ABSTRACT: The objective of this study was to test the hypothesis that feed additives such as chelated minerals, organic Se, yeast culture, direct-fed microbials, and Yucca schidigera extract would improve nutrient digestibility when included in an equine diet. Horses (Quarter Horse geldings 4.5 to 16 yr of age; mean BW 522 kg ± 46 kg) were acclimated to 100% pelleted diets formulated with (ADD) and without (CTRL) commercially available sources of the aforementioned additives followed by a 14-d collection period of feces and urine. Chelated sources of Cu, Zn, Mn and Co were utilized versus sulfated forms, at a 100% replacement rate. No significant differences among apparent the digestibility of DM, ADF, or NDF (P = 0.665, P = 0.866, P = 0.747, respectively) were detected between dietary treatments. Likewise, no differences in apparent digestibility of Cu (P = 0.724), Zn (P = 0.256), Mn (P = 0.888), Co (P = 0.71), or Se (P = 0.588) were observed. No differences were observed in serum Cu, Mn, or Co concentrations between ADD and CTRL at acclimation or collection time points (P > 0.05). While no difference in serum Zn concentrations were observed between ADD and CTRL groups at acclimation (P > 0.05), they were statistically higher at the collection time period for horses consuming CTRL (P < 0.0001). Whole blood Se concentration was greater in the CTRL group versus the ADD group both at acclimation (P = 0.041) and collection (P = 0.005) time periods. In reference to time, serum Cu concentrations increased (P = 0.012) for animals consuming CTRL, but not ADD (P > 0.05). Serum Zn concentrations of horses consuming both ADD (P = 0.021) and CTRL (P < 0.0001) increased over time from acclimation to collection time points. No time differences (P > 0.05) were observed in serum Mn concentrations. Serum Co concentrations increased over time in horses consuming both ADD (P = 0.001) and CTRL (P = 0.021). From acclimation to collection, whole blood Se concentration increased for horses consuming CTRL (P = 0.01) but not for ADD (P > 0.05). The results of this study indicate no effect on nutrient digestibility due to the inclusion of chelated minerals, organic Se, yeast culture, direct-fed microbials, and Yucca schidigera extract for horses at maintenance.

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

INTRODUCTION

The estimated 9.2 million horses in the United States (AHC, 2005) produce in excess of an estimated 78.5 million metric t of manure annually (ASAE, 2005). Both federal and state agencies include equine operations under environmental regulatory and accountability programs (Swinker, 2011). Meeting the nutrient requirement of these horses, as specified by the NRC (2007), can be accomplished with relative ease by feeding quality forages with properly formulated commercial feeds. However, feeding programs that minimize manure nutrient output and/or result in more environmentally stable nutrient forms are 2 strategies under investigation (Warren, 2006). Although limited studies exist specifically for horses, research with other livestock species can serve as a comparative reference. Certain feed additives such as chelated minerals,
direct-fed microbials (DFM), and Yucca schidigera extract have reduced nutrient excretion in manure and maintained, and in some cases improved, animal performance (Walraven et al., 2008, 2009a,b). These studies led to the development of products and feeding programs beneficial to both the animal and environment (Petersen, 2009). In the field of equine nutrition, more controlled research is needed to determine if nutrient sources and feed additives can influence nutrient bioavailability, digestibility, and nutrient excretion. The objective of this study was to test the hypothesis that equine diets formulated with chelated minerals, organic Se, yeast culture, DFM, and Yucca schidigera extract will improve nutrient digestibility and impact serum nutrient concentrations.

**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 number 807).

**Animals and Housing**

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

Throughout this study, subjects were singly housed to allow for individual measurement of feed intake and fecal and urinary output. Horses were housed outdoors in enclosures consisting of a partially covered stall (3.66 by 3.66 m) and an attached pen (3.66 by 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 reduce the opportunity for cross-contamination. Each stall contained a float-style drinker, which allowed ad libitum access to potable water; a plastic coated, wire holder 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 feces and/or urine. Equine hygiene harnesses were designated to an individual animal within treatment during the first study phase. Harnesses were assigned to another horse but remained with diet treatment to prevent potential cross contamination from the DFM during the second half of the study.

Basal ingredients of the 2 nutritionally complete, pelleted diets [ADD (with additives) and CTRL (without additives)] fed to American Quarter Horse (Equus caballus) geldings

| Table 1. Select composition of nutritionally complete, pelleted diets [ADD (with additives) and CTRL (without additives)] fed to American Quarter Horse (Equus caballus) geldings† |
|---|---|---|---|---|
| **ADD feed** | Amount, mg/kg | **CTRL feed** | Amount, mg/kg | **P-value** |
| Cu | 37.3 ± 2.63 | Cu | 43.2 ± 2.63 | P = 0.3587 |
| Zn | 167.3 ± 17.8 | Zn | 125.2 ± 17.9 | P = 0.2438 |
| Mn | 106.1 ± 5.77 | Mn | 107.6 ± 5.77 | P = 0.8789 |
| Co | 6.2 ± 0.33 | Co | 5.3 ± 0.33 | P = 0.3059 |
| Se | 1.4 ± 1.0 | Se | 2.1 ± 1.0 | P = 0.4411 |
| Yeast culture | 2.200 | – | – | – |
| Bacillus DFM | 500 | – | – | – |
| Yucca schidigera extract | 1.325 | – | – | – |

†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.

‡There was no added yeast culture, direct-fed microbials, or yucca extract in the CTRL feed. Added Cu, Zn, Mn, and Co were sulfate form and added Se source was sodium selenite.

§There were no differences in analyzed mineral concentration between diets as indicated in P-value column. Mineral amounts (mean ± SE; DM basis; n = 7) were analyzed by Michigan State University, Animal Health Diagnostics Laboratory, East Lansing, MI.

¶4-Plex (Zinpro Corporation, Eden Prairie, MN), formulated to provide 100% of required mineral based on NRC (2007).

5Sel-Plex (Alltech, Nicholasville, KY), formulated to provide 100% of required minerals based on NRC (2007).

6XPC Yeast Culture (Diamond V, Cedar Rapids, IA), formulated at 0.22% to provide a minimum of 10 g per horse/d when ADD feed was fed at a 4.5 kg per horse/d feeding rate.

7DFM = direct-fed microbials. MicroSource (DuPont, Waukesha, WI), formulated at 0.15% to provide a minimum of 1 × 10⁹ cfu per horse/d with a 4.5 kg per horse/d feeding rate.

8MicroAid (DPI Global, Porterville, CA), formulated at 0.1325% to provide 750 mg per horse/d.
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/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 diets fed exclusively 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 adjacently 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 based on BW data.

Transition of animals from the previous feeding regimen to experimental diets, along with the collection time periods, are outlined in Table 2. During the 14-d collection period, the amounts fed were defined by the individual concentrations of intake established during the acclimation period. Feed offered and orts remaining were weighed and documented twice daily (0700 and 1800 h) during all of the periods to quantify DMI. During the collection periods, total fecal mass was quantified twice daily and subsamples retained from each collection. Samples were dried, ground, and subsampled from d 1, 8, and 15 for analyses. In addition, fecal samples were taken on d 28 and 49 of the 49-d washout period to quantify *Bacillus* spores in the ADD diet to assess any carryover effect from the first phase of the crossover design. Total spore counts were determined after heat treatment at 85°C for 15 min and 48 h incubation at 32°C in Tryptic Soy Agar (Difco, Voigt Global Distribution, Lawrence, KS). Total MicroSource *Bacillus* (DuPont, Waukesha, WI) spore counts were based on colony morphology to distinguish the *B. licheniformis* strains. *Bacillus subtilis* was not distinguishable from other wild-type *Bacillus* and were not included in total MicroSource *Bacillus* counts.

Representative fecal samples were analyzed by Dairy One Forage Lab (Ithaca, NY) using wet-chemistry methods for DM (Goering and Van Soest, 1970), ADF (Ankom Technology, Ankom Technology, Macedon, NY; method 5), and NDF (Ankom Technology; method 6). Fecal minerals were measured using a modified inductively coupled plasma mass spectrometry (ICP-MS) method described by Wahlen et al. (2005). Apparent nutrient digestibility (%) was calculated as 100 × (nutrient intake − fecal nutrient excretion)/nutrient intake.

Blood samples were collected once weekly during the acclimation and collection periods. Serum samples (10 mL) for Cu, Zn, Mn, and Co analyses were collected using jugular venipuncture into plastic acid-washed, serum tubes (BD 368380; Becton Dickinson, Franklin Lakes, NJ). Whole blood samples (10 mL) for Se analyses were collected using jugular venipuncture into plastic whole blood tubes (BD 367861; Becton Dickinson). Harvested serum was stored frozen (−20°C) and whole blood was refrigerated before shipping. Samples were submitted to the Diagnostic Center for Population and Animal Health at Michigan State University (Lansing, MI) for mineral analyses using a modified ICP–MS method described by Wahlen et al. (2005). Statistical Analyses

A crossover design with sampling was used to test the digestibility parameters and a crossover with repeated measures was used for the blood-work parameters. Diet × trial interaction results were used to compare blood samples between dietary treatment groups and within each treatment group from the first blood sample during acclimation to the last blood sample from collection. Analysis of variance was performed with mixed models (SAS Inst. Inc., Cary, NC), and least squares means compared with Fisher’s least significant difference (*P* < 0.05).

### RESULTS

**Apparent Digestibility of DM and Nutrients in Diets**

There was no significant difference observed in apparent digestibility between ADD and CTRL diets for DM (*P* = 0.665, Fig. 1). In addition, there were no

---

**Table 2. Transition and collection periods applied for American Quarter Horse geldings fed 1 of 2 nutritionally complete, pellet diets as 100% of intake.**

| Period          | Objective                                      | Duration, d |
|-----------------|------------------------------------------------|-------------|
| Pretransition   | Transition from 50:50 alfalfa hay/bermuda hay to 50:50 bermuda:pelleted diet | 14          |
| Transition      | Transition from 50:50 bermuda:pelleted diet to 100 pelleted diet | 7           |
| Acclimation     | Allow animal to respond to dietary treatment   | 28          |
| Collection      | Quantify food intake, fecal and urinary output | 14          |
| Washout         | All horses offered CTRL (feed without additives) for duration of washout period | 7           |
| Transition      | Transition from washout diet to treatment diets | 7           |
| Acclimation     | Allow animal to respond to dietary treatment   | 28          |
| Collection      | Quantify food intake and fecal and urinary output | 14          |
differences observed in apparent digestibility of fiber fractions ADF ($P = 0.866$) and NDF ($P = 0.747$) between dietary treatments (Fig. 1).

No differences were observed for apparent Cu ($P = 0.724$), Zn ($P = 0.256$), Mn ($P = 0.888$), or Co ($P = 0.71$) digestibility between the 2 diets. There was also no difference ($P = 0.588$) in apparent Se digestibility between diets (Fig. 2).

**Blood Analyses**

Concentrations of serum Cu, Zn, Mn, Co, and whole blood Se were analyzed for differences between diets and over time. No differences were observed in serum Cu concentrations for horses eating the ADD vs. CTRL diets at acclimation ($P = 0.458$) or collection ($P = 0.052$) time points (Fig. 3A). However, serum Cu concentrations for those consuming CTRL did increase over time ($P = 0.012$) but not for animals consuming ADD ($P = 0.833$; Fig. 3B).

For serum Zn, no difference was observed between ADD and CTRL groups at acclimation ($P = 0.211$), but Zn concentrations of horses consuming CTRL were greater at the collection time period than that of horses on ADD ($P < 0.0001$; Fig. 4A). Serum Zn concentrations increased in horses consuming both ADD ($P = 0.021$) and CTRL ($P < 0.0001$) over time from the acclimation to the collection time points (Fig. 4B). No differences were observed in serum Mn concentrations between dietary treatment groups at acclimation ($P = 0.80$) or collection periods ($P = 0.333$; Fig. 5A). Likewise, no differences were observed in serum Mn concentrations of horses consuming ADD ($P = 0.975$) or CTRL ($P = 0.455$) over time (Fig. 5B).

Horses eating the CTRL diet had greater whole blood Se concentrations at acclimation ($P = 0.041$) and collection ($P = 0.005$) vs. ADD (Fig. 7A). In addition, whole blood Se concentration did not increase statistically for horses consuming ADD over time from the acclimation to the collection period ($P = 0.069$) but did increase for horses consuming CTRL ($P = 0.01$; Fig. 7B).

Analysis of fecal samples from the washout period for *Bacillus* spore enumeration indicated spore counts within typical ranges for all horses except 1 from each sampling. 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 based on multiple pilot studies in horses. Therefore, based on these data it appears with the 49-d washout period, MicroSource *Bacillus* concentrations were depleted below native background and were no longer present from the first phase of the crossover design.

**DISCUSSION**

Data collected were used to evaluate the influence of chelated minerals, organic Se, yeast culture, DFM, and *Yucca schidigera* extract on blood nutrient concentrations and digestibility in horses.

Yeast culture is defined as the dried product composed of yeast and the media it was grown on to preserve the fermenting activity of the yeast (AAFCO, 2012). Benefits of yeast culture inclusion in equine diets stem from the metabolites produced during the fermentation process.
which potentially stimulate the bacteria of the hindgut to increase their activity and therefore increase digestion as well as improve the desired bacterial populations found in the hindgut. The current study demonstrated no benefit in apparent digestibility of DM, ADF, or NDF from the inclusion of yeast culture in the diet of mature horses. These results agree with the work reported by Webb et al. (1985), Hall et al. (1989), and Markey et al. (2006) who reported no significant differences of apparent digestibility of nutrients by mature horses, 3 yr olds, or yearlings, respectively. The lack of effect on apparent digestibility could be attributed to insufficient intake or digestion and absorption of the yeast culture proximal to the hindgut (Webb et al., 1985; Hall et al., 1989). Conversely, Glade et al. (1986) reported significant increases of daily net N retention and increased hemicellulose digestibility with the addition of live yeast culture to the diet of yearling horses, as well as improved DM, ADF, and NDF digestibility in mature horses (Glade, 1991). Glade and Sist (1989) also reported significant increases in rate of BW gain and feed conversion efficiency in nursing foals and weanlings with supplementation of live yeast culture. These findings by Glade et al. (1986, 1989, 1991) suggest a positive influence of yeast culture supplementation on AA balance and N metabolism, which may result in enhanced growth in very young horses, although this was not the focus of the current study. Interestingly, the findings of Jouany et al. (2008) indicated significant increases in apparent digestibility of DM, ADF, NDF, and hemicelluloses. Some variation between findings can be attributed to the specific effect of the yeast culture strain, the concentration of viable cells within the live yeast culture used in the diet, the concentration of viable cells that reach the hindgut, and composition of the diet.
as well as differing experimental conditions and feeding protocols. The results in the current experiment did not demonstrate an effect of yeast culture at 0.22% of the diet on select apparent nutrient digestibility.

Selenium functions as an immunomodulator and antioxidant in selenoproteins such as glutathione peroxidase. Inorganic and organic sources of Se have been observed to be metabolized differently in other species with varying benefits from each source being documented (Deagen et al., 1987; Mahan et al., 1999; Schrauzer, 2000). The results in the current study indicated no improvement in apparent Se digestibility nor were any differences in whole blood Se status documented due to the inclusion of organic Se yeast compared with sodium selenite. The findings of this study are similar to those of Richardson et al. (2006), who reported no clear advantage of dietary organic (in the form of Zn-L-selenomethionine) vs. inorganic (sodium selenite) sources on the Se status of horses. The findings of Calamari et al. (2010) also indicated no effect of Se source or dosage level on plasma metabolites related to energy, protein, and mineral metabolism, acute phase proteins, and enzyme activities related to hepatocellular, hepatobiliary, or muscle damage. Conversely, Pagan et al. (1999) reported greater apparent digestibility as well as Se retention in horses receiving sources of Se yeast vs. sodium selenite. Variation among reported findings could be attributed to several factors including the Se status of the ADD subject, experimental design, or feeding protocols. The findings of the current study did not suggest any additional benefit of an organic Se yeast source over sodium selenite in equine diets. More work in this area is warranted to better understand optimal concentrations and source of Se supplementation in equine diets.

Trace minerals play an integral role in overall equine health and are required in a myriad of physiologic functions. Recently, the effects of the chemical form of mineral supplementation, organic (chelate) vs. inorganic (carbonate, sulfate, and/or oxide), on digestibility and retention have been widely debated. A growing body of research has documented differences in absorption, retention, and the bioavailability among the varying sources of mineral supplements in several species.
(Ashmead et al., 1985; Henry et al., 1986; Kegley and Spears, 1994; Bao et al., 2007). However, research results in equine are more limited and equivocal at best when examining the efficacy of chelated minerals. The current data indicated no increase in apparent digestibility of Cu, Zn, Co, or Mn when a supplemental 100% chelated mineral source was fed as compared with a 100% sulfate source. In addition, several studies show no benefit of adding chelated mineral sources over other forms. Baker et al. (2005) found that supplementing organic minerals vs. inorganic minerals to mature horses may decrease Cu digestibility and Cu and Zn balance. Wagner et al. (2005) found no increase in absorption and retention when feeding organic Cu, Zn, or Mn to mature miniature horses compared with oxide or sulfate forms. Furthermore, yearlings fed Cu, Zn, Mn, and Co with similar chelation biochemistry to the current study had no consistent improvements in mineral digestibility, mineral balance, or measured growth variables when compared with feeding inorganic minerals (Naile et al., 2005). In contrast, Baker et al. (2003) and Miller et al. (2003) documented improved digestibility and retention in exercised yearling horses fed organic sources of minerals. The variations in research results could be attributed to many factors such as age, growth, or initial mineral status of the horses involved in the study as well as the substitution rate of organic for inorganic mineral sources in the diet, experimental design, feeding protocols, and measurement parameters. Compounding this issue, many mineral requirements for horses of different ages and classes have yet to be elucidated (NRC, 2007), and as a result, commercial horse feed products are fortified beyond NRC recommendations to ensure the quality and performance of the product as well as oblige consumer demand. More work in this area is needed to determine the appropriate amounts of mineral fortification in equine diets that optimally meet the needs of the horses and reduce the excess mineral load on both the animal and the environment.

Bacillus organisms are some of the most commonly used DFM (i.e., probiotics) in animal diets. These organisms can be potent producers of extracellular degrading enzymes such as amylases, cellulases, lipases, and proteases (Ferrari and Schmidt, 1993), which have the potential to aid in nutrient digestion and feed use. A variety of benefits from inclusion of DFM in animal diets have been reported in several species such as enhanced nutrient absorption (Higginbotham and Bath, 1993) and reduced risk of acidosis (Huffman et al., 1992). Fuller (1989) observed an optimal intestinal microbial balance, and Mitchell and Kenworthy (1976) observed the inhibition of harmful bacterial growth. Fuller (1997) also reported that stressed animals show the greatest response to inclusion of DFM in the diet. Furthermore, Davis et al. (2008) indicated improved feed to gain ratio as well as decreased mortality with the inclusion of Bacillus-based DFM in swine diets. In contrast to the findings detected in the aforementioned work, no improvement of feed digestibility was observed in the current study. However, the current findings agree with the results of Booth et al. (2001) who reported no difference in apparent digestibility of DM, NDF, ADF, and other nutrients when DFM were fed to exercising horses. Swyers et al. (2008) reported decreased Na and increased Cu and Fe digestibility in horses, but overall the addition of either a single or mixed strain of DFM had only a limited effect on nutrient digestibility. This discrepancy in results across studies may be attributed to inclusion rate and usage directions of the DFM product, varying strains and concentrations of viable cells in the diet, the concentration of viable cells that reach the hindgut, and differing experimental conditions and feeding protocols. The DFM used in the current study (MicroSource) is designed to pass through the gastrointestinal tract to provide an inoculation of the

![Figure 7](image-url)
manure to affect odor, microbial decomposition, and manure solids. Therefore, the lack of effect on nutrient digestibility was expected.

_Yucca schidigera_ has been included in animal diets primarily for ammonia and odor control of manure via the binding of ammonia in digesta and fecal materials by the steroidal saponins found in the extract (Headon and Dawson, 1990). Additional reports have suggested improvements in digestion and absorption from the addition of _Yucca schidigera_ from decreased ammonia concentrations, which in turn increase the activity of intestinal flora and reduce the concentrations of environmental ammonia and reduce stress (Hale et al., 1961; Dziuk et al., 1981; Johnston et al., 1981). In addition, Wallace et al. (1994) reported strong antiprotozoal activity, which could serve as a defaunating agent in ruminants by complexing cholesterol in the cell membranes causing breakdown and cell lysis of all microorganisms except bacteria (Cheeke, 1999). Because dietary saponins can be neither absorbed nor metabolized by ruminants or nonruminants (Ellenberger et al., 1985; Preston et al., 1987), including _Yucca schidigera_ extract with the feedsource provides the most opportunity for benefit. The results of the current study indicate no benefit in apparent DM, ADF, or NDF digestibility due to the addition of _Yucca schidigera_ extract to equine diets. These findings are in partial agreement with Glade (1992), who reported no significant increase in fiber digestibility except for ADF. Glade (1992) further reported that _Yucca schidigera_ extract inclusion had no effect on the true digestibility of N but did significantly decrease the apparent digestibility of dietary N as evidenced by increased endogenous fecal excretion of N. These findings may be partially attributed to the effects of binding ammonia to saponins within the equine large intestine, which reduced the ammonia available for resorption and recycling. However, the complete effect of _Yucca schidigera_ extract on N processing in the equine large intestine has yet to be elucidated.

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 reflects diets that are commercially and reflects diets that are commercially available in the equine industry; advertised as having beneficial impacts for the environment. Furthermore, the species’ unique digestive physiology dictates 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. This 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. Lack of differences in the current study has led us to interpret that few if any of the additives had substantial benefit to horses.

Responsible stewardship of the environment as well as responsible management and optimal nutrition of horses is a common goal everyone involved in the horse industry must share. Ultimately, the nutrient composition of manure is influenced primarily by the diet of the horse and by its individual physiologic characteristics (Warren, 2006). Nutritionally similar diets can vary in apparent nutrient digestibility and produce similar nutrient excretions (Wilson, 2006). Decreasing excretion of nutrient excess can be accomplished with reduced nutrient inclusion rates in horse diets. Overcoming common practices that supply more N, P, and trace minerals than are required through diet formulation and the overuse of nutritional supplements may have a positive impact on excess nutrient excretion. Although the use of novel feed additives has shown some efficacy in other livestock species, these results suggest their benefit is limited with adult horses at maintenance. The unique gastrointestinal tract anatomy of the horse and resulting sequence of digestive processes may limit application of data from similar studies conducted with other species. Gaining a more complete understanding of the exact nutritional requirements of horses in all life stages can lead to the future development of commercial products designed to fit specific life stage and management requirements.

**LITERATURE CITED**

American Horse Council (AHC). 2005. The economic impact of the horse industry on the United States. American Horse Council Foundation, Washington, DC.

American Society of Agricultural Engineers (ASAE). 2005. Manure production and characteristics. ASAE Standard D384.2. ASAE, St. Joseph, MI. p. 1–19.

Ashmead, H. D., D. J. Graff, and H. H. Ashmead. 1985. Summary and implications. In: C. Thomas, editor, Intestinal absorption of metal ions and chelates. Charles C Thomas Pub Ltd., Springfield, IL.

Association of American Feed Control Officials (AAFCO). 2012. Official publication. AAFCO, West Lafayette, IN.

Baker, L. A., T. Kearney-Moss, J. L. Pipkin, R. C. Bachman, J. T. Haliburton, and G. O. Veneklasen. 2003. The effect of supplemental inorganic and organic sources of copper and zinc on bone metabolism in exercised yearling geldings. In: Proc. 18th EquineNutr. Physiol. Soc. Symp., East Lansing, MI. p. 100–105.
Baker, L. A., M. R. Wrigley, J. L. Pipkin, J. T. Haliburton, and R. C. Bachman. 2005. Digestibility and retention of inorganic and organic sources of copper and zinc in mature horses. In: Proc. 19th Equine Sci. Soc., Tucson, AZ. p. 100–105.

Bao, Y. M., M. Choct, P. A. Iji, and K. Bruerton. 2007. Effect of organically complexed copper, iron, manganese, and zinc, on boiler performance, mineral excretion, and accumulation in tissues. J. Appl. Poult. Res. 16:448–455.

Booth, J. A., P. A. Miller-Auwerda, and M. A. Rasmussen. 2001. The effect of Horse-Bac Liquid on nutrient digestibility, gut physiology, and the physical response to exercise in horses. In: Proc. 17th Equine Nutr. Physiol. Soc. Symp., Lexington, KY. p. 259–260.

Calamari, L., F. Abeni, and G. Bertin. 2010. Metabolic and hematological profiles in mature horses supplemented with different selenium sources and doses. J. Anim. Sci. 88:650–659.

Cheeke, P. R. 1999. Not just a pretty smell – Saponins in animal nutrition. Feed Mix 7:26–28.

Davis, M. E., T. Parrott, D. C. Brown, B. Z. de Rodas, Z. B. Johnson, C. V. Maxwell, and T. Rehberger. 2008. Effect of a Bacillus-based direct-fed microbial feed supplement on growth performance and pen cleaning characteristics of growing-finishing pigs. J. Anim. Sci. 86:1459–1467.

Deagen, J. T., I. A. Butler, M. A. Beilstein, and P. D. Whanger. 1987. Effects of dietary selenite, selenocysteine and selenomethionine on selenocysteinylase and glutathione peroxidase activities and on Se levels in rats tissues. J. Nutr. 117:91–98.

Dziuk, H. E., G. E. Duke, R. J. Buck, and K. A. Jamni. 1981. Studies of digestion in young turkeys with Yucca saponin added to the feed. Dep. Vet. Biology. University of Minnesota, MN.

Ellenberger, M. A., W. V. Rumpler, D. E. Johnson, and S. R. Goodall. 1985. Evaluation of the extent of ruminal urease inhibition by Bacillus-based cultures in yearling geldings in training. In: Proc. 16th Equine Nutr. Physiol. Soc. Symp., Raleigh, NC. p. 135–140.

Fuller, R. 1997. Probiotics 2: Applications and practical aspects. Chapman & Hall, London, UK.

Glade, M. J. 1991. Dietary yeast culture supplementation of mares during late gestation and early lactation. 1. Effects on dietary nutrient digestibilities and fecal nitrogen partitioning. J. Equine Vet. Sci. 11:10–16.

Glade, M. J. 1992. Effects of Yucca schidigera extract on feed utilization by equine weanlings. J. Equine Vet. Sci. 12:93–98.

Glade, M. J., and L. M. Biesiki. 1986. Enhanced nitrogen retention in yearling horses supplemented with yeast culture. J. Anim. Sci. 62:1635–1640.

Glade, M. J., and M. D. Sist. 1989. Supplemental yeast culture alters the plasma amino acid profiles of nursing and weanling horses. In: Proc. 11th Equine Nutr. Physiol. Soc. Symp., Stillwater, OK. p. 369–379.

Goering, H. K., and J. V. Van Soest. 1970. Forage fibre analyses (Apparatus, reagents, procedures, and some applications). Agric. Handbook No. 379. ARS-USDA, Washington, DC.

Hale, W. H., W. C. Sherman, W. M. Reynolds, and H. G. Luther. 1961. The value of certain steroidal sapogenins in rations of fattening lambs and cattle. Proc. Soc. Exp. Biol. Med. 106:486–489.

Hall, R. R., S. G. Jackson, J. P. Baker, and S. R. Lowry. 1989. Influence of yeast culture supplementation on ration digestion by horses. In: Proc. 11th Equine Nutr. Physiol. Soc. Symp., Stillwater, OK. p. 130–134.

Headon, D. R., and K. A. Dawson. 1990. The mode of action of De-Odorase. In: T. P. Lyons, editor, Biotechnology in the feed industry. 6th ed. Alltech, Nicholasville, KY.

Henneke, D. R., G. D. Potter, J. L. Kreider, and B. F. Yates. 1983. Relationship between condition score, physical measurements, and body fat percentage in mares. Equine Vet. J. 15:371–372.

Henry, P. R., C. B. Ammerman, and R. D. Miles. 1986. Bioavailability of manganese sulfate and manganese monoxide in chicks as measured by tissue uptake of manganese from conventional dietary levels. Jpn. Poult. Sci. 65:983–986.

Higginbotham, G. E., and D. L. Bath. 1993. Evaluation of Lactobacillus fermentation cultures in calf feeding systems. J. Dairy Sci. 76:615–620.

Huffman, R. P., K. K. Karges, T. I. Klonfeinstein, R. A. Stock, R. A. Britton, and L. D. Roth. 1992. The effect of Lactobacillus acidophilus on subacute ruminal acidosis. J. Anim. Sci. 70 (Suppl. 1):87 (Abstr.).

Johnston, N. L., C. L. Quarles, D. J. Fagerberg, and D. D. Caveny. 1981. Evaluation of Yucca saponin on broiler performance and ammonia suppression. Jpn. Poult. Sci. 60:2289–2292.

Jouany, J. P., J. Gobert, B. Medina, G. Bertin, and V. Julliand. 2008. Effect of live yeast culture supplementation on apparent digestibility and rate of passage in horses fed a high-fiber or high-starch diet. J. Anim. Sci. 86:339–347.

Kegley, E. B., and J. W. Spears. 1994. Bioavailability of feed-grade copper sources (oxide, sulfate, or lysine) in growing cattle. J. Anim. Sci. 72:2728–2734.

Mahran, D. C., T. R. Cline, and B. Richert. 1999. Effects of dietary levels of Se-enriched yeast and sodium selenite as Se sources fed to growing-finishing pigs on performance, tissue Se, serum glutathione peroxidase activity, carcass characteristics, and loin quality. J. Anim. Sci. 77:2172–2179.

Markey, A. D., and K. H. Kline. 2006. Effects of dietary fat and yeast culture supplementation on total tract digestibility by horses. Prof. Anim. Sci. 22:261–266.

Miller, E. D., L. A. Baker, J. L. Pipkin, R. C. Bachman, J. T. Haliburton, and G. O. Veneklasen. 2003. The effect of supplemental inorganic and organic forms of copper and zinc digestibility in yearling geldings in training. In: Proc. 18th Equine Nutr. Physiol. Soc. Symp., East Lansing, MI. p. 107–112.

Mitchell, I., and R. Kenworthy. 1976. Investigations on a metabolite from Lactobacillus bulgaricus which neutralizes the effect of enterotoxin from Escherichia coli pathogenic for pigs. J. Appl. Bacteriol. 41:163–174.

Naile, T. L., S. R. Cooper, D. W. Freeman, and C. R. Krehbiel. 2005. Effects of trace mineral source on growth and mineral balance in yearling horses. Prof. Anim. Sci. 21:121–127.

NRC. 2007. Nutrient requirements of horses. 6th rev. ed. Natl. Acad. Press, Washington, DC.

Pagan, J. D., P. Karnezos, M. A. P. Kennedy, T. Currier, and K. E. Hockstra. 1999. Effect of selenium source on selenium digestibility and retention in exercised Thoroughbreds. In: Proc. 16th Equine Nutr. Physiol. Soc. Symp., Raleigh, NC. p. 135–140.

Petersen, S. T. 2009. The potential ability of swine nutrition to influence environmental factors positively. J. Anim. Sci. 88 (Suppl.):E95-E101.

Preston, R. L., S. J. Battle, T. May, and S. R. Goodall. 1987. Influence of sarsapronin on growth, feed and nitrogen utilization in growing male rats fed diets with added urea or protein. J. Anim. Sci. 65:481–487.

Richardson, S. M., P. D. Siciliano, T. E. Engle, C. K. Larson, and T. L. Ward. 2006. Effect of selenium supplementation and source on the selenium status of horses. J. Anim. Sci. 84:1742–1748.
Schrauzer, G. N. 2000. Selenomethionine: A review of its nutritional significance, metabolism and toxicity. J. Nutr. 130:1653–1656.
Swinker, A. M. 2011. Update of nutrient management regulations and the equine industry. In: Proc. 9th Mid-Atlantic Nutr. Conf., Timonium, MD. p. 122–131.
Swyers, K. L., A. O. Burk, T. G. Hartsock, E. M. Ungerfeld, and J. L. Shelton. 2008. Effects of direct-fed microbial supplementation on digestibility and fermentation end-products in horses fed low- and high-starch concentrates. J. Anim. Sci. 86:2596–2608.
Wagner, E. L., G. D. Potter, E. M. Eller, P. G. Gibbs, and D. M. Hood. 2005. Absorption and retention of trace minerals in adult horses. Prof. Anim. Sci. 21:207–211.
Wahlen, R., L. Evans, J. Turner, and R. Hearn. 2005. The use of collision/reaction cell ICP-MS for the determination of elements in blood and serum samples. Spectroscopy 20: 84-89.
Wallace, R. J., L. Arthaud, and C. J. Newbold. 1994. Influence of *Yucca schidigera* extract on ruminal ammonia concentrations and ruminal microorganisms. Appl. Environ. Microbiol. 60:1762–1767.
Walraven, T., S. Carter, Lachman, J. Bundy, J. Jarrett, and B. De Rodas. 2008. Effects of EcoCare feed on growth performance and nutrient excretion of finishing pigs. J. Anim. Sci. 86 (E-Suppl. 2):578.
Walraven, T., S. Carter, M. Lachman, J. Bundy, J. Jarrett, and B. De Rodas. 2009a. Effects of EcoCare feed on mass balance of N and P during the swing finishing phase. J. Anim. Sci. 87 (E-Suppl. 3):51.
Walraven, T., S. Carter, M. Lachman, J. Bundy, J. Jarrett, and B. De Rodas. 2009b. Effects of EcoCare feed on mineral excretion of pigs during the finishing phase. J. Anim. Sci. 87 (E-Suppl. 2):511.
Warren, L. K. 2006. From oats to road apples: Modifying horse manure through nutrition. In: Proc. 4th Mid-Atlantic Nutr. Conf., Timonium, MD, p. 56–64.
Webb, S. P., G. D. Potter, and K. J. Massey. 1985. Digestion of energy and protein by mature horses fed yeast culture. In: Proc. 9th Equine Nutr. Physiol. Symp., East Lansing, MI. p. 64–67.
Wilson, J. A., C. W. Babb, and R. H. Prince. 2006. Protein and mineral digestibility of three pelleted equine feeds and subsequent nitrogen and phosphorus waste excretion. Prof. Anim. Sci. 22:341–345.