Phosphorus digestibility and phytate degradation by yearlings and mature horses\(^1,2\)

A. L. Fowler, T. L. Hansen, L. A. Strasinger, B. E. Harlow, and L. M. Lawrence\(^3\)

Department of Animal and Food Sciences, University of Kentucky, Lexington 40506

**ABSTRACT:** Inorganic P is often added to growing horse diets because organic P, or phytate-P, is believed to have lower digestibility. If horses can efficiently digest organic P, then the need for inorganic P may be reduced. Much of the P in grain-based concentrates fed to growing horses is in the form of phytate-P. Little is known about the ability of growing horses to degrade phytate-P or whether horse age affects mineral digestion in horses. The objective of this study was to examine the effect of age on P, Ca, and Mg digestibility as well as phytate-P degradation. Four yearling geldings and 4 mature geldings were fed a diet of alfalfa cubes, timothy cubes, and a pelleted concentrate. The diet contained 0.28% total P and 17.4% of that P was in the phytate form. There was a 14-d diet adaptation period followed by a 4-d fecal collection period. Apparent total tract P digestibility was higher for yearlings than mature geldings (\(P = 0.036\); 7.7 and –6.6% for yearlings and mature geldings, respectively). Phytate-P disappearance was 94.8% and did not differ between ages (\(P = 0.190\)). Apparent Ca digestibility was lower in mature geldings (\(P = 0.043\)), but apparent Mg digestibility did not differ between ages (\(P = 0.414\)). Phytate is broken down in the gastrointestinal tract, but the low P digestibilities suggest that either degradation occurs after the site of P absorption or liberated P is recycled back into the gastrointestinal tract. Yearlings can utilize organic P as well as mature horses; therefore, diets without inorganic P are acceptable for growing horses.

**Key words:** equine, fecal collections, mineral, phosphorus, phytate


**INTRODUCTION**

Recent concerns have been raised about P being a water pollutant as well as being a dwindling nonrenewable resource. Inorganic P is commonly added to horse feeds to ensure adequate P intake, but this practice increases the use of this limited resource and may cause excess P excretion as well. Therefore, more attention has been placed on maximizing P utilization efficiency in the animal industry to lessen these impacts.

A large portion of the P in grains is found as phytate-P (Eeckhout and De Paepe, 1994) and is broken down by phytase, an enzyme produced by gut microflora. Phytate-P is less available to monogastric animals that lack a large microbial community to hydrolyze the phytate molecule (Pointillart, 1991). Hintz et al. (1973) found that phytate-P was half as available to horses as inorganic P and many commercial equine feeds include additional P from inorganic sources to ensure adequate available P. However, recent studies have reported phytate-P to have the same digestibility as inorganic P in horses (Hainze et al., 2004; Van Doorn et al., 2004). Furthermore, Lavin et al. (2013) measured the degradation of phytate-P in mature horses to be greater than 90%. If phytate-P is already available, inorganic P supplementation may be unnecessary in equine feeds.

Although it appears that phytate is able to be degraded by the adult horse, there have been no studies examining phytate-P digestibility in growing horses. Cymbaluk et al. (1989) suggested that young horses...
have a greater capacity to digest and absorb P than mature horses but the amount of phytate-P was not considered. Conversely, phytate-P utilization increases with increasing age in poultry (Olukosie et al., 2007). Whether or not growing horses would be able to break down and utilize phytate-P as efficiently as mature horses is unclear.

The objective of this experiment was to evaluate P digestibility and phytate degradation by yearlings and mature horses when fed a diet containing no added inorganic P. The hypotheses were that yearlings would have greater total P digestibilities than mature horses but both ages would be able to similarly degrade phytate.

**MATERIALS AND METHODS**

All procedures were approved by the Institutional Animal Care and Use Committee at the University of Kentucky.

**Animals**

Four mature geldings (1 Quarter Horse, 1 Standardbred, 1 Thoroughbred, and 1 Thoroughbred—Paint cross; 10.5 ± 7.5 yr; 535 ± 43.6 kg [mean ± SD]) and 4 yearling Thoroughbred geldings (19 ± 1 mo and 478 ± 61.1 kg [mean ± SD]) were used. Before the start of the adaptation, horses were maintained in fields containing cool-season grasses. Mature horses were fed 2 kg/d and yearlings were fed 3 kg/d of a commercially available concentrate. Horses were vaccinated for rabies (EquiRab; Intervet, Summit, NJ), eastern equine encephalitis, western equine encephalitis, tetanus, West Nile virus, equine influenza, and rhinopneumonitis (Prestage V + WNV; Intervet) in the spring preceding the experiment. All horses were vaccinated in the fall for equine influenza and rhinopneumonitis (Calvenza 03; Boehringer-Ingelheim, Ingelheim am Rhein, Germany) 3 mo before beginning the experiment. All horses were maintained on a regular deworming schedule for control of internal parasites and were maintained on a regular dental evaluation schedule. Horses were brought into the barn for a few hours each day to get them acclimated to the stalls before adaptation began.

The experiment was conducted in 2 blocks with 2 mature horses and 2 yearlings used in each block. Each block consisted of a 14-d adaptation period and a 4-d total fecal collection.

**Diets and Adaptation Period**

The goal was to feed a low-P diet that contained no added inorganic P. A large number of ingredients were screened and then a pelleted concentrate was custom formulated with selected ingredients (McCauley Bros., Versailles, KY; Table 1). In addition to the custom formulated concentrate, horses received timothy cubes (Ontario Dehy Inc., Goderich, ON, Canada) and alfalfa cubes (Wyoming Hay Cubes, Riverton, WY). Two batches of timothy cubes were used over the course of the experiment due to feed availability at the start of the study. The first block of horses received batch 1 and the second block received batch 2. The nutrient compositions of the individual diet components and of the total diet (cubes plus concentrate) are shown in Table 2. All horses received a diet consisting of 50% timothy cubes, 35% concentrate, and 15% alfalfa cubes. The total amount of feed fed to each horse provided adequate P to meet their requirement (25.1 g/d for yearlings and 15.9 g/d for mature geldings; NRC, 2007). Diets were formulated to meet or exceed the requirements for other nutrients (NRC, 2007).

During the 14-d adaptation phase, the horses were acclimated to stalls with rubber-matted floors (4.5 by 4.5 m) and to wearing fecal collection harnesses (Bun-Bag, Sagle, ID). Horses stayed in stalls during the night and were turned out in dry lots during the day. They were given ad libitum access to water in the stalls and the dry lots. Horses were fed half of their daily allotment of concentrate twice daily (0730 and 1500 h) and the total daily allotment of alfalfa and timothy hay cubes were fed in the afternoon (1500 h). Three days before the start of the collection phase, they were housed in the stalls 24 h/d. Horses were hand walked for 15 min twice daily and they were fed half of their daily ration (concentrate and cubes) every 12 h (0800 and 2000 h). Feed intake was measured daily by collecting and weighing any ors after each meal and each horse’s BW was re-

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>35</td>
</tr>
<tr>
<td>Barley</td>
<td>24</td>
</tr>
<tr>
<td>Soybean hulls</td>
<td>20</td>
</tr>
<tr>
<td>Flaxseed</td>
<td>15</td>
</tr>
<tr>
<td>Molasses</td>
<td>5.2</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>0.5</td>
</tr>
<tr>
<td>McCauley Trace Mineral Premix²</td>
<td>0.1</td>
</tr>
<tr>
<td>McCauley Vitamin Premix³</td>
<td>0.1</td>
</tr>
<tr>
<td>Pres Toxi-check⁴</td>
<td>0.1</td>
</tr>
</tbody>
</table>

¹Custom mixed at McCauley Bros., Versailles, KY.
²The trace mineral premix provided the following amounts of minerals per kilogram of concentrate: 26.25 mg of Cu, 60 mg of Mn, 0.4 mg of Se, and 75 mg of Zn.
³The vitamin premix provided the following amounts of vitamins per kilograms of concentrate: 9.750 IU of vitamin A, 1,760 IU of vitamin D₃, 234 IU of vitamin E, 0.01 mg of biotin, 40.8 mg of pantothenic acid, 1.9 mg of vitamin K, 9.7 mg of thiamine, 6.1 mg of niacin, 6.5 mg of riboflavin, 2.9 mg of folic acid, 6.8 mg of pyridoxine, and 0.03 mg of vitamin B₁₂.
⁴Mold inhibitor additive. Lucta USA, Inc., Northbrook, IL.
corded 3 times per week using a large animal platform scale (TI-500BWL; Transcell Technology, Inc., Buffalo Grove, IL).

During the 4-d collection phase, horses were managed as they had been for the previous 3 d. Two horses had minimal amounts of orts, which were weighed at the end of every 24-h period and saved for future analysis. Horses were given ad libitum access to water and consumption was measured daily. Water buckets were weighed at least every 12 h to record the weight of the water consumed as well as every time buckets were refilled. Water volume was estimated assuming that 1 kg water = 1 L water. Water samples were taken daily for P analysis.

**Fecal Collection Period**

Horses were fitted with fecal collection harnesses beginning on d 1 of the collection period and monitored closely during the 4-d period to ensure that all feces were collected in the bags. Feces were compiled for each horse and thoroughly mixed at the end of each 24-h period. A subsample, 10% of the total fecal weight per day, was collected from each horse and frozen for later analysis to measure and calculate digestibility of P, phytate-P, Ca, and Mg.

**Sample Analysis**

All feed samples, orts, and feces were dried in a 55°C forced-air oven for 24 h or until there was no further loss of weight to determine DM. Samples were then ground to pass through a 1-mm screen on a Wiley mill (Arthur H. Thomas Co., Philadelphia, PA). Duplicate ground samples of feed, orts, and feces were analyzed for phytate-P (measured as inositol hexakisphosphate) by anion exchange (Latta and Eskin, 1980). Samples of the water that was offered to the horses were sent to the Kentucky Geological Survey laboratory (Lexington, KY) to be analyzed for total P using a colorimetric method.

In preparation for mineral analysis, duplicate samples of feed, feces, and orts were ashed overnight at 600°C. Ashed samples were then boiled in 40 mL of 4 N HCl for 20 min, quantitatively transferred to a 250-mL volumetric flask, and diluted to volume with deionized water. A 25-mL aliquot of this solution was used to determine P by a gravimetric quimociac assay (Shaver, 2008). Another aliquot of this solution was used to determine Ca and Mg using atomic absorption (Bowers and Rains, 1988). Dilutions for Ca and Mg analysis were made as needed using a sodium chloride solution (1 g sodium chloride/L deionized water).

**Calculations and Statistical Analysis**

All digestibility calculations were performed using values obtained from the methods described above. In the case of orts, the analyzed amount of nutrient in the refused feed was subtracted from the total amount of nutrient offered in the diet to obtain nutrient intakes. The amount of P in the water consumed by the horses was included in the nutrient intake for P. Apparent digestibility of P, phytate-P, Ca, and Mg was calculated as \(\frac{[\text{nutrient intake} - \text{fecal nutrient}]}{\text{nutrient intake}} \times 100\%\). True digestibility of P, Ca and Mg was calculated as \(\frac{[\text{nutrient intake} - (\text{fecal nutrient} - \text{fecal nutrient endogenous loss})]}{\text{nutrient intake}} \times 100\%\). Estimates of fecal endogenous losses were obtained from the NRC (2007). Urinary P is very low (<2 mg P/kg BW) when P intake is less than 50 mg/kg BW (Schryver et al., 1971b); therefore, P absorption was estimated as P intake – fecal P.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Timothy cubes,(^1) Block 1</th>
<th>Timothy cubes,(^1) Block 2</th>
<th>Alfalfa cubes(^2)</th>
<th>Concentrate</th>
<th>Total diet,(^3) Block 1</th>
<th>Total diet,(^3) Block 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE, Mcal/kg(^4)</td>
<td>2.05</td>
<td>1.98</td>
<td>2.46</td>
<td>3.19</td>
<td>2.51</td>
<td>2.48</td>
</tr>
<tr>
<td>CP, %(^4)</td>
<td>10.50</td>
<td>10.50</td>
<td>20.20</td>
<td>12.70</td>
<td>12.70</td>
<td>12.70</td>
</tr>
<tr>
<td>NDF, %(^4)</td>
<td>63.90</td>
<td>66.10</td>
<td>37.80</td>
<td>27.10</td>
<td>47.10</td>
<td>48.20</td>
</tr>
<tr>
<td>ADF, %(^4)</td>
<td>40.70</td>
<td>42.60</td>
<td>31.60</td>
<td>21.00</td>
<td>32.40</td>
<td>33.40</td>
</tr>
<tr>
<td>Ca, %(^4)</td>
<td>0.33</td>
<td>0.54</td>
<td>2.11</td>
<td>0.38</td>
<td>0.61</td>
<td>0.72</td>
</tr>
<tr>
<td>P, %(^4)</td>
<td>0.23</td>
<td>0.20</td>
<td>0.23</td>
<td>0.37</td>
<td>0.28</td>
<td>0.26</td>
</tr>
<tr>
<td>Ca:P</td>
<td>1.43:1</td>
<td>2.70:1</td>
<td>9.17:1</td>
<td>1.03:1</td>
<td>2.18:1</td>
<td>2.77:1</td>
</tr>
<tr>
<td>Phytate-P, %(^5)</td>
<td>0.039</td>
<td>0.026</td>
<td>0.034</td>
<td>0.082</td>
<td>0.053</td>
<td>0.047</td>
</tr>
<tr>
<td>Mg, %(^4)</td>
<td>0.17</td>
<td>0.20</td>
<td>0.25</td>
<td>0.23</td>
<td>0.20</td>
<td>0.22</td>
</tr>
</tbody>
</table>

\(^{1}\)Ontario Dehy Inc., Goderich, ON, Canada.
\(^{2}\)Wyoming Hay Cubes, Riverton, WY.
\(^{3}\)Total diet consisted of 15% alfalfa cubes, 35% concentrate, and 50% timothy cubes.
\(^{4}\)Analysis performed by Dairy One, Ithaca, NY.
\(^{5}\)Analyzed using anion exchange method (Latta and Eskin, 1980).
The experimental unit was horse and the number of replicates in each age group was 4. The effect of age on total tract nutrient digestibilities was determined using ANOVA with age and block as main effects (SAS 9.2; SAS Inst. Inc., Cary, NC). Each group of 4 horses (2 mature geldings and 2 yearling geldings) that were collected at the same time was treated as a block. Results were considered significant when $P < 0.05$ and a trend was declared when $0.05 < P < 0.1$.

### RESULTS AND DISCUSSION

#### Phosphorus

Values for P intakes, fecal P, P absorbed, and apparent and true P digestibilities are shown in Table 3. Yearlings consumed 25.1 g P/d (53 mg/kg BW) compared with 15.9 g P/d (29.5 mg/kg BW) for the mature geldings ($P < 0.0001$). For 18-mo-old horses maturing to 600 kg, the NRC (2007) recommends feeding 24.7 g/d, which is very close to the amount consumed by the yearlings. The average P requirement for the mature geldings based on their initial BW is 15.8 g/d, which is also very close to the amount they consumed.

The yearlings ingested more P than the mature geldings and subsequently excreted more fecal P than the mature geldings ($P = 0.0007$). These results agree with the findings of others who have shown that fecal P excretion increases with increasing P intake in horses (Schryver et al., 1971b). Consequently, P retention is approximately equivalent to apparent absorbed P. For the yearlings, mean P retention was 4.08 mg P/kg BW. The NRC (2007) estimates that 19-mo-old horses will retain 4.16 mg P/kg BW, which is very close to the value observed here even if the small amount of P in the urine is considered. In a study with exercised yearlings consuming 38.9 to 71.1 mg P/kg BW, P retention was reported to be between 1.11 to 3.78 mg P/kg BW (Ogren et al., 2013), which is also close to the P retention in the yearlings used in this study. However, Oliveira et al. (2008) fed 12-mo-old yearlings 79.68 to 113.08 mg P/kg BW and reported P retention as 25.20 to 47.43 mg/kg BW, but the values

<table>
<thead>
<tr>
<th>Item</th>
<th>Yearling</th>
<th>Mature gelding</th>
<th>Pooled SEM</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intake, g/d</td>
<td>25.09</td>
<td>15.91</td>
<td>2.41</td>
<td>0.0030</td>
</tr>
<tr>
<td>Intake, mg/kg BW</td>
<td>52.59</td>
<td>29.49</td>
<td>2.04</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Fecal excretion, g/d</td>
<td>23.17</td>
<td>17.02</td>
<td>3.29</td>
<td>0.0440</td>
</tr>
<tr>
<td>Fecal excretion, mg/kg BW</td>
<td>48.51</td>
<td>31.37</td>
<td>3.30</td>
<td>0.00005</td>
</tr>
<tr>
<td>Apparent digestibility, %</td>
<td>7.73</td>
<td>–6.56</td>
<td>7.10</td>
<td>0.0366</td>
</tr>
<tr>
<td>True digestibility, %²</td>
<td>42.03</td>
<td>27.40</td>
<td>7.61</td>
<td>0.0418</td>
</tr>
<tr>
<td>True digestibility, %³</td>
<td>26.79</td>
<td>27.40</td>
<td>7.35</td>
<td>0.0018</td>
</tr>
<tr>
<td>Apparent absorbed, g/d⁴</td>
<td>1.92</td>
<td>–1.11</td>
<td>1.15</td>
<td>0.0143</td>
</tr>
<tr>
<td>Apparent absorbed, mg/kg BW⁴</td>
<td>4.08</td>
<td>–1.89</td>
<td>2.33</td>
<td>0.0152</td>
</tr>
</tbody>
</table>

¹$n = 4$.
²Calculated using fecal endogenous losses of 10 mg P/kg BW for mature horses and 18 mg P/kg BW for growing horses (NRC, 2007).
³Calculated using fecal endogenous losses of 10 mg P/kg BW for mature and growing horses (NRC, 1989).
⁴Absorption calculated as P intake minus fecal P excretion.
reported by Oliveira et al. (2008) are much higher than suggested by the NRC (2007) for horses of that age. Higher P retention would be expected in younger, more rapidly growing yearlings. Among these studies, it appears that P retention is affected by age and may also increase with increasing P intake in growing horses. Nonetheless, yearlings in the present study were able to retain the expected NRC (2007) amount of P when fed a diet consisting of only organic P sources.

Because mature horses are not growing and dietary P is mostly needed to replace fecal endogenous losses and minimal external losses (hair, skin, sweat, hooves, etc.), it was expected that retention would be 0 when mature horses were fed the required amount of P. Average P retention for the mature gelling in this study was –1.89 mg/kg BW and was not different from 0 (P = 0.1662), indicating that losses were as predicted by the NRC (2007). Lavin et al. (2013) reported that mature horses consuming a diet that supplied 39 to 59 mg P/kg BW, compared with 53 mg P/kg BW in this study, also had balances that were close to 0. However, Hintz et al. (1973) reported that mature ponies fed wheat bran diets containing 66 to 121 mg P/kg BW retained anywhere from 6 to 24 mg P/kg BW. Because these ponies were fed a relatively low-forage diet (around 40–50% forage) while being confined in metabolism crates, it is possible that the ponies were gaining weight during the study and P deposited in the new tissue accounted for the higher retention.

Phytate Disappearance

Because availability of phytate-P is believed to be less than inorganic P sources, it was of interest to explore phytate-P breakdown in these yearlings and mature horses. Values for phytate-P intakes, fecal phytate-P, and phytate-P disappearances are shown in Table 4. Phytate-P disappearance was calculated as the amount of phytate-P that was consumed versus the amount of phytate-P that was excreted in the feces. Phytate-P disappearance was not affected by age (P > 0.10) and averaged 94.8% across both age groups. Lavin et al. (2013) also reported that phytate disappearance was 94% in mature horses ingesting an average of 10 mg phytate-P/kg BW. The data shown here suggest that horses can degrade almost all of the phytate supplied in the diet. In cattle, ruminal microbes efficiently hydrolyze phytate-P before absorption occurs in the small intestine and total tract phytate disappearance has been reported as high as 94 to 99% (Clark et al., 1986; Morse et al., 1992). Similarly, only trace amounts of phytate-P have been detected in the manure of pigs fed a diet that contained half of its total P bound to phytate (Leytem et al., 2004). Pigs do not utilize phytate-P as effectively as inorganic P, even though their hindgut microbial communities have the ability to break down phytate, because breakdown occurs past the point of P absorption. It appears that cattle, pigs, and horses have a high capacity to break down phytate across the entire gastrointestinal tract but differ in their ability to absorb the liberated P.

As described above, most of phytate-P is broken down in the gastrointestinal tract of the horse; however, the fate of the liberated P is unclear. The majority of phytate-P breakdown in horses is attributed to microbial phytase activity in the hindgut and the main site of P absorption in the horse is in the large colon, but some P absorption also occurs in the lower small intestine (Schryver et al., 1972). Because phytate-P breakdown and P absorption occur in the same segment of the gastrointestinal tract, it may be possible that the liberated P is not efficiently absorbed. Therefore, whereas phytate-P may be hydrolyzed in the gastrointestinal tract, most of the liberated P could be excreted in the manure. The inability of the liberated phytate-P to be absorbed may also explain the low P digestibilities seen in the current study. Alternatively, the horses could have absorbed the liberated P and recycled it back into the gut to be excreted in the feces (Schryver et al., 1972), which would also explain the low P digestibility.

Yearlings and mature horses both liberated the same percentage of phytate-P but yearlings had higher apparent and true P digestibility. One explanation for higher apparent P digestion by younger horses is that the younger horses retain more P for growth and bone development whereas the mature gatings are secreting the absorbed but unneeded P back into their gastrointestinal tracts to be excreted. Schryver et al. (1972) found that P is secreted into the upper small intestine and the cecum and absorbed in the lower small intestine and the lower large colon. Because urinary P excretion is low in horses, it seems that horses secrete excess P back into their gastrointestinal tract when P intake exceeds the P requirement. The digestibilities of P may appear low in mature horses due to low P requirements and increased P recycling. Greater P retention in growing horses may lead to less recycling and greater P digestibility.

An explanation for the difference in true digestibility between the age groups could be related to the endoge-
The presence of phytate in the diet has been known to influence the digestibility of Ca and Mg. Values for Ca intakes, fecal Ca, apparent Ca absorbed, and apparent and true Ca digestibilities are shown in Table 5. Yearlings ingested 128.31 mg Ca/kg BW and the mature geldings ingested 71.72 mg Ca/kg BW (P < 0.0001), which was sufficient to meet the Ca requirements of both age groups of horses.

The yearlings had greater fecal Ca than mature geldings (P = 0.0011). Increasing Ca intake increases fecal Ca excretion as well as Ca absorption (Schryver et al., 1970). In the current study, the apparent amount of Ca absorbed from the gastrointestinal tract was calculated as Ca intake minus fecal Ca excretion. Because urine is an important route of excretion for Ca and Mg, the retention of these minerals could not be calculated, as urine was not collected. Apparent Ca absorption was 65.28 and 30.43 mg Ca/kg BW for yearlings and mature geldings, respectively (P = 0.0002). The greater Ca absorption for the yearlings shows that either the increased Ca intake or a greater need for Ca due to growth caused an increase in absorption. Cymbaluk et al. (1989) reported that yearlings absorbed 79.6 mg Ca/kg BW when fed 208 mg Ca/kg BW, which is comparable to what was observed in the current experiment. Buchholz-Bryant et al. (2001) reported that 2- and 3-yr-old horses absorbed 46.8 mg Ca/kg BW when fed 142.5 mg Ca/kg BW and mature horses absorbed 26.9 mg/kg BW when fed 65.0 mg/kg BW. The values for the mature horses are similar, but the yearlings in the current study absorbed slightly higher amounts of Ca (by 18.48 mg/kg BW) than the 2 and 3 yr olds being fed similar amounts of Ca (Buchholz-Bryant et al., 2001), possibly because they were younger.

Average apparent Ca digestibility was 50.71% by the yearlings and 42.59% by the mature geldings (P = 0.0432). True Ca digestibility was calculated using endogenous losses of 20 mg Ca/kg BW for mature horses and 36 mg Ca/kg BW for growing horses (NRC, 2007). Calculated true Ca digestibility was 78.85 and 70.64% by yearlings and mature geldings, respectively (P = 0.0617). Pagan (1994) reported that the average apparent Ca digestibility by mature horses was 44.4% and true Ca digestibility was around 75%, which are very similar to the values seen in this study. For 17-mo-old horses, Cymbaluk et al. (1989) reported that the average true Ca digestibility was 50.9%, which is much lower than the true digestibility by yearlings observed in the current study (78.7%). The NRC (2007) estimates true Ca digestibility at 50% for all ages of horses but mentions that younger horses may be closer to 70%, which more closely estimated the true Ca digestibility calculated in the current study. Because Ca digestibility can be influenced by many variables and determining a digestibility value to be applied to all groups of horses may be impossible, a conservative digestibility value was used by the NRC (2007) to calculate requirements to avoid Ca deficiencies.

There are many factors that can influence Ca digestibility in horses. High amounts of P and phytate-P have been shown to decrease Ca digestibility. Phytate forms an insoluble complex with Ca that renders Ca unavailable for absorption in the gastrointestinal tract (Taylor, 1965). Apparent Ca digestibility in mature horses decreased from 42.4 to 26.4% when fed 1 and 55% of the total P as phytate-P, respectively (Van Doorn et al.,

### Table 5. Mean intake, fecal excretion, apparent total tract digestibility, true digestibility, and apparent absorbed amount of calcium for yearlings and mature geldings

<table>
<thead>
<tr>
<th>Item</th>
<th>Yearling1</th>
<th>Mature gelding1</th>
<th>Pooled</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intake, g/d</td>
<td>60.99</td>
<td>38.87</td>
<td>5.04</td>
<td></td>
<td>0.0016</td>
</tr>
<tr>
<td>Intake, mg/kg BW</td>
<td>128.31</td>
<td>71.72</td>
<td>4.01</td>
<td></td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Fecal excretion, g/d</td>
<td>30.09</td>
<td>22.42</td>
<td>4.41</td>
<td></td>
<td>0.0574</td>
</tr>
<tr>
<td>Fecal excretion, mg/kg BW</td>
<td>63.03</td>
<td>41.28</td>
<td>4.62</td>
<td></td>
<td>0.0011</td>
</tr>
<tr>
<td>Apparent digestibility, %</td>
<td>50.71</td>
<td>42.59</td>
<td>4.26</td>
<td></td>
<td>0.0432</td>
</tr>
<tr>
<td>True digestibility, %</td>
<td>78.85</td>
<td>70.64</td>
<td>4.85</td>
<td></td>
<td>0.0617</td>
</tr>
<tr>
<td>Apparent absorbed, g/d</td>
<td>30.91</td>
<td>16.46</td>
<td>2.09</td>
<td></td>
<td>0.0002</td>
</tr>
<tr>
<td>Apparent absorbed, mg/kg BW3</td>
<td>65.28</td>
<td>30.43</td>
<td>5.19</td>
<td></td>
<td>0.0002</td>
</tr>
</tbody>
</table>

1n = 4.
2Calculated using fecal endogenous losses of 20 mg Ca/kg BW for mature horses and 36 mg Ca/kg BW for growing horses (NRC, 2007)
3Absorption calculated as Ca intake minus fecal Ca excretion

endogenous losses used to calculate true digestibility. Estimates of true digestibility for common feeds are used to calculate daily P requirements (NRC, 2007). Consequently, under- or overestimating true digestibility could lead to excessive or deficient P intakes by horses, respectively. True digestibility is calculated from apparent digestibility adjusted for endogenous losses. An estimated endogenous P loss of 10 mg/kg BW is used for mature horses and 18 mg/kg BW is used for growing horses (NRC, 2007). However, recent research has suggested that the endogenous fecal losses of growing horses may not be greater than mature horses. Ogren et al. (2013) suggested that fecal endogenous P losses were 10 mg/kg BW for yearlings in training and Oliveira et al. (2008) reported that rapidly growing yearlings had fecal endogenous P losses of 8.42 mg/kg BW. If the endogenous fecal P loss of 10 mg/kg BW is used to calculate true digestibility by the yearlings in the current study, the true P digestibility decreases from 42.03 to 26.79%, which is very different than the true P digestibility calculated for mature horses (Table 3). More research on the actual fecal endogenous losses of growing horses is necessary to calculate accurate true digestibilities.

**Calcium Digestibility**

The presence of phytate in the diet has been known to influence the digestibility of Ca and Mg. Values for Ca intakes, fecal Ca, apparent Ca absorbed, and apparent and true Ca digestibilities are shown in Table 5. Yearlings ingested 128.31 mg Ca/kg BW and the mature geldings ingested 71.72 mg Ca/kg BW (P < 0.0001), which was sufficient to meet the Ca requirements of both age groups of horses.

The yearlings had greater fecal Ca than mature geldings (P = 0.0011). Increasing Ca intake increases fecal Ca excretion as well as Ca absorption (Schryver et al., 1970). In the current study, the apparent amount of Ca absorbed from the gastrointestinal tract was calculated as Ca intake minus fecal Ca excretion. Because urine is an important route of excretion for Ca and Mg, the retention of these minerals could not be calculated, as urine was not collected. Apparent Ca absorption was 65.28 and 30.43 mg Ca/kg BW for yearlings and mature geldings, respectively (P = 0.0002). The greater Ca absorption for the yearlings shows that either the increased Ca intake or a greater need for Ca due to growth caused an increase in absorption. Cymbaluk et al. (1989) reported that yearlings absorbed 79.6 mg Ca/kg BW when fed 208 mg Ca/kg BW, which is comparable to what was observed in the current experiment. Buchholz-Bryant et al. (2001) reported that 2- and 3-yr-old horses absorbed 46.8 mg Ca/kg BW when fed 142.5 mg Ca/kg BW and mature horses absorbed 26.9 mg/kg BW when fed 65.0 mg/kg BW. The values for the mature horses are similar, but the yearlings in the current study absorbed slightly higher amounts of Ca (by 18.48 mg/kg BW) than the 2 and 3 yr olds being fed similar amounts of Ca (Buchholz-Bryant et al., 2001), possibly because they were younger.

Average apparent Ca digestibility was 50.71% by the yearlings and 42.59% by the mature geldings (P = 0.0432). True Ca digestibility was calculated using endogenous losses of 20 mg Ca/kg BW for mature horses and 36 mg Ca/kg BW for growing horses (NRC, 2007). Calculated true Ca digestibility was 78.85 and 70.64% by yearlings and mature geldings, respectively (P = 0.0617). Pagan (1994) reported that the average apparent Ca digestibility by mature horses was 44.4% and true Ca digestibility was around 75%, which are very similar to the values seen in this study. For 17-mo-old horses, Cymbaluk et al. (1989) reported that the average true Ca digestibility was 50.9%, which is much lower than the true digestibility by yearlings observed in the current study (78.7%). The NRC (2007) estimates true Ca digestibility at 50% for all ages of horses but mentions that younger horses may be closer to 70%, which more closely estimated the true Ca digestibility calculated in the current study. Because Ca digestibility can be influenced by many variables and determining a digestibility value to be applied to all groups of horses may be impossible, a conservative digestibility value was used by the NRC (2007) to calculate requirements to avoid Ca deficiencies.

There are many factors that can influence Ca digestibility in horses. High amounts of P and phytate-P have been shown to decrease Ca digestibility. Phytate forms an insoluble complex with Ca that renders Ca unavailable for absorption in the gastrointestinal tract (Taylor, 1965). Apparent Ca digestibility in mature horses decreased from 42.4 to 26.4% when fed 1 and 55% of the total P as phytate-P, respectively (Van Doorn et al.,
Apparent Mg digestibility by mature horses was similar to the Ca digestibility observed for horses consuming the low-phytate diet in the study performed by Van Doorn et al. (2004), suggesting that the level of dietary phytate used here (17.4% of total P as phytate-P) did not greatly influence Ca digestibility. Schryver et al. (1971a) reported that decreasing the Ca:P ratio from 2:1 to 0.29:1 decreased absorption of Ca from 7 to 3.7 g/100 kg, respectively. In the current study, the Ca:P ratio was between 2:1 and 3:1 to minimize the effect of Ca:P ratio on either Ca or P digestibility. These ratios are greater than the ones fed by Schryver et al. (1971a) and are unlikely to hinder Ca digestibility.

**Magnesium Digestibility**

Values for Mg intakes, fecal Mg, apparent Mg absorbed, and apparent and true Mg digestibilities are shown in Table 6. The yearlings consumed 43.12 mg Mg/kg BW and the mature geldings consumed 24.29 mg Mg/kg BW (P = 0.0024), which was sufficient to meet the requirements for both yearlings and mature horses.

Yearlings excreted more fecal Mg than the mature geldings (P = 0.0038). However, even though fecal Mg excretion was higher for the yearlings, the younger horses apparently absorbed more than the mature horses (Table 6; P = 0.0094).

There was no difference in apparent or true Mg digestibility between the 2 age groups (P > 0.10). The mean apparent Mg digestibility across both age groups was 39.8%. Mean true Mg digestibility was estimated at 59.2% by both age groups. Van Doorn et al. (2004) reported that the apparent Mg digestibility by mature horses was 41% when fed a low-P diet, which is very close to the average value determined for the horses in the current study. Pagan (1994) also reported average apparent Mg digestibility to be around 37% and true Mg digestibility to be 52% for mature horses, which are slightly lower than the values seen in the current study. The NRC (2007) used a true digestibility value of 40% to calculate Mg requirements for all classes of horses, which is much lower than the values calculated in this study and found in the literature. Using a low true digestibility value could result in overestimated Mg requirements but ensures that requirements for absorbable Mg would be met in most situations.

**Conclusions**

Overall, this study indicates that yearlings have a greater ability to digest P than mature geldings but that both ages can liberate almost all of the phytate-P in the diet. If P requirements can be met with organic P, adding inorganic P to diets may not be necessary. Phosphorus requirements could possibly be reduced to eliminate recycling of P into the gastrointestinal tract and subsequently reduce the excretion of P into the environment. Additional research is warranted to confirm P recycling into the gastrointestinal tract and determine influencing factors.

**LITERATURE CITED**


