



7     **Abstract**

8             The objective was to estimate the annual phosphorus (P) excretion from pigs in Korea based on P  
9 and phytate-P concentrations in commercial swine diets. Fifty-eight samples from commercial diets for  
10 various growth stages of pigs were collected from 16 swine farms and analyzed for P and phytate-P  
11 concentrations. The P concentrations ranged from 0.54% to 0.66%. Phytate-P contents in the piglet phase  
12 1 and 2 diets were less (0.19% and 0.22% vs. 0.28% to 0.31%;  $p < 0.05$ ) than those in the growing pig or  
13 sow diets. Fecal P excretion was calculated based on total P, phytate-P, and phytase concentrations: fecal  
14 P excretion (g/day) = [total P in feed (g/kg) – apparent total tract digestible (ATTD) P in feed (g/kg)] × feed  
15 intake (kg/day). The Gompertz model was adapted to estimate feed intake from suckling to finishing pigs,  
16 from birth to 121.5 kg body weight (BW), on days 0 to 180. Feed intake for gestating and lactating sows  
17 was adapted from the NRC. The ATTD P in the feed was estimated using the following equation: ATTD P  
18 (g/kg) =  $0.135 + 0.649 \times \text{total P (g/kg)} - 0.445 \times \text{phytate-P (g/kg)} + 0.470 \times \text{phytate-P} \times (1 - e^{-0.824 \times \text{phytase}})$ .  
19 The phytase concentration in all diets was assumed to be 500 FTU/kg. Urinary P excretion for the market  
20 swine was estimated using the following equation: Urinary P excretion (g/day) = BW (kg) × 0.007 (g/kg  
21 BW/day). The urinary P excretion for reproductive sows was adapted from a previous study. The total  
22 annual P excretion for market pigs was estimated to be 1.94 kg/year, which is equivalent to a pig with a  
23 BW of 44.1 kg at 93 days of age. For gestating and lactating sows, the total annual P excretion was estimated  
24 to be 3.26 kg/year and 6.89 kg/year, respectively. Assuming a population ratio of 91:7:2 for market pigs,  
25 gestating sows, and lactating sows, the annual P excretion from all market and breeding swine in Korea  
26 was estimated to be 2.13 kg/year.

27     **Keywords (3 to 6):** Phosphorus excretion, Pigs, Swine diets

28

## INTRODUCTION

Phosphorus (P) plays a crucial role in both the skeletal system and various physiological functions in pigs [1]. In cereal grains, grain by-products, and oilseed meals, approximately two-thirds of P exists in the form of phytate-P with low digestibility in pigs [2,3]. Although exogenous phytase is commonly supplemented in commercial swine diets to improve P digestibility, phytate-P is not completely digested [4-6]. Unabsorbed P is excreted through swine feces, posing a potential risk of environmental pollution such as eutrophication [7,8]. Additionally, the quantities of excreted P would vary based on the types of feed ingredients included, the phytate-P concentration, and the phytase supplementation in swine diets [4-6].

An accurate estimation of P excretion from pigs is essential on a regional or national scale to develop efficient strategies for managing P excretion. Although European Union members routinely assess P excretion in individual countries [9-13], such data are lacking in Korea. In addition, the models for estimating P excretion from swine production developed more than 20 years ago [9-11] would not represent the present pig diets in Korea as the usage of phytase in swine diets has dramatically increased during the last 2 decades. The swine NRC [1] suggests models for pig growth and feed intake that are reasonably close to the Korean pig production systems. Therefore, this study aimed to estimate the annual P excretion per pig in Korea using the total P and phytate-P concentrations in commercial swine diets employing the models in the literature.

## MATERIALS AND METHODS

### Sample collection and chemical analyses

A total of 58 commercial swine diet samples were collected from 16 swine farms in Korea during various growth stages of pigs (Table 1). The diet samples were categorized into piglet phase 1 (7 to 15 kg; n = 11), piglet phase 2 (15 to 25 kg; n = 11), growing phase (25 to 50 kg; n = 10), finishing phase (50 to 121.5 kg; n = 7), gestation phase (n = 9), and lactation phase (n = 9). All samples were finely ground (< 0.1 mm) and stored at 4 °C in the refrigerator until chemical analyses. The diet samples were analyzed for P using the molybdenum blue method (method 995.11) by UV spectrophotometer (UV-2450, Shimadzu, Kyoto, Japan) after dry-ash sample preparation as described by the AOAC [14]. Additionally, phytate-P in the diet samples was also analyzed using the commercial phytic acid assay kit (K-PHYT, Megazyme, Bray, Ireland) and the UV spectrophotometer (UV-2450, Shimadzu, Kyoto, Japan).

### Calculations

61 To estimate the daily body weight (BW) for market pigs, the NLIN procedure of SAS (SAS Inst.  
62 Inc., Cary, NC, USA) with nonlinear regression was used based on BW and age data from the NRC [1].  
63 The equation used in the Gompertz model [15] was:

64

$$65 \text{ Gompertz model: } Wt \text{ (kg)} = Ae^{-be^{-kt}}$$

66

67 where  $Wt$ , represents the age at time  $t$  (day),  $A$  was the BW of the mature pig,  $b$  was the growth ratio,  $k$  was  
68 the maturing rate, and  $e$  was the natural logarithm.

69

$$70 \text{ Gompertz model: } BW \text{ (kg)} = 217.4e^{-4.6919e^{-0.0116t}}$$

71

72 where  $t$  represents the age of the market pigs ( $R^2 = 0.999$  and  $p < 0.001$ ). The feed intake of market pigs  
73 was estimated using the default metabolizable energy (ME) intake equations for gilts and barrows and the  
74 effective ME content of the diet suggested by the NRC [1], as follows:

75

$$76 \text{ Feed intake for market pigs (kg/day, as-fed basis)} = \text{default ME intake, gilts and barrows (kcal/day)} \div \\ 77 \text{ effective ME content of the diet (kcal/kg)} \div \text{feed wastage correction coefficient}$$

78

79 where the average of default ME intake for gilts and barrows was calculated based on the default ME intake  
80 curves suggested by the NRC [1]. The values of 3,300 kcal/kg for the effective ME content of the diet and  
81 5% feed wastage were also applied based on the assumption suggested by NRC [1]. The feed wastage  
82 correction coefficient was 0.95. The feed intake for gestating and lactating sows was set at 2.12 and 5.34  
83 kg/day, respectively, adapted from the NRC [1].

84

85 Fecal P excretion from pigs was estimated using the total P concentration in the diet, apparent total  
86 tract digestible (ATTD) P concentration in the diet, and feed intake as independent variables:

87

$$88 \text{ Fecal P excretion (g/day)} = [\text{total P in diet (g/kg)} - \text{ATTD P in diet (g/kg)}] \times \text{feed intake (kg/day)}$$

89

90 The ATTD P in the diet was estimated using the total P, phytate-P, and phytase concentrations in  
91 the diet as independent variables, following the prediction equation suggested by Sung and Kim [6]:

92

$$93 \text{ ATTD P (g/kg)} = 0.135 + 0.649 \times \text{total P (g/kg)} - 0.445 \times \text{phytate-P (g/kg)} + 0.470 \times \text{phytate-P (g/kg)} \\ 94 \times (1 - e^{-0.824 \times \text{phytase}})$$

95

96 where the total P and phytate-P concentrations in the diet were based on the analyzed data, and the phytase  
97 concentration in the diet was assumed to be 500 phytase unit (FTU)/kg for all diets. Urinary P excretion for  
98 market pigs was estimated using the following equation suggested by the NRC [1]:

99

$$100 \quad \text{Urinary P excretion (g/day)} = \text{BW (kg)} \times 0.007 \text{ (g/kg BW/day)}$$

101

102 The urinary P excretion for gestating and lactating sows was assumed to be 2.50 and 2.40 g/day,  
103 respectively, based on the report by Grez-Capdeville and Crenshaw [16].

104

105 Total P excretion from the pigs was calculated as the sum of fecal and urinary P excretions:

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$$107 \quad \text{Total P excretion (g/day)} = \text{fecal P excretion (g/day)} + \text{urinary P excretion (g/day)}$$

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109 The weighted mean of P excretion for breeding sows was calculated based on an estimated country  
110 population ratio of 80:20 for gestating sows and lactating sows. Additionally, P excretion for the entire pig  
111 was calculated based on an estimated country population ratio of 91:7:2 for market pigs, gestating sows,  
112 and lactating sows [17]. An example illustrating the calculation of the weighted mean of total P excretion  
113 for the entire swine population is presented in Figure 1.

114

115

## 116 **Statistical analyses**

117 Data for P and phytate-P in the diet were analyzed using the MIXED procedure of SAS (SAS Inst.  
118 Inc., Cary, NC, USA). Each phase was included as a fixed variable in the model. Least squares means were  
119 calculated for the dietary total P and phytate-P concentrations for each phase and were compared using the  
120 PDIFF option. Each diet was considered an experimental unit. Statistical significance was set at  $p < 0.05$ .

121

## 122 **RESULTS**

123 The total P concentrations in the diet ranged from 0.54 to 0.66% and did not differ among the  
124 phases (Table 1). Dietary phytate-P concentrations in the piglet phases were lower ( $p < 0.05$ ) than those in  
125 other phases.

126 Fecal, urinary, and total P excretions for market pigs from 7 to 121.5 kg BW at 27 to 180 days of  
127 age were 4.93, 0.40, and 5.33 g/day, respectively (Table 2). For gestating sows, fecal, urinary, and total P  
128 excretion were 6.70, 2.50, and 9.20 g/day, respectively. Fecal, urinary, and total P excretion of lactating  
129 sows were 19.31, 2.40, and 21.71 g/day, respectively. Estimated annual total P excretion was 1.94 kg/year  
130 for market pigs, 3.26 kg/year for gestating sows, and 6.89 kg/year for lactating sows. Collectively, the

131 weighted mean of the total P excretion for the entire swine population in Korea was 5.83 g/day or 2.13  
132 kg/year.

133 As the age of the pig increases, daily P excretion increases from 0.98 g/day to 7.65 g/day for fecal  
134 P excretion and from 0.05 g/day to 0.85 g/day for urinary P excretion (Figure 2). From 7 to 121.5 kg BW  
135 at ages of 27 to 180 days, the total P excretion for market pigs is 5.33 g/day or 0.82 kg/pig per production  
136 cycle. The representative BW for the P excretion is 44.1 kg at the age of day 93.

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## DISCUSSION

139 In market pigs diets, the analyzed total P concentration of the commercial diets for piglet and growing  
140 phases closely matched the requirement estimates in the NRC [1]. However, the analyzed total P  
141 concentrations in finishing diets for pigs weighing over 75 kg were greater than the NRC requirement  
142 estimates. This deviation in the finishing phase is likely attributed to the assumption that the same diet was  
143 provided to the pigs from 50 kg until marketing of pigs in the present work. As pigs grow, their nutrient  
144 requirements and concentrations in the diet gradually decrease [1]. Nevertheless, in the Korean swine  
145 production system, the diet for growing phase is sometimes fed to growing and finishing phases [18].  
146 Feeding growing diets to finishing pigs is likely a strategy to cope with challenging production conditions,  
147 such as hot summers and cold winters in Korea, where feed replacement can be difficult. Therefore, it was  
148 assumed that P intake exceeded the requirements for finishing pigs in this study, resulting in higher P  
149 excretion compared to diets that marginally met the P requirements for finishing pigs.

150 In the gestating and lactating sow diets, the analyzed P concentrations were similar to or higher than  
151 the values suggested by the NRC [1]. The P content in the gestating sow diets (0.66%) exceeded the NRC  
152 [1] requirement estimates (ranging from 0.38 to 0.62%, total P basis), which are based on variables  
153 including parity, anticipated gestational weight gain, anticipated litter size, and days of gestation. Similarly,  
154 the P content in the lactating sow diets (0.66%) either exceeded or closely matched the requirement  
155 estimates (ranging from 0.54 to 0.67%, total P basis), considering variables such as parity, post-farrowing  
156 BW, litter size, lactation length, and mean daily weight gain of nursing pigs. Variations between the P  
157 concentration of diets in the present study and the suggested requirement estimates by the NRC [1] can be  
158 attributed to the inclusion of safety margins for nutrients in the diet formulation process, especially for the  
159 gestating and lactating sow diets, which are typically fed as a single diet throughout each phase.

160 Research on P utilization and excretion in pigs has been conducted in several countries [9-13].  
161 Phosphorus excretion can be expressed in two ways. The first expression quantifies the amount of P  
162 excreted by pigs during their entire life or during a specific production period in kilograms per pig. For  
163 example, Jongbloed et al. [11] reported a P excretion of 0.19 kg/pig for piglets weighing from 7.5 to 30 kg  
164 BW in Denmark. Additionally, CORPEN reported a P excretion of 0.74 kg/pig for pigs from wean to finish

165 (8 to 108 kg) in France [19]. This approach is particularly relevant for the production cycle of market pigs,  
166 which consists of approximately 6 months from birth to slaughter. The second expression for P excretion  
167 was the annual amount (kg/year), typically applied to breeding sows that live for more than a year [9,10].  
168 Our study provides information on P excretion in market pigs based on age and BW, allowing for  
169 conversion to production period-based excretion as well as daily or yearly excretion values.

170 The breeding sows were categorized as gestating or lactating. In typical commercial swine farms,  
171 newborn piglets have a suckling period lasting 3 to 4 weeks, with a weaning weight of approximately 6.5  
172 to 7.5 kg. This study assumed that nutrient intake during the suckling period was solely from sow milk.  
173 Consequently, the amount of feed intake from the diet for pigs under 7.0 kg was set to zero. Therefore, the  
174 estimated P excretion of market pigs ranged from 7 to 121.5 kg BW at ages of 27 to 180 days.

175 The estimated P excretion for market pigs with a BW ranging from 7 to 121.5 kg in this study agreed  
176 with values reported in the literature [9-13,19]. However, P excretion for breeding sows (4.25 kg/year) in  
177 this study was relatively lower than the values reported in the literature. CORPEN [19] reported sow P  
178 excretion in France as 5.10 kg/year (with standard feeding) and 6.50 kg/year (with 2-phase feeding).  
179 Jongbloed et al. [11] also reported sow P excretion as 6.92 kg/year in Denmark, 6.71 kg/year in France, and  
180 4.04 kg/year in The Netherlands. These discrepancies are likely due to factors not considered in the  
181 estimation of P excretion for breeding sows in this study, such as phytase efficacy [20], variations in P  
182 digestibility during gestation and lactation periods [21], and reproductive performance. Another important  
183 factor for discrepancies is the amount of P excretion for suckling pigs. Studies on P excretion in sows have  
184 reported the amounts of P excretion measured with their offspring [9-11,13,19]. However, the present study  
185 did not consider the P excretion for suckling pigs because the estimation was based on the P and phytate-P  
186 concentrations in commercial diets. More research on P excretion from suckling pigs is needed.

187 The BW specifications for pigs in different growth stages vary among the NRC [1], CVB [22], and  
188 Korean Feeding Standards for Swine [23]. The Gompertz growth curve for BW was adapted using NRC [1]  
189 data. However, the calculation of ATTD P (g/kg of diet) to determine fecal P excretion utilized the actual  
190 weights of pigs fed each diet, as outlined in Table 1. Consequently, fecal P excretion in market pigs was  
191 calculated based on the phase feeding of the four different diets throughout their lifetime.

192 For pigs weighing over 7 kg, ATTD P was calculated based on the analyzed data for total P and  
193 phytate-P contents in each diet fed according to their weight. The prediction equation for ATTD P in the  
194 diet, as suggested by Sung and Kim [6], was applied by incorporating the total P, phytate-P, and a constant  
195 phytase concentration of 500 FTU/kg in all diets, a common phytase supplementation level in commercial  
196 swine diets [24]. As a result, the ATTD P values varied depending on the total P and phytate-P content of  
197 the diets. Therefore, Figure 2 illustrating P excretion, confirms the discontinuation in excretion levels at the  
198 point of diet transition.

199 Based on the results of this study, the annual excretion of fecal P was calculated by multiplying the  
200 fecal P excretion (Table 2; kg/year) by the entire swine population in Korea (11.1 million pigs; [17]),  
201 resulting in 20,994 tons/year. We validated this annual fecal P excretion by comparing it with the production  
202 weight of swine feed in Korea. Utilizing data on the production weight of swine feed for respective phases  
203 in Korea in 2022 [18] and dietary ATTD P (Table 1; [6]), we calculated the annual fecal P excretion to be  
204 19,062 tons/year. This amount of excretion closely approximates the estimated annual fecal P excretion in  
205 the present study, indicating that the present estimations employing the NRC [1] models were fairly  
206 reasonable.

207 Sung and Kim [6] reported that the prediction equation for ATTD P may not be applicable to sows  
208 because it is based on observations from growing pigs. Additionally, variations in phytase efficacy [25] and  
209 P digestibility [21,26] may occur depending on the gestating or lactating stage of the sow and even during  
210 the gestation period. However, because of the lack of an alternative prediction equation that can estimate  
211 ATTD P based solely on the dietary concentrations of P and phytate-P, the equation suggested by Sung and  
212 Kim [6] was utilized. The calculated ATTD P values for gestating and lactating sows using this equation  
213 were higher than the values recommended by the NRC [1] for gestating and lactating sows. Consequently,  
214 the P excretion estimated in this study for breeding sows may have been underestimated compared to the  
215 actual values.

216 Taken together, the P excretion of pigs for each growing phase was estimated based on the total P  
217 and phytate-P concentrations in commercial swine diets. The total annual P excretion for market pigs was  
218 estimated to be 1.94 kg/year, equivalent to a pig with a BW of 44.1 kg at 93 days of age. For gestating and  
219 lactating sows, the total annual P excretion was estimated to be 3.36 kg/year and 7.92 kg/year, respectively.  
220 Assuming a population ratio of 91:7:2 for market pigs, gestating sows, and lactating sows, the annual P  
221 excretion from all market and breeding swine in Korea was estimated to be 2.15 kg/year. Further research  
222 is required to validate our estimation through *in vivo* experiments using commercial diets.

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300 **Table 1.** Phosphorus (P) and phytate-P concentration in commercial swine diet in Korea (as-fed basis)

Category	BW, kg	<i>n</i>	Total P, %		Phytate-P, %	
			Mean	SD	Mean	SD
Piglet phase 1	7 to 15	11	0.59	0.11	0.19 <sup>b</sup>	0.06
Piglet phase 2	15 to 25	11	0.60	0.11	0.22 <sup>b</sup>	0.07
Growing phase	25 to 50	10	0.58	0.10	0.30 <sup>a</sup>	0.06
Finishing phase	50 to 121.5	7	0.54	0.10	0.28 <sup>a</sup>	0.07
Gestating sow	-	9	0.66	0.12	0.30 <sup>a</sup>	0.05
Lactating sow	-	9	0.66	0.07	0.31 <sup>a</sup>	0.04
SEM	-	-	0.03	-	0.02	-
<i>p</i> -value	-	-	0.152	-	< 0.001	-

301 <sup>a-b</sup> Means within a column without a common superscript letter differ ( $p < 0.05$ ).

302 **Table 2.** Estimated fecal, urinary, and total phosphorus (P) excretion of various growth phases in pigs

	Market pig					Breeding sow			Entire pig <sup>3)</sup>
	Piglet phase 1	Piglet phase 2	Growing phase	Finishing phase	Overall <sup>1)</sup>	Gestating sow	Lactating sow	Overall <sup>2)</sup>	
BW range, kg	7 to 15	15 to 25	25 to 50	50 to 121.5	7 to 121.5	-	-	-	-
Age range, day	27 to 48	49 to 66	67 to 100	101 to 180	27 to 180	-	-	-	-
Total P in diet, g/kg	5.91	6.01	5.78	5.44	5.65	6.57	6.64	-	-
ATTD P in diet <sup>4)</sup> , g/kg	3.42	3.40	3.03	2.86	3.04	3.54	3.56	-	-
Feed intake, kg/day	0.57	0.98	1.60	2.58	1.89	2.21	6.26	-	-
Total P intake, g/day	3.38	5.92	9.22	14.04	10.68	14.52	41.60	-	-
ATTD P intake, g/day	1.96	3.35	4.83	7.39	5.75	7.83	22.28	-	-
Daily P excretion									
Fecal P excretion, g/day	1.42	2.57	4.39	6.65	4.93	6.70	19.31	9.17	5.32
Urinary P excretion, g/day	0.07	0.14	0.26	0.61	0.40	2.50	2.40	2.48	0.59
Total P excretion <sup>5)</sup> , g/day	1.50	2.71	4.65	7.26	5.33	9.20	21.71	11.65	5.90
Yearly P excretion									
Fecal P excretion, kg/year	0.52	0.94	1.60	2.43	1.80	2.44	7.05	3.35	1.94
Urinary P excretion, kg/year	0.03	0.05	0.09	0.22	0.15	0.91	0.88	0.91	0.21
Total P excretion, kg/year	0.55	0.99	1.70	2.65	1.94	3.36	7.92	4.25	2.15

303 <sup>1)</sup> Weaning to finishing pigs from 7 to 121.5 kg body weight at ages of 27 to 180 days.

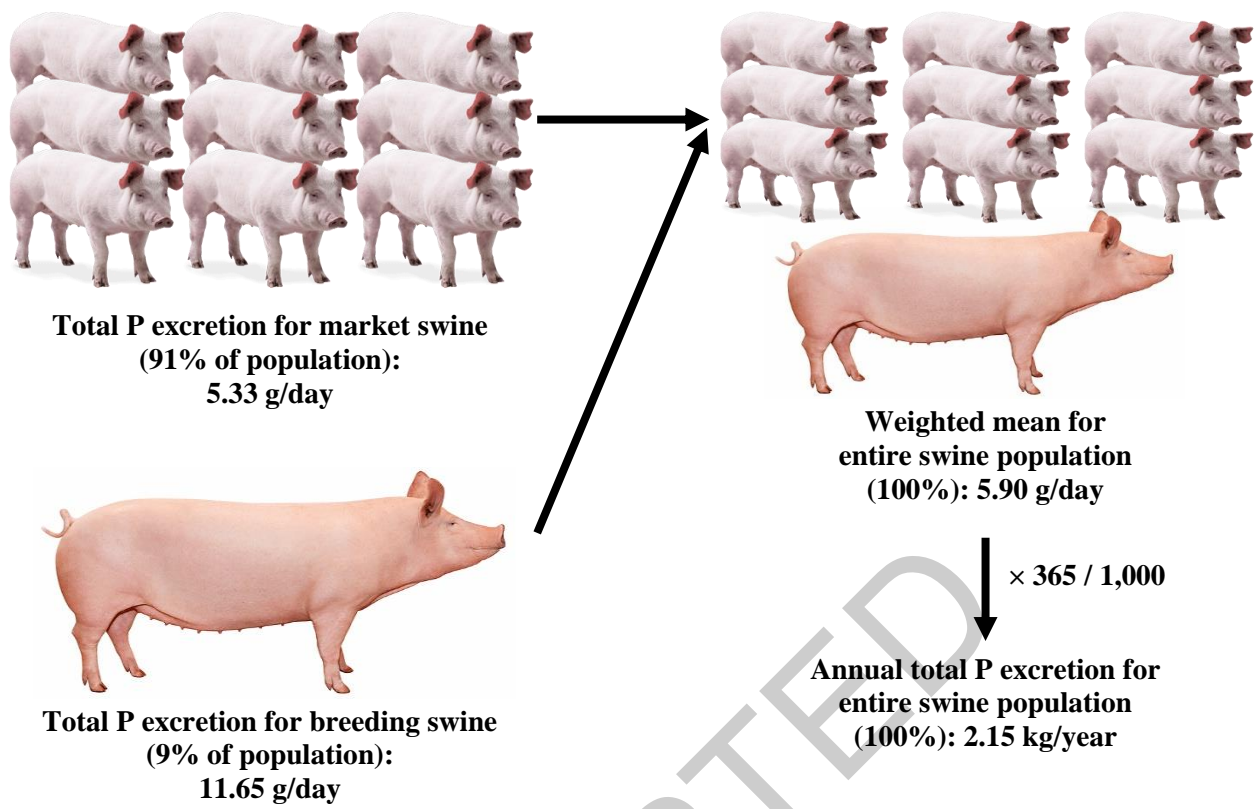
304 <sup>2)</sup> Phosphorus excretion for the breeding sows was calculated based on the assumption of a population ratio of 80:20 for gestating sows and lactating  
305 sows.

306 <sup>3)</sup> Phosphorus excretion for the entire pig was calculated based on the assumption of a population ratio of 91:7:2 for market pigs, gestating sows, and  
307 lactating sows.

308 <sup>4)</sup> The ATTD P in the diet was estimated using the total P, phytate-P, and phytase concentrations in the diet as independent variables, from the literature  
309 [6]. Phytase concentration was assumed to be constant at 500 FTU/kg in all diets.

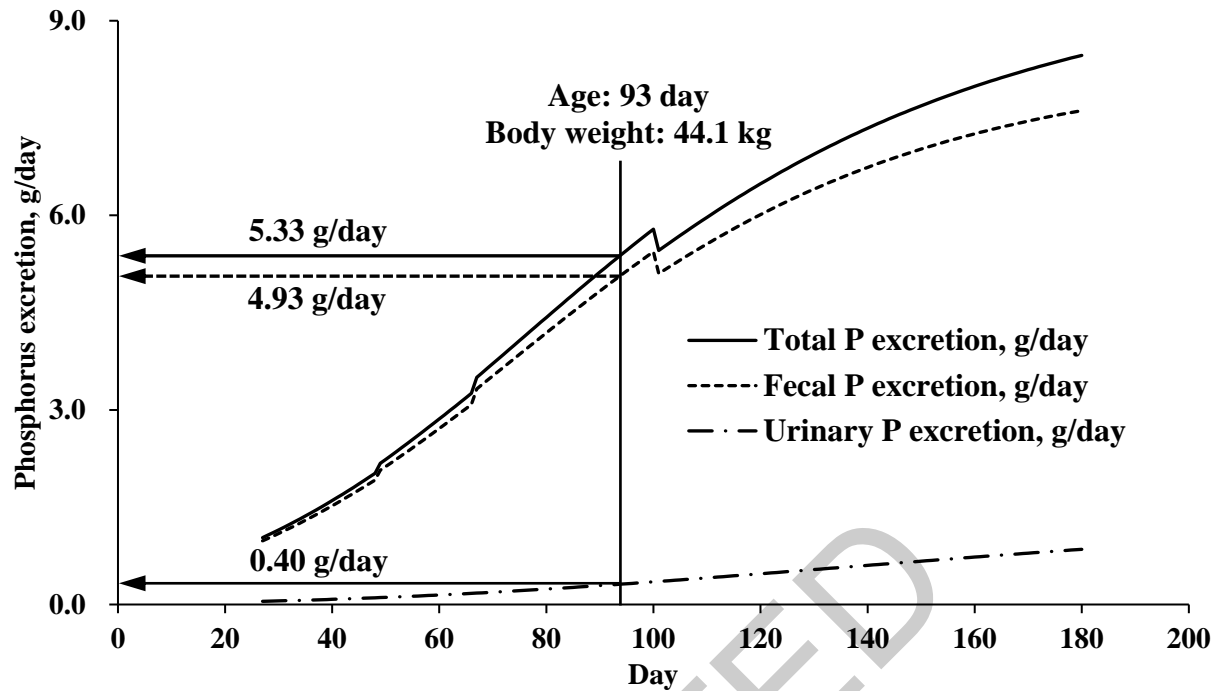
310 <sup>5)</sup> Total P excretion = fecal P excretion + urinary P excretion.

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**Figure 1. An example illustrating the calculations from total phosphorus (P) excretion per pig per day to weighted mean of total P excretion for overall swine population per pig per year.**



317  
 318 **Figure 2. Estimated fecal, urinary, total phosphorus (P) excretion of market pigs from 7 to 121.5**  
 319 **kg body weight at ages of 27 to 180 days.** The fecal P excretion was estimated using the total P, phytate-  
 320 P, and apparent total tract digestible (ATTD) P concentrations in the diets, and feed intake as independent  
 321 variables. The ATTD P in the diet was estimated using the total P, phytate-P, and phytase concentrations  
 322 in the diet as independent variables, as suggested by Sung and Kim [6]. Urinary P excretion for market pigs  
 323 was estimated using the equation suggested by the NRC [1]. The mean fecal, urinary, and total P excretion  
 324 for market pigs were 4.93, 0.40, and 5.33 g/day, respectively, equivalent to a pig weighing 44.1 kg BW at  
 325 the age of day 93.