Availability of Phosphorus Contained in Poultry Litter for Lambs

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ABSTRACT Percentage net phosphorus availability (NPHA) and net phosphorus utilization (NPHU) of the phosphorus contained in heat-sterilized poultry litter (PL) as compared to feed grade dicalcium phosphate (DCP) for lambs was assessed by the "slope" method. The method was based on the evaluation of the function of apparent phosphorus absorption (NPHA), or retention (NPHU), on phosphorus intake. Nitrogen retention was also evaluated. Plasma inorganic phosphorus concentration as a function of phosphorus intake was evaluated and compared to NPHA and NPHU. The percentage of NPHA was found to be 63.7 and 39, and that of NPHU was 63 and 38 for the phosphorus supplied by DCP and PL, respectively. Thus, the NPHA or NPHU for the phosphorus contained in PL is 60.9 and 60.3% of that of DCP, respectively. The slope ratio between the two phosphate supplements as observed for plasma inorganic phosphorus concentrations was similar to those found for NPHA and NPHU but the coefficient of variation was 5 times higher. Nitrogen digestibility was not affected by the level of phosphorus in the diets. Correlation between nitrogen retention and NPHA or NPHU was, however, significant (P < 0.05). The slopes of dependence of N retention upon phosphorus intake were 2.81 and 1.6 (P < 0.05) for DCP and PL treatments, respectively, and the ratio between the slopes was 0.57, close to the ratio of NPHU in PL to DCP-supplemented diets. J. Nutr. 111: 405–411, 1981.

INDEXING KEY WORDS phosphorus availability • poultry litter • lambs

Feeding poultry litter (PL, excreta mixed with bedding) was initiated over two decades ago (1). The practice has been increasing in use probably due to the soaring prices of ruminant feedstuffs and waste disposal problems. While the utilization of energy and nitrogen from PL by ruminants has been extensively studied (2–4), only one study concerned the utilization of phosphorus contained in poultry excreta (5). The increased use of least-cost or maximum profit diet formulation for ruminants calls for a more precise knowledge of the biological availability of nutrients. This is especially true in cases where the feedstuffs is incorporated into a diet in a relatively small proportion, but still contributes a considerable part of a certain nutrient.

In diets that are used in Israel, sugar beet pulp or citrus pulp and peels are combined with cottonseed hulls and/or straw and with PL to produce a complete diet to be fed to a moderately growing ruminant. In such a diet most of the phosphorus is contributed by the supplemented PL. An average of 70% of phosphorus (P) retention by cows and steers from air-dried poultry manure (PM,
TABLE 1
Composition of the experimental diets

Experimental treatment | 1 | 2 | 3 | 4 | 5
--- | --- | --- | --- | --- | ---
Phosphorus source | Basal | DCP | DCP | PL | PL |
--- | --- | --- | --- | --- | ---
A. Ingredients

% air dry matter

| Experimental treatment | 1 | 2 | 3 | 4 | 5 |
--- | --- | --- | --- | --- | ---
Basal concentrate | 99.33 | 99.36 | 99.30 | 97.60 | 95.95 |
Urea | — | — | — | — | — |
Limestone | 0.32 | 0.35 | 0.35 | 0.17 | 0.12 |
Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

B. Composition

| Experimental treatment | 1 | 2 | 3 | 4 | 5 |
--- | --- | --- | --- | --- | ---
Phosphorus | 0.114 | 0.143 | 0.182 | 0.143 | 0.182 |
Calcium | 0.878 | 0.878 | 0.878 | 0.878 | 0.878 |
Total N | 1.813 | 1.803 | 1.808 | 1.810 | 1.810 |
Digested energy, kcal/kg | 3.050 | 3.050 | 3.055 | 3.056 | 3.056 |

1 The basal concentrate was composed of: dehydrated citrus and sugar beet pulps, 28.42% each; cottonseed hulls, 21.31%; blood meal, 8.88%; corn flour, soybean oil and glucose monohydrate, 3.55% each; sodium chloride, 2.14%; trace elements and vitamins according to (9), 0.11%, methionine 0.07%. 2 To equalize total N and non-protein nitrogen content of the diets. 3 Calculated from digestible energy values of feedstuffs presented by NRC 1975, and for the PL as presented by Tagari et al. (9).

excreta only) was earlier reported (5) but with no comparison to a standard source of phosphorus. Balance techniques have been commonly used to obtain values of phosphorus utilization in terms of percentage absorption (6). These techniques, however, determined apparent absorption with no allowances for the endogenous phosphorus excretion. In the present study, the "slope method" (7) has been adopted for balance technique, used in sheep to obtain the percentage of net phosphorus utilization (NPHU) of heat-sterilized PL.

MATERIALS AND METHODS

Animals and diets

Thirty Awassi lambs (fat tail), 4–5 months old and weighing 39.6 ± 3.3 kg (mean ± SD) were distributed into five groups and placed in metabolism cages. During an adaptation period of 20 days, they were fed the basal diet (table 1) supplemented with sufficient dicalcium phosphate. They were then fed the experimental diets for 20 days. Collection of excreta was made during the final 10-day period. The diets in amounts detailed in table 2 were fed in two equal portions of 0700 and 1600 hours. Feed residues were collected and analyzed. Blood samples were obtained from the jugular vein on alternate days during the last 6 days, 3 hours after the morning meal. Heparin was used as an anti-coagulant. The blood samples were immediately centrifuged and the resulting plasma was extracted with 10% trichloroacetic acid. Details of the experimental procedures were given previously (8).

The experimental diets and their chemical composition are given in tables 1A and 1B, respectively. The digestible energy allowance was about 4,000 kcal/day, according to the National Research Council [NRC] (10), and the phosphorus intake was between 1.6 and 2.5 g/day (table 2) supplied either by dicalcium phosphate (DCP) or heat-sterilized PL previously described (9). The highest phosphorus intake was lower than the
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TABLE 2

Animal allocation and feed allowance to lambs fed a basal diet (treatment 1) or diets supplemented with phosphorus of dicalcium phosphate (treatments 2, 3) or poultry litter (treatments 4, 5)

<table>
<thead>
<tr>
<th>Treatment No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal data</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of lambs</td>
<td>6</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Body weight, kg</td>
<td>44.9</td>
<td>43.2</td>
<td>44.1</td>
<td>43.1</td>
<td>43.6</td>
<td>3.3</td>
</tr>
<tr>
<td>Daily feed intake</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concentrate mixture, g</td>
<td>1,395</td>
<td>1,335</td>
<td>1,387</td>
<td>1,320</td>
<td>1,359</td>
<td>115</td>
</tr>
<tr>
<td>Wheat straw, g</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>P intake, mg</td>
<td>1,600</td>
<td>1,892</td>
<td>2,423</td>
<td>1,852</td>
<td>2,409</td>
<td>119</td>
</tr>
<tr>
<td>Digestible energy intake, kcal</td>
<td>4,212</td>
<td>4,080</td>
<td>4,240</td>
<td>4,030</td>
<td>4,150</td>
<td>342</td>
</tr>
</tbody>
</table>

1 From the analysis of variance table. 2 One lamb of each treatment 2 and 4 went off feed during the balance trial as a result of a inflamed preputium that appeared after the rubber funnels were attached to their abdomen for urine collection. 3 One lamb went off feed during the balance trial due to a hoof that was damaged by the wire mesh at the bottom of the metabolic cage.

NRC (10) allowance for lambs of this age and weight. A fixed daily amount (100 g) of chopped straw was fed to supply roughage.

Chemical methods

Total N in feeds was determined by the Kjeldahl method (11). Phosphorus in feedstuffs, feces and plasma filtrate was determined according to Gomori (12). When a low Ca:P ratio in feed or fecal samples was expected, 5 ml of 5 M CaCl₂ was added to the sample before ashing. The phosphorus concentration in urine was determined by the micro method described by Chen et al (13). Calcium in feeds was determined according to Welcher (14).

Calculation and statistical analysis

Apparent absorption was calculated according to the equation Pab = PI - PF, where Pab is apparent absorption of phosphorus and PI and PF denote the phosphorus intake and fecal phosphorus, respectively. Phosphorus retention was calculated according to the equation PR = PI - (PF + PU) where PU is urinary phosphorus excretion. Net phosphorus absorption is defined as NPHA = Va/PI where Va is the absorption of feed phosphorus (true absorption). The apparent P absorption is then,

\[ Pab = NPHA \cdot PI - Pend \]

where Pend is the endogenous excretion, independent of P intake. NPHA is then the slope of a plot of Pab versus PI·NPHU (net phosphorus utilization) and is calculated similarly from phosphorus retention. The slopes were compared by analysis of covariance according to Snedecor and Cochran (15). Analysis of variance for the differences between treatments means, was also carried out according to Snedecor and Cochran (15). The relative availability of phosphorus from PL was calculated by dividing the NPHA or NPHU of PL by that of dicalcium phosphate.

RESULTS

The results of phosphorus balance are presented in figure 1. The supplementation of the basal diet by additional phosphorus of DCP or PL origin resulted in increased P absorption at a rate different for the two sources or levels. Urinary phosphorus excreted was only 3–14% of the absorbed phosphorus and tended to increase with increased P intake, from both DCP and PL (fig. 1c). This change, however, was not significant (P > 0.05). Thus, most of the absorbed phosphorus was retained.

Net phosphorus absorption (NPHA) and utilization (NPHU)

The calculation of NPHA and NPHU was carried out according to the basal
assumption outlined. The dependence of phosphorus absorption upon P intake (PI) was examined separately for the DCP and PL supplementation, taking into account the basal and two levels of P added (fig. 1). The functions did not significantly deviate from linearity. It is apparent from the regressions presented that the NPHA (fig. 1a) and NPHU (fig. 1b) from DCP was 63.7 ± 6 and 63 ± 6, respectively and that of PL was 39 ± 4.4 and 38 ± 6%, respectively. The differences between the regression coefficients (slopes) for both DCP and PL absorption and retention were significant (P < 0.05), according to the analysis of covariance. It may therefore be concluded that the relative availability of P from PL as related to that from DCP was 60.9% and 60.3% as calculated from NPHA and NPHU, respectively.

Plasma phosphorus concentrations

Plasma P concentrations increased with the increase in the level of phosphorus supplementation, regardless of source. The dependence of inorganic plasma P concentrations 3 hours after feeding upon P intake was examined separately for DCP and PL-fed groups, and was found (table 3) to be significant (P < 0.05). The coefficients of both regressions were examined for their covariance and were not found to differ (P > 0.05) from each other.

Nitrogen digestibility and retention

Amounts of N consumed by the lambs fed the different experimental diets were similar. The nitrogen digestibility in the different treatments was similar (table 4) as expected (16), indicating that even the lowest P intake supported regular ruminal and intestinal degradative and absorptive activities. The regression between nitrogen retention and phosphorus intake was examined separately for the DCP and PL treatments, 1, 2, 3 or 1, 4, 5, respectively. The regression for DCP was:

\[ Y = 2.81X - 4.06 \ (r = 0.63, \ P < 0.001) \]

and for PL:

\[ Y = 1.60X - 1.9 \ (r = 0.621, \ P < 0.01) \]

where Y and X denote nitrogen and phosphorus intake respectively. These functions did not significantly deviate from linearity. Nitrogen retention was, however, significantly affected by phosphorus intake. A highly significant correlation between phosphorus and nitrogen retention was found. The regression between the two was:

\[ Y = 4.25X - 2.5 \]

\[ (n = 27, \ r = 0.81, \ P < 0.001) \]
TABLE 3

Plasma inorganic phosphorus (Pi) concentrations (A) and their regression (B) on phosphorus intake (PI) in lambs fed diets containing a basal amount of phosphorus or supplemented with dicalcium phosphate (DCP) or poultry litter (PL) at two levels of P supplementation each

<table>
<thead>
<tr>
<th>Treatment No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma Pi, mg/dl</td>
<td>6.97&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.71&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8.42&lt;sup&gt;c&lt;/sup&gt;</td>
<td>7.42&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8.10&lt;sup&gt;*&lt;/sup&gt;</td>
<td>0.11</td>
</tr>
</tbody>
</table>

B. Dependence of Pi, mg/dl on PI, g/day

<table>
<thead>
<tr>
<th>Phosphorus source</th>
<th>Intercept</th>
<th>b</th>
<th>s&lt;sub&gt;b&lt;/sub&gt;</th>
<th>r</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCP&lt;sup&gt;1&lt;/sup&gt;</td>
<td>17</td>
<td>6.85</td>
<td>1.60 ± 0.91</td>
<td>0.671</td>
<td>P &lt; 0.01</td>
</tr>
<tr>
<td>PL&lt;sup&gt;2&lt;/sup&gt;</td>
<td>16</td>
<td>7.05</td>
<td>0.95 ± 0.66</td>
<td>0.505</td>
<td>P &lt; 0.05</td>
</tr>
</tbody>
</table>

<sup>1</sup> Treatments 1, 2 and 3.  <sup>2</sup>Treatments 1, 4 and 5.  <sup>abc</sup> Means within the same line not sharing a common letter differ (P < 0.05).

DISCUSSION

In the present study, the NPHA was calculated from the dependence of amounts of phosphorus absorbed upon P intake as determined by feeding lambs at three levels of phosphorus. The calculation of NPHU by the slope method was suggested for birds by Hurwitz (7). Another method of feeding P at two different levels and calculating the NPHA from the ratio of P absorbed/P intake (17), was also reported. Both methods described assume that the dependence of P absorption upon P intake is linear and that endogenous P is independent of P intake.

The assumption of linearity has been confirmed in this study.

Phosphorus intake, NPHA and plasma inorganic phosphorus (Pi) concentration

The balance experiment reported in the present study was simultaneously accompanied by measurements of plasma phosphorus concentrations; a significant dependence of plasma inorganic P concentration upon P intake was found (table 3). Furthermore the ratio between the slopes of PL/DCP-phosphorus supplementation observed—0.95/1.60 = 0.593—was very close to that observed for the NPHA or NPHU ratios which were 0.609 and 0.603, respectively. This similarity in PL/DCP

TABLE 4

Nitrogen digestion and retention (g/day) in lambs fed diets containing a basal amount of phosphorus or supplemented with dicalcium phosphate (DCP) or poultry litter (PL) at two levels of P supplementation

<table>
<thead>
<tr>
<th>Treatment Source of P supplementation</th>
<th>1 Basal</th>
<th>2 DCP</th>
<th>3 +DCP</th>
<th>4 +PL</th>
<th>5 +PL</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of lambs</td>
<td>6</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>N excretion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In feces</td>
<td>12.18</td>
<td>11.84</td>
<td>11.56</td>
<td>10.60</td>
<td>10.47</td>
<td>0.39</td>
</tr>
<tr>
<td>In urine</td>
<td>11.29</td>
<td>9.37</td>
<td>8.53</td>
<td>9.56</td>
<td>9.30</td>
<td>0.31</td>
</tr>
<tr>
<td>N absorbed</td>
<td>11.22</td>
<td>10.34</td>
<td>11.79</td>
<td>10.46</td>
<td>10.47</td>
<td>0.76</td>
</tr>
<tr>
<td>N digestibility, %</td>
<td>47.9</td>
<td>46.6</td>
<td>50.4</td>
<td>49.7</td>
<td>46.8</td>
<td>1.85</td>
</tr>
<tr>
<td>N retained</td>
<td>-0.07&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.97&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.26&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.91&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.58&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.19</td>
</tr>
</tbody>
</table>

<sup>abc</sup> Means within the same line not sharing a common letter differ significantly (P < 0.05).
slope ratios to those of NPHA may point to plasma P concentrations as a possible criterion for P availability measurements. Cohen (18, 19) found no correlation between the inorganic plasma phosphorus concentration and that found in the grasses ingested by grazing calves. Other authors (20, 21) experimenting with animals kept indoors concluded that the concentration of plasma or serum inorganic phosphorus was a sensitive and reliable indicator of the amount of available phosphorus ingested. The coefficient of variation for the NPHA and NPHU in the present experiment was about 10–11% of the slope as compared to 56–69% of the slope for the dependence of plasma phosphorus concentrations upon phosphorus intake (table 3).

The regression of Pi upon P retention in the present study was:

\[ Y = 2.55X - 2 \]

\( (Sb = 0.49, r = 0.703, P < 0.01) \)

where Y and X denote Pi plasma inorganic phosphorus concentrations (mg/dl) and X phosphorus retention (g/day). The coefficient of variation was about 20% of the slope for this criterion. However, a greater number of animals or prolonged periods of adaptation to the diets or of blood sampling may be necessary to reduce the experimental error and obtain a reasonably predictable equation.

**NPHA, NPHU and nitrogen retention**

The level of phosphorus intake had no effect on the amounts of digested nitrogen. However, it affected significantly the N retention, and when the latter was related to P intake, significant dependences were found and were presented. The ratio of the dependence (or slopes) of N retained upon P intake for PL/DCP treatments was 1.60/281 = 0.569 which is very close to the corresponding ratio for NPHU, 0.603.

The coefficient of regression (slope) of nitrogen retention (NR) upon phosphorus retention (PR) was 4.25. This figure is similar to the average ratio of N/P in the carcass of growing lambs, which was found to vary from 2.0 to 2.5% N and 0.45 to 0.61% P (22).

**Availability of phosphorus of PL origin**

The phosphorus present in PL may be either of phytate or inorganic origin as excreted by the chick. Early studies of Common (23) showed that 68.1–72.8% of the ingested phytic acid was excreted by chicks. On the other hand, recent studies have shown that no phytate phosphorus could be recovered in the feces of calves (24). An earlier study of Tillman and Brethour (25) reported an apparently similar availability of 62.9 and 69.6% from Ca-phytate salt and monocalcium phosphate, respectively. Lofgreen (26), however, reported only a 33% availability of phosphorus from Ca-phytate sources, which was about 66% of the availability found for phosphorus of dicalcium phosphate in the same experiment. Ellis and Tillman (27) also reported a 25.5% availability of phosphorus from wheat bran, of which about 70% of its phosphorus content is of natural phytic acid origin (28).

The slightly higher NPHA for PL (39%) than the availability quoted for phytate phosphorus (22.5–33%) is probably due to the presence of some inorganic phosphorus in PL, in addition to phytin.

The NPHA for lambs from heat-sterilized PL found in the present work was 60% as related to NPHA from DCP. A higher percentage of phosphorus absorption and retention from air-dried poultry manure by non-lactating and lactating cows and by steers of 70% was reported by Bull and Reid (5), but was not compared to that of dicalcium phosphate. Furthermore, the experiments reported here were conducted with young lambs whereas those reported by Bull and Reid (5) were conducted with older cattle, which are known to absorb phosphorus less efficiently. The difference in efficiency in P absorption in the present study as compared to that reported by Bull and Reid (5) might have resulted from the heat sterilization of the PL used in the present study as was also suggested as a possible cause of its low N digestibility (9).
LITERATURE CITED


