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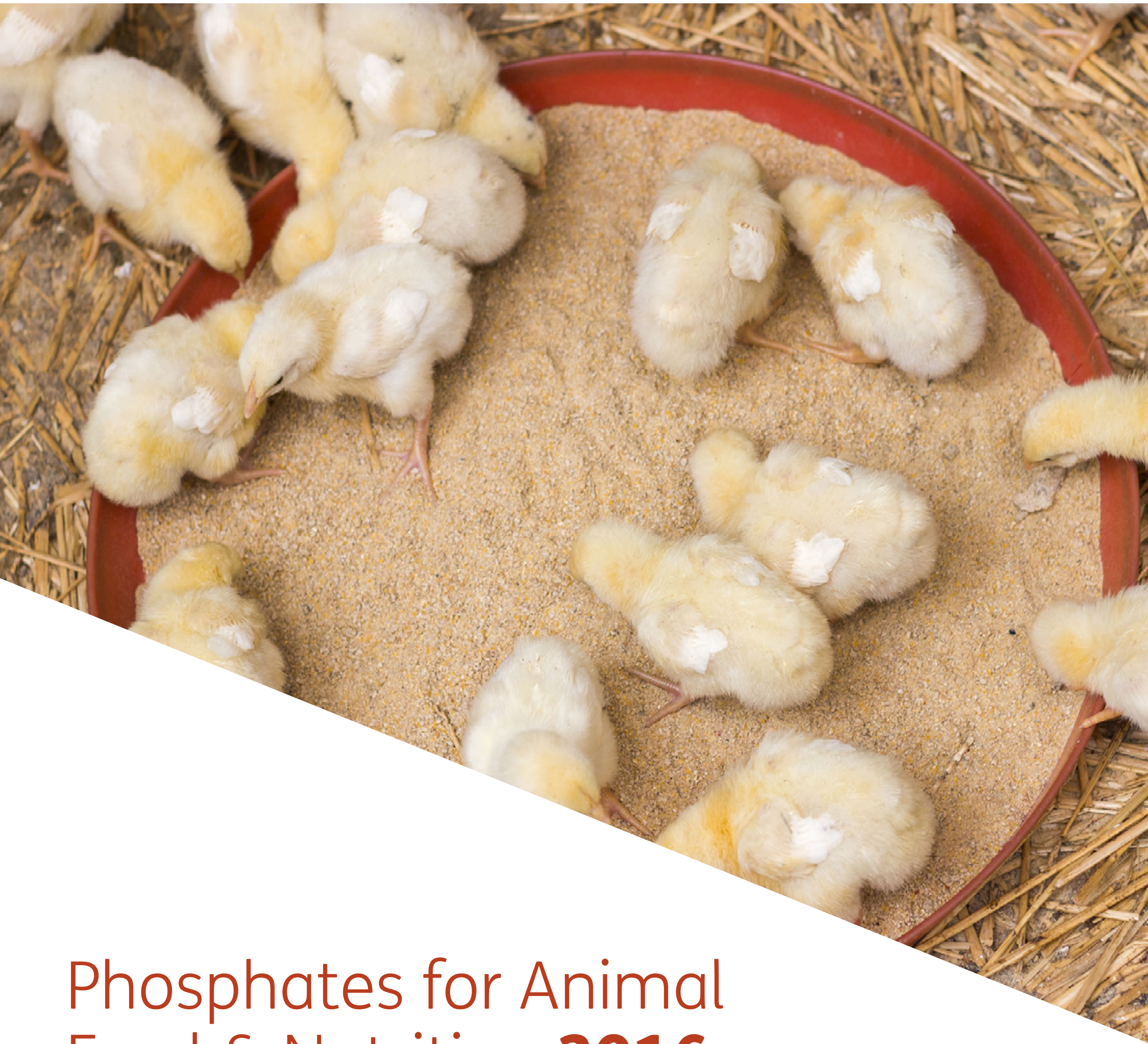

Phosphates for Animal Feed & Nutrition **2016**

Monocalcium phosphate; Dicalcium phosphate; Tricalcium phosphate; Defluorinated phosphate; Orthophosphoric acid; Meat and Bone meal

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Executive Summary

A variety of phosphates are used in animal feeds, ultimately as a source of the element phosphorus which is essential for both plant and animal life. Phosphorus is the second most important mineral in the body after calcium and comprises on average 10g/kg of body weight. It has more functions in the animal body than any other mineral nutrient (McDonald *et al*., 1990).

Phosphorus is also curious in that it alone amongst the major biochemical elements, carbon, hydrogen, nitrogen, oxygen and sulphur, does not have a significant volatile phase. Volatile liquids and gasses such as water, nitrogen, oxygen, carbon dioxide and hydrogen sulphide are common on planet earth but there is no volatile phosphorus. Phosphine gas (PH_3) exists but is only sparingly present in the atmosphere.

Most of the phosphorus on our planet is found in crustal rock which is the ultimate source of phosphorus for animal and human nutrition. Phosphorus is found in the form of phosphate minerals known as rock phosphate. The most common form is the mineral apatite with a chemical formula of $Ca_5(PO_4)_3$.

A major biochemical difficulty in the utilization of phosphorus is that most naturally occurring calcium phosphates have low chemical reactivity and are very poorly soluble in water. Paradoxically, the very biochemical essence of life on earth depends on multiple chemical reactions carried out in an aqueous environment. Consequently, it has been necessary to develop chemical procedures to convert basic mineral phosphates into more bioavailable forms for use as crop fertilizers and in animal feeds.

Various phosphates are important industrial chemicals and the largest application of phosphate is as fertilizer which takes up about 80% of world phosphate. The phosphate use in animal feeds is relatively small and accounts for only about 5% of world phosphate consumption (CEH, 2013). Nevertheless, this 5% of world phosphate is absolutely critical for efficient modern animal production.

The use of phosphates plays an increasingly strategic and fast-growing role in animal feed and nutrition, particularly in China and other emerging markets, where meat and livestock consumption is rising on economic growth and demand from the middle classes.

This report focuses on the differing nutrient requirements of poultry, swine and cattle, and how phosphates are seen as increasingly essential to animal health vitality and development.

The author also covers world phosphate resources, looking at major producers of rock phosphate and their supply potential for the future. Leading manufacturing companies are also examined.

Further detailed information is provided on Monocalcium phosphate, dicalcium phosphate, tricalcium phosphate, defluoirinated phosphate, orthophosphoric acid, meat and bone meal.

Other important issues explored include continued security of supply, legislative controls, phosphate digestibility in livestock and other animals, and environmental and water impacts.

As there is a predicted expansion in demands for phosphate an important question is whether a depletion of phosphate rock reserves, accompanied by a "peak phosphorus" event, might occur any time soon.

Currently, worldwide reserves of rock phosphate are estimated at some 60-67 Gt (gigatonnes = billion tonnes) (Table 1). It is evident from this table that the reserves in Morocco and Western Sahara are the absolute largest, comprising almost 75% of total world reserves. A grand total of 82% of phosphate rock reserves is located in North Africa and the Middle East. The political instability in these regions could lead to disruption in the supply of rock phosphate in the short term and also in the future, but the inherent availability of rock phosphate is not an issue.

Table 1: Major reserves of rock phosphate

Location	Phosphate rock reserve (Gt)p	Proportion of world total (%)
Morocco and Western Sahara	50.0	74.6
China	3.70	5.5
Algeria	2.20	3.2
Syria	1.80	2.7
South Africa	1.50	2.2
Russia	1.30	1.9
Jordan	1.30	1.9
USA	1.10	1.6
Australia	1.03	1.5
World	67.00	100.0

Adapted from: Jasinski, (2015).

In addition, there are other deposits of rock phosphate of varying grades that may or may not be economically extractable amounting to between 290 and 460 Gt. (Jasinski, 2013, Scholz and Wellmer, 2015).

There is obviously a finite amount of rock phosphate on this planet, as for all other basic commodities, and it is a non-renewable resource. However, there are several Western European projects (Germany, Italy, Netherlands) in the pipeline, focused on phosphorus recycling in municipal sewage and in organic waste.

Nevertheless, the large estimates of rock phosphate reserves strongly suggest that rock phosphate will not become physically scarce for a very long time probably for 300-400 years. Furthermore, as the annual production of rock phosphate concentrate is approximately 200 Mt (mega tonne = million tonne) or 0.2 Gt, then a reserve of 60-67 Gt does not indicate any imminent arrival of "peak phosphorus" or of an impending depletion of phosphate rock reserves.

Table 4: Fluorine limits for animal feeds in the EU

Feed	Fluorine limit (ppm)
Complementary feed: -containing < 4% phosphorus -containing > 4% phosphorus	 500 125 per 1% phosphorus
Complete feed	150
Complete feed for pigs	100
Complete feed for poultry (except chicks) and fish	350
Complete feed for chicks	250
Complete feed for cattle, sheep and goats: in lactation others	 30 50

A comparison of the bioavailability of phosphorus for broilers from various sources compared to a reference, hydrated monosodium phosphate (MSP) is given in Table 6. This table also shows absolute values of phosphorus retention. In comparative or absolute terms, the monocalcioum phosphates (MCP) are highly ranked, with the dicalcium phosphates (DCP) only slightly behind. Monodicalcium phosphate (MCDP) was quite good. Phosphoric acid (PPA) and monoammonium phosphate (MAP) also score well in the comparative listing.

Table 6: Relative bioavailability and phosphorus retention for broilers of various phosphorus sources

Phosphorus source	Relative bioavailability (%)	Phosphorus retention (%)
MSP.H_2O	100	92
MCP.H_2O	91	84
MCP.$0H_{2O}$	88	81
DCP.$2H_2O$	86	77
DCP.$0H_2O$	76	55
MDCP	80	79
MAP	94	
PPA	83	

Adapted from: Jongbloed *et al*., (2002)

PHOSPHORUS BIOAVAILABILITY IN PIGS

The results for the bioavailability of phosphorus for pigs is shown in Table 7. As in broilers phosphorus from MCP seems to be most highly bioavailable.

Table 7: Relative bioavailability and apparent phosphorus digestibility for pigs of various phosphorus sources

Phosphorus source	Relative bioavailability (%)	Apparent digestibility (%)
MSP.H_2O	100	91
MCP	94	83
MDCP	83	69
DCP.$2H_2O$	76	64
DCP.$0H_2O$	75	64

Adapted from: Jongbloed *et al*., (2002)

Table 9: Best available techniques to reduce total phosphorus excreted while meeting the nutritional needs of the animals.

Technique	Description
Multiphase feeding with a diet formulation adapted to the specific requirements of the production period.	This requires feed to match the phosphorus requirements of the animal to the phosphorus supply more accurately depending on the animal weight and/or production stage.
Use of authorised feed additives which reduce total phosphorus excreted.	Substances such as microorganisms or preparations such as enzymes (*e.g.* phytase) are added to feed or water in order to favourably affect feed efficiency. by improving the digestibility of phytate phosphorus in the feedstuffs or affecting the gastrointestinal flora.
Use of highly digestible inorganic phosphates for the partial replacement of conventional sources of phosphorus in the feed.	Requires the availability of highly digestible inorganic phosphates

Adapted from: IPPC (2015)

There are basically three strategies to reduce environmental pollution by phosphorus:

(1) Reduce phosphorus content in feeds.

(2) Improve phosphorus utilization from the feed.

(3) Increase the efficiency by which animals incorporate dietary phosphorus into food products.

Much work has been done to decrease the amount of phosphorus fed to dairy cattle and to improve efficiency of phosphorus utilization. The long-term impact of reducing the phosphorus content of dairy cow concentrates over a four-year period had no serious negative effects (Ferris *et al.*, 2010a). Winter concentrates had phosphorus concentrations reduced from 7.1 to 4.4 g/kg DM. Neither food intake, milk production or cow fertility were affected with low dietary phosphorus levels. Further studies confirmed that there were no adverse effects on cow health or fertility when high producing dairy cows were fed low phosphorus diets (Ferris *et al.*, 2010b). Reducing dietary phosphorus had no effect on the apparent digestibility of the rations offered, while phosphorus excretion to the environment was reduced by an average of 27g/day. It is clearly possible to substantially reduce the phosphorus content of dairy cow diets which has the valuable potential to reduce phosphorus loss to the environment.

A model of phosphorus digestion and metabolism in dairy cows indicated that with a phosphorus intake of 75g/day the total tract digestibility was only 38% (Hill *et al.*, 2008). Phytate phosphorus digestibility in the rumen however was 74%, due to phytase activity from rumen micro-organisms. Milk synthesis used 30% of absorbed phosphorus, and 1% was excreted in urine. The model also predicted that changing total phosphorus concentration in the diet had a greater effect on total phosphorus excretion than changing any fraction of phosphorus in the diet. Total phosphorus excreted was not very sensitive to altering phytase activity.

Table 10: Total phosphorus, phytate phosphorus and bioavailability of phosphorus in feed ingredients

Feed ingredient	Total P (g/kg)	Phytate P (g/kg)	Proportion of phytate P (%)
Barley	3.21	1.96	61.0
Maize	2.62	1.88	71.6
Sorghum	3.01	2.18	72.6
Wheat	3.07	2.19	71.6
Rapeseed meal	9.72	6.45	66.4
Cottonseed meal	10.02	7.72	77.1
Soyabean meal	6.49	3.88	59.9
Rice bran	17.82	14.17	79.5
Wheat bran	10.96	8.36	76.3

Adapted from: Selle and Ravindran (2008).

Table 11: Endogenous phytase activity in feed ingredients

Feed ingredient	Phytase activity (FTU/kg)
Barley	348
Maize	25
Sorghum	35
Wheat	503
Rapeseed meal	5
Cottonseed meal	11
Soyabean meal	42
Rice bran	129
Wheat bran	2173

Adapted from: Selle and Ravindran (2008).

Despite endogenous phytase the phytate salt is poorly digested by monogastric animals and much of the native phosphorus in feed ingredients is lost as a nutrient and excreted in the manure. Furthermore, phytate can reduce the utilisation of nutrients other than phosphorus by binding to them (Lenis and Jongbloed 1999). Thus, the presence of phytate in animal feeds can result in reduced efficiency of nutrient utilization and hence increased cost of feeding and environmental pollution.

Table 14: Effect of microbial phytase on apparent digestibility of phosphorus in feeds and excretion of phosphorus in faeces in growing pigs from 35-70 kg liveweight

Phosphorus	Feed (1)		Feed (2)	
Utilization	Control	Phytase	Control	Phytase
P digestibility (%)	20	46	34	56
P in faeces (g/kg DM)	21.0	13.6	16.3	10.9

Feed (1): maize/soyabean. Feed (2): soyabean/sunflower/tapioca/maize by-products

Adapted from: Simmons *et al*., (1990).

In ruminants, the microbial population itself has a phosphorus requirement and this is particularly important for the degradation of plant cell walls in the ruminant feed. If sufficient phosphorus is not supplied through the diet, microbial activity of the rumen may be impaired. This will result in a reduction in microbial protein synthesis and organic matter digestibility which are crucial for milk production in dairy cows.

Rumen micro-organisms synthesizes phytase, which allows digestion of phytate. Ruminants can very effectively retain phytate-phosphorus with <5% of the ingested phytate-phosphorus being recoverable in excreta; (Morse *et al*., 1992). This degradation of phytate takes place almost entirely in the rumen.

However, in high-producing ruminants, especially in dairy cows, faster passage rate and suboptimal rumen fermentation conditions may limit ruminal phytate degradation, because of the short-duration exposure of the phytate to microbial phytase (Humer and Zebeli, 2015).

Supplementation of ruminant diets with phytase generally showed no effect on milk yield and dry matter intake. Moreover, faecal phosphorus excretion was enhanced in phytase supplemented diets (Humer and Zebeli, 2015). There does not seem to be any advantage in supplementing ruminant feeds with commercial phytase as an enhancement of phosphorus excretion is certainly not desired.

SUPERDOSING OF PHYTASE

Poultry feeds are usually supplemented with phytase at 500 to 750 FTU/kg feed. However, a substantial part of dietary phytate (IP6), around 50%, remains undegraded in the digestive tract, perhaps partly due to mineral phosphorus that is also present in the diet. Recently, high doses of phytase beyond the current industry standards (>2,500 FTU/kg) have attracted research attention in an attempt to maximize the hydrolysis of feed phytate.

Superdosing of phytase entails using higher phytase levels in feed in an attempt to further breakdown the metabolites of phytic acid; inositol-5-phosphate (IP5), inositol-4-phosphate (IP4) and inositol-3-phosphate (IP3). These lower phytate esters have been shown to be related to poor digestion of protein, energy and minerals, suggesting that they also have an anti-nutritional effect. The argument is based on the premise that with standard phytase dosing, mostly phytate itself is degraded, generating other anti-nutritional

Table 15: Phosphorus equivalence of phytase as affected by physiological status and age of birds

Poultry type	Age	FTU to replace 1 g inorganic phosphorus
Broilers	<14 days	570
Broilers	<40 days	850
Broilers	0-21 days	939
Broilers	21-49 days	<400
Broilers	0-42 days	938
Layers	20-24 weeks	192
Layers	36 weeks	312

Adapted from: Singh (2008)

Older birds seem to require less phytase to replace 1g of inorganic phosphorus compared with younger birds (Singh, 2008; Kornegay *et al.,* 1996). Adding 750 FTU/kg feed may completely substitute for 0.8g/kg inorganic phosphorus supplementation in corn or wheat based diets for growing broilers (Peng *et al.,* 2003).

Two studies were conducted by Jendza *et al.,* (2006) to determine the efficacy of an *Escherichia coli*-derived phytase and its equivalency relative to inorganic phosphorus from monosodium phosphate in broilers and starter pigs. Five hundred FTU/kg was equivalent to the addition of 0.72, 0.78, and 1.19g/kg of inorganic phosphorus from monosodium phosphate in broiler diets based on gain, feed intake, and bone ash, respectively. With starter pigs at 10kg over 28 days, 500 FTU/kg was equivalent to the addition of 0.49 and 1.00g/kg of inorganic phosphorus from monosodium phosphate based on average daily gain and bone ash, respectively.

In general, manufacturers' recommended levels of commercially available phytases can replace inorganic phosphorus levels by 1.2g/kg (0.12%) in pig diets (Jacela *et al*., 2010). As the amount of phytase added to a diet increases, the release of phosphorus from phytate also increases in a curvilinear fashion. This means that phosphorus release diminishes with each additional unit of phytase until additional dietary levels of phytase fail to result in a further response.

A detailed study with starter broilers (0–21 days), indicated that on the basis of tibia ash, the non-phytate-phosphorus requirement was 3.9g/kg (0.39%) for diets based on normal maize. This could be reduced to 2.9g/kg (0.29%) by addition of phytase at 800 FTU/kg (Waldroup *et al.,* (2000).

In common practice, phytase is added to most poultry and pig feeds at a standard inclusion level of 500 FTU/kg and 300 FTU/kg in layer diet and probably a phosphorus equivalence of 1.0g (0.1%) or slightly higher can be assumed. This would amount to a saving of 10kg/tonne of available phosphorus in the feed. Commercial recommendations are frequently much higher ranging from 1.0 to 2.9g/kg or 10 to 29 kg/tonne phosphorus which could be replaced by phytase. Phytase addition to poultry diets has consistently been shown to allow the reduction of inorganic phosphorus supplements.

note however, that such are-alignment of phosphorus in livestock diets would not necessarily mean cheaper feeds because of the difficulty of sourcing ingredients for a balanced feed (Withers *et al*., 2015).

By more judicious use of feed phosphorus, significant reductions can be made (Ferris *et al.,* 2010a; 2010b). Dairy cows on a grassland-based system producing approximately 8000 to 9000 litres of milk per lactation were fed over multiple lactations on high and low phosphorus diets. The winter diets contained 4.9 and 3.6g phosphorus/kg for the high and low phosphorus diets respectively and the summer diets contained 4.2 and 3.6g phosphorus/kg for the high and low phosphorus diets respectively. There were no apparent adverse effects on feed intake, milk output or milk composition. These results suggest that it is feasible to reduce dietary phosphorus supply without having a detrimental effect on cow performance.

REDUCE PHYTATE CONTENT IN FEED INGREDIENTS

Another possible strategy to improve utilisation of phosphorus in feeds is to reduce the phytate content of cereal grains by plant breeding techniques. Low phytate maize seems also to have higher levels of available phosphorus than standard maize. Normal yellow dent maize had a total phosphorus of 0.23% and non-phytate phosphorus of 0.03%, compared to a low phytate maize with total phosphorus of 0.27% and non-phytate phosphorus of 0.17% (Waldroup *et al*., 2000). Feeding low phytic acid maize in poultry diets was able to reduce phosphorus excretion in the manure (Li *et al*., 2000).

Low phytate soyabeans have also been developed. A soyabean line obtained by mutagenesis had 70% of the total phosphorus as inorganic phosphorus compared with 15% in normal cultivars (Wilcox *et al*., 2000). In a trial with pigs, apparent digestibility of phosphorus was greater for pigs fed diets containing the low phytate soyabean meal (48.9 *versus* 42.4%). The use of low phytate soyabean meal also reduced the total phosphorus excreted (Powers *et al*., 2006).

Feeding low phytate maize with low phytate soyabean meal, and phytase significantly improved phosphorus digestibility and dramatically decreased phosphorus excretion (Table 16) (Hill *et al.*, 2014). This could reduce the negative impact of phosphorus from pig manure on the environment.

Table 16: Effect of low phytate maize and soyabean meal on phosphorus digestibility and excretion in grower pigs

Maize type	Normal		Low phytate	
Soyabean type	Normal		Low phytate	
Phytase (FTU/kg)	0	510	0	510
Digestibility (%)	34.1	44.9	48.2	60.1
Total excreted (g/day)	3.76	3.14	2.90	2.28

Adapted from: Hill *et al*., (2014).