Endogenous phosphorus loss in ruminants: A review

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Abstract

Phosphorus (P), a major mineral in animal nutrition is currently a focus of the livestock industry. This is because of its high fecal excretion by livestock and the subsequent environmental pollution, especially in the eutrophication of lakes and surface water. Areas of intensive animal husbandry and dairy farms where P is fed in excess are particularly affected. Ruminants must be fed according to precise net requirement to reduce excessive loss in feces. The knowledge of fecal endogenous loss is necessary to precise maintenance P requirement. Variation exists in the endogenous fecal loss and P availability values in feedstuffs among different countries. Quantitative information on these indices is needed. Salivary P, dry matter intake and physical nature of diets are major determinants of endogenous P loss but the mechanisms surrounding their role are yet to be clearly defined. Uniform, precise and acceptable method of estimating endogenous P loss in ruminants is to be developed. A lot of studies have been carried out on P metabolism in recent times but some aspects of the metabolism in ruminants are poorly understood. This review attempts to discuss these problems in the light of past and recent findings on P loss with a view to exploring areas for further research.

Key words: Endogenous P loss, maintenance requirement, P metabolism, salivary P, ruminants, environmental pollution.

Introduction

Intensive animal production system is becoming more popular in the developing world. This is necessitated by the need to increase animal protein to meet the demand of the rapidly growing population. Trends in animal nutrient management have been to maximize output of useful products like eggs, milk and meat. Meeting the nutrient requirements to maximize these products is essential to successful intensive animal production system. Phosphorus (P) is one of the important nutrients in animal nutrition. The importance is underscored by its role in body functions. P is a major constituent of the bone and an important part of nucleic acids DNA and RNA, essential for genetic information transfer. Furthermore, P is an important component of many coenzymes and compounds involved in energy metabolism (ATP, ADP). In fact, it is generally accepted that P has more metabolic functions in the body than calcium 1 and it has more known biological functions than any other mineral element 2.

P has often been fed in excess of daily requirements in amounts that have neither beneficial nor detrimental effects on cow health and performance 3,4. Recently, ruminants’ diets in Europe were reported 5 to typically contain more P than recommended. Significant overfeeding of P often is common practice on dairy farms 6,7. Similar observations were made in North America 8. Ruminants excrete P mainly in the feces and dietary excessive P increases the excretion of P subsequently affecting environmental quality 9,10. P is currently one of the most polluting nutrients in areas of animal husbandry concentrations 11 and it is a major fresh water pollutant 12. Application of manure to farms often leads to build up of P in the soil as manure is applied to meet crop need of nitrogen. However, P:N ratio in manure is about twice the P:N ratio need of crops. The resultant excess P released into the environment through water run off contaminates surface waters causing eutrophication. It therefore becomes imperative to determine the exact requirement of P to avoid wastage, unnecessary cost and environmental pollution. According to Bravo et al. 13, understanding the determinants of fecal endogenous P flow will help to precisely determine the net P requirements for maintenance. Furthermore, Dias et al. 14 posited that the knowledge of endogenous P in ruminants is important because the obligatory losses are used to determine the mineral requirements. When requirements are accurately established, ruminants can be fed accordingly. There have been moves to reduce P in the diets of livestock, however, reducing P in the diet of ruminants before precise determination of the requirements can be counterproductive in terms of animal performance. Presently, a lot of discrepancies exist in the estimation of P requirements of ruminants whose maintenance estimates are based on endogenous losses in urine and feces. The need to synchronize current and past findings is pertinent. The objective of this review is therefore to summarize available information in literature on endogenous P loss with a view to identifying possible areas for further research in ruminants.

P Metabolism in Ruminants

Basic understanding of P metabolism is fundamental to the mechanisms of endogenous P loss. The metabolism of P in ruminants is complex and the kinetics of its homeostasis has not been fully understood. Vitti et al. 14 proposed a model of whole body metabolism in goats involving four pools of P: 1) the gut...
lumen, 2) blood, 3) bone and 4) soft tissue. A continuous in-flow and out-flow takes place among these pools depending on the animal’s P nutrition. About 80-85% of P in the body is found in bones and teeth. Bone is an active tissue that undergoes metabolic changes due to the presence of osteoblasts and osteoclasts. These bone components form and resorb bone respectively. According to Dias, bones represent an important reserve of P that can be mobilized for animal function. P in soft tissues is equally mobilized but in lower proportions. Dairy cows mobilize P from body reserves to compensate for excretion of P in milk and feces. Hydroxypatite is the source of mobile P in bone for regulating blood P. Parathyroid hormone (PTH) and dihydroxycholecalciferol stimulate bone resorption. However, the mechanisms that control withdrawal, the conditions that trigger withdrawal and the rate and extent of bone P withdrawal without affecting animal performance seem to be poorly understood. Ruminants secrete P into the rumen via the saliva and salivary P can be substantial. Ruminants can secrete P in saliva in higher concentrations than in blood plasma, reabsorption in the small intestine is however regulated according to need. Valk et al. reported an average salivary P concentration of 245 mg L\(^{-1}\) in cows fed according to requirement. The saliva is involved in transferring P from the plasma to the digestive tract by clearing plasma P at amounts below the renal threshold. Phosphorus concentration in blood plasma is about 4 to 6 mg dL\(^{-1}\) for adult cattle. The main intestinal absorption site is the proximal duodenum where P absorption or by passive diffusion. Work toward improving an understanding of P metabolism has increased in recent times but little is known about the blood and soft tissue P pools of the body and their rates of inflow and outflow in goats and other ruminants.

Endogenous P Loss
Endogenous P has been defined as the amount of P that is regularly and unavoidably lost from the body when animals are maintained on a low or preferably a P-free diet. The two sources of endogenous phosphorus loss in ruminants are the feces and the urine. Total endogenous P is represented by the sum of fecal endogenous P and P excreted in the urine. Excreted under specific nutritional conditions later discussed in this paper, it is widely accepted that ruminants excrete P mainly in the feces. This fecal P loss is made up of unabsorbed dietary P (exogenous) and endogenous P (mainly unabsorbed P from the saliva, intestinal cells and digestive secretions). Rumen microbial P that escaped solubilisation during post rumen digestion has also been recently implicated as a potential source of fecal endogenous P. Spiekers et al. suggested partitioning fecal P into three fractions: the unavailable part of dietary P which can be absorbed under no conditions, the inevitable loss which has to be excreted under actual nutritional and physiological conditions and the regulatory portion which is a homeostatic reaction that depends on P intake of the animal. Fecal endogenous P was reported to constitute more than 66% of total fecal P in cattle and sheep. Bravo et al. reported an average of 0.85 of total fecal P with the remaining 0.15 as unabsorbed dietary P. Rate of urinary excretion of P is generally low in ruminants; though high urinary excretion has been reported in some cases.

Endogenous Fecal P Loss and the Maintenance Requirement
Maintenance requirement of P is the endogenous fecal P loss (inevitable fecal loss) when P supply is just below or just meets the true requirement. According to Valk and Beymen, the basis for P recommendation system is the factorial method involving the net requirement for maintenance and milk production and the true absorption coefficient. Valk et al. indicated that there is agreement only with regards to P needed for milk production, however, estimates of net P requirement for maintenance vary from 8.6 to 22.1g/600 kg cow per day and the true absorption coefficient ranges from 50 to 70% units.

In the past, net maintenance requirement level had been expressed as a function of body live weight, based on fecal P excretion extrapolated to zero P intake. The ARC calculated maintenance P requirements based on a fixed fecal loss of P 10 mg kg\(^{-1}\) live weight (LW) and absorption coefficients of 0.58 and 0.78 for 12 months old cattle weighing over 300 kg and for younger and lighter cattle respectively. According to Ternouth, the Australian Standing Committee on Agriculture based their calculation of maintenance P requirements on a constant endogenous fecal loss of P 20 mg kg\(^{-1}\) LW and an absorption coefficient of 0.70. Tammenga compared P feeding recommendations by different countries (Table 1). As of that time, maintenance requirement and percentage availability of P varied widely between the countries.

The trend has, however, changed in some countries where maintenance requirement is now expressed as a function of DMI. Germany GfE and NRC adopted this change based on the findings of Spiekers et al. and AFRC. Spiekers et al. using 2 groups of lactating cows fed low P at different P intakes, calculated excretion of fecal endogenous P as a function of DMI. The excretion of fecal P was similar between groups being 1.20 and 1.22 g kg\(^{-1}\) DMI day\(^{-1}\) for the low and high intake groups respectively. They estimated an absorption coefficient of total P as 80% (cows fed close to true requirement) and therefore set the maintenance requirement for lactating cows at 1.0 g kg\(^{-1}\) of dietary dry matter consumed. This value is inclusive of an additional 0.002 g kg\(^{-1}\) body weight (BW) endogenous P excreted in the urine. The importance of relating the ruminant maintenance requirement for P to dry matter intake has also been investigated and reported in sheep and goats. The various data suggest that the main differences in P recommendations lie in the maintenance requirement (based on endogenous fecal P) and the true absorption coefficient. The values adopted by any P recommendation body will depend on these two factors.

Table 1. P requirements for dairy cattle.

<table>
<thead>
<tr>
<th>Maintenance</th>
<th>Milk production</th>
<th>Availability</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>g kg(^{-1})BW</td>
<td>g kg(^{-1}) FCM</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>0.0286</td>
<td>1.98</td>
<td>50</td>
<td>USA</td>
</tr>
<tr>
<td>0.042</td>
<td>1.50</td>
<td>60</td>
<td>Netherlands</td>
</tr>
<tr>
<td>0.0207</td>
<td>1.56</td>
<td>58</td>
<td>Great Britain</td>
</tr>
<tr>
<td>0.062</td>
<td>1.25</td>
<td>70</td>
<td>France</td>
</tr>
<tr>
<td>0.040</td>
<td>1.66</td>
<td>60</td>
<td>Germany</td>
</tr>
</tbody>
</table>

Techniques in the Study of Endogenous P
Endogenous fecal loss cannot be easily quantified by standard chemical procedures. This is because it is found in the feces.
together with unabsorbed dietary P and the problem is in distinguishing between these two in feces. Several methods involving isotopes have been devised to surmount this barrier. In ruminants, $^{32}$P radioisotope has been used to distinguish dietary P from endogenous fecal P. Specific methods include: comparative balance method, dual tracer or double isotope technique, computed compartment analysis and isotope dilution technique. A number of workers have used one or a combination of these methods to study P metabolism and endogenous P loss. The methods include: balance and isotope dilution technique $^{14}$, $^{15}$, $^{27}$, $^{33}$, $^{44}$-$^{47}$, markers and radioisotope $^{48}$. Grace $^{49}$ and Schneider et al. $^{50}$ used radioisotope to study distribution of P by applying compartmental models, and Boston et al. $^{31}$ studied the kinetics of $^{32}$P after intravenous injection using a compartmental analysis computer program. Isotope dilution technique is based on a single parenteral injection into the animal body. This therefore enables a distinction between exogenous and endogenous by reference to the isotope enrichment in the blood plasma or feed and feces. Therefore isotope dilution allows direct and quantitative measurements of mineral fluxes and provides strong estimates of endogenous fecal excretion of minerals $^{52}$.

Measuring fecal endogenous P using labeling dilution technique especially with a radioactive isotope is very demanding $^5$ and difficult especially in respect to handling radioactive materials and disposing the experimental animals $^{53}$. Bravo et al. $^{12}$ obtained a model of prediction of endogenous P flow by multi regression analysis using ingested P, total fecal P and urinary P. Endogenous fecal P = 0.555 + 0.105 x INTp + 0.216 x FECp – 0.196 x URIp, where INTp = intake of P g day$^{-1}$, URIp = urine P and endogenous fecal P = g day$^{-1}$. According to the authors, the empirical model gave a relatively precise prediction ($r^2 = 0.88$). Rajaratne $^{29}$ also studied endogenous P using as a model sheep maintained by intragastric secretion. AFRC $^{43}$ and NRC $^2$ developed prediction equations for calculating endogenous fecal P flow: Endogenous Fecal P = 0.000108 INT$_{DM}$ – 0.09 (AFRC Model); Endogenous P = 0.001 INT$_{DM}$ + 0.002 BW (NRC Model), where INT$_{DM}$ = dry matter intake g day$^{-1}$ and BW = body weight in kg.

Endogenous fecal P is variable $^{34}$ and many researchers have reported different values under different conditions as shown in Table 2.

**Factors Affecting Endogenous P Loss**

Fecal endogenous P loss is not a constant but varies according to P-intake needed to meet a given requirement $^{27}$-$^{45}$, $^{46}$. The following are the major determinants of fecal endogenous P loss.

**Dry matter intake:** Ternouth and Davies $^{42}$ argued that endogenous fecal losses are related to dry matter intake (DMI). Ternouth $^{47}$ indicated that there is a family of relationships relating endogenous fecal P losses to dry matter intake depending on concentration of plasma P. In his study with sheep fed low P barley straw diets he observed that endogenous P varied with dry matter intake, this he, however, attributed to lower salivary P secretion. AFRC $^{41}$ reported similar finding in sheep fed concentrate diet attributing the effect to salivary flow rate, changes in flow and hence salivary P secretion. Maekawa et al. $^{56}$ reported a significant relationship between DMI and the total amount of saliva produced by cows during eating. Coates and Ternouth $^{31}$ suggested that P requirements should not be based on a constant endogenous fecal P value because endogenous fecal P level is affected by dietary dry matter and P intakes. An obligatory endogenous P loss for growing cattle ranging from 9-17 mg kg BW$^{-1}$ related to DMI in the range of 10-25 g DM kg BW$^{-1}$ has been reported by Ternouth et al. $^{37}$. AFRC $^{41}$ and NRC $^2$ also stated that endogenous fecal P depends on DMI and quality of feed signifyed by the concentrate versus roughage content of ration. Scott et al. $^{25}$, however, reported that DMI did not affect overall rate of endogenous P secretion but rather the partitioning of P excretion between urine and feces.

**P intake:** It is generally accepted that P-intake affects endogenous fecal P loss. Scott et al. $^{25}$ suggested that total endogenous fecal P excretion depends more on P intake than on DMI. Bravo et al. $^{12}$ developed the following model for this relationship based on the quantitative analysis of 56 experiments with 1317 animals: PFECE$_{ENDO}$/BW = 1.17 x 10$^{-2}$ (±0.08 x 10$^{-2}$) + 0.250 (±0.01) x PING/BW ($r^2 = 0.68$, $P<0.01$), where PFECE$_{ENDO}$ = endogenous fecal P (g day$^{-1}$), BW = body weight (kg) and PING = P ingested (g).

Endogenous fecal P was observed to increase linearly with ingested P when related to body weight or to DMI. This stance is consistent with the report of several other workers $^{29}$, $^{33}$, $^{58}$-$^{61}$. In a study with growing lambs fed grossly deficient to just adequate P diets, Braithwaite $^{45}$ observed that endogenous fecal flow of P increased in direct relation to increased P intake. This was in spite of the high P requirement of the deficient lambs. In a similar study with growing calves, Challa and Braithwaite $^{25}$ reported a significant increase in endogenous fecal loss of P with increased P intake. Furthermore, Vitti et al. $^{15}$ in a study with growing goats given various concentration of P observed that in spite of the need to retain P by goats on P-deficient diets, goats excreted endogenous P through the feces, this loss was positively

**Table 2. Estimated values of endogenous fecal P in ruminants fed different diets.**

<table>
<thead>
<tr>
<th>Species</th>
<th>Diet</th>
<th>Fecal endogenous P</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamb</td>
<td>$^a$Def.–adequateP</td>
<td>28.9–45.6 mg day$^{-1}$ kg BW$^{-1}$</td>
<td>Braithwaite $^{35}$</td>
</tr>
<tr>
<td></td>
<td>$^b$Chd-grd straw–High P</td>
<td>17.3–19.9 mg day$^{-1}$ kg BW$^{-1}$</td>
<td>Ternouth $^{47}$</td>
</tr>
<tr>
<td></td>
<td>$^c$Chd-grd straw–Low P</td>
<td>14.4–22.8 mg day$^{-1}$ kg BW$^{-1}$</td>
<td>Ternouth $^{47}$</td>
</tr>
<tr>
<td></td>
<td>$^d$Chd or grd hay</td>
<td>10.0–14.0 mg day$^{-1}$ kg BW$^{-1}$</td>
<td>ARC $^{26}$</td>
</tr>
<tr>
<td></td>
<td>$^e$Co-grd straw</td>
<td>1.67 – 1.78 g day$^{-1}$</td>
<td>Scott et al. $^{70}$</td>
</tr>
<tr>
<td></td>
<td>Sugarcane bagasse, hay and citrus</td>
<td>0.84 – 0.85 g day$^{-1}$</td>
<td>Scott et al. $^{70}$</td>
</tr>
<tr>
<td>Sheep</td>
<td>$^f$Chd or grd hay</td>
<td>1.7–2.5 g day$^{-1}$</td>
<td>Dias et al. $^{44}$</td>
</tr>
<tr>
<td></td>
<td>Low–medium P</td>
<td>12.1–22.8 mg day$^{-1}$ kg BW$^{-1}$</td>
<td>Challa and Braithwaite $^{27}$</td>
</tr>
<tr>
<td></td>
<td>Low–High P</td>
<td>0.2–0.9 g day$^{-1}$</td>
<td>Vitti et al. $^{15}$</td>
</tr>
<tr>
<td>Calves</td>
<td>$^g$High CaP-Low CaP</td>
<td>0.401–5.80 g day$^{-1}$</td>
<td>Martz et al. $^{55}$</td>
</tr>
<tr>
<td>Goats</td>
<td>Cows (Dairy)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^a$Def = Deficient P to adequate P diet, $^b$Chd–grd straw = Chopped to ground straw diet, $^c$Chd or grd hay = Chopped to ground hay diet, $^d$Co-grd straw = Coarse to ground straw, $^e$High CaP-Low CaP = High calcium and phosphorus – Low calcium and phosphorus
correlated to P intake. These results indicate that whether ruminants are on diets that meet their P requirement or not an increase in endogenous fecal P loss with increase in P intake is inevitable.

**Physical form of diet.** Most of the relevant studies did not relate the physical nature of diet directly to fecal endogenous P loss but rather to salivary secretion and saliva flow. However, since fecal endogenous P is largely from unabsorbed salivary P, any factor impacting salivary P will definitely affect fecal endogenous P loss. Quantitative analysis of data from 8 different studies involving 126 animals revealed that dietary physical form affects salivary P. Wu et al. 62 reported that forage type, form and particle size may influence the rate of salivation and salivary P concentration. Scott and Buchan 37 also reported that the physical nature of a diet is known to be an important factor influencing salivary secretion, with flow rates being highest when poor quality roughage diets are fed. Reduced rates of salivary secretion have been associated with highly digestible concentrate diets 63, 64, finely ground diets 65 and pelleted diets 66. These differences in daily salivary secretion rates between diets have been attributed to differences in salivary flow rate 36, 66, 67. Mechanical grinding of diet before feeding may lead to decreased rumination and hence reduced salivary flow rate. Yano et al. 60 observed an increase in salivary P contribution to the duodenal P flow in sheep fed long hay compared to those fed short hay while AFRC 41 reported an increase in fecal endogenous P loss in sheep fed higher proportion of hay or hay in loose form as compared to pelleted hay. Ternouth 47 in his study with sheep on ground and chopped straw also identified the physical form of diet as one of the factors governing fecal endogenous P loss. In contrast, he reported an increase in endogenous fecal P loss with sheep on the ground straw, and attributed this finding to lower DM digestibility and consequent higher fecal dry matter of the sheep or to differences in the rate of flow and concentration of P in the intestinal digesta. Scott et al. 70 observed that at different P intakes the response of salivary P secretion to diet form varies. They suggested that at P intakes above requirement, a change from finely ground diet to a coarse one may increase P excretion by stimulating salivation while at low P intakes the impact of the physical nature of diet would be smaller. This is because an increase in saliva flow rate can be offset by a reduction in the concentration of P in saliva and an increase in reabsorption of P from the small intestine. While many authors agreed that salivation is affected by dietary forage source and amount through chewing activity 62, 71, 72 Maekawa et al. 56 observed that the net increase in salivary secretion due to increased chewing time was not as great as often thought. Their study revealed that increase in chewing time was not associated with a similar increase in saliva volume because the increase in saliva output as a result of increased chewing time was partially offset by decreased salivation during resting time.

**Salivary P.** There have been some controversies over the role of salivary P secretion in P homeostasis in the ruminants 25, 27, 46. This controversy is not unconnected with a lack of information on endogenous fecal loss of P 27. According to Ternouth 47, because of the high rate of P secretion by the salivary glands, factors affecting this secretion or its reabsorption may influence endogenous losses since endogenous fecal P losses result almost entirely from unabsorbed salivary P. Dias et al. 14 reported that endogenous P excreted in feces comes mainly from saliva and represents an important loss of P. Salivary P is a product of salivary P volume and concentration 20, 24, 27 where salivary P concentration is related to plasma P concentration while salivary P volume is related to DMI. Furthermore, Bravo 12 posited that salivary P flux or secretion (P_{sal}) is determined by the daily salivary flux (F_{sal} in L day^{-1}) and the saliva P content (CP_{sal} in g L^{-1}) indicating that P_{sal} = CP_{sal} X F_{sal}. The daily salivary flow is mainly influenced by DMI and dietary fiber content 73. The relationship between salivary P and plasma P is probably because of the primary role of saliva in transferring P from the plasma to the digestive tract 29. This explains why plasma P concentration was observed to rise when the parotid vein was ligated 75. Challa et al. 48 in their experiment with growing calves on different P intake observed that endogenous fecal P loss increased in direct relation to salivary P secretion even in animals fed on P deficient diet. They concluded that increase in salivary P secretion as a result of increase in P supply is not a means of eliminating excess P as some workers have assumed but rather that increased salivary P is uncontrolled and related to serum P concentration. Another possible explanation for the inevitable increase in salivary P secretion by animals even when on low P diets is that rumen microbial population needs a level of P to ensure normal functioning. Increase in salivary P under this condition may be a way of meeting the rumen microbial P requirement by the animal body. This mechanism is probably made possible by resorption of P from bone into the blood as controlled by the parathyroid hormone and hence to the saliva via the serum. This stance is consistent with the observation of Erdman 71 that ruminants maintain homeostasis in the rumen ecosystem through supply of buffers obtained from salivary secretion. Many workers 65-74, 79 agreed that serum P determines the rate of salivary P secretion and that salivary P secretion increases in direct relation to serum P concentration. Ternouth et al. 78 noted that salivary secretion of P is related to its flow rate, the significance of the flow rate has been discussed previously under the effect of physical form of diet. The relationship seems to suggest that as DMI and the coarseness of feed affect saliva flow due to increased rumination, saliva flow also affects saliva P secretion. Saliva P concentration on the other hand was reported 23, 25 to be inversely proportional to saliva flow at fixed P intake. Bailey 64 and Bailey and Balch 80 observed that the relationship is however curvilinear. Furthermore, Wu et al. 62 observed that total salivary P output may not necessarily increase even when salivary volume increases because the concentration of P in saliva may decrease as the rate of salivation increases as noted by Cohen 81. However, factors affecting level of P secretion in saliva are not as well defined as those affecting salivary flow 37.

**Absorption efficiency:** The process of P absorption is one of the major factors influencing endogenous fecal output 24. The calculation of the true absorption of a mineral is dependent on the determination of endogenous fecal loss of the mineral 55. Since the degree of absorption of a mineral greatly affects the amount available for metabolism, therefore, the values for true absorption are used to establish mineral requirement. According to Valk and Beymen 38, the basis for the P recommendation systems is the factorial method and it involves the net requirement for maintenance and milk production and absorption efficiency. Braithwaite 61 reported that the efficiency of P absorption
decreased as the intake of P increased. Absorption also depends on the availability of P from feedstuffs. Availability values of 0.64, 0.70 and 0.90 have been recommended for forages, concentrates and inorganic P sources respectively. Availability may vary within the same class of feedstuff, e.g., oil seed-based concentrate diets may differ in availability from other cereal-based diets while silage-based diet may also differ from hay-based diet. Few experimental findings are, however, available on P availability in ruminants. Furthermore, dietary phytate P may affect the digestive availability of P especially when phytate P escapes solubilisation in the rumen.

Urinary P Loss
This is an alternative path of P excretion in ruminants and it is usually quantitatively negligible especially when compared with some monogastrics. Walker and Al-Ali reported a range of 0.5-1.3 mg kg^{-1} day^{-1} urinary P excretion for preruminant lambs fed low P diets, while Ternouth reported 0.33-0.48 mg kg BW^{-1} for sheep fed on chopped or ground straw. The role of urinary P loss in P homeostasis has been debated and Braithwaite posited that urinary P contributes to P homeostasis in ruminants. Scott and Buchan observed that when sheep were fed on concentrates, the consequential reduction in salivary flow rate changed from a coarse to a finely ground diet or from roughage to concentrate diet, the consequential reduction in salivary flow rate and hence rate of removal of P from circulation was accompanied by an increase in urinary P. This increase led to a decrease in fecal and endogenous fecal P but no change was observed in the P balance. Tomas and Sommers made similar observation when salivary flow was reduced in sheep by surgical means. Dias et al. suggested that both salivary P secretion and urinary secretion are determined by serum P concentration but urinary P is negligible at P intakes below those needed to supply requirements. However, when growth requirement had been met urinary P excretion did increase as serum P concentration exceeded renal threshold. Different workers in the field of P metabolism have suggested an inter-relationship among saliva flow, nature of diet and changes in the partitioning of P excretion in urine and feces. Scott and Buchan observed that when sheep were changed from a coarse to a finely ground diet or from roughage to concentrate diet, the consequential reduction in salivary flow rate and hence rate of removal of P from circulation was accompanied by an increase in urinary P. This increase led to a decrease in fecal and endogenous fecal P but no change was observed in the P balance. Tomas and Sommers made similar observation when salivary flow was reduced in sheep by surgical means. Dias et al. observed a higher urinary P of 10% in sheep fed hydrolysed sugarcane bagasse (HSB) compared to those fed HSB and lucerne hay or HSB and citrus pulp. They attributed the result to the roughage quality of HSB which was considered low because of the fibre disarrangement. Feeding poor quality coarse roughage has the same effect as feeding concentrate diets, because both reduce eating, rumination times and flow rate. However, in their study, excretion of P in the urine was not related to either plasma P or fecal P as reported by some other workers.

Conclusions
P has become a major focus of the livestock nutritional management in recent times. The determination of endogenous P loss is essential to precise estimation of P requirements for maintenance. There is a general agreement that endogenous P loss is mainly through the feces except under certain nutritional conditions when urinary P excretion is high. Several methods have been devised to estimate the endogenous P loss, the popular technique among these is the use of radioisotope. Dietary factors have been found to affect endogenous P loss through their effect on salivary P flow and salivary P secretion. However, their effect has not been clearly defined. There is a need to investigate and clarify further the mechanisms involved in salivary P concentration under different nutritional conditions. With several studies conducted on P metabolism already, attention should be shifted to areas that are less understood. There is a need to develop technology for the study of bone P resorption, inflow and outflow of P from the blood and soft tissues. Developing a generally acceptable and convenient method for the estimation of endogenous P loss is also highly pertinent to ensuring adequate nutritional management in ruminant P nutrition. This attempt will provide a panacea for the menace of excessive fecal P excretion and environmental pollution.

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