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Environmental management and prediction of nitrogen and phosphorus excretion by beef cattle

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INTRODUCTION

Beef cattle retain only a portion of the nutrients they consume, the remainder is lost in feces, urine, respiration, eructation, and flatulence (BCNRM, 2016). The excretion distributed in well-managed pastures (extensive systems) represents little, if any, impact because the soil–plant system has the capacity to use and to retain the majority of the nutrients from manure. However, in drinking, rest or supplementation areas, there is an agglomeration of animals and soil compaction and the manure accumulated may represent an environmental problem. In feedlot, due the large concentration of animals, the large amounts of feces and urine that accumulate on pen surfaces can runoff into surface water, leaching into soil or volatilizing to gases such as methane, ammonia, nitrous oxide and, in some situations, hydrogen sulfite.

Precision feeding is a great opportunity to reduce nutrient excretion. Feedlot nutrition will play a role in meeting challenges such as nutrient management (Klopfenstein and Erickson, 2002) in the meat production chain. Environmental regulations in developed countries have addressed the need to reduce the excretion of certain compounds, especially nitrogenous compounds (N) and phosphorus (P), due to the pollution of soil and water and atmosphere for N.

True protein is the nutrient with the highest unit cost in beef cattle diets, and its inclusion in an unbalanced way in the diet results in increased production costs as well as increased excretion of nitrogen primarily in urine but also in feces (Cavalcante et al., 2005). Phosphorus is the mineral that contributes most to environmental pollution and is considered a significant polluter of water in many countries (Tamminga, 1992; Valk et al., 2000). Thus, the reduction of nitrogen and phosphorus losses is an environmental, social and economic concern.

Ruminant production systems are considered a major source of nitrogen and phosphorus excretion to the environment (Neeteson, 2000; Schroder et al., 2003). Intensified production increases the excretion of contaminants in manure. According to Tamminga (1992), the diet management was made with minimal if any concern about the nitrogen excretion in feces and urine. Nowadays, the environmental impact of animal feeding operations is a growing concern (Cole et al., 2006; Staerfl et al., 2012; Patra and Lalhriatipuii, 2016).

Rational control of nitrogen and phosphorus inputs (e.g., fertilizers remain and animal manure) is the primary way of reducing environmental problems in the agriculture. Cole (2003) proposed the use of precision feeding, defined as the feeding management of cattle in order to do not decrease their performance but decrease the nutrient concentration in the diet and thus also reduce the nutrient excretion in the environment. A tool for the use of this management would be the appropriate formulation of diets to meet the nutritional requirements of cattle, reducing the excretion of polluting compounds without decrease animal performance.

Reduced nitrogen and phosphorus excretion can result in lower environmental impact and greater economic profit to the production system by reducing the use of nitrogen and phosphorus sources.

The development of control strategies is a complex issue but extremely important. The properly design of animal facilities, avoiding the superficial runoff or infiltration to ground water is essential. In addition, management and composting of manure in intensive systems is a huge opportunity of generation of bio-fertilizers and/or bio-energy that minimize the environmental beef cattle of the activity and can create additional profits to the production system.

Thus, our objective was to develop equations that would be useful for the prediction of nitrogen and phosphorus excretion by beef cattle under tropical conditions.

EQUATIONS PROPOSED BY BCNRM (2016) EVALUATION

The BCNRM (2016) incorporated information regarding the environmental impact of livestock farming. Prior to generating new equations for nitrogen and phosphorus excretion, prediction equations of nitrogen and phosphorus excreted (Geisert et al., 2010; Waldrip et al., 2013; Dong et al., 2014) as proposed by BCNRM (2016), were tested for appropriateness for these database. The tested equations are presented below.

$$\text{Urinary N (g/d)} = -21.18 + 0.56 \times \text{NI}$$
[Waldrip et al., 2013]

$$\text{Fecal N (g/d)} = 24.28 + 0.15 \times \text{NI}$$
[Waldrip et al., 2013]

$$\text{Urinary N (g/d)} = -14.12 + 0.51 \times \text{NI}$$
[Dong et al., 2014]

$$\text{Fecal N (g/d)} = 15.82 + 0.20 \times \text{NI}$$
[Dong et al., 2014]

$$\text{Urinary N (g/d)} = 2.39 + 0.55 \times \text{NI} - 3.36 \times \text{DMI}$$
[BCNRM, 2016]

$$\text{Total P (g/d)} = 0.82 + 0.57 \times \text{P intake}$$
[Geisert et al., 2010]

where NI is nitrogen intake (g/d); DMI is dry matter intake (kg/d) and P intake is phosphorus intake (g/d).

The equations proposed by BCNRM (2016) were tested using the BR-CORTE (2016) database. For nitrogen excretion was used 751 individual data (Table 12.3) and for phosphorus excretion was used 178 individual data (Tables 12.8 and 12.10).

The equations for nitrogen excretion (Waldrip et al., 2013; Dong et al., 2014) use nitrogen intake as an independent variable. The BCNRM (2016) proposed an equation for predicting urinary N excreted using the nitrogen intake and dry matter intake as independent variables. The equations cited by BCNRM (2016) system do not correctly estimated excretion of nitrogen ($P < 0.05$; Table 12.1). The equation showed from low to high systematic bias (4 to 38%). The lack of accuracy to estimate the excretion of N can be explained by the small number of young animals, with lower nitrogen intake, in the database used to generate the equations and also due to genetic factors.

The proposed equation for P excretion (Geisert et al., 2010) did not correctly estimate the excretion of P for BR-CORTE data ($P < 0.05$; Table 12.1); however, a high CCC value was obtained. The lack of accuracy in estimating the excretion of P can be explained by genetic factors, because animals used by Geisert et al. (2010) differ from Zebu and crossbred animals used under tropical conditions.

Thus, is necessary to develop equations consistent with the environmental and genetic conditions in Brazil. Therefore, BR-CORTE (2016) generated new equations, based on a more robust database, and with a greater number of observations to estimate the nitrogen and phosphorus excretion by beef cattle under tropical conditions. These estimates are of critical importance for beef cattle production systems under such conditions as it assists in environmental issues and can identify management practices to reduce excretions.

Table 12.1 - Regression analysis, concordance correlation coefficient (CCC), bias correction (Cb) and mean square error of prediction (MSEP) decomposition between the predicted and observed values of nitrogen and phosphorus excretion

Item	Waldrip et al. (2013)		Dong et al. (2014)		BCNRM (2016)	Geisert et al. (2010)
	Fecal N	Urinary N	Fecal N	Urinary N	Urinary N	Total P
Regression analysis[1]	-	-	-	-	-	-
r^2	0.71	0.53	0.71	0.53	0.50	0.60
H_0: a = 0 and b = 1	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
CCC	0.59	0.72	0.71	0.72	0.69	0.76
Cb	0.70	0.98	0.84	0.99	0.97	0.99
MSEP	274	654	219	576	521	3.63
Mean bias (%)	0.28 (0.11)	6.40 (0.98)	1.39 (0.64)	10.3 (1.80)	24.0 (4.60)	0.07 (2.04)
Systematic bias (%)	106 (38.5)	199 (30.5)	48.9 (22.4)	118 (20.4)	19.4 (3.71)	0.13 (3.68)
Random errors (%)	168 (61.4)	448 (68.5)	168 (77.0)	448 (77.8)	478 (91.7)	3.43 (94.3)

[1] Linear regression between predicted and observed values by means of nitrogen and phosphorus excretion equations.

NITROGEN

Metabolism of nitrogen in animal and environment

Most protein sources have high digestibility for ruminants, often above 90% of true digestibility. Roughages and energy concentrates have lower digestibility. The indigestible protein is excreted in feces, while the digested protein is converted into amino acids which can be used for animal tissue synthesis or oxidized for ATP production with consequent production of urea in liver, partially filtered in kidney and excreted in urine. Part of the urea may be recycled back to the gastrointestinal tract and assimilated by the microorganisms. However, a portion of the nitrogen in microorganisms is excreted in feces as a residue of microbial nitrogenous compounds (Satter et al., 2002).

Most of the nitrogen consumed by beef cattle is excreted in feces and urine, and the loss of N by hair/scurf is of minor relevance. In manure, the nitrogen is present mostly in the form of ammonia or organic nitrogen. These compounds are derived from undigested feedstuff in the gastrointestinal tract, indigestible microbial crude protein, endogenous nitrogen, urea and also ammonia.

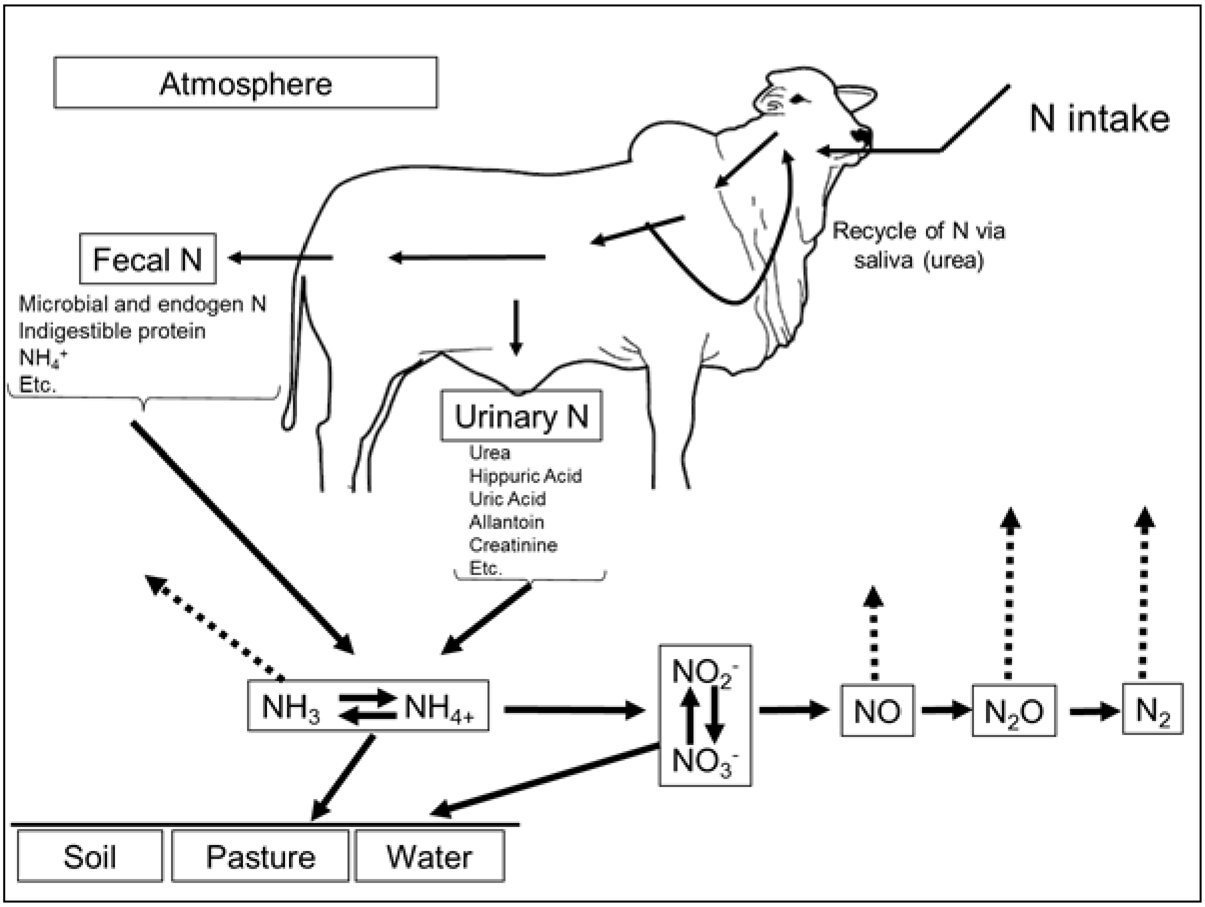
It is known that the efficiency of nitrogen assimilation by animals is low; this results in high levels of nitrogen excretion (Steinfeld et al., 2006). The nitrogen retention in animal product ranges from 5 to 20% of the total consumed. According to Hutchings et al. (1996), nitrogen use efficiency of beef cattle is approximately 10%. Detmann et al. (2014) using a database of animal on pasture under tropical condition found an average of 11.6% for the apparent nitrogen use efficiency. The average of nitrogen excretion, for this database, was 70%, analyzing 466 individual data, thus, on average 30% of N was retained, and this retention was higher than the average found in literature. Some causes of low nitrogen retention can be related to grazing system with low quality of forage (low N supply) or feedlot diets excessive in nitrogen, due to overestimated animal's requirements or use of inconsistent requirement systems to the climate conditions and animals (genetic groups).

According to Menezes et al. (2016), nitrogen metabolism is affected by the levels of crude protein in the diet, and urinary and fecal N excretion increases linearly with protein intake. If protein contents in the diet are higher than the animal nutritional requirements, it results in an increase of N excretion, mainly via urine. Therefore, the reduction in nitrogen excretion by meeting the nutritional requirements of animals, without decreasing performance, has great potential to reduce environmental impact of beef cattle production and increase economic returns of producers.

The environmental concern about nitrogen is related to three main routes of this nutrient: losses as ammonia volatilization to the atmosphere, nitrate diffusion in soil and groundwater, and denitrification and nitrous oxide emission in the atmosphere (Scheme 12.1). According to De Klein and Eckard (2008), nitrification and denitrification are the two major soil microbial processes that result in losses of nitrogen in the form of nitric oxide (NO) and nitrous oxide (N_2O).

Nitrification is an aerobic process where ammonium (NH_4^+) is oxidized to nitrite (NO_2^-), which is in turn oxidized to nitrate (NO_3^-), yielding N_2O as a by-product. This process is favored in well drained soils (appropriate aeration), high levels of NH_4^+ and elevated temperature. However, the proportion of N lost as N_2O through nitrification is minor. In contrast, denitrification is an anaerobic process where NO_3^- is reduced to N_2, being N_2O produced as the intermediate of the reaction. Denitrification is increased in wet soils, compacted soils, high temperatures, high concentration of NO_3^- and presence of reducing sources (C-labile) in soil. Thus, under tropical conditions, greater N_2O emissions from the denitrification are observed in the rainy season, being insignificant these emissions in the dry season.

In addition, the N losses due to the volatilization of NH_3 resulting from the deposition of urine are higher in the typical Brazilian summer, characterized by high temperatures and humidity.



Scheme 12.1. Summary of the nitrogen cycle.

According to IPCC (2006), the direct N_2O emissions from cattle excreta (without distinguishing between feces and urine) is 2% of the total N present in excreta. In indirect emissions, for each kg of excreta nitrogen deposited on the soil, 20% are volatilized and 30% leached. From the 20% volatilized, 1% is emitted in the form of N_2O, and from the 30% leached, 0.75% will be emitted as N_2O. However, these factors were produced in temperate conditions and may be inappropriate for the Brazilian climate and soil conditions. Furthermore, studies conducted in Brazil (Sordi et al., 2014; Lessa et al., 2014; Cardoso et al., 2016) suggest that N_2O emission factors of excreta should be considered separately, considering the type of excreta (feces or urine), to produce more accurate estimates of the environmental impact of livestock. These studies showed that the N_2O emission factor for feces is smaller than that emission from urine, and these emissions are minimal (or do not exist) in the dry season.

Lessa et al. (2014), using urine labelled with ^{15}N, evaluated the nitrogen lost through the deposition of urine in *Brachiaria brizantha* cv Marandu pasture in the tropical savannah region. They observed that 65% of N remained in the system, about 30% was lost as ammonia and the remaining 5% was emitted as N_2O or percolated. Additionally, the direct emission of N_2O considering feces and urine found by the authors (0.7% of the nitrogen excreta) was lesser than 2% adopted by IPCC (2006).

Sordi et al. (2014) evaluated the N_2O emissions in the feces and urine of cattle in a subtropical Brazilian pasture. The authors measured average direct N_2O emissions: 0.26% for urine and 0.15% for feces. They concluded that the value adopted by the IPCC (2006) is overestimated under Brazilian subtropical conditions. However, according to the authors, these results may be different depending on the animal's diet, excreted urine volume and microclimate conditions.

Cardoso et al. (2016), evaluating the effect of the addition of different quantities of cattle urine and feces deposited in *Pangola* grass in southeastern Brazil on N_2O emissions, observed that the average emission was 0.18% for feces, regardless of the amount of manure applied (1.2, 1.8 or 2.4 kg). However, N_2O emissions decreased linearly with increasing in urine volume applied (1, 1.5 and 2 L). The authors attributed this decrease in emission factors with increased urine volume due to the greater flows of urine in the soil, carrying deeper the urea-N, and thus, reducing the availability of nitrogen for N_2O production.

The nitrogen in feces (mainly undigested dietary, microbial and endogenous proteins) differs substantially from the N in the urine (mainly urea, allantoin, hippuric acid, creatinine, ammonia and uric acid); the latter is more soluble and rapidly metabolized by microorganisms, which influences the rate of emission of each source (fecal or urinary N) as well as the severity of the environmental impact (Chizzotti et al., 2016). Thus, for a more precise estimate of the environmental impact of livestock, the prediction of urinary N excretion must be accounted separately from the fecal N excretion.

Data used to develop the equations using meta-analysis and cross-validation

The data used to estimate the parameters of the equations were collected from experiments with beef cattle (Nellore and crossbred), including information on all variables considered relevant to nitrogen excretion (feces and urine). The information collected for each observation included: body weight (BW), metabolic body weight ($BW^{0.75}$), percentage of crude protein in the diet (% CP), dry matter intake (DMI), total digestible nutrients intake (TDN) and nitrogen intake (NI).

The database included 751 observations from 18 theses and dissertations (Table 12.2), which investigated nitrogen intake and excretion, total digestible nutrients intake and body weight. Descriptive statistics (minimum, maximum, mean, and standard deviation) for all variables used in the development of prediction equations of nitrogen excretion is shown in Table 12.3.

Spearman's correlations were used to determine variables influencing nitrogen excretion via urine and feces in beef cattle. After this correlation, stepwise procedure was used to select the model variables. Then, a meta-analysis (St-Pierre, 2001), considering random effects from different studies was used to generate new prediction models. The meta-analysis was performed in order to examine the significance of the evaluated parameters. Several models and different variables were tested; the choice of the best fitted models was based on Akaike's information criterion (AIC).

From the information collected for the selected variables (Table 12.3), we performed a meta-analysis to select the variables that significantly influence N excretion in feces and urine. The effects of independent variables were considered significant for a *P* value lower than 0.05.

Body weight, TDN and nitrogen intake significantly affected fecal N excretion. Dry matter intake and nitrogen intake significantly affected urinary N excretion.

Table 12.2 - Description of database used in the development of nitrogen excretion equations

Author	Year	n	Genetic group	Sex
Dias	1998	25	Crossbred	Bulls
Ladeira	1998	20	Nellore	Bulls
Cardoso	1999	25	Crossbred	Bulls
Tibo	1999	25	Crossbred	Bulls
Rennó	2003	64	Crossbred	Bulls
Dias	2005	12	Nellore	Heifers
Veras	2006	37	Nellore	Bulls, steers and heifers
Chizzotti	2007	29	Crossbred	Bulls
Marcondes	2007	18	Nellore	Bulls, steers and heifers
Marcondes	2010	27	Nellore and crossbred	Steers
Campos	2011	25	Nellore	Bulls
Cesario	2011	16	Crossbred	Bulls
Costa e Silva	2011	53	Nellore	Bulls
Rotta	2012	32	Crossbred	Bulls
Rufino	2014	40	Nellore	Bulls
Costa e Silva	2015	258	Nellore	Cows, bulls, steers and heifers
Louzada	2015	29	Nellore	Bulls and heifers
Menezes	2015	16	Nellore	Bulls

Table 12.3 - Descriptive statistics of the data used to fit the regression equations to estimate nitrogen excretion via urine and feces in beef cattle

Variables[1]	n	Mean	Standard deviation	Minimum	Maximum
BW, kg	751	312.73	123.23	34.94	671.78
DMI, kg/d	751	6.40	3.16	0.76	14.84
TDNI, kg/d	751	4.40	2.08	0.83	9.89
NI, g/d	751	134.84	65.70	24.53	328.00
Fecal N, g/d	751	43.97	23.96	6.36	167.35
Urinary N, g/d	466	47.68	30.93	4.83	178.61

[1] BW = body weight; DMI = dry matter intake; TDNI = total digestible nutrients intake; NI = nitrogen intake.

After evaluating the best models, it was used the cross-validation method (leave-one-out) using the REG procedure in SAS to generate the parameters for nitrogen excretion prediction equations (Table 12.4). The solutions of the fixed effects of the prediction equations for N excretion via urine and feces with their respective coefficient of determination (R^2) are shown in Table 12.4. In both equations, there was a positive relationship between nitrogen intake and excretion, corroborating with other studies (Cole, 2003; Marini and Van Amburgh, 2003; Menezes et al., 2016).

For urinary N excretion, two equations were proposed, one based only on nitrogen intake and other one based on nitrogen intake and DMI. Predictions of N excretion proposed by Waldrip et al. (2013) and Dong et al. (2014), and used by BCNRM (2016), also showed a positive correlation between nitrogen intake and excretion. These authors observed better fit of the prediction equations using the N intake than the percentage of crude protein in the diet, and the same behavior was observed in the present database.

Table 12.4 - Solution of fixed effects of prediction equations based on significant variables with their respective coefficients of determination (R^2) for fecal and urinary nitrogen excretion

Item	Fecal N, g/d	Urinary N, g/d (Eq. 12.1)	Urinary N, g/d (Eq. 12.2)
Intercept	$2.549_{\pm 0.034}$	$3.262_{\pm 0.087}$	$3.819_{\pm 0.090}$
BW	$0.048_{\pm 0.0002}$	-	-
DMI	-	$3.680_{\pm 0.042}$	-
TDNI	$-3.469_{\pm 0.020}$	-	-
NI	$0.296_{\pm 0.0005}$	$0.177_{\pm 0.002}$	$0.344_{\pm 0.0008}$
R^2	0.585	0.545	0.530

[1] BW = body weight; DMI = dry matter intake; TDNI = total digestible nutrients intake; NI = nitrogen intake.

Adequacy of equations

After obtaining the urinary and fecal nitrogen excretion equations, we proceeded the validation using the Model Evaluation System software (MES; Tedeschi, 2006). There were used for the validation thirteen independent papers published between 2006 and 2015 in the journals: Brazilian Journal of Animal Science, Brazilian Journal of Veterinary and Animal Sciences and Semina. These data reported treatment average, totaling 45 averages for fecal N excretion and 50 averages for urinary N excretion (Table 12.5).

The prediction efficiency was evaluated by estimating the concordance correlation coefficient (CCC) and the mean square error of prediction, as proposed by Tedeschi (2006).

Table 12.5 - Descriptive statistics of the variables for validation of the proposed equations for nitrogen excretion

Variables[1]	n	Mean	Standard deviation	Minimum	Maximum
BW, kg	50	285.69	72.36	118.41	521.62
DMI, kg/d	50	5.55	1.41	2.80	8.37
TDNI, kg/d	50	3.59	0.85	1.20	5.14
NI, g/d	50	115.19	34.40	23.05	193.67
Fecal N, g/d	45	40.31	11.99	15.82	65.92
Urinary N, g/d	50	43.38	22.21	4.79	102.74

[1] BW = body weight; DMI = dry matter intake; TDNI = total digestible nutrients intake; NI = nitrogen intake.

The results of the validation of equations for predicting nitrogen excretion by beef cattle under tropical conditions are shown in Table 12.6. According to Mayer's test the intercept and the slope of the regression of observed and predicted values did not differ from zero and one ($P > 0.05$), respectively, suggesting that the estimates were accurate in predicting the N excretion by beef cattle.

The CCC indicates the accuracy and precision of the model. The equations proposed correctly estimated the fecal and urinary N excretion by beef cattle. In the decomposition of MSEP (Table 12.6), the majority of the errors are random, demonstrating that there is no over or underestimation of proposed equations.

A comparison of both equations proposed for urinary N excretion revealed that the equation based on nitrogen intake alone as independent variable (Equation 12.2) had greater accuracy and a lower mean square error of prediction (MSEP).

The similarity of predicted and observed nitrogen excretion is shown in Figure 12.1. The data are similarly disposed around the identical line (dotted line).

Table 12.6 - Regression analysis, concordance correlation coefficient (CCC), bias correction (Cb) and mean square error of prediction (MSEP) decomposition between the predicted and observed values of nitrogen excretion

Item	Prediction equation of nitrogen excretion		
	Fecal N	Urinary N (Eq. 12.1)	Urinary N (Eq. 12.2)
Regression analysis[1]	-	-	-
r^2	0.453	0.270	0.431
H_0: a = 0 and b = 1	0.131	0.902	0.526
CCC	0.64	0.40	0.55
Cb	0.95	0.77	0.83
MSEP	86.37	354.47	282.15
Mean bias (%)	4.98 (5.77)	0.51 (0.14)	0.005 (0.002)
Systematic bias (%)	2.80 (3.25)	0.99 (0.28)	7.44 (2.638)
Random errors (%)	78.59 (90.98)	352.97 (99.58)	274.705 (97.36)

[1]Linear regression between predicted and observed values by means of nitrogen excretion via urine and feces equations.

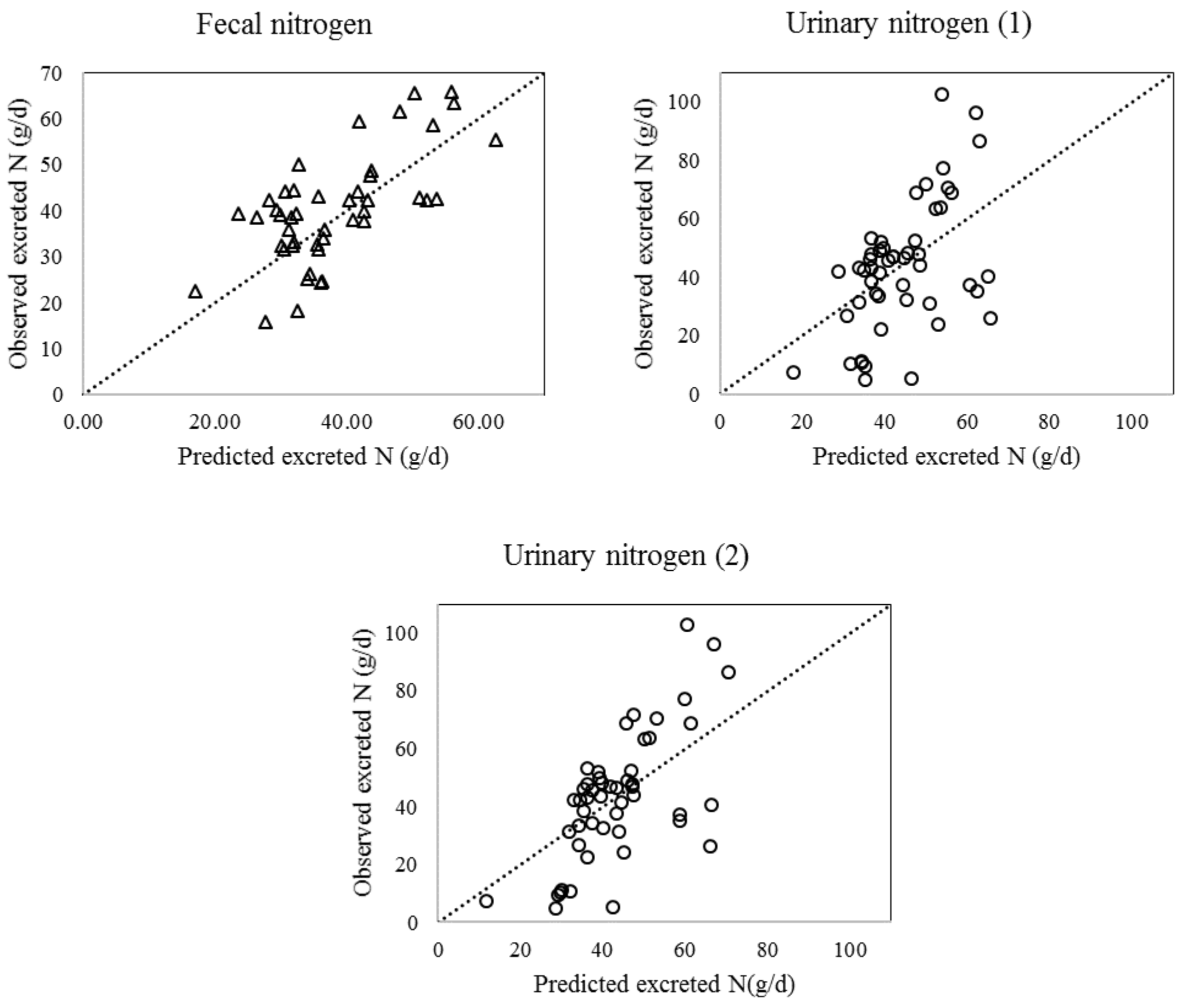


Figure 12.1 - Relationship between the observed values of fecal and urinary nitrogen excretion and those determined by the proposed equations. Predicted values are plotted on the X axis and the observed values are on the Y axis. The dotted line represents the ideal line (Y = X), intercept = 0 and slope = 1.

It is possible to meet the nutritional requirements of animals while reducing the crude protein in the finishing diet, which would also result in reduced intake of CP and N excreted to the environment (Cole et al., 2006). Thus nitrogen content in the diet can directly influence its excretion, explaining the use of this variable in the proposed equations. The excess of protein in the diet results in increased urinary urea excretion.

The optimization of microbial protein synthesis in the rumen can increase the efficiency of N use, which leads to decreased losses (Reynal and Broderick, 2005). The efficient growth of the microorganisms in the rumen and consequently optimization of microbial protein synthesis depends on the available energy (TDN; Dijkstra et al., 1998), justifying the use of TDN variable in fecal N excretion equation.

PHOSPHORUS

Metabolism of phosphorus in animal and environment

Phosphorus, despite being component of nucleic acids and having important structural role, is also involved in animal performance. Until recently, the recommendations of dietary P were conducted to ensure any deficit (safety margin), aiming maximum performance (Klopfenstein et al., 2002). But nowadays, environmental concerns began to be related to its excretion. With the increasing demand for environmental sustainability in all agricultural sectors, P excess in soil is considered as dangerous for the environment as its scarcity (Pfeffer et al., 2005). Another important point of the P, is the fact that it is a non-renewable source and 90% of its demand is used for food production (Gunther, 2005). Steen (1998) has estimated that the global commercial P reserves will be exhausted from 50 to 100 years. Thus, the rational use of this mineral is essential.

Phosphorus goes into the rumen in two main ways: via saliva (recycling) and via diet (Scheme 12.2). The phosphorus recycling supplies partially the requirements of the rumen microorganisms, and it is responsible for 50% of the phosphorus that enters in the rumen (Kincaid and Rodehutscord, 2005). Sathler (2015), working with two levels of phosphorus in the diet of Nellore, observed net recycling of P to the rumen, ranging from 13.96 to 23.35 g of P/d in animals consuming between 5.51 to 13.73 g of P/d.

Most minerals are absorbed in the small intestine by specific transporters. The primary site for P absorption is the small intestine, with an average of 67.3% of the amount reaching this site, and the large intestine absorption of phosphorus is about 25.5% (Pfeffer et al., 2005; Sathler, 2015). The excess of phosphorus in the diet causes an increase in urinary excretion and in concentration in saliva which causes increase in phosphorus lost in feces (Underwood and Suttle, 1999). Phosphorus fecal excretion is a function of the intake (Geisert et al., 2010), showing a positive correlation.

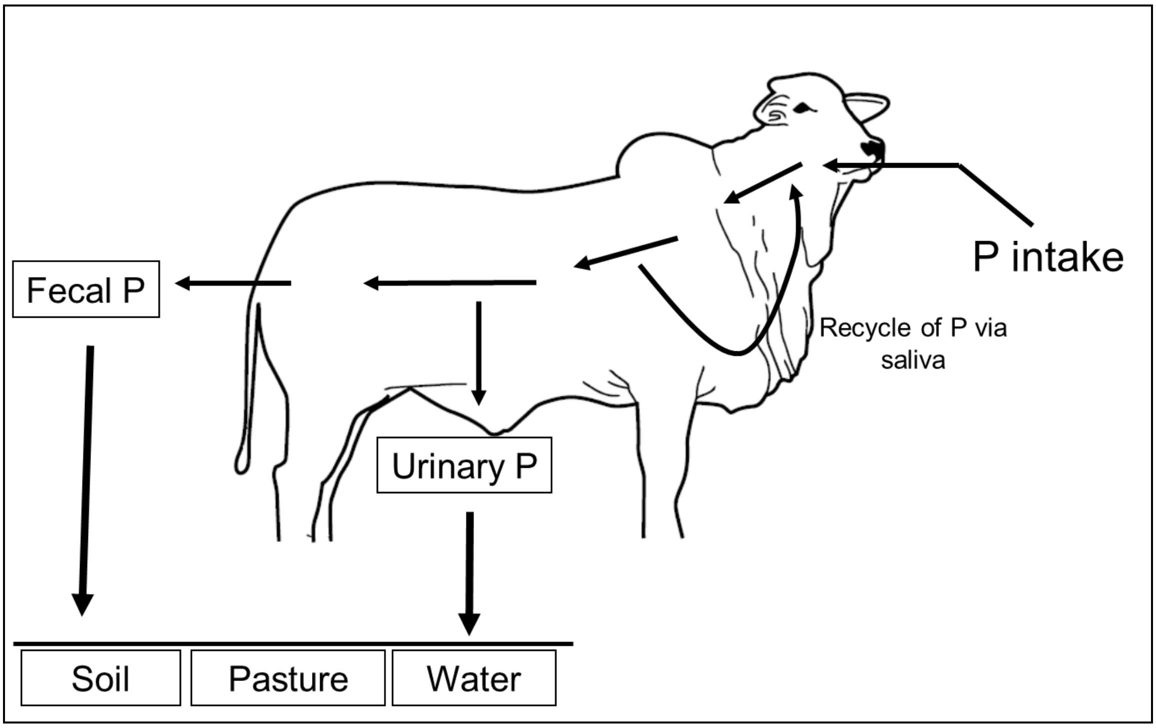
Phosphorus fractions in feces are: the phosphorus contained in diets that have not been solubilized; phosphorus derived from microorganisms and endogenous losses, and phosphorus intake above the requirements of the animal (in ruminants, the major portion is excreted in feces).

The combination of phosphorus derived from microorganisms and endogenous sources in feces accounts for about half of total fecal phosphorus (Conrad, 1999), but this proportion varies depending on the amount of excess phosphorus in the diet. In the present database, urinary P represented only 9.6% of the total excreted. According to some studies, 90% of the total P excretion is via feces being only a marginal amount related to the urinary excretion (Braithwaite, 1985; Wylie et al., 1985; Martz et al., 1990; Khorasani and Armstrong, 1992; Bortolussi et al., 1996). Geisert et al. (2010), working with five different levels of P in the diets observed average of only 2.1 g/d of urinary P (10.8% of total phosphorus excreted). Phosphorus is excreted in the urine after the requirements of maintenance and production are met (Vitti et al., 2000; Geisert et al., 2010).

Various studies have used the NRC (1996) recommendations to make more accurate recommendations regarding the optimal level of phosphorus in the diet for beef cattle. Researches conducted at the

University of Nebraska - USA by Erickson et al. (1999 and 2002), noted that varying the P levels in the diet from 0.14 to 0.40 for feedlot cattle, suggested that the recommendations of NRC (1996) were overestimated by 30%. This reduction of P in the diet has cost implications in diets and also environmental implications. Prados et al. (2015) concluded that the estimates of the BR-CORTE (Valadares Filho et al., 2010) and NRC (2000) were overestimated in, respectively, 14 and 43% for crossbred cattle. According to BCNRM (2016), most of feed grains and by-products used in feedlot diets contain at least 0.25% P, and that it is not necessary supplemental phosphorus. However, in extensive systems, based on tropical pastures phosphorus supplementation is essential, but must be done with discretion to do not waste this noble and expensive element, by using sources with good P solubility.

Phosphorus excreted to the environment can undergo mineralization-immobilization, which involves sorption reactions in clays, oxides and hydroxides in soil and solubilization by microorganisms and plants. The phosphorus is hardly runoff because Brazilian soils have high levels of iron and aluminum oxides, and kaolinite group clays, and they are able to immobilizing the phosphorus by specific adsorption. However, in cases of compacted soils or high concentration of manure, the phosphorus can be washed away during rain, reaching water bodies, and contributing to a procedure known as eutrophication. Eutrophication is the accumulation of nutrients dissolved in water, which favors the growth of algae and cyanobacteria, obstructing the passage of light and causing fish death from lack of oxygen when the algae die and go into deterioration.



Scheme 12.2. Summary of the phosphorus cycle.

Data used to develop the equations using meta-analysis and cross-validation

The data used to estimate the parameters of the equations were collected from experiments with beef cattle (Nellore and crossbred), which included information on all variables considered relevant to phosphorus excretion. The information collected for each observation included: body weight (BW), dry matter intake (DMI), phosphorus intake (P intake) and excretion of phosphorus.

The database included 178 observations from eight theses and dissertations (Table 12.7). Data were randomly separated into: one database to development of equations (142 observations) and one database for validation (36 observations, 20% of each study). Descriptive statistics (minimum, maximum, average and standard deviation) of data for developing the equations is listed in Table 12.8.

The procedure for developing the equations was the same as previously presented for nitrogen.

Table 12.7 - Description of database used in the development of phosphorus excretion equations

Author	Year	n	Genetic group	Sex
Souza	2009	20	Nellore and crossbred	Heifers
Marcondes	2010	8	Nellore and crossbred	Steers
Gionbelli	2010	7	Nellore	Heifers
Prados	2012	17	Crossbred	Bulls
Zanetti	2013	17	Crossbred	Steers
Costa e Silva	2015	45	Nellore	Heifers and steers
Sathler	2015	25	Nellore	Bulls
Prados	2016	39	Nellore	Bulls

Using the variables presented in Table 12.8, the variables that significantly influenced phosphorus excretion were selected. The effects of independent variables were considered significant for a level of probability lower than 0.05. The model used for fecal phosphorus excretion included the following terms: body weight and phosphorus intake. Due to the low contribution of the urinary P, urinary P excretion equation was not generated, but it was generated an equation accounting for the total P excretion.

Table 12.8 - Descriptive statistics of the data used for phosphorus excretion estimation in beef cattle

Variables[1]	n	Mean	Standard deviation	Minimum	Maximum
BW, kg	142	265.80	70.69	125.00	423.00
P intake, g/d	142	11.69	4.66	3.34	22.60
Fecal P, g/d	142	6.59	2.78	1.71	17.55
Total P, g/d	142	7.30	2.97	1.92	18.77

[1] BW = body weight; P intake = phosphorus intake.

After the evaluation of models and variables to be included in the equations, we used the cross-validation method (leave-one-out) using the REG procedure in SAS to generate the parameters for the prediction equations of phosphorus excretion. The solution of the fixed effects of the prediction equations for P excretion and their respective coefficients of determination (R^2) is shown in Table 12.9.

Table 12.9 - Solution of fixed effects of prediction equations based on significant variables and coefficients of determination (R^2) for phosphorus excretion

Item	Fecal P	Total P
Intercept	$1.473_{\pm 0.043}$	$1.895_{\pm 0.044}$
BW	$-0.0019_{\pm 0.0002}$	$-0.0030_{\pm 0.0002}$
P intake	$0.482_{\pm 0.0035}$	$0.530_{\pm 0.0036}$
R^2	0.607	0.630

[1] BW is body weight; P intake = phosphorus intake.

Adequacy of equations

After obtaining the phosphorus excretion equations, it was proceeded the validation. This was performed using the Model Evaluation System program (MES; Tedeschi, 2006). Thirty-six independent data from the total database were used for this validation of phosphorus predictions (Table 12.10), as previously mentioned.

Prediction efficiency was assessed by estimating the concordance correlation coefficient (CCC) and mean square error of prediction (MSEP), according to Tedeschi (2006).

Table 12.10 - Descriptive statistics of the variables for validation of the proposed equations for phosphorus excretion

Variables	n	Mean	Standard deviation	Minimum	Maximum
BW, kg	36	271.29	82.98	125.00	416.50
P intake, g/d	36	13.16	4.20	3.43	20.97
Fecal P, g/d	36	7.13	2.64	1.80	13.43
Total P, g/d	36	7.72	2.75	2.04	14.51

[1] BW = body weight; P intake = phosphorus intake.

Table 12.11 shows the result of the validation of equations for the prediction of phosphorus excretion by beef cattle under tropical conditions. Considering the Mayer's test ($P > 0.05$), the equations are appropriate to estimate the fecal and total phosphorus excretion.

Considering the MSEP decomposition, it can be seen that most of the errors are random, showing that the proposed equations do not tend to over- or underestimation.

Table 12.11 - Regression analysis, concordance correlation coefficient (CCC), bias correction (Cb) and mean square error of prediction (MSEP) decomposition between the predicted and observed values of phosphorus excretion

Item	Prediction equation of phosphorus excretion	
	Fecal P	Total P
Regression analysis[1]	-	-
r^2	0.42	0.44
H_0: a = 0 and b = 1	0.74	0.50
CCC	0.61	0.63
Cb	0.95	0.95
MSEP	4.010	4.272
Mean bias (%)	0.03 (0.65)	0.11 (2.68)
Systematic bias (%)	0.04 (1.04)	0.06 (1.31)
Random errors (%)	3.94 (98.31)	4.10 (96.01)

[1]Linear regression between predicted and observed values by means of phosphorus excretion equations.

The similarity in estimated and observed phosphorus excretion values is shown in Figure 12.2. The values are similarly disposed around the identical line (dotted line).

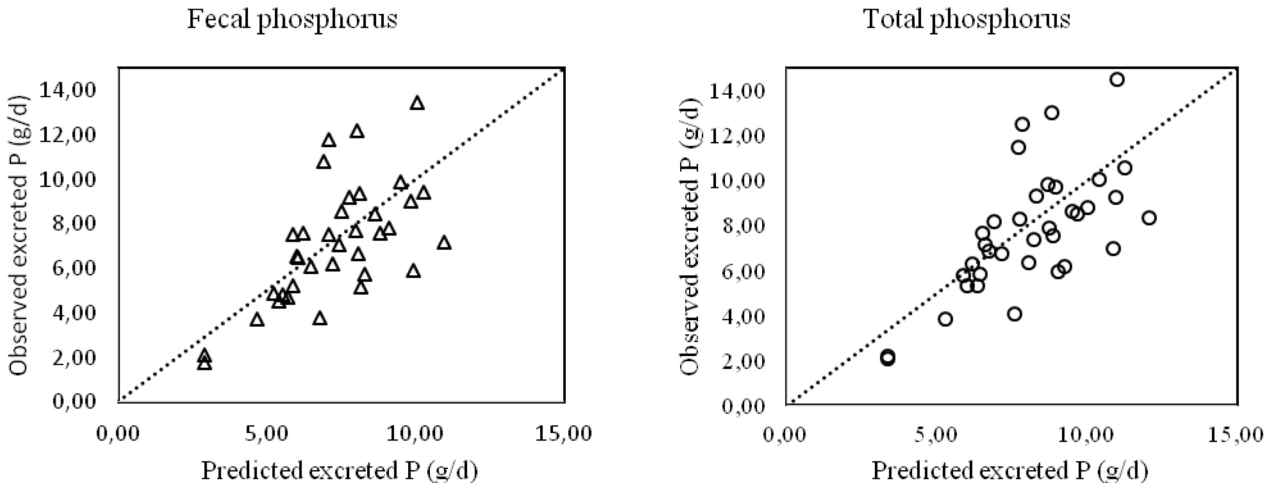


Figure 12.2 - Relationship between the observed values of phosphorus excretion and those determined by the proposed model. Predicted values are plotted on the X axis and the observed values are on the Y axis. The dotted line represents the ideal line (Y = X), intercept = 0 and slope = 1.

Both equations show positive correlation between phosphorus intake and excretion; corroborating with other authors (Prados et al., 2015; Prados, 2016) who observed that increasing the concentration of phosphorus in the diet results in increased fecal P excretion. Geisert et al. (2010) proposed an equation for the total P excretion, with a positive relationship between P intake and excretion.

FINAL CONSIDERATIONS

The prediction of nitrogen and phosphorus excretion is important for modeling nutrient cycling in the beef cattle production system and for assessing the impact of changes in dietary formulation over the excretion of these nutrients to the environment. Reductions in phosphorus content and crude protein in the diet do not adversely affect performance and therefore represent important strategy to reduce the environmental impact of livestock farming.

The following equations are proposed to estimate the fecal and urinary excretion of nitrogen and phosphorus by beef cattle under tropical conditions:

Fecal N (g/d) = 2.55 + 0.048 × BW – 3.47 × TDNI + 0.30 × NI

Urinary N (g/d) = 3.26 + 3.68 × DMI + 0.18 × NI

Urinary N (g/d) = 3.82 + 0.34 × NI

Fecal P (g/d) = 1.47 – 0.0019 × BW + 0.48 × P intake

Total P (g/d) = 1.90 – 0.0030 × BW + 0.53 × P intake

where: BW is body weight (kg); TDNI is total digestible nutrients intake (kg/d); NI is nitrogen intake (g/d); DMI is dry matter intake (kg/d); P intake is phosphorus intake (g/d).

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