Short communication: Comparison of predicted dietary phosphorus balance using bioavailabilities from the NRC (2001) and Virginia Tech model

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ABSTRACT

The objective of the current work was to use digestion coefficients from the Feng et al. (2015) model (Virginia Tech model) to calculate P bioavailability of common feeds used in dairy production. Compared with the bioavailability calculated by the Virginia Tech model, using the NRC (2001) P absorption coefficient of 0.64 for forages would underestimate the bioavailabilities of alfalfa hay, alfalfa silage, corn silage, grass hay, and mixed mainly legume silage. For concentrates, using the NRC (2001) P absorption coefficient of 0.70 would overestimate the bioavailabilities of corn grain but underestimate bioavailability of high-moisture corn. Two dairy diets were formulated using nutrient values from the NRC (2001): a standard diet that includes minimal by-products, and a by-product diet that has reduced corn and soybean meal which was replaced with corn gluten feed, distillers grains, hominy feed, and wet brewers grains. For each diet, total bioavailable P was calculated using availability values from the NRC (2001) and the Virginia Tech model. Comparison of P balance (the difference between required and bioavailable P) for each diet was made using the 2 sets of bioavailabilities for a reference cow weighing 682 kg, producing 38.6 kg of milk/d (3.5% fat and 3.0% true protein, 100 d in milk), and consuming 23 kg of dry matter/d, yielding an absorbed P requirement of 59.4 g/d. The standard diet supplied 56.69 and 53.52 g of bioavailable P per day using bioavailabilities from the NRC (2001) and Virginia Tech models, respectively, resulting in a P balance of -2.71 and -5.88 ± 0.26 g/d. The by-product diet provided 75.75 and 78.47 g/d of bioavailable P, yielding P balances of 16.35 and 19.07 ± 0.37 g per day, respectively, using the 2 sets of bioavailabilities. Using P bioavailabilities for individual ingredients that were based on the Virginia Tech model resulted in different

bioavailable P levels thus resulted in differing dietary P balances in a field setting.

Key words: phosphorus, bioavailability, balance

Short Communication

Phosphorus contamination of surface water can cause eutrophication, with negative effects on aquatic life. This problem can be minimized by feeding diets to animals that are balanced to just meet but not exceed their true P requirements. However, minimizing diet cost often results in the use of by-product feeds, which generally have high P content (e.g., distillers grains, corn gluten feed, and brewers grains; Ternouth, 1990). Although these diets typically have elevated dietary P content, the bioavailability of the P in the by-products is not well known. To minimize the risk of underfeeding P, producers will often add supplemental inorganic P to the diet. In a survey conducted by Harrison et al. (2012), 54.8% of the respondents replied that the greatest barrier to reducing P in the diet was the uncertainty of P content of feedstuffs, and 69.7% indicated that knowing the P availability of ingredients from different sources would assist them in diet formulation.

The current requirement system for dairy (NRC 2001) applies common P bioavailability factors across broad classes of ingredients (0.64 for forages and 0.70 for concentrates) with more diversity for individual mineral supplements. Although this approach captures some of the apparent differences between ingredients, the bioavailability values assigned are poorly supported because of sparse data. The bioavailability of P in different feeds can be different due to grain processing (Duskova et al., 2001; Amezcua and Parsons, 2007), grain type (Benzie et al., 1959; Bravo et al., 2002; Kebreab et al., 2004), and exogenous enzymes (Knowlton et al., 2007).

Some of the observed difference in bioavailability can be explained by the form of P in each feed. The Hill et al. (2008) model considered 3 pools of P: inorganic P (**Pi**), phytate P (**Pp**), and nonphytate organic P (**Po**). When the model was fitted to observed data from several digestions studies, it was found that these chemical

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entities do indeed have varying digestibility in different parts of the digestive tract (Feng et al., 2015). Thus, this model can be used to calculate digestibilities for each of the 3 fractions in each part of the digestive tract and those values used to assign bioavailability values to individual feeds based on the P fractions in each feed.

The objective of the current work was to use the digestion coefficients derived by Feng et al. (2015) to calculate P bioavailability for common feeds used in cattle production and to determine the effect of using those factors on formulation of a standard diet and a high by-product diet for lactating cattle.

Equations Used to Derive P Bioavailabilities of Common Feeds

Bioavailable P values of feed ingredients were derived from the Feng et al. (2015) model based on the ruminal and intestinal digestibilities of Pp and Po using Monte Carlo simulation. For reference purposes, available P was assumed equal to Pi consumed plus that liberated by digestive action (i.e., Pi was assumed to be 100% available). Bioavailable P was assumed to equal total Pi absorption from the digestive tract. Because no ru-

mental absorption was observed, total Pi absorbed from the digestive tract was the sum of absorption from the small intestine (SI) and the large intestine (LI):

$$P_{Bioavailability} = P_{iAbsorbed} = P_{iAbsorbed,SI} + P_{iAbsorbed,LI}, \quad [1]$$

where the respective absorption rates were a function of the flow of Pi in the respective gut segments times absorption efficiency ($AE_{PiSI} = 0.81$ and $AE_{PiLI} = 0.15$), which was defined as the ratio of Pi absorbed to total amount of Pi entering the respective gut segment:

$$P_{iAbsorbed,SI} = P_{iAvailable,SI} \times AE_{PiSI}, \quad [2]$$

$$P_{iAbsorbed,LI} = P_{iAvailable,LI} \times AE_{PiLI} \\ = (F_{PpPi,LI} + F_{PoPi,LI} + F_{PiLI}) \times AE_{PiLI}, \quad [3]$$

where available Pi in the SI was the sum of feed Pi plus Pi arising from degradation of Pp and Po in the rumen assuming phytase cleaves one molecule of Pi from Pp (equation [4]) and the remainder is transferred to the Po pool. Digestion of Po was not observed in the SI.

Table 1. Phosphorus availability and bioavailability (g/g) of commonly used feeds in cattle production

Feed ¹	N ²	Mean of P fraction			Availability ³		Bioavailability ³
		Pi	Pp	Po	SI	LI	
Alfalfa hay	16	0.553	0.015	0.433	0.921	0.213	0.78
Alfalfa silage	14	0.874	0.004	0.122	0.978	0.197	0.82
Almond hulls	2	0.855	0.0	0.145	0.975	0.198	0.82
Barley, grain	6	0.147	0.662	0.192	0.826	0.183	0.69
Brewers grains, wet	9	0.119	0.580	0.300	0.823	0.191	0.69
Canola meal	4	0.083	0.84	0.077	0.811	0.172	0.68
Citrus pulp, wet	1	0.610	0.0	0.390	0.932	0.211	0.79
Corn gluten feed	5	0.332	0.416	0.248	0.865	0.192	0.73
Corn, grain, ground dry	9	0.098	0.728	0.174	0.815	0.180	0.69
Corn, grain, high moisture	13	0.475	0.301	0.221	0.896	0.193	0.75
Corn silage	4	0.920	0.0	0.080	0.986	0.194	0.83
Distillers grains with solubles, wet	3	0.453	0.207	0.340	0.897	0.203	0.76
Distillers grains with solubles, dried	13	0.451	0.265	0.285	0.894	0.198	0.75
Grass hay	21	0.671	0.021	0.308	0.942	0.206	0.79
Hominy	4	0.098	0.832	0.073	0.814	0.172	0.68
Mixed mainly legume silage	1	0.530	0.040	0.430	0.916	0.212	0.77
Soybean meal, solvent 48% CP	5	0.072	0.489	0.441	0.821	0.201	0.69
Soy hulls	2	0.160	0.448	0.392	0.837	0.199	0.71
Whole cottonseed	3	0.113	0.743	0.143	0.818	0.178	0.69

¹The value listed for each feed is the average from different regions of the United States. The regions were east north central (IN, IL, OH, MI, WI); east south central (AL, KY, MS, TN); Mid-Atlantic (DE, NJ, NY, PA); mountain (AZ, CO, ID, HI, MT, NM, NV, UT, WY); New England (CT, MA, ME, NH, RI, VT); Pacific (AK, CA, OR, WA); south Atlantic (FL, GA, MD, NC, SC, VA, WV); west north central (IA, KS, MN, MO, NE, ND, SD); and west south central (AR, LA, OK, TX).

²Number of feed samples analyzed.

³Availability was defined as the sum of inorganic P in the diet and that liberated in the digestive tract. Bioavailability was defined as total P absorbed from the digestive tract.

$$P_{i\text{Available},SI} = \frac{1}{6} \times DC_{Pp,Deg,Rum} \times Pp_{Feed} + DC_{Po,Deg,Rum} \times \left(\frac{5}{6} \times DC_{Pp,Deg,Rum} \times Pp_{Feed} + Po_{Feed} \right) + P_{iFeed}, \quad [4]$$

Available Pi in the LI was the sum of Pi flowing from the SI (F_{PiLI}) and degradation of Po ($F_{PoPi,LI}$) and Pp ($F_{PpPi,LI}$) via microbial action in the LI:

$$F_{PiLI} = P_{i\text{Available},SI} \times (1 - AE_{PiSI}), \quad [5]$$

$$F_{PoPi,LI} = DC_{Po,Deg,LI} \times \left\{ \frac{5}{6} \times DC_{Pp,Deg,LI} \times \left[(1 - DC_{Pp,Deg,Rum}) \times Pp_{Feed} \right] + (1 - DC_{Po,Deg,Rum}) \times Po_{Feed} \right\}, \quad [6]$$

$$F_{PpPi,LI} = \frac{1}{6} \times DC_{Pp,Deg,LI} \times \left[(1 - DC_{Pp,Deg,Rum}) \times Pp_{Feed} \right]. \quad [7]$$

Thus, bioavailability can be calculated from the P fractions in the feed given digestion coefficients (**DC**) derived by Feng et al. (2015) ($DC_{Pp,Deg,Rum}$, 0.923; $DC_{Po,Deg,Rum}$, 0.825; $DC_{Pp,Deg,LI}$, 0.301; $DC_{Po,Deg,LI}$, 0.5). A list of bioavailabilities for common ingredients is provided in Table 1. The NRC (2001) predicted constant P absorption coefficients for forages (0.64) and concentrates (0.70). In Table 1, corn silage has the highest P bioavailability (0.83), whereas canola has the lowest (0.68). Compared with the bioavailability from the Virginia Tech model, using the NRC (2001) value of 0.64 for forages underestimates the P bioavailabilities of alfalfa hay, alfalfa silage, corn silage, grass hay, and mainly legume silage. For concentrates, using the NRC (2001) value of 0.70 for concentrates overestimates the P bioavailabilities of corn grain but underestimates P bioavailabilities of high-moisture corn. Thus, using aggregated absorption coefficients as indicated in NRC (2001) could reduce P feeding precision.

Comparison of 2 Diets Using P Bioavailabilities from the NRC (2001) and Virginia Tech Models

For diet formulation purposes, a reference state was chosen as a cow weighing 682 kg, producing 38.6 kg of milk/d (3.5% fat and 3.0% true protein, 100 DIM), and consuming 23 kg of DM/d with a total absorbed P requirement of 59.4 g/d. With targeted NE_L , MP, Ca, and P concentrations as constraints, 2 dairy diets were formulated using nutrient values from the NRC (2001): a standard diet that included minimal by-products, and

a by-product diet that had corn gluten feed, distillers grains, hominy feed, and wet brewers grains substituted for a portion of the corn and soybean meal. Feed ingredients and nutrient composition of the 2 diets are listed in Table 2. For each diet, total bioavailable P supply was calculated using bioavailability values from the NRC (2001) and the values in Table 3. Phosphorus balance (difference between P requirement and bioavailable P supplied) was compared for the 2 sets of P bioavailabilities within each diet. The P content of commonly used by-products (e.g., distillers grains, corn gluten feed, and brewers grains at 0.5–1.0% P) is high (Udén et al., 1980), resulting in higher P content for the by-product diet (0.46%) as compared with the standard diet (0.32%). The standard diet supplied 56.69 g/d of bioavailable P when calculated using bioavailability values from the NRC (2001) and 53.52 g/d of bioavailable P using the values from Table 3. The variance estimates of dietary bioavailable P using Virginia Tech bioavailabilities were obtained by considering the variances of the terms used in the equations (Monte

Table 2. Standard and high by-product diets for reference cow (DMI 23 kg/d, 52 mo old, 682 kg of BW, 38.6 kg of milk/d with 3.5% fat and 3.0 true protein, 100 DIM)

Feed ingredient	%, DM basis	
	Standard diet	High by-product diet
Alfalfa silage	14.55	12.07
Corn silage	49.68	37.80
Corn grain, ground dry	15.53	5.15
Soybean meal, solvent 48% CP	8.72	3.48
Blood meal, ring dried	1.25	0.90
Whole cottonseed	7.06	0.00
Hydrolyzed tallow	0.96	0.00
Hominy	0.00	12.30
Brewers grains, wet	0.00	8.20
Distillers grains with solubles, dried	0.00	12.57
Corn gluten feed	0.00	5.27
Limestone	0.96	0.98
Magnesium oxide	0.10	0.10
Salt	0.29	0.29
Sodium bicarbonate	0.59	0.59
Sodium selenite	0.02	0.02
Vitamin premix	0.29	0.29
Nutrient composition ¹		
CP	16.5	17.9
NE_L (Mcal/kg)	1.63	1.61
NDF	34.5	36.3
Forage NDF	28.6	22.2
ADF	23.0	21.0
Ca	0.8	0.7
P	0.32	0.46
Pi	0.17	0.22
Pp	0.10	0.15
Po	0.05	0.09
Ether extract	5.0	4.1

¹Pi = inorganic P; Pp = phytate P; Po = nonphytate organic P.

Table 3. Comparison of the 2 diets using bioavailability values from the NRC (2001) and Virginia Tech model

Diets	Total dietary P (g/d)	Bioavailable P supplied (g/d)	Balance ¹ (g/d)
Standard diet with NRC P bioavailability	69	56.69	−2.71
Standard diet with Virginia Tech model P bioavailability	69	53.52	−5.88 ± 0.26
Byproduct diet with NRC P bioavailability	115	75.75	16.35
Byproduct diet with Virginia Tech model P bioavailability	115	78.47	19.07 ± 0.37

¹Balance is calculated as the difference between bioavailable P supplied (g/d) and absorbed P requirement by the reference state cow (59.4 g/d). Variance estimates of the dietary P balance were determined for the Virginia Tech model using the reported parameter estimates (Feng et al., 2015) with a Monte Carlo simulation approach. Comparable variance estimates for the NRC model could not be determined due to lack of information.

Carlo approach). The uncertainties of dietary bioavailable P for NRC (2001) could not be determined due to a lack of information. Given an absorbed P requirement of 59.4 g/d for the reference state, the standard diet yielded a P balance of −2.71 and -5.88 ± 0.26 g/d using the 2 sets of P bioavailabilities, respectively. The by-product diet supplied 75.75 and 78.47 g/d of bioavailable P using bioavailabilities from the NRC (2001) and Table 3, respectively, resulting in P balances of 16.35 and 19.07 ± 0.37 g/d, respectively. It can be seen that using P bioavailabilities from the Virginia Tech model provided a lower predicted P balance for the standard diet (-5.88 vs. -2.71 ± 0.26 g/d) but a higher predicted P balance for the by-product diet

(19.07 ± 0.37 vs. 16.35 g/d) as compared with using bioavailabilities from the NRC (2001) model.

It is important to recognize that the above true absorption coefficient calculation does not consider losses of recycled salivary P in the gut, which is considered part of the P requirement, and any comparisons of model values to total-tract digestion should add the recycling losses to the unabsorbed fraction to get a fecal value. The model of Feng et al. (2015) was used to predict salivary P losses for a range of P intakes for animals at requirement, and the resulting data were regressed on P intake to derive an empirical prediction of the loss (Figure 1). This was completed using a young growing heifer, an older heifer, and a lactating cow with low, medium, and high milk production. Dietary P fractions were set to the reference diet described in Feng et al. (2015; Pp 40%, Po 30.7%, and Pi 29.3%), and P intake was manipulated to generate 0 P balance for each animal. Salivary recycling and loss of salivary P in feces were both linearly related to total P intake. Thus, one could calculate endogenous P losses due to salivary P recycling in the gut, at requirement, from total P intake.

Using the revised P bioavailability values of Feng et al. (2015) does affect calculated P balance and thus would affect final diet formulation if solving for P requirements with available P as a constraint. The added precision in using these values could allow diets to be more balanced, reducing the fear of P deficiency of the diet. This should result in reduced P loading to surface water in association with cattle production.

Figure 1. Salivary P recycling (●) and P loss (▲) due to salivary recycling at different dietary P intakes. The *P*-value for salivary P recycling is 0.0005, with standard errors for slope and intercept 0.098 and 6.460, respectively; the *P*-value for P loss is 0.0154, with standard errors for slope and intercept 0.041 and 2.682, respectively. The root mean square errors for salivary P and P loss are 7.029 and 2.919, respectively.

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