, G.H. Lacy, E.T. Kornegay, D.R. Russell, and P.F. Umbeck. 1998. Soybeans transformed with a fungal phytase gene improve phosphorus availability for broilers. Poult. Sci. 77:878-881.
- Dilger, R.N., E.M. Onyango, J.S. Sands, and O. Adeola. 2004. Evaluation of microbial phytase in broiler diets. Poult. Sci. 83:962-970.
- Feedinfo News Service. 31/01/2008. Feed Phosphate Crisis Triggered by Raw Material Price Dispute.
- Fent, R.W., G.L. Allee, D.M. Webel, J.D. Spencer, T.S. Torrance, and A.L. Sutton. 2005. The evaluation of nutritional strategies to reduce phosphorus excretion in pigs from 12 kg to market. J. Anim. Sci. 83(Suppl. 1):389(Abstr.).
- Harper, A.F., E.T. Kornegay, and T.C. Schell. 1997. Phytase supplementation of low-phosphorus growing-finisher pig diets improves performance, phosphorus digestibility, and bone mineralization and reduces phosphorus excretion. J. Anim. Sci. 75:3174-3186.
- Jendza, J. A., R. N. Dilger, S. A. Adedokun, J. S. Sands, and O. Adeola. 2005. *Escherichia coli* phytase improves growth performance of starter, grower, and finisher pigs fed phosphorus-deficient diets. J. Anim. Sci. 83:1882-1889.

- Jendza, J.A., R.N. Dilger, J.S. Sands, and O. Adeola. 2006. Efficacy and equivalency of an *Escherichia coli*-derived phytase for replacing inorganic phosphorus in the diets of broiler chickens and young pigs. *J. Anim. Sci.* 84:3364-3374.
- Johnston, S.L., S.B. Williams, L.L. Southern, T.D. Bidner, L.D. Bunting, J.O. Matthews, and B.M. Olcott. 2004. Effect of phytase addition and dietary calcium and phosphorus levels on plasma metabolites and ileal and total-tract nutrient digestibility in pigs. *J. Anim. Sci.* 82:705-714.
- Kadzere, C.T., E. van Heugten, J.S. Sands, R. Maguire, and M. Morrow. 2007. Effect of an *Escherichia coli*-derived phytase on nutrient digestibility in corn-soybean meal based diets for growing pigs. *J. Anim. Sci.* 85(Suppl. 1):307(Abstr.).
- Kornegay, E.T., and H. Qian, 1996. Replacement of inorganic phosphorus by microbial phytase for young pigs fed on a maize-soyabean-meal diet. *Brit. J. Nutr.* 76:563-578.
- NRC. 1994. Nutrient Requirements of Poultry. 9<sup>th</sup> rev. ed. Natl. Acad. Press, Washington, DC.
- NRC. 1998. Nutrient Requirements of Swine. 10<sup>th</sup> rev. ed. Natl. Acad. Press, Washington, DC.
- Olukosi, O.A., A.J. Cowieson, and O. Adeola. 2007. Age-related influence of a cocktail of xylanase, amylase, and protease or phytase individually or in combination in broilers. *Poult. Sci.* 86:77-86.
- Pallauf, V.J., D. Hohler, G. Rimbach, and H. Neusser. 1992. Effect of microbial phytase supplementation to a maize-soya-diet on the apparent absorption of phosphorus and calcium in piglets. *J. Anim. Physiol. Anim. Nutr.* 67:30-50.
- Pillai, P.B., T. O'Connor-Dennie, J.L. Emmert. 2006. Efficacy of an *Escherichia coli* phytase in broilers fed adequate or reduced-phosphorus diets and its effect on carcass characteristics. *Poult. Sci.* 85:1737-1745.
- Ravindran, V., P.C. Morel, G.G. Partridge, M. Hruby, and J.S. Sands. 2006. Influence of an *Escherichia coli*-derived phytase on nutrient utilization in broiler starters fed diets containing varying concentrations of phytic acid. *Poult. Sci.* 85:82-89.
- Shirley, R. B., and H. M. Edwards, Jr. 2003. Graded levels of phytase past industry standards improve broiler performance. *Poult. Sci.* 82:671-680.
- Simons, P.C., H.A. Versteegh, A.W. Jongbloed, P.A. Kemme, P. Slump, K.D. Bos, M.G.

- Wolters, R.F. Beudeker, and G.J. Verschoor. 1990. Improvement of phosphorus availability by microbial phytase in broilers and pigs. *Brit. J. Nutr.* 64:525-540.
- Tamim, N.M., R. Angel, and M. Christman. 2004. Influence of dietary calcium and phytase on phytate phosphorus hydrolysis in broiler chickens. *Poult. Sci.* 83:1358-1367.

Table 1. Utilization of quantitative efficacy estimates of OptiPhos maintained growth performance and bone mineralization and reduced phosphorus excretion relative to control diets containing only inorganic phosphorus to meet dietary available phosphorus requirements.

Experiment and dietary treatments	Growth rate (g/d)	Gain/feed (g/kg)	Bone measure		Phosphorus excretion (g/d)
			strength (kg)	ash (g)	
<i>Fent et al., 2005</i> <sup>2</sup>					
1. P adequate	808 <sup>a</sup>	377	249.9 <sup>a</sup>	9.0 <sup>a</sup>	—
2. As 1 to 91 kg, no iP thereafter	779 <sup>b</sup>	374	212.5 <sup>b</sup>	8.0 <sup>c</sup>	—
3. As 1 minus 0.12% P + 500 FTU/kg OptiPhos	804 <sup>ab</sup>	378	266.5 <sup>a</sup>	8.7 <sup>ab</sup>	—
4. As 1 minus 0.20 to 0.10% iP + OptiPhos <sup>3</sup>	799 <sup>ab</sup>	369	250.1 <sup>a</sup>	8.4 <sup>bc</sup>	—
5. As 1 minus all iP + 1,000 FTU/kg OptiPhos <sup>4</sup>	775 <sup>b</sup>	381	243.0 <sup>ab</sup>	8.5 <sup>bc</sup>	—
Pooled SEM	10 <sup>6</sup>	3	8.7 <sup>7</sup>	0.2 <sup>7</sup>	—
<i>Augsburger et al., 2006</i> <sup>5</sup>					
1. P-adequate	949	404	—	7.8 <sup>a</sup>	6.70 <sup>a</sup>
2. As 1 minus 0.13% P	889	405	—	6.1 <sup>c</sup>	3.54 <sup>b</sup>
3. As 2 plus 500 FTU/kg OptiPhos	962	411	—	7.5 <sup>a</sup>	3.70 <sup>b</sup>
4. As 1 minus all iP + OptiPhos <sup>3,4</sup>	940	417	—	6.9 <sup>b</sup>	2.06 <sup>c</sup>
Pooled SEM	17	4 <sup>8</sup>	—	0.1 <sup>6</sup>	0.47 <sup>7</sup>

<sup>1</sup>Metacarpals taken from four pigs per pen at the end of each trial. Bones were fat-extracted in Fent et al. (2005).

<sup>2</sup>These data represent means of six pens of barrows fed their experimental diets from approximately 12 to 125 kg body weight.

<sup>3</sup>OptiPhos was supplemented to diets at 1,000 FTU/kg to approximately 50 kg, 500 FTU/kg to approximately 91 kg, and 300 FTU/kg to the end of the trial.

<sup>4</sup>In these treatments, phytase supplementation was the only dietary means of meeting the requirement for available P. Up to 53 kg body weight in Fent et al. (2005) and 49 kg body weight in Augspurger et al. (2006), it was known that dietary available P concentrations were deficient relative to required concentrations to maximize bone mineralization (Augsburger et al. 2006; Fent et al., 2005) and growth rate (Fent et al. 2005).

<sup>5</sup>These data represent means of 12 replicate-pens of gilts (PIC 337 × C22) fed their experimental diets from approximately 22 to 129 kg body weight.

<sup>6</sup>Effect of dietary treatment,  $P < 0.05$ .

<sup>7</sup>Effect of dietary treatment,  $P < 0.01$ .