Final Project Report to “Ontario Pork Producers' Marketing Board (OPPMB) - Ontario Pork”

“Determination of Optimal True Digestible Calcium (Ca) to Phosphorus (P) Ratio in Grower-Finishing Pigs for Minimizing Phosphorus Excretion”

(Ontario Pork Project # 09-023; University of Guelph Project # 049440)

(August 08, 2011)

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Determination of Optimal True Digestible Calcium to True Digestible Phosphorus Ratio in Growing-Finishing Pigs for Minimizing Phosphorus Excretion

Summary

The primary objective of this study conducted with two experiments was to determine the effect of changes in dietary true digestible calcium (Ca) to true digestible phosphorus (P) ratio on growth performance, efficiency of P utilization and manure P excretion and to recommend an optimal dietary true digestible Ca to true digestible P ratio for grower pigs fed corn and soybean meal (SBM) based diets. The experiment 1 was carried out to measure true fecal digestibility of Ca and P and the fecal gastrointestinal endogenous outputs of these nutrients associated with a corn and soybean SBM-based diet for the grower pig by the substitution method. Twelve Yorkshire weanling barrows, with average initial and final body weights (BW) of 23.2 and 31.1 kg, were fed two diets according to a completely randomized design. The diets were corn and SBM-based and contained two levels (on as-fed basis) of Ca and P with the lower-nutrient diet formulated by replacing corn and SBM with 25.52% corn starch. Titanium oxide (0.30%, as-fed basis) was included as a digestibility marker. Each experimental period consisted of 15 d with 10-d adaptation and 4-d collection of representative fecal samples. Pigs fed the lower-nutrient diet (diet 2) tended to have a reduced average daily gain ($P = 0.07$) and were associated with a decreased ($P = 0.02$) feed conversion efficiency. True fecal digestibility ($\%$, means plus pooled standard error, $n = 6$) of Ca ($53.57 \pm 12.69$) and P ($43.78 \pm 16.74$) as well as the fecal endogenous outputs (g/kg dry matter intake, means plus pooled standard error, $n = 12$) of Ca ($0.91 \pm 0.20$) and P ($1.31 \pm 0.15$) associated with the diets were determined by the substitution method. The experiment 2 was conducted with 36 Yorkshire grower barrows of average initial and final BW of 24.15 and 33.83 kg and the pigs were fed six diets for six blocks according to a completely randomized block design. The six diets were corn and SBM-based and contained six total Ca to total P ratios (diet 1, 0.60:1; diet 2, 0.74:1; diet 3, 0.81:1; diet 4, 1.26:1; diet 5, 1.00:1; and diet 6: 1.33:1), and true fecal digestible Ca to true fecal digestible P ratios (diet 1, 0.86:1;
diet 2, 0.73:1; diet 3, 1.09:1; diet 4, 1.08:1; diet 5, 2.16:1; and diet 6, 1.87:1) formulated by supplementing gradient levels of limestone with dietary P content meeting the recommended requirement standard. Titanium oxide (0.30%, as-fed basis) was included as a digestibility marker. Each experimental period consisted of 15 d with 10-day adaptation and 4-day collection of representative fecal and urinary samples as well as total volumes of urinary excretions. Changes in the dietary Ca to P ratio had no effects ($P > 0.05$) on the average daily feed intake. Changes in the dietary Ca to P ratio had a linear effect ($P < 0.05$) on the average daily gain with excellent responses occurred in diets 2-4. Changes in the dietary Ca to P ratio had linear, quadratic and cubic effects ($P < 0.05$) on the feed conversion ratio with excellent responses also occurred in diets 2-4. However, due to a large variability, changes in the dietary Ca to P ratio had no effects ($P > 0.05$) on the efficiency of digestive and post-absorptive utilization of dietary Ca and P. Efficiency of whole body P retention was numerically high in diets 2, 3 and 4 but very low in diet 6. We conclude that changes in dietary Ca to P ratio have significant effects on growth performance. Dietary true digestible Ca to true digestible P ratio of 0.90:1 to 1.10:1 equivalent to total Ca to total P ratio of 0.70:100 to 1.20:1:00 may be optimal for feeding grower pigs.

**Key Words:** Dietary Ca to P ratio; Growth performance; Phosphorus utilization; Grower pigs
Present Status

Excessive excretion of phosphorus (P) in manure from intensive swine production is a major environmental issue (Jongbloed et al., 1991). Crops use much less P than nitrogen, and application of swine manure with excessive amounts of P to fields readily results in accumulation of P in surface soil. This eventually leads to run-off and leaching of P into surface water resources and causes eutrophication of the surface water system (Mallin, 2000).

It is known that much of the P excretion can be minimized through better feeding regimes (Poulsen, 2000). Two major factors are causing inefficient P utilization and excessive P excretion in pigs. The first factor is due to the presence of phytate P. About 50% of total dietary P is in the phytate form. Phytate P is not be digested by pigs unless the digestive enzyme called “phytase” is provided. Dietary supplementation of microbial phytase (Simons et al., 1990), development of novel phytase pigs (Golovan et al., 2001) and introduction of new crop cultivars that produce grains with low phytate P (Spencer et al., 2000) are the suggested ways of improving phytate-P utilization in pigs. The second factor is over supplementation of inorganic phosphate salts and limestone in swine diets due to the lack of information on true digestible P and calcium (Ca) requirements and an optimal true digestible P to Ca ratio in pigs. The present total Ca to available P ratio was recommended with a large margin ranging from 2:1 to 3:1 (NRC, 1998). This can potentially cause two major problems to intensive swine feeding. Firstly, inaccurate Ca to P ratio results in bone problems especially in pigs fed microbial phytase and tin he phytase pig. Secondly, inaccurate dietary Ca to P ratio reduces both Ca and P retention and increases their manure excretions.

Our Related Work and Progress

Ca and P related research. Nutritive value of P in feed ingredients for swine is traditionally measured by the apparent digestibility studies and the slope-ratio assay and was considerably underestimated (Fan et al., 2001; Shen et al., 2002; Ajakaiye et al., 2003). As supported by Ontario Pork, OMAFRA-University of Guelph Research Programs and NSERC during the past
several years, we have developed a novel methodology for measuring true fecal P and Ca digestibility and the fecal gastrointestinal endogenous P and Ca levels (Fan et al., 2000; 2001). We reported that true fecal P digestibility in soybean meal was underestimated by about 25% for both post-weaned and growing-finishing pigs (Fan et al., 2001; Ajakaiye et al., 2001). In corn, true fecal P digestibility was underestimated by 30-38% (Shen et al., 2002; 2003). Furthermore, true Ca and P digestibility in corn-soybean meal compound diet mixture can be measured by the substitution method (Fang et al., 2007; Fan et al., 2008).

**Objectives**

This project is to address the following specific objectives in developing a practical low-P and low-Ca hog-feeding regime based on formulation of diets on the basis of true digestible P and Ca supply. The major objective is to determine are to i) determine optimal true digestible Ca to P ratio values; and ii) examine the effect of changing Ca to P ratio on growth performance and efficiency of Ca and P utilization as well as manure N and P excretion in growing-finishing pigs fed corn and soybean meal (SBM)-based diets. Ontario Pork research priorities addressed: the proposed project is targeting at improving environment and reducing feeding cost through accurate determination of true digestible Ca to P ratio value in the grower and finishing pig for minimizing P and Ca overfeeding and excessive excretion in manure.

**Return to Industry**

Sustainable issues: Phosphorus related pollution is a major environmental issue facing the Ontario pork industry. Ontario is implementing more stringent regulations regarding farm nutrient management. Present hog feeding practice produces manure high in P and Ca contents with a large proportion in the water-soluble form that is readily leached and/or run-off into the environment. Conduction of the proposed project shall help Ontario pork producers and swine feed industry tackle the manure P management issue through reducing total and soluble P excretion in manure.
Feeding costs: According to our estimation, the total amount of dicalcium phosphate and limestone needed for supplementation is at about 5 kg for marketing each pig weighing about 110 kg. Conducting this project shall provide data in support of a potential reduction of about 40% of the current dietary levels of these mineral salts. This represents about $5 million saving on feeding cost by using 40% less dicalcium phosphate and limestone per year, only in Ontario. This project is our continued effort to help the industry reduce this cost.

**Literature Review**

Accurate determination of bioavailability of P in feed ingredients and the formulation of swine diets on the basis of bioavailable P supply are essential to ensure efficient P utilization (Jongbloed et al., 1991). Traditionally, bioavailability of P in feed ingredients is usually measured by the apparent digestibility studies and the slope-ratio assay (Cromwell, 1980; Jongbloed et al. 1991; Fan et al., 2001).

As supported by a research grant from Ontario Pork (year 1999-2002), we are the first in demonstrating that the nutritive value of P in feed ingredients for pigs were considerably underestimated by using the traditional methodology widely used in European countries and in the United States (Fan et al., 2001). True P digestibility in soybean meal was determined to be 50% much higher than the average P availability value of 25% reported in the literature (Fan et al., 2001; Ajakaiye et al., 2003). True P digestibility in corn was measured to be 57% considerably higher than the average P availability value of 22% reported for corn in the literature using the traditional methodology (Shen et al., 2002; 2003). In addition, Ca digestibility in soybean meal was determined to be 67 and 97%, respectively, in post-weaned and growing-finishing pigs (Fan et al., 2000; Ajakaiye et al., 2001).

On the other hand, excessive amounts of supplemental P and Ca salts are used in swine diets due to underestimation in the nutritive values of P in feed ingredients. This has caused two inevitable results: high level of fecal P and a large proportion of P in the readily mobile and water-soluble form (Fan et al., 2001). In addition, information on true digestible P to Ca ratio...
value is also essential in diet formulation. At the present, Ca to P ratio values for pigs at different stages were determined on the basis of total Ca and/or total and apparent digestible P supply and used in the present diet formulation (NRC, 1998). Therefore, it is essential to measure true digestible P to Ca ratio value to guide diet formulation for minimizing P excretion. Furthermore, correct dietary Ca to P ratio is also important to ensure efficient Ca and P deposition and bone health. Recent studies by Gao et al. (2002) and Rideout et al. (2002) suggest that about 50% of the total dietary Ca is excreted in feces due to overfeeding of supplemental Ca salts. Thus, it is also crucial to measure accurate true digestible dietary Ca to P ratio value for pigs of different growing stages.

**Materials and Methods**

*Animals and Management*

For the experiment 1 of this study, twelve Yorkshire post-weaned barrows, with average initial and final body weights (BW) of 23.2 and 31.1 kg, were used. For the experiment 2 of this study, 36 Yorkshire post-weaned barrows, with average initial and final BW of 24.15 and 33.83 kg, were used. All the barrows were acquired from the University of Guelph Arkell Swine Research Station and transported to the animal wing in the Department of Animal and Poultry Science at the University. The barrows were placed in an environmentally controlled room (20-22°C) and individually housed in floor pens (Fan et al., 2001). The barrows were fed twice daily at 0900 and 1600 h, respectively, close to *ad libitum* intake (about 5% of the barrow’s body weight) for a total duration of 15 days. Water was available from a low-pressure drinking nipple. The floor pens were cleaned daily. All procedures relating to the use of the pigs were approved by the University of Guelph Animal Care Committee has, and the pigs were cared for in accordance with guidelines established by the Canadian Council on Animal Care (1993).
Experimental Diets and Study Design

For the experiment 1, two corn and SBM-based diets were formulated to contain two levels (as-fed basis) of CP (17.33 and 12.13%), Ca (0.54 and 0.29%), and P (0.54 and 0.39%) with the lower CP, Ca and P diet formulated by replacing corn and SBM with 25.52% cornstarch (Table 1.1). For the experiment 2, six corn and SBM-based diets were formulated to contain six levels of total Ca to total P ratio (diet 1, 0.60:1; diet 2, 0.74:1; diet 3, 0.81:1; diet 4, 1.26:1; diet 5, 1.00:1; and diet 6: 1.33:1), and true fecal digestible Ca to true fecal digestible P ratios (diet 1, 0.86:1; diet 2, 0.73:1; diet 3, 1.09:1; diet 4, 1.08:1; diet 5, 2.16:1; and diet 6, 1.87:1) formulated by supplementing gradient levels of limestone with dietary P contents meeting the NRC (1998) requirement standard (Table 2.1). The dietary inclusion of CP, essential AA, digestible energy, minerals, and vitamins were equivalent to or in excess of the recommended concentrations in grower pigs as suggested by the NRC (1998) for the experiment 2. Titanium oxide (0.30%, as-fed basis) was included as a digestibility marker in both experiments. Canola oil was included in the diets for both experiments to balance the digestible energy contents of the diets and to reduce dust during diet mixing and feeding. For the experiment 1, the barrows were randomly assigned to the two experimental diets and fed according to a completely randomized. For the experiment 2, the barrows were randomly assigned to the six experimental diets and fed according to a completely randomized block design for six experimental blocks. Each experimental block lasted for 15 days with 10 days of adaptation and 4 days of collecting needed samples.

Measurements, Sample Collections and Processing

Daily feed allowances and leftover feeds were measured and recorded. Body weights of the experimental pigs were recorded on day 15 of each experimental block periods. Representative fresh fecal samples were collected at 2-h intervals in the daytime between days 11 and 14 days after a 10-day pre-adjusting period for each of the test blocks. Urine samples were obtained using a funnel-shaped metal tray secured to the base of the webbed floor of the metabolic crate. Urine flowed from the metal tray into a collection container placed in an electronic cooler.
beneath the metabolic crate. A suitable volume of concentrated hydrochloric acid solution was regularly added into the collection container to ensure acidic pH of the collected urine to reduce microbial activity and urea degradation and ammonia (NH₃) loss during the collection period. All the barrows were sacrificed on day 15. Fresh samples were collected in containers with sealed lids and immediately stored at 4°C for the duration of the period. The total volume of urine collected each day was measured, recorded and only a fraction of the daily collected urine was sampled. Collected fecal and urinary samples were stored at 4°C for the remainder of the experimental period. At the conclusion of the experiments, representative fecal samples were freeze-dried, ground to be homogenous mixture and stored at 4°C in sealed containers. Diet, corn, and soybean meal samples were taken immediately after the diet mixing, were then ground to be homogenous and stored at 4°C in sealed containers.

**Chemical and Molecular Analyses**

Analyses of dry matter were carried out according to Association of Official Analytical Chemists (AOAC) methods (1990). Total Ca content in diet, fecal and urine samples were analyzed by inductively coupled plasma (ICP)-mass spectrometry via commercial services in School of Environmental Science at the University of Guelph. Titanium oxide (TiO₂) content in diet and fecal samples was analyzed according to Leone (1973).

**Calculations and Statistical Analyses**

In order to obtain dietary true digestible Ca to true digestible P ratio and efficiency of true digestive and post-absorptive utilization of dietary Ca and P, true fecal Ca and P digestibility associated with corn and SBM based diets were measured by the substitution method from the experiment 1 according to Fang et al. (2007) and Fan et al. (2008) from equation (1).

\[
D_T = \frac{(P_{A2} - P_{A1}) \times 100}{(P_{D2} - P_{D1})}
\]

(1)

Where \(D_T\) is true nutrient digestibility of the dietary ingredient (%); \(P_{A2}\) is the apparent digestible nutrient content (g/dry matter intake) from the higher-P diet; \(P_{A1}\) is the apparent digestible
nutrient content (g/dry matter intake) from the lower-nutrient diet; $P_{D2}$ is total dietary nutrient content from the higher-nutrient diet; and $P_{D1}$ is total dietary nutrient content from the lower-nutrient diet.

The fecal endogenous losses of CP, Ca and P associated with corn and SBM based diets for both experiments 1 and 2 were then calculated according to Fan et al. (2008) from equation (2).

$$P_E = \left[ (D_{Ti} - D_{Ai}) \times P_{Di} \right] / 100\%$$

(2)

Where $D_{Ti}$ is the true nutrient digestibility of the diet (%); $D_{Ai}$ is apparent nutrient digestibility of the diet (%); $P_E$ is endogenous fecal nutrient loss (g/kg dry matter intake); and $P_{Di}$ is the nutrient content of the diet (g/kg DM diet).

Based on the apparent fecal nutrient digestibility and the levels of endogenous fecal nutrient losses estimated, true nutrient (CP, Ca and P) digestibility of the diets for the experiment 2 were determined according to equation (3).

$$D_{Ti} = D_{Ai} + \left( \frac{P_E}{P_{Di}} \right) \times 100\%$$

(3)

The efficiency of digestive and post-absorptive utilization (% on dietary intake) of CP, Ca, and P utilization were partitioned according to Rideout and Fan (2004) and Rideout et al. (2007a). The individual pig was the experimental unit. All the statistical analyses were conducted using the GLM and mixed models of SAS (SAS Inst. Inc., Cary, NC) for a completely randomized block design.

**Results and Discussion**

**Experiment 1**

In order to obtain dietary true fecal digestible Ca to true fecal digestible P ratio and to further investigate the effect of changes in dietary true digestible calcium (Ca) to true digestible phosphorus (P) ratio on growth performance and the efficiency of dietary Ca and P utilization, the experiment 1 was conducted to measure true fecal digestibility and the fecal endogenous
losses of Ca and P associated with corn and SBM based diets for grower pigs by the substitution method. There was no difference \((P = 0.22)\) in average daily feed intake between the two groups of grower pigs fed the test diets. As expected, pigs fed the lower-nutrient diet formulated according to principles of the substitution method in the experiment 1 had lower average daily gain \((P = 0.07)\) and poor feed conversion ratio \((P = 0.02)\) over the 15-d experimental period (Table 1.2).

However, feeding pigs on the lower-nutrient diet (diet 2) formulated according to principles of the substitution method in the experiment 1 did not appear to affect the digestive function in the pig, as the apparent dry matter (DM) digestibility was higher \((P = 0.03)\) in diet 2 (the low-nutrient diet) compared with diet 1 (the normal-nutrient diet) (Table 1.3). The higher apparent DM digestibility in diet 2 compared with diet 1 is likely due to the fact that starch was more digestible than corn and SBM as observed by Fan et al. (2001). On the other hand, the apparent Ca and P digestibility values were lower \((P < 0.05)\) in diet 2 than in diet 1 (Table 1.3). This is likely due to the fact that the dietary Ca and P contents were lower (Ca, 0.54 vs. 0.29%; P, 0.54 vs. 0.39%) and the relative fecal endogenous Ca and P contributions would be much higher in the diet 2 compared with in the diet 1, resulting in the lower apparent Ca and P digestibility values, as demonstrated in our previous studies (Fan et al., 1994).

True fecal digestibility and the fecal endogenous losses of Ca and P associated with corn and SBM based diets for the post-weaned pigs were measured by the substitution method (Table 1.4). This is the first report of measuring true fecal nutrient digestibility values and fecal gastrointestinal endogenous nutrient outputs for a diet mixture in grower pigs by using the substitution method, while this method has been applied for feed ingredients in grower pigs (Fang et al., 2007).

True fecal Ca digestibility (53.57%) in the corn and SBM based diet determined from this study is surprisingly low and was associated with a large variability (SE = 12.69%) giving the fact that limestone and dicalcium phosphate were supplemented. On the other hand, the fecal endogenous Ca loss (0.91 g/DM intake) measured from this study is associated with a similar
variability (SE = 0.20 g/DM intake, Table 1.4). Very little information is available in the literature regarding estimation of both true Ca digestibility and the endogenous fecal Ca loss in grower pigs. Whole body Ca homeostasis control at the digestive level is very much a complex and is a balance between absorption and the endogenous secretions along the entire intestinal tract (Rideout et al., 2007a). Much research work still needs to be conducted to understand dietary and physiological factors affect true fecal Ca digestibility and the fecal gastrointestinal endogenous Ca loss in the pig.

True fecal P digestibility (43.78%) in the corn and SBM based diet determined from this study was close to the average true P digestibility values reported for corn and SBM for growing pigs (Fan et al., 2008). However, the fecal endogenous P loss (1.31 g/kg dry matter intake) measured from this study was much higher than the range of values reported in the literature for corn and SBM in the both weanling and grower-finisher pigs, as compiled by Fan et al. (2008).

**Experiment 2**

It should be pointed out that the analyzed dietary Ca content in diet 5 was lower than expected in comparison with the other diets especially diets 4 likely due to diet mixing error. Based on the fecal endogenous Ca and P loss values measured from the experiment 1, true fecal Ca and P digestibility values were calculated for the diets used in the experiment 2 and dietary true digestible Ca to true digestible P ratio values were also calculated (Tables 2.2-2.3). Changes in the dietary Ca to P ratio had no effects on average daily feed intake, however, have an linear effect on average daily gain ($P < 0.05$) with excellent responses occurred in diets 2 and 4 corresponding to true digestible Ca to true digestible P ratio of 0.70:1 and 1.10:1 during the 15-d growth performance measured (Table 2.2). Furthermore, changes in the dietary Ca to P ratio had linear, quadratic and cubic effects ($P < 0.05$) on the feed conversion ratio with excellent responses also occurred in diets 2-4. It has been well documented that a wide dietary Ca to P ratio would reduce growth performance in pigs (NRC, 1998). The optimal responses in the 15-d
average daily gain occurred in diets 2 and 4 were likely resulted from corresponding increases in the feed conversion efficiency (Table 2.2).

However, due to a large variability, changes in the dietary Ca to P ratio had no effects ($P > 0.05$) on the efficiency of digestive and post-absorptive utilization of dietary Ca and P. Efficiency of whole body P retention was numerically high in diets 2, 3 and 4 but very low in diet 6. However, efficiency of whole body Ca retention did not follow the similar pattern among the diets (Table 2.3). We conclude that changes in dietary Ca to P ratio have significant effects on growth performance. Dietary true digestible Ca to true digestible P ratio of 0.90:1 to 1.10:1 equivalent to total Ca to total P ratio of 0.70:100 to 1.20:100 may be optimal for feeding grower pigs.

**Acknowledgement**

This research has been possible through the financial support of Ontario Pork, Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA)-University of Guelph Partnership Program and the Canada-Ontario Research and Development (CORD) Program, an initiative of the federal-provincial-territorial Agricultural Policy Framework designed to position Canada's agri-food sector as a world leader. The Agricultural Adaptation Council administers the CORD Program on behalf of the province. We also thank Ntinya Johnson for participating in the pig growth performance research activities.
TABLE 1.1

Diet formulation for measuring true Ca and P digestibility and the fecal endogenous Ca and P outputs in grower pigs (20 – 50 Kg) by the substitution method.

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>High-nutrient diet (Diet 1)</th>
<th>Low-nutrient diet (Diet 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean meal</td>
<td>27.07</td>
<td>18.95</td>
</tr>
<tr>
<td>Corn</td>
<td>66.00</td>
<td>46.2</td>
</tr>
<tr>
<td>Cornstarch&lt;sup&gt;1&lt;/sup&gt;</td>
<td>2.71</td>
<td>28.23</td>
</tr>
<tr>
<td>Solka-Flock&lt;sup&gt;TM&lt;/sup&gt; (100% cellulose)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.00</td>
<td>2.98</td>
</tr>
<tr>
<td>L-Lys-HCL (79% L-Lys)&lt;sup&gt;3&lt;/sup&gt;</td>
<td>0.17</td>
<td>0.119</td>
</tr>
<tr>
<td>L-threonine (100%)&lt;sup&gt;3&lt;/sup&gt;</td>
<td>0.05</td>
<td>0.035</td>
</tr>
<tr>
<td>Animal fat</td>
<td>1.10</td>
<td>1.10</td>
</tr>
<tr>
<td>Iodized salt</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>Limestone (38.5% Ca)&lt;sup&gt;4&lt;/sup&gt;</td>
<td>0.84</td>
<td>0.59</td>
</tr>
<tr>
<td>Dicalcium phosphate (22% Ca)&lt;sup&gt;4&lt;/sup&gt;</td>
<td>0.86</td>
<td>0.60</td>
</tr>
<tr>
<td>Vitamin-mineral premix&lt;sup&gt;5&lt;/sup&gt;</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Titanium oxide&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Total (100 kg)</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Nutritive values (as-fed basis):

<table>
<thead>
<tr>
<th>Nutritive value</th>
<th>High-nutrient diet (Diet 1)</th>
<th>Low-nutrient diet (Diet 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter (DM, %)&lt;sup&gt;7&lt;/sup&gt;</td>
<td>86.91</td>
<td>87.65</td>
</tr>
<tr>
<td>DE (MJ/kg)&lt;sup&gt;8&lt;/sup&gt;</td>
<td>14.58</td>
<td>14.74</td>
</tr>
<tr>
<td>CP (%)&lt;sup&gt;8&lt;/sup&gt;</td>
<td>17.33</td>
<td>12.13</td>
</tr>
<tr>
<td>Total Ca (%)&lt;sup&gt;7&lt;/sup&gt;</td>
<td>0.54</td>
<td>0.29</td>
</tr>
<tr>
<td>Total P (%)&lt;sup&gt;7&lt;/sup&gt;</td>
<td>0.54</td>
<td>0.39</td>
</tr>
<tr>
<td>Total Ca to total P ratio&lt;sup&gt;9&lt;/sup&gt;</td>
<td>1.00</td>
<td>0.74</td>
</tr>
<tr>
<td>NDF (%)&lt;sup&gt;8&lt;/sup&gt;</td>
<td>9.94</td>
<td>9.94</td>
</tr>
<tr>
<td>ADF (%)&lt;sup&gt;8&lt;/sup&gt;</td>
<td>4.39</td>
<td>3.07</td>
</tr>
<tr>
<td>Cellulose plus hemicellulose (%)&lt;sup&gt;8&lt;/sup&gt;</td>
<td>5.54</td>
<td>6.86</td>
</tr>
</tbody>
</table>

<sup>1</sup>Casco Inc., Etobicoke, ON, Canada.

<sup>2</sup>Solka-Flock<sup>TM</sup>: commercial cellulose product from International Fiber Corporation, North Tonawanda, New York.
Degussa AG, Feed Additives, Hanau-Wolfgang, Germany.

Country Solvents and Chemicals LTD., Guelph, ON, Canada.

Roche Vitamins Canada Inc., Cambridge, ON, Canada. Supplied the following vitamins and minerals per kg pre-mix: vitamin A, 2,000,000 IU; vitamin D3, 200,000 IU; vitamin E, 8,000 IU; vitamin K, 500 mg; pantothenic acid, 3,000 mg; riboflavin, 1,000 mg; folic acid, 400 mg; niacin, 5,000 mg; thiamine, 300 mg; pyridoxine, 300 mg; vitamin B12, 5,000 mcg; biotin, 40,000 mg; choline, 100,000 mg; Se, 60 mg; I, 100 mg; Cu, 3,000 mg; Fe, 20,000 mg; Mn, 4,000 mg; Zn, 21,000 mg.

Titanium oxide used as a digestibility marker, Fisher Scientific, Fair Lawn, NJ.

Analyzed values.

Calculated values according to data compiled by NRC (1998).

Calculated values by using analyzed contents.
TABLE 1.2

Responses in growth performance measured during the experimental d 1-15 for the growing pigs fed corn and soybean meal-based diets formulated at two levels of dietary crude protein (CP), calcium (Ca) and phosphorus (P) levels for measuring true Ca and P digestibility and the fecal endogenous Ca and P outputs associated with the diet mixture.

<table>
<thead>
<tr>
<th>Items</th>
<th>Diet 1</th>
<th>Diet 2</th>
<th>SEM(^1)</th>
<th>Probability(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADFI(^3), kg/pig .d</td>
<td>1.0757</td>
<td>1.1318</td>
<td>0.030</td>
<td>0.2185</td>
</tr>
<tr>
<td>ADG(^4), kg/pig . d</td>
<td>0.5778</td>
<td>0.4778</td>
<td>0.035</td>
<td>0.0682</td>
</tr>
<tr>
<td>Feed to gain ratio, kg/kg</td>
<td>1.8617</td>
<td>2.3688</td>
<td>0.029</td>
<td>0.0187</td>
</tr>
</tbody>
</table>

\(^1\)Pooled standard error of means (n = 6).

\(^2\)Probability of significance.

\(^3\)ADFI: average daily feed intake.

\(^4\)ADG: average daily gain.
**TABLE 1.3**

Apparent fecal digestibility values (%) of dry matter (DM), calcium (Ca) and phosphorus (P) in the experimental diets measured for the grower pigs fed the corn and soybean meal-based diets

<table>
<thead>
<tr>
<th>Items</th>
<th>Diet 1</th>
<th>Diet 2</th>
<th>SEM$^1$</th>
<th>Probability$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td>80.78</td>
<td>83.52</td>
<td>0.78</td>
<td>0.0303</td>
</tr>
<tr>
<td>Ca</td>
<td>39.38</td>
<td>25.92</td>
<td>5.03</td>
<td>&gt; 0.0500</td>
</tr>
<tr>
<td>P</td>
<td>22.50</td>
<td>14.08</td>
<td>4.04</td>
<td>&gt; 0.0500</td>
</tr>
</tbody>
</table>

$^1$Pooled standard error of means (n = 6).

$^2$Probability of significance levels.
**TABLE 1.4**

True fecal digestibility values and the fecal endogenous outputs of calcium (Ca) and phosphorus (P) associated with the corn and soybean meal-based diets for the growing pigs measured by the substitution method.

<table>
<thead>
<tr>
<th>Items</th>
<th>True digestibility(^1) (%)</th>
<th>Fecal endogenous loss(^2) (g/kg DM intake)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca</td>
<td>53.57 ± 12.69</td>
<td>0.91 ± 0.20</td>
</tr>
<tr>
<td>P</td>
<td>43.78 ± 16.74</td>
<td>1.31 ± 0.15</td>
</tr>
</tbody>
</table>

\(^1\) Parameter estimates ± pooled SE (n = 6) calculated from the Equation 1 described in the Materials and Methods section.

\(^2\) Parameter estimates ± pooled SE (n = 12) calculated from the Equation 2 described in the Materials and Methods section.
TABLE 2.1
Composition of the experimental diets for examining the effect of changes in dietary calcium (Ca) to phosphorus (P) ratios on performance, Ca and phosphorus (P) utilization in grower pigs fed corn and soybean meal-based diets

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Diet 1</th>
<th>Diet 2</th>
<th>Diet 3</th>
<th>Diet 4</th>
<th>Diet 5</th>
<th>Diet 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean meal</td>
<td>27.07</td>
<td>27.07</td>
<td>27.07</td>
<td>27.07</td>
<td>27.07</td>
<td>27.07</td>
</tr>
<tr>
<td>Corn</td>
<td>66.00</td>
<td>66.00</td>
<td>66.00</td>
<td>66.00</td>
<td>66.00</td>
<td>66.00</td>
</tr>
<tr>
<td>Cornstarch&lt;sup&gt;1&lt;/sup&gt;</td>
<td>3.87</td>
<td>3.29</td>
<td>2.71</td>
<td>2.13</td>
<td>1.55</td>
<td>0.97</td>
</tr>
<tr>
<td>L-Lys-HCL (79% L-Lys)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td>L-threonine (100%)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Animal fat</td>
<td>0.50</td>
<td>0.80</td>
<td>1.10</td>
<td>1.40</td>
<td>1.70</td>
<td>2.00</td>
</tr>
<tr>
<td>Iodized salt</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>Limestone (38.3% Ca)&lt;sup&gt;3&lt;/sup&gt;</td>
<td>0.28</td>
<td>0.56</td>
<td>0.84</td>
<td>1.12</td>
<td>1.40</td>
<td>1.68</td>
</tr>
<tr>
<td>Dicalcium phosphate (22% Ca)&lt;sup&gt;3&lt;/sup&gt;</td>
<td>0.86</td>
<td>0.86</td>
<td>0.86</td>
<td>0.86</td>
<td>0.86</td>
<td>0.86</td>
</tr>
<tr>
<td>Vitamin-mineral premix&lt;sup&gt;4&lt;/sup&gt;</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Titanium oxide&lt;sup&gt;5&lt;/sup&gt;</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Total (100 kg)</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Nutritive values (as-fed basis):

- Dry matter (DM, %)<sup>6</sup> | 87.55  | 87.65  | 87.84  | 87.80  | 88.13  | 88.08  |
- DE (MJ/Kg)<sup>7</sup>        | 14.54  | 14.56  | 14.57  | 14.58  | 14.59  | 14.61  |
- CP (%)<sup>7</sup>             | 17.33  | 17.33  | 17.33  | 17.33  | 17.33  | 17.33  |
- Total Ca (%)<sup>6</sup>       | 0.40   | 0.43   | 0.51   | 0.67   | 0.59   | 0.73   |
- Total P (%)<sup>6</sup>        | 0.67   | 0.58   | 0.63   | 0.63   | 0.59   | 0.55   |
- Total Ca to total P ratio<sup>8</sup> | 0.60   | 0.74   | 0.81   | 1.26   | 1.00   | 1.33   |
- NDF (%)<sup>7</sup>            | 9.94   | 9.94   | 9.94   | 9.94   | 9.94   | 9.94   |
- Cellulose plus hemicellulose (%)<sup>7</sup> | 5.54   | 5.54   | 5.54   | 5.54   | 5.54   | 5.54   |

<sup>1</sup>Casco Inc., Etobicoke, ON, Canada.

<sup>2</sup>Degussa AG, Feed Additives, Hanau-Wolfgang, Germany.
Country Solvents and Chemicals LTD., Guelph, ON, Canada.

Roche Vitamins Canada Inc., Cambridge, ON, Canada. Supplied the following vitamins and minerals per kg pre-mix: vitamin A, 2,000,000 IU; vitamin D3, 200,000 IU; vitamin E, 8,000 IU; vitamin K, 500 mg; pantothenic acid, 3,000 mg; riboflavin, 1,000 mg; folic acid, 400 mg; niacin, 5,000 mg; thiamine, 300 mg; pyridoxine, 300 mg; vitamin B12, 5,000 mcg; biotin, 40,000 mg; choline, 100,000 mg; Se, 60 mg; I, 100 mg; Cu, 3,000 mg; Fe, 20,000 mg; Mn, 4,000 mg; Zn, 21,000 mg.

Titanium oxide used as a digestibility marker, Fisher Scientific, Fair Lawn, NJ.

Analyzed values.

Calculated values according to data compiled by NRC (1998).

Calculated values by using analyzed contents.
TABLE 2.2
The effect of six gradient levels of dietary calcium (Ca) to phosphorus (P) ratios on growth performance in the grower pigs fed corn and soybean meal-based diets

<table>
<thead>
<tr>
<th>Items</th>
<th>Diet 1</th>
<th>Diet 2</th>
<th>Diet 3</th>
<th>Diet 4</th>
<th>Diet 5</th>
<th>Diet 6</th>
<th>SEM¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Ca/P ratio</td>
<td>0.608:1</td>
<td>0.74:1</td>
<td>0.81:1</td>
<td>1.26:1</td>
<td>1.00:1</td>
<td>1.33:1</td>
<td></td>
</tr>
<tr>
<td>True digestible Ca/P ratio</td>
<td>0.86:1</td>
<td>0.73:1</td>
<td>1.09:1</td>
<td>1.08:1</td>
<td>2.16:1</td>
<td>1.87:1</td>
<td></td>
</tr>
<tr>
<td>ADFI, kg/pig•d</td>
<td>1.24</td>
<td>1.18</td>
<td>1.45</td>
<td>1.22</td>
<td>1.18</td>
<td>1.18</td>
<td>0.03</td>
</tr>
<tr>
<td>ADG², kg/pig•d</td>
<td>0.65</td>
<td>0.71</td>
<td>0.67</td>
<td>0.66</td>
<td>0.59</td>
<td>0.60</td>
<td>0.03</td>
</tr>
<tr>
<td>Gain to feed ratio³, kg/kg</td>
<td>0.52</td>
<td>0.60</td>
<td>0.58</td>
<td>0.54</td>
<td>0.50</td>
<td>0.51</td>
<td>0.02</td>
</tr>
</tbody>
</table>

¹Pooled standard error of means (n = 6).
²Linear effects (P < 0.05).
³Linear, quadratic and cubic effects (P < 0.05).
TABLE 2.3
The effect of six gradient levels of dietary calcium (Ca) to phosphorus (P) ratios on efficiency (% of total dietary intake) of digestive and post-absorptive utilization of dietary calcium (Ca) and phosphorus (P) in the grower pigs fed corn and soybean meal-based diets

<table>
<thead>
<tr>
<th>Items</th>
<th>Diet 1</th>
<th>Diet 2</th>
<th>Diet 3</th>
<th>Diet 4</th>
<th>Diet 5</th>
<th>Diet 6</th>
<th>SEM(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Ca/P ratio</td>
<td>0.60:1</td>
<td>0.74:1</td>
<td>0.81:1</td>
<td>1.26:1</td>
<td>1.00:1</td>
<td>1.33:1</td>
<td></td>
</tr>
<tr>
<td>True digestible Ca/P ratio</td>
<td>0.86:1</td>
<td>0.73:1</td>
<td>1.09:1</td>
<td>1.08:1</td>
<td>2.16:1</td>
<td>1.87:1</td>
<td></td>
</tr>
<tr>
<td>True Ca digestibility, %</td>
<td>53.44</td>
<td>39.55</td>
<td>45.17</td>
<td>37.87</td>
<td>52.99</td>
<td>36.82</td>
<td>5.28</td>
</tr>
<tr>
<td>True P digestibility, %</td>
<td>43.06</td>
<td>42.17</td>
<td>40.23</td>
<td>37.23</td>
<td>33.67</td>
<td>22.41</td>
<td>3.46</td>
</tr>
<tr>
<td>True Ca retention, %</td>
<td>37.61</td>
<td>33.33</td>
<td>37.13</td>
<td>21.09</td>
<td>45.62</td>
<td>22.90</td>
<td>6.30</td>
</tr>
<tr>
<td>True P retention, %</td>
<td>37.37</td>
<td>39.59</td>
<td>38.16</td>
<td>35.96</td>
<td>32.02</td>
<td>20.90</td>
<td>3.52</td>
</tr>
</tbody>
</table>

\(^1\)Pooled standard error of means (n = 6).
References Cited


