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Meta-analysis of factors that affect the utilization efficiency of phosphorus in lactating dairy cows

G. Klop,*[1] J. L. Ellis,* A. Bannink,† E. Kebreab,‡ J. France,§ and J. Dijkstra*
*Animal Nutrition Group, Wageningen University, PO Box 338, 6700 AH Wageningen, the Netherlands
†Wageningen UR Livestock Research, PO Box 65, 8200 AB Lelystad, the Netherlands
‡Department of Animal Science, University of California, 2111 Meyer Hall, One Shields Ave., Davis 95616
§Centre for Nutrition Modelling, Department of Animal and Poultry Science, University of Guelph, Guelph, ON N1G 2W1, Canada

ABSTRACT

A meta-analysis investigation based on literature data was conducted to estimate the effect size of nutritional and animal factors on phosphorus (P) excretion in feces and concentrations of P in milk. Two data sets were created for statistical analysis: One to derive prediction equations for P in feces (25 studies; 130 treatments) and another for P in milk (19 studies; 94 treatments). Prediction equations were derived using mixed model regression analysis with a random effect for study, and equations were evaluated based on values for Bayesian information criterion (BIC), root mean square prediction error (RMSPE), and concordance correlation coefficient (CCC) statistics. In terms of RMSPE and CCC values, fecal P excretion was best predicted by P intake, where P in feces (g/d) = $-3.8(\pm3.45)$ + $0.64(\pm0.038)$ × P intake (g/d) (RMSPE: 18.3%, CCC: 0.869). However, significant effects of crude protein [g/kg of dry matter (DM)], neutral detergent fiber (g/kg of DM), and milk yield (kg/d) on fecal P excretion were also found. Despite a lack of improvement in terms of RMSPE and CCC values, these parameters may still explain part of the variation in fecal P excretion. For milk P, expressed as a fraction of P intake, the following equation had the highest CCC and the lowest RMSPE value: P in milk as a fraction of P intake (g/g) = $0.42(\pm0.065)$ + $0.23(\pm0.018)$ × feed efficiency (i.e., fat- and protein-corrected milk yield/dry matter intake) − $0.11(\pm0.0199)$ × P in feed (g/kg of DM) (RMSPE: 19.7%; CCC: 0.761). Equations derived to predict fecal P as a fraction of P intake (g/g) or milk P content (g/kg) could not adequately explain the observed variation and did not perform well in terms of RMSPE and CCC values. Examination of the residuals showed that P balance was a seemingly confounding factor in some of the models. The results presented here can be used to estimate P in feces and milk based on commonly measured dietary and milk variables, but could also be used to guide development of mechanistic models on P metabolism in lactating dairy cattle. Factors to consider in future research and modeling efforts regarding efficiency of P use include the effects of dietary neutral detergent fiber, crude protein, starch, variation in P content of milk, and effects of P resorption from bone and body tissues during early lactation.
Key words: meta-analysis, phosphorus, dairy cow

INTRODUCTION

Concerns about the environmental burden caused by nutrient leaching from agricultural soils into the environment and the existing or upcoming stringent regulatory measures on nutrient management in intensive animal agriculture (e.g., US Clean Water Act; EU Water Framework Directive) make it imperative to strive for more efficient phosphorus (P) utilization on dairy farms. Improving P use efficiency in intensive dairy farming would benefit the environment. Moreover, global mineral P resources are expected to become more scarce and thus more expensive during the coming decades (Cordell et al., 2009).

It is commonly recognized that total P intake is the major determinant of fecal P excretion in dairy cattle. Research has shown that a positive relationship exists between P intake and fecal P excretion (Morse et al., 1992; Ekelund et al., 2005; Kebreab et al., 2005), and several short- and long-term studies with dairy cattle indicate that feeding less P can reduce fecal P excretion into the environment (Brintrup et al., 1993; Wu et al., 2000; Ferris et al., 2010). However, effects of nutritional factors other than P intake on efficiency of P use are less evident from the literature and warrant further investigation. In addition to dietary factors, animal factors including parity (Knowlton et al., 2001), lactation stage (Knowlton and Herbein, 2002; Ekelund et al., 2006), and milk production level (Valk et al., 2002) may contribute to variation in use of dietary P, through direct or indirect effects. An additional issue may be variation in the P content of milk but infor-

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[1]Corresponding author: geronda.klop@wur.nl

mation related to this variation is scarce (Wu et al., 2000). Excretion of P in urine is quantitatively of minor importance (NRC, 2001).

A quantitative analysis of literature data regarding P metabolism in ruminants was previously published by Bravo et al. (2003a,b,c). However, out of the 100 studies included in their analysis, only 6 were studies with lactating dairy cows. Moreover, their work was limited to studies published before May 1999 (Bravo et al., 2003a) and a considerable body of work on P metabolism in dairy cattle has been published since that time. The primary aim of this work, therefore, was to perform a meta-analysis on literature data to estimate the effect size of nutritional factors on the efficiency of P utilization in dairy cattle. In addition, the potential influence of production parameters; for example, milk yield and milk composition, was considered.

MATERIALS AND METHODS

Database

Web of Science (Thomson Reuters, New York, NY) was used to search for peer-reviewed publications that reported at least P intake and P excretion in feces or milk, in experiments with dairy cows. In addition, the reference lists of relevant review articles and book chapters were systematically checked for useful publications.

Initially, 42 studies, representing 146 treatments, were retained in the database. Animals within treatments were, if reported, described by parity, physiological state, lactation stage, treatment diet composition, DMI, milk production, milk composition and P-balance data. In some studies, treatments were repeatedly fed during different experimental periods and therefore the total number of observations in the initial database was 235. This initial database contained a large number of missing values, as not all variables of interest were reported for each study. From this initial database, 2 subsets of data were created: a subset for P excretion in feces (**PF** equations) and another subset for P in milk (**PM** equations). Observations with missing values for the parameters of interest were excluded from the analysis. The 2 database subsets had 13 studies in common.

Phosphorus in Feces. This database subset comprised data from lactating dairy cows from 25 studies (Martz et al., 1990; Morse et al., 1992; Spiekers et al., 1993; Delaquis and Block, 1995; Khorasani et al., 1997; Knowlton et al., 2001, 2002; Wu et al., 2001, 2003; Knowlton and Herbein, 2002; Guyton et al., 2003; Kebreab et al., 2005; Kincaid et al., 2005; Shore et al., 2005; Wu, 2005; Ekelund et al., 2006; Kamiya et al., 2006a; Knowlton et al., 2007; Dann et al., 2008; Moreira et al., 2009; Myers and Beede, 2009; Taylor et al., 2009; Van Straalen et al., 2009; Herrera et al., 2010; Puggaard et al., 2011) and included 130 treatment means. The response variable of interest was P excretion in the feces, both in grams per day and as a fraction of P intake. The available prediction variables in this data set were milk yield (kg/d), DMI (kg/d), dietary NDF (g/kg of DM), CP (g/kg of DM), and P (g/kg of DM), and the database is described in Table 1. The effect of calcium (Ca) content of the diet was never significant in the initial exploratory analyses of the general database, and therefore was not used as a selection criterion during the compilation of this data subset.

Phosphorus in Milk. This database subset contained 94 treatment means from 19 studies (Martz et al., 1990; Spiekers et al., 1993; Delaquis and Block, 1995; Knowlton et al., 2001, 2002; Knowlton and Herbein, 2002; Valk et al., 2002; Guyton et al., 2003; Borucki Castro et al., 2004; Kincaid et al., 2005; Peterson et al., 2005; Roche et al., 2005; Shore et al., 2005; Kamiya et al., 2006b; Odongo et al., 2007; Dann et al., 2008;

Table 1. Descriptive statistics of the fecal P data subset (n = 130)

Variable	Mean	Median	SD	Minimum[1]	Maximum[2]	Skewness[3]	Kurtosis[4]
Milk yield (kg/d)	34.9	34.9	8.88	15.7	52.8	−0.21	−0.76
DMI (kg/d)	22.0	22.2	3.52	11.3	29.0	−0.29	−0.27
Dietary CP (g/kg of DM)	169	169	14.7	122	213	0.45	1.77
Dietary NDF (g/kg of DM)	335	337	48.3	262	482	0.36	−0.25
Dietary P (g/kg of DM)	4.1	3.9	0.98	1.5	6.7	0.59	0.57
P intake (g/d)	88.3	82.0	26.93	29.4	179.7	0.86	1.15
Fecal P (g/d)	53.7	49.3	21.04	15.3	118.8	0.82	0.46
Fecal P/P intake (g/g)	0.60	0.60	0.11	0.33	0.89	−0.09	−0.34

[1]Minimum value in the subset database.

[2]Maximum value in the subset database.

[3]The degree of asymmetry of a distribution around its mean, where $0 \pm 2 \times SE_{skewness}$ is considered normal. For the fecal P database, $2 \times SE_{skewness} = 0.43$.

[4]Indicates the relative peakedness of or flatness of a distribution, where $0 \pm 2 \times SE_{kurtosis}$ is considered normal. For the fecal P database, $2 \times SE_{kurtosis} = 0.35$.