Effects of added chelated trace minerals, organic selenium, yeast culture, direct-fed microbials, and Yucca schidigera extract in horses: II. Nutrient excretion and potential environmental impact

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ABSTRACT: The objective of this study was to test the hypothesis that an equine diet formulated with chelated trace minerals, organic selenium, yeast culture, direct-fed microbials (DFM) and Yucca schidigera extract would decrease excretion of nutrients that have potential for environmental impact. Horses were acclimated to 100% pelleted diets formulated with (ADD) and without (CTRL) the aforementioned additives. Chelated sources of Cu, Zn, Mn, and Co were included in the ADD diet at a 100% replacement rate of sulfate forms used in the CTRL diet. Additionally, the ADD diet included organic selenium yeast, DFM, and Yucca schidigera extract. Ten horses were fed the 2 experimental diets during two 42-d periods in a crossover design. Total fecal and urine collection occurred during the last 14 d of each period. Results indicate no significant differences between Cu, Zn, Mn, and Co concentrations excreted via urine ($P > 0.05$) due to dietary treatment. There was no difference between fecal Cu and Mn concentrations ($P > 0.05$) based on diet consumed. Mean fecal Zn and Co concentrations excreted by horses consuming ADD were greater than CTRL ($P < 0.003$). Differences due to diet were found for selenium fecal ($P < 0.0001$) and urine ($P < 0.0001$) excretions, with decreased concentrations found for horses consuming organic selenium yeast (ADD). In contrast, fecal K (%) was greater ($P = 0.0421$) for horses consuming ADD, whereas concentrations of fecal solids, total N, ammonia N, P, total ammonia, and fecal output did not differ between dietary treatments ($P > 0.05$). In feces stockpiled to simulate a crude composting method, no differences ($P > 0.05$) due to diet were detected for particle size, temperature, moisture, OM, total N, P, phosphate, K, moisture, potash, or ammonia N ($P > 0.05$). Although no difference ($P = 0.2737$) in feces stockpile temperature due to diet was found, temperature differences over time were documented ($P < 0.0001$). In conclusion, the addition of certain chelated mineral sources, organic Se yeast, DFM, and Yucca schidigera extract did not decrease most nutrient concentrations excreted. Horses consuming organic selenium as part of the additive diet had lower fecal and urine Se concentrations, as well as greater fecal K concentrations.

Key words: environment, equine, feed additives, nutrient excretion

INTRODUCTION

Environmental concerns from agriculture waste have focused on N and P outputs from dairy, swine, poultry, and cattle concentrated animal feeding operations with solutions to contamination under intense study (Knowlton and Cobb, 2006). Concentrations of Cu and Zn in swine manure are also a concern (Jongbloed and Lenis, 1992), with the potential for metal levels to exceed land application regulations (Foulkes et al., 2006). Therefore, nutrient and sediment accumulation as well as diminished water quality have resulted in environmental regulation across all animal agriculture species, including horses (Swinker, 2011). A limited amount of research is available regarding equine runoff, but a small study demonstrated that sur-
face runoff from horse paddocks posed environmental risk (Airaksinen et al., 2007). Therefore, it is imperative the equine industry be proactive in research regarding impacts of animal waste.

Chelated minerals, direct-fed microbial (DFM), and *Yucca schidigera* extract used individually or in combination as part of swine, poultry, or dairy diets may improve production and decrease nutrient excretion (Higginbotham and Bath, 1993; Wallace et al., 1994; Bao et al., 2007; Burkett et al., 2009). The efficacy of these additives in horses has not been clearly shown, and equine-specific research is limited (Glade, 1992; Wagner et al., 2005; NRC, 2007; Swyers et al., 2008). Hence, research from other livestock species can serve as guidelines for research design and comparative conclusions (Petersen, 2009). Advanced nutritional technologies can potentially reduce nutrient excretion (Warren, 2006); therefore, research is needed to define practices that alter nutrient digestibility and environmental impact. The objective of this study was to test the hypothesis that an equine diet formulated with chelated trace minerals, organic selenium, yeast culture, DFM, and *Yucca schidigera* extract will decrease nutrient excretion and reduce the potential environmental impact of equine waste.

**MATERIALS AND METHODS**

Use of the animals indicated in this study was reviewed and approved by the California Polytechnic State University Institutional Animal Care and Use Committee (protocol 807).

**Animals and Housing**

Ten American Quarter Horse (*Equus caballus*) geldings (4.5 to 16 yr of age; mean BW 522 ± 46 kg) were included in this study. Individual BW was monitored using a digital load bar scale (Tru-Test MP800, Tru Test Inc., Mineral Wells, TX; readability 0.5 kg) during study transition, acclimation, and collection periods. Equine body condition was also assessed at the same interval by 3 trained observers as described by Henneke et al. (1983) to monitor general health (data not shown).

Throughout this study, subjects were individually housed to allow measurement of feed intake and fecal and urinary output. Horses were housed outdoors in enclosures consisting of both a partially enclosed, covered stall (3.66 × 3.66 m) and an attached open pen (3.66 × 7.32 m). Facilities allowed each animal visual, olfactory, auditory, and limited tactile contact with others within treatment group. Empty animal spaces were maintained between treatment groups to prevent cross contamination. Each stall contained a float-style drinker, which allowed ad libitum access to potable water; a plastic-coated wire hold-

er, which provided ad libitum access to iodized salt bricks; and a 265-L stock tank (Rubbermaid 4244, Rubbermaid Commercial Products, LLC. Winchester, VA) for feeding. Stall floors were covered with rubber mats, and the open pen substrate was compacted decomposed granite. No bedding was used in animal enclosures.

All study animals were acclimated to equine hygiene harnesses (Equisan Marketing, Pty., Ltd., South Melbourne, Victoria, Australia) before the study to facilitate total collection of uncontaminated feces and urine. Equine hygiene harnesses were designated to an individual animal within diet treatment during the first phase of the study. During the second phase, harnesses were assigned to another horse but remained with diet treatment to prevent potential cross contamination.

Basal ingredients of the 2 nutritionally complete, pelleted feeds (CTRL = without additives, ADD = with additives) were formulated to a minimum 11% CP, 4% crude fat, 23% crude fiber, and 47% NDF (as-fed basis), with treatments differing in added mineral sources, yeast culture, DFM, and the addition of *Yucca schidigera* extract (Table 1). Consistent with feed industry practice, trace minerals (Cu, Mn, Zn, Co, Se) were included to meet or exceed the nutrient requirements of adult horses at maintenance (NRC, 2007). The CTRL diet was formulated with added amounts of sulfated Cu, Mn, Zn, and Co, whereas the ADD diet was formulated with AA complexes of the same trace minerals. The CTRL diet contained sodium selenite as the selenium source, and the ADD diet contained selenium yeast. The DFM quantity added was determined via 2 pilot studies conducted at Purina Animal Nutrition Center (Gray Summit, MO). The final DFM inclusion rate was formulated to meet or exceed intake quantities efficacious in other species (Davis et al., 2008). *Yucca schidigera* extract was included to deliver a minimum of 750 mg per horse per day based on manufacturer recommendations. The pelleted ADD and CTRL feeds used in the study were manufactured in 2 batches, with 7 samples of feed taken across the 2 batches for nutritional and statistical analysis (Table 1).

**Experimental Design and Sample Collection**

A randomized, crossover design was used with each of the 2 diets fed at 100% of the daily intake of the animal. Diet treatments were randomly assigned to 1 of 2 groups each of 5 stalls, so that animals on like treatments were adjacent housed. Horses were randomly assigned to 1 of 2 initial diet treatments. Once assigned to a treatment, animals were randomly assigned locations within the stall-treatment group. Total daily diet quantities were offered at 2.0% BW, with amounts adjusted weekly on the basis of BW data.
Table 1. Select composition of nutritionally complete pelleted diets with (ADD) and without additives (CTRL), DM basis

<table>
<thead>
<tr>
<th>Feed</th>
<th>Amount, mg/kg</th>
<th>Feed</th>
<th>Amount, mg/kg</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu1</td>
<td>37.3 ± 2.63</td>
<td>Cu</td>
<td>43.2 ± 2.63</td>
<td>0.3587</td>
</tr>
<tr>
<td>Zn2</td>
<td>167.3 ± 17.8</td>
<td>Zn</td>
<td>125.2 ± 17.9</td>
<td>0.2438</td>
</tr>
<tr>
<td>Mn3</td>
<td>106.1 ± 5.77</td>
<td>Mn</td>
<td>107.6 ± 5.77</td>
<td>0.8789</td>
</tr>
<tr>
<td>Co4</td>
<td>6.2 ± 0.33</td>
<td>Co</td>
<td>5.3 ± 0.33</td>
<td>0.3059</td>
</tr>
<tr>
<td>Se5</td>
<td>1.4 ± 1.0</td>
<td>Se</td>
<td>2.1 ± 1.0</td>
<td>0.4411</td>
</tr>
<tr>
<td>K</td>
<td>11,971 ± 870.0</td>
<td>K</td>
<td>11125 ± 870.0</td>
<td>0.1432</td>
</tr>
<tr>
<td>Yeast culture6</td>
<td>2200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bacillus5</td>
<td>500</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DFM7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yucca schidigera extract8</td>
<td>1325</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Wheat middlings, alfalfa meal, ground rice hulls, ground beet pulp, molasses, soybean oil, ground corn, calcium carbonate, calcium lignin sulfonate, sodium chloride, calcium propionate, vitamin E, L-lysine, vitamin D, vitamin A, and vitamin B12.
2 There was no added yeast culture, direct-fed microbials (DFM), or yucca extract in the CTRL feed. Added Cu, Zn, Mn, and Co sources were sulfate form, and added Se source was sodium selenite.
3 There were no differences in analyzed mineral concentration between diets as indicated in the P-value column. Mineral amounts (mean ± SE, DM basis, 7 samples from 2 batches of feed) were analyzed by Animal Health Diagnostics Laboratory, Michigan State University, East Lansing, MI.
4 5-plex (Zinpro Corporation, Eden Prairie, MN) formulated to provide >100% of required minerals based on NRC (2007).
5 Sel-Plex (Alltech, Nicholasville, KY), formulated to provide >100% of required minerals based on NRC (2007).
6 XPC Yeast Culture (Diamond V, Cedar Rapids, IA), formulated at 0.22% to provide a minimum of 10 g·horse⁻¹·d⁻¹ when ADD feed was fed at a 4.54 kg·animal⁻¹·d⁻¹ feeding rate.
7 MicroSource (DuPont, Waukesha, WI), formulated at 0.15% to provide a minimum of 1 × 10⁹ cfu·head⁻¹·d⁻¹ with a 4.54 kg·animal⁻¹·d⁻¹ feeding rate.
8 MicroAid (DPI Global, Porterville, CA) state, formulated at 0.1325% to provide 750 mg·animal⁻¹·d⁻¹.

Transition of animals from the previous feeding regimen to experimental diets and the collection time periods are outlined in Table 2. During the 14-d collection period, the amounts fed were defined by the individual levels of intake established during the acclimation period. Feed offered andorts remaining were weighed and documented twice daily (0700 and 1800 h) during all the periods to quantify DMI.

During the collection periods, total fecal and urine mass was quantified twice daily (0600 and 1800 h). An additional 500-g composite sample, 250 g feces and 250 g urine, by weight, was created from samples collected on d 1, 8, and 15 and was stored in screw top jars and refrigerated (7.2°C) for shipping. This composite sample was analyzed for total ammonia with the 50:50 ratio recommended by the laboratory performing the assay. Urine samples for trace mineral analyses were collected directly into a 50-mL polypropylene tube on urination rather than from sample excreted into the hygiene harness on d 15.

Fecal and composite sample measurements of DM, total N, ammonia N, P, K, and total ammonia were performed by A&L Great Lakes Laboratories (Fort Wayne, IN) using methods outlined by Peters (2003). Fecal and urine samples were submitted to Michigan State University Diagnostic Center for Population and Animal Health (Lansing, MI) for mineral analyses using a modified inductively coupled plasma mass spectrometry (ICP-MS) method as described by Wahlen et al. (2005).

Three 364-L containers per treatment were used to stockpile feces generated from each diet. A weighed, composite fecal sample from the morning collection that represented an equal amount of feces from each animal (2 kg) was added to each container daily. Starting on collection d 1, temperature and moisture were recorded every 10 min for 21 d using independent sensors (HOBO S-TMB-M006, S-SMA-M005, Onset Computer Corporation, Cape Cod, MA) placed at equal distance in each container connected to an automated data logger (HOBO H21–001, Onset Computer Corporation, Cape Cod, MA). Temperature and moisture logging started when the first samples were added to the bins (d 1) and continued for 7 d after the addition of the last sample (d 14) until the core samples were collected (d 21). This sample was a single core representing the vertical profile of stockpiled feces from each container and mixed homogenously before analysis.

Stockpiled feces were measured for percent moisture, total N, ammonia N, P, phosphate, K, potassium, and OM on the basis of the methods outlined by Thompson (2001). Stockpiled manure particle size was measured via a modified Penn State shaker box method (Kononoff et al., 2003).

Additional fecal samples were collected on d 28 and 49 of the 49-d washout period (Table 2) to quantify Bacillus spores in the ADD diet to assess any carryover effect from the first phase of the crossover design. All colonies with morphologies similar to Microsource
Bacillus colonies were determined to be below the mean background level of native spore formers, which was determined to be $2.51 \times 10^5$ cfu/g on the basis of multiple pilot studies in horses.

**Statistical Analysis**

A crossover design with sampling was used to test feces and urine measurement parameters, and a crossover with repeated measures was used for the stockpiled feces temperature parameter. Analysis of variance was done with mixed models (SAS Inst. Inc., Cary, NC) and least squares means compared with Fisher’s LSD ($P < 0.05$). Data are presented as mean ± SE.

**RESULTS**

There was no difference in mean daily fresh fecal output for ADD and CTRL diets ($P = 0.5644$). Further, no significant differences between concentrations of most minerals in urine (Table 3) or feces (Table 4) excreted by horses consuming either the ADD or CTRL diet were detected ($P > 0.05$). Significant differences ($P < 0.003$) were documented between the ADD and CTRL diets for mean fecal Zn and Co (Table 4). Likewise, differences ($P < 0.0001$) for mean fecal and urinary selenium excretions were found for horses assigned to the ADD and CTRL diets (Fig. 1).

There were no treatment differences in fecal variables relevant to the environmental impact of equine waste (Table 5). The mean MicroSource spore (MSS) numeration was found to be significantly different ($P = 0.0343$) between the ADD and CTRL diets (Fig. 2), whereas the mean total spore (TS) numeration showed no difference ($P = 0.1177$). Fecal K (%) was shown to be different ($P = 0.0421$) in horses consuming the ADD vs. CTRL diet (Fig. 3).

Feces stockpile measurements were not significantly different between any characteristics in ADD and CTRL (Table 6). Although no difference ($P = 0.2737$) of feces stockpile temperature due to diet was found, a significant difference of feces stockpile temperature due to time was documented ($P < 0.0001$; Fig. 4).

### Table 3. Urinary mineral excretion (μg/mL, as excreted) of 2 nutritionally complete, pelleted diets with (ADD) and without additives (CTRL) by American Quarter Horse geldings

<table>
<thead>
<tr>
<th>Mineral</th>
<th>ADD</th>
<th>CTRL</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>0.03 ± 0.01</td>
<td>0.03 ± 0.01</td>
<td>0.6990</td>
</tr>
<tr>
<td>Zn</td>
<td>0.08 ± 0.01</td>
<td>0.09 ± 0.01</td>
<td>0.2169</td>
</tr>
<tr>
<td>Mn</td>
<td>41.51 ± 8.12</td>
<td>26.96 ± 8.03</td>
<td>0.2007</td>
</tr>
<tr>
<td>Co</td>
<td>97.36 ± 6.89</td>
<td>93.51 ± 6.88</td>
<td>0.3738</td>
</tr>
</tbody>
</table>

### Table 4. Fecal mineral excretion (μg/g, DM basis) of 2 nutritionally complete, pelleted diets with (ADD) and without additives (CTRL) by American Quarter Horse geldings

<table>
<thead>
<tr>
<th>Mineral</th>
<th>ADD</th>
<th>CTRL</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>68.30 ± 2.67</td>
<td>69.82 ± 2.65</td>
<td>0.5057</td>
</tr>
<tr>
<td>Zn</td>
<td>338.5 ± 75.3</td>
<td>259.8 ± 75.3</td>
<td>0.0021</td>
</tr>
<tr>
<td>Mn</td>
<td>271.46 ± 20.8</td>
<td>267.18 ± 20.8</td>
<td>0.6127</td>
</tr>
<tr>
<td>Co</td>
<td>11.59 ± 0.70</td>
<td>10.23 ± 0.70</td>
<td>0.0027</td>
</tr>
</tbody>
</table>

Figure 1. Mean (±SE) fecal (DM basis) and urinary (as excreted) Se for 2 nutritionally complete, pelleted diets with (ADD) and without additives (CTRL) by American Quarter Horse geldings. Significant differences ($P < 0.0001$) are denoted by differing superscripts.
DISCUSSION

Data collected in this study were used to evaluate the effects of including chelated trace minerals, organic selenium, yeast culture, DFM, and *Yucca schidigera* extract in equine diets on nutrient excretion and potential environmental impact of equine waste. Research has demonstrated mixed results on the benefit of certain dietary supplements related to equine digestibility and performance (Pagan et al., 1999; Booth et al., 2001; Ott and Johnson, 2001; Markey and Kline, 2006; NRC, 2007). However, no study has reported data related to the effects of these additives on nutrient excretion or manure characteristics associated with environmental impact. Research conducted with other livestock species has shown improvements in the reduction of nutrient excretion and modification of manure characteristics to reduce the environmental impacts of waste and still maintain and in some cases improve production and animal performance (Johnston et al., 1981; Headon and Dawson, 1990; Petersen, 2009; Walraven et al., 2009b).

The results of this study indicated no differences in urinary mineral concentration for Cu, Zn, Mn, or Co. There were also no differences in fecal mineral concentration for Cu and Mn. However, fecal Zn and Co concentrations were greater in horses consuming ADD vs. CTRL. This may be explained by the numerically greater Zn and Co concentrations found in the ADD diet, despite the lack of a statistical difference between the diets. Additionally, it could be attributed in part to endogenous mineral excretion to maintain homeostasis (Naile et al., 2005). Work by Naile (2003) also indicated that mineral excretions in feces and urine were overall similar between organic and

Table 6. Characteristics of stockpiled feces produced by American Quarter Horse geldings fed 1 of 2 nutritionally complete, pelleted diets with (ADD) and without additives (CTRL)  

<table>
<thead>
<tr>
<th>Item</th>
<th>ADD</th>
<th>CTRL</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base feces, %</td>
<td>29.45 ± 5.81</td>
<td>35.48 ± 5.81</td>
<td>0.2258</td>
</tr>
<tr>
<td>3-mm feces, %</td>
<td>53.63 ± 9.03</td>
<td>46.97 ± 9.03</td>
<td>0.1649</td>
</tr>
<tr>
<td>9-mm feces, %</td>
<td>14.88 ± 3.48</td>
<td>11.17 ± 3.48</td>
<td>0.4794</td>
</tr>
<tr>
<td>Temperature, °C</td>
<td>16.10 ± 0.83</td>
<td>17.85 ± 0.83</td>
<td>0.2737</td>
</tr>
<tr>
<td>Total N, % DM</td>
<td>1.42 ± 0.04</td>
<td>1.44 ± 0.04</td>
<td>0.6837</td>
</tr>
<tr>
<td>P, % DM</td>
<td>0.99 ± 0.03</td>
<td>0.99 ± 0.03</td>
<td>1.0000</td>
</tr>
<tr>
<td>Phosphate, % DM</td>
<td>2.28 ± 0.07</td>
<td>2.28 ± 0.07</td>
<td>0.9896</td>
</tr>
<tr>
<td>K, % DM</td>
<td>0.80 ± 0.06</td>
<td>0.76 ± 0.06</td>
<td>0.6145</td>
</tr>
<tr>
<td>Moisture, %</td>
<td>66.49 ± 0.85</td>
<td>65.46 ± 0.85</td>
<td>0.5474</td>
</tr>
<tr>
<td>Potash, % DM</td>
<td>0.96 ± 0.07</td>
<td>0.91 ± 0.06</td>
<td>0.6101</td>
</tr>
<tr>
<td>OM, % DM at 550°C</td>
<td>78.98 ± 1.0</td>
<td>80.37 ± 1.0</td>
<td>0.5076</td>
</tr>
<tr>
<td>Ammonia N, mg/kg DM</td>
<td>411.50 ± 104.80</td>
<td>378.00 ± 104.80</td>
<td>0.8053</td>
</tr>
</tbody>
</table>

1Total ammonia is from urine/fecal composite sample, with total amount of ammonia volatilized over 72 h.
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Although there was a statistically significant increase in fecal and urine excretion in the CTRL group, this may be due to a greater Se concentration in the CTRL feed and not because of the selenium yeast inclusion in the ADD feed. There was a substantial numerical difference in Se between the 2 test diets with only 2 batches of feed manufactured for the study. This variability of Se content may influence excretion, but the small number of feed batches does not allow this difference to be detected statistically when analyzing dietary content. Further, it is clear that more research is required to completely elucidate the exact selenium requirement of horses. The benefit or detriment of increased selenium retention should be better defined for horses, considering the narrow margin of safety and highly variable distribution in soil and plants in different geographic regions.

Through the course of this study, specific fecal variables that have the greatest potential to impact the environment were monitored for differences between the ADD and CTRL diets. Only the MSS counts and the percentage of fecal K were shown to be different. It stands to reason that the fecal output of horses consuming the ADD diet, which contained the specific MicroSource microbial populations, would contain greater concentrations of those spores. However, it should be noted that TS count was similar between the 2 diets. Of note, a greater fecal K (%) was found by feeding the ADD diet, whereas studies in other species reported reduced K in feces due to dietary additives (Petersen, 2009; Walraven et al., 2009b). Interestingly, when K was analyzed in the stockpiled feces, differences were not detected. Other parameters measured in the equine feces showed no differences due to dietary treatment. These variations may be attributed to vast differences in gastrointestinal tract anatomy and metabolic function between equine and other species of livestock. More work with such additives in equine nutrition is required to completely elucidate any benefit from reduction of nutrient excretion.

To gain a better understanding of the comprehensive environmental impact of equine waste, feces stockpiles were evaluated. Of the variables documented, only the temperature of the feces stockpiles over time were found to be different, with the highest temperatures reached between the fourth and sixth day. The results of this study vary from reports of other species, which indicated reduced ammonia emissions, reduced OM, decreased time to clean (i.e., break apart solid waste) and reduced nutrient waste (Walraven et al., 2008, 2009a; Petersen, 2009). To the knowledge of the authors, no other studies have measured these parameters in horse feces. Perhaps the relatively dry nature of horse feces, its stockpile procedure in the current study, physiological differences between animal species, or other factors explain the lack of differences in compost characteristics in this experiment.

Figure 4. Mean (+SE) daily temperature of stockpiled feces produced from horses fed pelleted feeds. Significant differences (P < 0.0001) by time are denoted by differing superscripts.

inorganic sources but that high variation was also evident at high dietary inclusion rates. Wagner et al. (2005) additionally reported that Cu, Zn, or Mn mineral source did not affect retention in adult horses. In contrast, Baker et al. (2005) showed increased retention in organic sources of Cu and Zn, which would presumably lead to less excretion. It is important to note, however, that previous research in horses has focused on retention as it relates to animal health and not as it relates to environmental impact. Further, experimental protocols for all aforementioned equine studies varied widely in percentage of organic mineral inclusion rates, ratios of organic to inorganic minerals within a dietary treatment, type of organic mineral used, and type of horse studied, along with other scientific design differences. The results of this study also vary from results reported in other species regarding excretion of minerals from chelated vs. inorganic sources. For example, Bao et al. (2007) documented a decrease of mineral excretion due to the inclusion of chelated minerals in poultry diets when fed at low dietary inclusion rates. Other studies (Burkett et al., 2006, 2009) have also reported reduced excretion of metals using organic trace minerals; however, their experimental comparison included very high concentrations of sulfate minerals or no mineral supplementation, and therefore, a direct comparison with the current study is difficult.

Decreased concentrations of urinary and fecal Se were found in horses consuming organic Se from the ADD diet compared with CTRL. These findings agree with the results of Pagan et al. (1999), which documented decreased concentrations of fecal Se when horses ate organic Se yeast. On the other hand, Pagan et al. (1999) found no differences in mean daily urinary Se concentrations when horses were fed organic Se vs. sodium selenite. Mahan and Parrett (1996) also documented increased organic selenium retention in growing pigs. Variations among equine studies and between species could be attributed to a variety of physiologic factors, including the mode of transport as a selenoprotein (organic form) or hydrogen selenide (inorganic form; Combs and Combs, 1986) as well as variations in tissue uptake of the 2 forms. Alternatively, a more simple explanation of dietary differences could also justify the results.

Of note, a greater fecal K (%) was found by feeding the ADD diet, whereas studies in other species reported reduced K in feces due to dietary additives (Petersen, 2009; Walraven et al., 2009b). Interestingly, when K was analyzed in the stockpiled feces, differences were not detected. Other parameters measured in the equine feces showed no differences due to dietary treatment. These variations may be attributed to vast differences in gastrointestinal tract anatomy and metabolic function between equine and other species of livestock. More work with such additives in equine nutrition is required to completely elucidate any benefit from reduction of nutrient excretion.
As with any research, there are limitations in methodology and study design that must be considered when interpreting and practically applying results. In the current study, the authors are aware that there is no true control for each individual dietary additive included in the ADD feed. However, the study was designed to partially follow a model that has been successful in the swine industry (Walraven et al., 2008, 2009a,b) and also reflects diets that are commercially available, some of which, with multiple additives, are advertised as having beneficial impacts for the environment. Further, the species unique digestive physiology makes nutritional studies of this type time-consuming, labor intensive, and expensive. The current study was 161 d in length. Individual testing of 5 additives would have increased the study length to over 700 d, which was not within the scope of our research capabilities. In the opinion of the authors, potential confounding factors of multiple additives could be more problematic had there been numerous, clearer, significant results between dietary treatments. In that case, we could only speculate if an individual or combination of additives was creating the result, leaving more questions than answers. The lack of differences in the current study has led us to interpret that few if any of the additives had substantial benefit to horses. In addition, mineral concentrations in both feeds were set at >100% requirement (NRC, 2007). In this case, the authors followed industry standards and recommended inclusion rates from the manufacturers of the additives. Dietary mineral content was more than what animals at maintenance might typically use; therefore, this may limit the interpretation of these findings relative to mineral absorption and excretion. We acknowledge that further research should be performed to clarify bioavailability and excretion when minerals are added at requirement vs. industry standard concentrations.

In conclusion, diet is the single greatest factor affecting feces characteristics and, in turn, the environmental impact of equine waste. Both nutritional composition and bioavailability of nutrients need to be carefully examined to better meet the daily requirements of the horse and minimize nutrient output. More research is required in equine nutrition to ascertain how to formulate feeds and potentially incorporate feed additives to benefit both horses and the environment.

LITERATURE CITED


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