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ESTIMATION OF PASTURE DRY MATTER INTAKE AND ITS PRACTICAL APPLICATION IN GRAZING MANAGEMENT FOR HORSES

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Summary

Pasture is a valuable source of nutrients for grazing horses. Pasture can provide some or all of the horse’s digestible energy, crude protein, vitamin A and E requirements; although pasture’s ability to provide minerals is variable to limited. In order to fully realize the value of pasture, dry matter intake must be accurately estimated to account for intake of pasture derived nutrients. Several estimates of pasture dry matter intake have been published for horses grazing over periods ranging from 3 to 24 h. A pasture dry matter intake prediction equation was developed using these data. The equation is useful in accounting for pasture nutrient intake relative to requirements, as well as to determine the length of time horses should have access to pasture in order to consume a target intake (e.g., that necessary to consume daily maintenance digestible energy requirements and maintain body weight).

Introduction

Pasture is an excellent source of nutrients for grazing horses. In fact there are many situations where horses graze continuously and consume far more nutrients than required. The excess nutrient consumption has negative economic and horse health consequences. Therefore strategies aimed at controlling pasture nutrient intake are valuable tools in managing grazing horses. One approach to controlling pasture nutrient intake is to restrict the amount of time a horse grazes based on an estimates of pasture dry matter intake (DMI), pasture nutrient concentrations and the horse’s nutrient requirements. These three factors (pasture DMI, pasture nutrient concentration and horse nutrient requirements) can be used to calculate the amount of time at pasture that is necessary for the horse to consume only the required nutrients. However, this approach is not without challenges.

This paper will discuss the nutritional value of pasture in feeding horses, the value of controlling pasture nutrient intake and challenges associated with estimating pasture nutrient intake its practical application.

Nutritional Value of Pasture for Horses

Well managed pasture can make a significant contribution to a horse’s daily nutrient requirements. Pasture’s greatest contributions are made toward digestible energy (DE) (i.e., calories) and crude protein requirements. Digestible energy values for grass pasture have been reported to range from 1.78 to 2.74 Mcal/kg DM (mean ± S.D. 2.26 ± 0.48 Mcals/kg DM; n = 6959; Dairy One, 2011). This range is includes most of the range of DE requirements for horses, expressed on a dietary concentration basis (i.e., 1.67 to 3 Mcals/kg DM; NRC, 2007). The lower values of this range correspond to mature idle horses with maintenance only requirements; while the upper values correspond to a five-month-old
weanling. A similar situation exists when crude protein concentrations of grass pasture are compared with the range of crude protein requirements for horses in various physiological states. Crude protein values for grass pasture can range from 7.5 to 22.7% (mean ± S.D. 15.2 ± 7.6%, n = 9,335; Dairy One, 2011) compared to requirements ranging from 6.3% (mature idle) to 13.9% (5-month old weanling). These findings demonstrate clearly that grass pasture can provide some or all of a horse’s DE and crude protein requirements, depending upon the horse’s physiological status and forage quality.

Pasture is a more variable source of minerals. In some cases pasture can contain adequate amounts of minerals relative to requirements; whereas in others it tends to be deficient. The concentrations of Ca and P reported for 9,432 samples range from 0.27 to 0.82 % (mean ± S.D. 0.55 ± 0.28%) and 0 to 0.78% (mean ± S.D. 0.29 ± 0.49%) respectively (Dairy One, 2011). The range of Ca and P requirements for horses is 0.2 (mature idle) to 0.8% (5-month old weanling), and 0.14 to 0.45%, respectively (NRC, 2007). Therefore pasture is not viewed as a consistent source of Ca and P in many cases, especially for lactating mares and growing horses. Pasture also generally lacks the ability to provide Na, Cl, Cu and Zn. Selenium may or may not be deficient depending upon the region geographical location. Most of the Great Plains and Rocky Mountain regions in the US have Se-rich soils whereas other areas are extremely deficient (e.g., Great Lakes regions, Pacific NW and most of the Eastern half of the US).

Pasture can be an excellent source of some required fat soluble vitamins (e.g., pro-vitamin A and vitamin E). An unpublished study conducted at North Carolina State University that evaluated seasonal changes in vitamin E and beta-carotene (pro-vitamin A) over a 12-month period reported mean pasture vitamin E concentrations of 195 ± 59 IU/kg DM (range = 100 to 300 IU/kg), which is well above the requirement range of 80 to 100 mg/kg DM (NRC, 2007). The lowest concentrations were reported during the months of December through February; while the greatest concentrations occurred from May through August. These results suggest pasture is an excellent source of vitamin E, even during seasons of the year when concentrations are lowest. Beta-carotene is metabolized by the horse to retinol providing vitamin A equivalents. Each milligram of beta-carotene is assumed to provide the horse with 400 IU of vitamin A (NRC, 2007). The mean beta-carotene concentration reported in the aforementioned study was 34 ± 25 mg/kg DM, which equates to 13,600 IU/kg DM of vitamin A. Horses require between 3,000 to 4,800 IU/kg DM (NRC, 2007). Although the beta-carotene concentration provides vitamin A equivalents well above the requirement; there is no likelihood of vitamin A toxicity in that the conversion of beta-carotene to vitamin A is significantly reduced at high concentrations (i.e., the horse received considerably less than 400 IU/mg beta-carotene).

In summary pasture can provide some or all of a horse’s DE, CP, vitamin A and E requirements. Pasture’s ability to provide minerals is variable to limited. Nonetheless it is clear to see from the above examples that pasture is an excellent source of many important nutrients for horses.

The Value of Controlling Pasture Nutrient Intake

Because pasture can be a plentiful source of nutrients for horses, often having the potential to provide more nutrients than required, the ability to control intake is sometimes desirable. The following example demonstrates the value of controlling pasture nutrient intake with regard to feed costs and horse health. Consider a small acreage operation with two 500 kg mature idle horses grazing 5 acres of pasture containing an average annual herbage mass of 1,300 kg DM/acre and having an average DE concentration of 2.26 Mcals/kg DM. If the horses grazed pasture at a rate of 2.5% of body weight per day they would each consume 28.85 Mcals/d which is 11.58 Mcals greater than required (16.67 Mcals/d). A DE intake of 20 Mcal above maintenance DE is required per kg of BW gain and an increase in 1 body condition score unit requires approximately 18 kg of body weight gain (NRC, 2007). Given these assumptions the two horses in this example would gain just under 1 body condition score unit per month. In order for the
horses to consume maintenance only requirements and maintain body weight and body condition the horses pasture DMI would have to be decreased to approximately 1.5% of body weight. Decreasing the pasture DMI rate to 1.5% of body weight would allow the horses to graze the 5 acres of pasture for 220 days as compare to 130 days for a pasture DMI rate of 2.5% of body weight (assuming a grazing efficiency of 50%). The additional 90 days of grazing resulting from restricting pasture DMI rate to 1.5% of body weight saves $445 in hay costs assuming that two horses would require 18.5 kg hay/d containing an average of 2 Mcals/kg DM and 90% DM (16.67 Mcals/2 Mcals/kg DM x 2 horses / 0.9) costing $0.267/kg as fed ($4.85/40 lb bale).

The above example demonstrates the importance of controlling pasture nutrient intake in some cases. In the example above the maximum DE intake for a single horse weighing 500 kg, assuming 2.5% of body weight in DM, is 28.85 Mcals/d. This amount of daily DE intake exceeds the daily requirements for several feeding classes of horses (e.g., gestating mares, breeding stallions, light through heavy work) in addition to the mature idle horses used in the example above (NRC, 2007). In conclusion pasture's nutritional value cannot be fully appreciated unless one considers the horse's daily DM intake potential. Furthermore pasture's nutrition value cannot be used efficiently in many cases unless pasture nutrient intake can be regulated to avoid excess intake.

Estimates of Pasture DMI Rate and its Practical Application

Pasture DMI rates for a 24-h period have been reported to range from 1.4 to 3% of BW (Glunk and Siciliano, 2011; Grace et al., 2002b; Grace et al., 2002a; Longland et al., 2011a). Several additional studies report pasture DMI over a period shorter than 24 h (Chavez et al., 2011a; Chavez et al., 2011b; Dowler, 2009; Duren et al., 1989; Glunk and Siciliano, 2011; Ince et al., 2005; Ince et al., 2011; Longland et al., 2011b). Values associated with shorter grazing bouts are useful for managing horses having limited pasture access. There is evidence to suggest that DMI rate is not constant over a 24-h period and is accelerated as time allowed for grazing is restricted. Dowler (2009) reported pasture DMI rate during the first four hours of grazing was 1.6 times greater (1.47 g DM kg·BW⁻¹·h⁻¹) than that (0.9 g DM · kg BW⁻¹ · h⁻¹) in the 4-h period that followed. Glunk and Siciliano (2011) reported that DMI rate, expressed as g DM · kg BW⁻¹ · h⁻¹ for 6, 9, and 24 h grazing periods were 78, 57 and 29% of that for a 3-h period. The lack of a constant DMI rate over a 24 h period makes prediction of pasture DMI difficult when grazing occurs for only a fraction of the day. Extrapolation of 24-h DMI to shorter periods may underestimate the actual intake due to increased DMI associated with restricted grazing time. Therefore, data (23 means) from 12 studies measuring pasture DMI of horses (including yearlings, mature idle, and lactating mares) and ponies over periods ranging from 3 to 24 h was used to develop a prediction equation for pasture DMI (g DM/kg BW) as a function of hours of pasture access. The PROC REG function of SAS was used according to Walker (Walker, 2002). The model was \( y = \sqrt{x} \), where \( y = \) pasture DMI (g DM/kg BW) and \( x = \) pasture access (h). The square root of pasture access was used as a means of fitting non-linear data using linear methodology. The final equation was \( y = 5.12\sqrt{x} - 2.86 \) (R² = 0.7; P < 0.001). The model predicts a pasture DMI of 11.11 kg/d or 2.2% of BW for a 500 kg BW horse, which is a reasonable pasture DMI for a 24-h period (NRC, 2007).

The DMI rate prediction equation above can be used to estimate DMI for horses and ponies grazing for periods ranging from 3 to 24 h, provided pasture quantity is adequate. The predicted DMI can be used to evaluate nutrient intake from pasture and more effectively balance rations for grazing horses. Additionally, the equation can be rearranged to calculate the number of hours of grazing required to obtain a target DE intake. For example: a 500 kg mature idle horse requiring 16.67 Mcals DE/d would need to consume 7.4 kg of pasture containing 2.26 Mcals DE/kg DM (value reflects an average grass pasture energy concentration as stated previously). When expressed per unit of BW, the 500 kg horse requires 14.8 g DM/kg BW. This value can be entered into the prediction equation, which can then be solved for \( x \) (i.e., hours of pasture access). The horse in this example would require approximately 12 h
(11.9 h) of pasture access to consume 7.4 kg DM and 16.67 Mcals DE and meet its maintenance energy requirement. This approach conserves pasture and reduces feeding costs as well as preventing unnecessary weight gain, as was illustrated in the preceding section.

The DMI rate prediction equation above is far from perfect and should be used with caution as it does not consider all factors. Other factors that influence pasture DMIR include herbage mass available for grazing (Dowler, 2009), physiological status of the horse (Grace et al., 2002b), environmental temperature (Glunk and Siciliano, 2011), forage chemical composition, plant maturity and plant specie (Dowler, 2009; Fleurance et al., 2010; Fleurance et al., 2009). The effect of these factors on pasture DMI rate requires further study in horses. However, the prediction equation above can serve as a starting point to build upon in the future.

References

OPTIMIZING EQUINE FORAGE USE

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Summary

Pastures are an affordable way to feed horses, resulting in approximately one-third the cost of hay. Optimizing the use of pasture in the equine diet begins with careful selection of cool-season pasture grasses. Recent grazing palatability and persistence research found that planting mixtures of Kentucky bluegrass, orchardgrass, perennial ryegrass, and fescues achieved a balance between horse preference and maximum forage persistence and yield. Hay is likely the most expensive dietary component for all classes of post-weaned horses and few horse owners can escape the need to feed hay at some time during the year. Optimizing hay use starts with reducing harvest and feeding losses. Reducing harvest losses of large round-bales was achieved by bailing large round-bales at ≤ 15% moisture or wrapping hay in plastic. Unwrapped large round-bales of hay baled at ≥ 17% moisture molded and resulted in hay unsuitable for horse consumption. Further improvements in forage utilization can be made during feeding. The use of a round-bale feeder resulted in reduced hay waste, increased hay intake, and maintenance of horse weight compared to not utilizing a feeder, which resulted in 57% hay waste. More efficient round-bale feeder types included the Waste Less, Hayhut, and the Covered Cradle which all resulted in ≤ 11% hay waste. Soaking hay in water is a common strategy used to manage horses diagnosed with laminitis, Polysaccharide Storage Myopathy (PSSM) and hyperkalemic periodic paralysis (HYPP). Previous research has determined that hay should be less than 10 and 12% non-structural carbohydrate (NSC) for horses diagnosed with PSSM and laminitis, respectively, and less than 1% potassium (K) for horses diagnosed with HYPP. Soaking alfalfa hay was not necessary as NSC levels were already below 10 and 12%. Soaking orchardgrass hay for 15 to 30 minutes reduced NSC levels below 12 and 10%, respectively. Soaking alfalfa and orchardgrass hays for 12 hours was necessary to reduce K levels below 1%. Consequently, soaking hays for 12 hours resulted in 17 to 20% dry matter losses and excessively high Ca:P ratios. Thus, owners should rely on forage analysis as the primary method of determining the appropriate hay for horses, especially when feeding diseased horses. Hay soaking should only be used if acceptable hay is not available and for short (15 to 30 minutes) durations. To optimize forage use in the horse diet, pasture grasses should be selected based on horse preference and grass persistence, hay should be baled dry (≤ 15% moisture), round-bale feeders should be utilized, and forage testing should be done prior to selecting and feeding hay for horses, especially when feeding diseases horses.

Introduction

The diet of most classes of post-weaned horses should be comprised mainly of forages (NRC, 2007). Forages may be provided as fresh (grazed pasture) or dried (hay). In order to most efficiently utilize forages in the horse diet, research is needed to identify methods that maximize pasture use and minimize hay waste during harvesting and feeding. This paper focuses on methods that optimize pasture grass utilization by horses, minimize hay harvest losses, and reduce feeding waste by utilizing feeders and selecting appropriate hay types when feeding diseased horses.
Optimizing Forage Use from Pasture

Cool-season perennial grasses are the foundation of productive horse pastures in the North Central, Central, and Eastern U.S. Pastures are an affordable way to feed horses, resulting in approximately one-third the cost of hay (Sheaffer et al., 2009). Previous research showed horses preferred orchardgrass (*Dactylis glomerata*), timothy (*Phleum pretense*), smooth bromegrass (*Bromus inermis*), and festulolium (*Festulolium braunii*) while some varieties of tall fescue (*Schedonorus phoenix*) and Kentucky bluegrass (*Poa pratensis*) had low palatability (Olson et al., 2009; Wilson et al., 2004). New cool-season grass varieties are being marketed for use in grazing systems, but few have been evaluated for persistence and palatability in equine grazing systems. The objectives of the following research were to evaluate grazing preferences, persistence and yield of twelve cool-season grasses under horse grazing.

Research was conducted in St. Paul, MN during the 2011 growing season, using stands of grasses established on August 13, 2009. The experimental design was a randomized complete block with four replications. Grass species included ‘Barolex’ tall fescue, ‘Hidden Valley’ meadow fescue (*Festuca pratensis*), ‘Everett’ quackgrass (*Elytrigia repens*), ‘Agassiz’ smooth bromegrass, ‘Fleet’ meadow bromegrass (*Bromus biebersteinii*), ‘Marathon’ reed canary grass (*Phalaris arundinacea*), ‘Survivor’ perennial ryegrass (*Lolium perenne*), ‘Winneton’ timothy, ‘Ginger’ Kentucky bluegrass, ‘Garrison’ creeping foxtail (*Alopecurus arundinaceus*), and ‘Baridana’ orchardgrass. Soil pH, phosphorus, and potassium levels were adjusted according to university recommendations and 56 kilograms of nitrogen per hectare was applied in April and June of 2011. Four adult Quarter Horse-type horses (1 mare, 3 geldings; 538 kg ±38 kg in body weight; 21.5 ±6.5 years of age) were used for the duration of the grazing study (May through September). Horses grazed two replicates for eight hours on day one, and two replicates for eight hours on day two, resulting in two consecutive days of grazing each month. Grazing was initiated based on grass height and maturity; most grasses were in the vegetative to boot stage of maturity at the start of grazing each month. Prior to each grazing, plots were visually assessed for percent ground cover on a scale of 0 (bare ground) to 100 (100% ground cover) to determine persistence. Following grazing, grass removal was assessed on a scale of 0 (no grazing activity) to 100 (100% of the plants were grazed) to determine preference. After assessment, all plots were mowed to 9 cm and allowed to regrow.

Throughout the grazing season, horses demonstrated strong preferences for specific grasses (*P* < 0.01). Timothy, perennial ryegrass, Kentucky bluegrass and meadow fescue were most preferred (Table 1). Creeping foxtail and meadow bromegrass were least preferred (*P* < 0.01). To investigate the relationship between grass removal and forage quality, univariate regressions of percent grass removal on forage quality components were performed. Acid detergent fiber (*P* < 0.01) was negatively correlated, while non-fiber carbohydrate (*P* = 0.02) was positively correlated with horse preference (*R*²=0.53 and 0.43, respectively). Horses grazing preference has previously been correlated with low fiber and high carbohydrate levels (Longland and Byrd, 2006). Grasses also differed in persistence under horse grazing (*P* < 0.01). Orchardgrass and meadow fescue were most persistent while reed canarygrass, smooth bromegrass, meadow bromegrass, and creeping foxtail were least persistent (Table 1).

Forage yield, where yield was the sum of all pre-grazing yields from each period, was different among grass varieties (*P* < 0.01; Table 1). Orchardgrass, meadow fescue, and tall fescue had the highest yield at greater than 9,000 kg/ha. Timothy, smooth bromegrass, meadow bromegrass, and creeping foxtail had the lowest yield, with less than 6,500 kg/ha. Based on these results, planting mixtures of Kentucky bluegrass, orchardgrass, perennial ryegrass, and fescues should achieve a balance between horse preference and forage persistence and yield.
Table 1. Preference, persistence and yield of cool-season grasses under horse grazing.

<table>
<thead>
<tr>
<th>Grass Species</th>
<th>Preference</th>
<th>Persistence</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% visual removal</td>
<td>% ground cover</td>
<td>kg/ha</td>
</tr>
<tr>
<td>Timothy</td>
<td>77&lt;sup&gt;a&lt;/sup&gt;</td>
<td>67&lt;sup&gt;de&lt;/sup&gt;</td>
<td>6,495&lt;sup&gt;de&lt;/sup&gt;</td>
</tr>
<tr>
<td>Perennial Ryegrass</td>
<td>69&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>82&lt;sup&gt;c&lt;/sup&gt;</td>
<td>7,166&lt;sup&gt;cd&lt;/sup&gt;</td>
</tr>
<tr>
<td>Kentucky Bluegrass</td>
<td>62&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>86&lt;sup&gt;ed&lt;/sup&gt;</td>
<td>8,510&lt;sup&gt;abc&lt;/sup&gt;</td>
</tr>
<tr>
<td>Meadow Fescue</td>
<td>60&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>91&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>9,630&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>Quackgrass</td>
<td>58&lt;sup&gt;bed&lt;/sup&gt;</td>
<td>78&lt;sup&gt;c&lt;/sup&gt;</td>
<td>8,062&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>Smooth Bromegrass</td>
<td>56&lt;sup&gt;bcde&lt;/sup&gt;</td>
<td>53&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>6,047&lt;sup&gt;de&lt;/sup&gt;</td>
</tr>
<tr>
<td>Tall Fescue</td>
<td>52&lt;sup&gt;cdef&lt;/sup&gt;</td>
<td>85&lt;sup&gt;c&lt;/sup&gt;</td>
<td>9,182&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>Reed Canarygrass</td>
<td>48&lt;sup&gt;def&lt;/sup&gt;</td>
<td>60&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>6,942&lt;sup&gt;cd&lt;/sup&gt;</td>
</tr>
<tr>
<td>Orchardgrass</td>
<td>42&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>91&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10,078&lt;sup&gt;ab&lt;/sup&gt;</td>
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<tr>
<td>Meadow Bromegrass</td>
<td>42&lt;sup&gt;fg&lt;/sup&gt;</td>
<td>64&lt;sup&gt;de&lt;/sup&gt;</td>
<td>6,495&lt;sup&gt;de&lt;/sup&gt;</td>
</tr>
<tr>
<td>Creeping Foxtail</td>
<td>32&lt;sup&gt;f&lt;/sup&gt;</td>
<td>48&lt;sup&gt;f&lt;/sup&gt;</td>
<td>4,927&lt;sup&gt;f&lt;/sup&gt;</td>
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</tbody>
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Within a column, means without a common superscript letter are statistically different.

Optimizing Forage Use from Hay

Few horse owners can escape the need to feed hay at some time during the year. Hay is likely the most expensive dietary component for all classes of post-weaned horses, and the average adult maintenance horse fed 100% of their diet as hay (at 2.5% body weight) will consume 5 tons of hay each year. The price of hay in the U.S. has dramatically increased over the past year due to increases in fuel, agricultural inputs (i.e. fertilizer and land rent), transportation costs, and severe weather conditions (i.e. drought, flooding, and wild fires; NASS, 2010). The following results aim to improve hay utilization through improved harvesting and feeding efficiencies, thus reducing feeding costs for horse owners.

Harvest Efficiency

In an effort to avoid rain and other adverse weather conditions, hay is often baled before it is adequately dry, resulting in mold development and reduced forage quality (Rotz and Muck, 1994 and Montgomery et al., 2009). The development of mold in baled hay is positively correlated with the moisture concentration of the hay at baling (Roberts, 1995). It is common knowledge that horses are highly sensitive to several molds, and that ingesting moldy feed can result in both short-term and long-term respiratory problems, specifically heaves, and gastrointestinal problems, such as colic (Smith and Girish, 2008). In Sweden, researchers investigated wrapping individual round bales of grass hay in plastic at 35% moisture (Muhonen, et al., 2009). Wrapping bales at this moisture level resulted in minimal fermentation, and the resulting forage was offered to equines without causing adverse health effects. Although common in Europe, feeding bales wrapped in plastic is not common in the U.S. horse industry. The objectives of the following research were to determine the effects of initial bale moisture and plastic wrapping on mold formation in large round-bales of orchardgrass hay.

In 2009, 24 4 x 5-foot round-bales were baled and tied with three revolutions of net wrap from a 15 ha orchardgrass hay field. All harvested forage was obtained from the initial growth (first crop). Targeted moisture ranges at the time of baling included less than 15% (low moisture), 18 to 25% (intermediate moisture), and 30 to 35% (high moisture). Moisture at time of baling was estimated with a forage moisture probe and later confirmed through forage analysis. Immediately following baling, each bale was cored six times, and samples were analyzed for forage quality. After sampling, three temperature data loggers were placed in each bale about 61 cm from either flat end of the bale at depths of 38, 71 and 114 cm from the top of the bale. After temperature sensors were placed, four bales from each treatment
were immediately wrapped six times with one mil plastic wrap using a bale wrapper. Bales were stored outside on a well-drained sod surface in one continuous row running east and west; bales were arranged in a completely randomized design with four replications. Temperature sensors recorded temperature every hour for 10 weeks. At the end of 10 weeks, the temperature sensors were removed, and six additional cores samples were taken from each bale to determine forage quality and mold counts. Heating degree-days (HDD) were computed as the summations of the daily increment by which the average internal bale temperature was greater than 30°C (Coblentz and Hoffman, 2009). Data were analyzed and significance was declared at the $P < 0.05$ level of confidence.

Table 2. Initial moisture concentrations and heating characteristics of orchardgrass hays.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Initial Bale Moisture</th>
<th>Maximum Temperature</th>
<th>HDD$^{&gt;30°C}$</th>
<th>Mold cfu/g</th>
</tr>
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<tbody>
<tr>
<td>Unwrapped</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Moisture (LM)</td>
<td>12.4</td>
<td>46</td>
<td>47</td>
<td>26,000</td>
</tr>
<tr>
<td>Intermediate Moisture (IM)</td>
<td>21.3</td>
<td>63</td>
<td>640</td>
<td>7,100,000</td>
</tr>
<tr>
<td>High Moisture (HM)</td>
<td>33.4</td>
<td>82</td>
<td>1,216</td>
<td>5,300,000</td>
</tr>
<tr>
<td>Wrapped</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Low Moisture (LMW)</td>
<td>12.3</td>
<td>49</td>
<td>100</td>
<td>51,000</td>
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<tr>
<td>Intermediate Moisture (IMW)</td>
<td>18.0</td>
<td>50</td>
<td>155</td>
<td>19,000</td>
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<tr>
<td>High Moisture (HMW)</td>
<td>25.9</td>
<td>43</td>
<td>86</td>
<td>26,000</td>
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<tr>
<td>SEM</td>
<td>14.0</td>
<td>2</td>
<td>103</td>
<td>9,90,000</td>
</tr>
<tr>
<td>Contrasts</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IM, HM vs. LM</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>IM vs. HM</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.22</td>
</tr>
<tr>
<td>LMW, IMW, HMW vs. LM</td>
<td>&lt;0.01</td>
<td>0.60</td>
<td>0.58</td>
<td>0.94</td>
</tr>
<tr>
<td>IMW, HMW vs. LMW</td>
<td>&lt;0.01</td>
<td>0.45</td>
<td>0.87</td>
<td>0.94</td>
</tr>
<tr>
<td>IMW vs. HMW</td>
<td>&lt;0.01</td>
<td>0.04</td>
<td>0.64</td>
<td>0.87</td>
</tr>
</tbody>
</table>

superscript a Heating Degree Days (HDD) is the summations of the daily increment by which the average internal bale temperature was greater than 30°C.

Initial bale moisture differed among treatments (Table 2; Martinson et al., 2011a). Maximum bale temperatures for high and intermediate moisture bales were greater compared to low moisture bales ($P < 0.01$). Wrapping bales, regardless of moisture at the time of baling, resulted in maximum temperatures similar to low moisture bales ($P = 0.60$). These results agree with previous research that determined alfalfa (Medicago sativa L.) and mixed grass-legume hays baled at moisture concentrations less than 15% are relatively stable in terms of mold growth and forage quality (Montgomery et al., 1986). Accumulated HDD was different among low, intermediate and high moisture bales ($P < 0.01$; Table 2). However, no difference in HDD was observed between the wrapped bales, regardless of moisture at the time of baling, and the low moisture unwrapped bales ($P > 0.05$). Greater amounts of HDD accumulation is an indicator of microbial activity and molding.

Low moisture bales had lower mold counts comparable to intermediate and high moisture bales ($P < 0.01$). Wrapping bales, regardless of moisture at the time of baling, resulted in similar mold counts to low moisture bales ($P = 0.94$). All feeds contain some level of mold, even feeds properly harvested and stored. Table 3 outlines feeding risks and cautions developed for livestock based on mold counts (mold counts total the amount of all mold species found in a sample). Using these recommendations, all wrapped and low moisture bales would be considered desirable equine forage. Intermediate and high
moisture unwrapped bales resulted in greater than 5 million cfu/g of mold, and were not appropriate equine feeds.

Maintaining forage quality and reducing mold growth was achieved by baling dry hay (12% moisture) or wrapping, regardless of initial moisture, round-bales of orchardgrass hay. Wrapping higher-moisture orchardgrass round-bales is an effective method for maintaining forage quality. However, the stability of higher moisture bales after unwrapping needs further investigation.

Table 3. Livestock feeding risks* at various mold counts (Adams et al., 1993).

<table>
<thead>
<tr>
<th>Mold Count</th>
<th>Feeding Risks and Cautions*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 500,000 cfu/g</td>
<td>Low risk</td>
</tr>
<tr>
<td>½ to 1 million</td>
<td>Relatively safe</td>
</tr>
<tr>
<td>1 to 2 million</td>
<td>Feed with caution</td>
</tr>
<tr>
<td>2 to 3 million</td>
<td>Closely observe animals and performance</td>
</tr>
<tr>
<td>3 to 5 million</td>
<td>Dilute with other feeds</td>
</tr>
<tr>
<td>Over 5 million</td>
<td>Discontinue feeding</td>
</tr>
</tbody>
</table>

*Risks refer primarily to effect of mold without regard to possible mycotoxin content.

Feeding Efficiency

Selecting a Round-Bale Feeder

Many horse owners find round-bales convenient, less labor intensive, and more affordable than other hay types, but report an inability to control horse weight gain and excessive hay waste. Hay waste has been found to be higher for horses fed coastal bermudgrass (Cynodon dactylon) and alfalfa round-bales without a feeder (38% and 31%, respectively) compared to utilizing a ring feeder (2% and 9%, respectively) (McMillan et al., 2010). When fed to beef cattle, different round-bale feeder designs resulted in different amounts of wasted hay (Buskirk et al., 2003). Several types of round-bale feeders exist; however, little research has been done to characterize hay waste resulting from different round-bale feeders when fed to horses. The objectives of this research were to determine hay waste, intake and economics of nine round-bale feeders and a no-feeder control when used during horse feeding.

In June of 2010, 50 round-bales were baled from a pure stand of orchardgrass. Round-bales were stored until fed, and prior to storage, each round-bale was individually weighed and analyzed for forage quality. Nine round-bale feeders were tested, including the Cinch Net, Cone, Covered Cradle, Hayhut, Hay Sleigh, Ring, Tombstone, Tombstone Saver and Waste Less (Figure 1). Five feeders were evaluated on days 1-20, followed by four feeders and the no-feeder control on days 21-40. Each feeder was placed on the ground in a dirt paddock. Groups of five adult Quarter Horse and Thoroughbred geldings and open mares (means: 11 yr, 541 kg of body weight) were fed hay in each feeder over a four day period. Every fourth day, groups of horses were rotated among paddocks, weighed, and a new round-bale was placed in each feeder. In all, 25 horses fed off each feeder for 20 consecutive days. Horses had unlimited access to shelter, water, a trace mineralized salt block, and hay in the feeder. Hay that fell onto the ground surrounding the feeder was considered waste and was collected daily starting at 9:00 am. Care was taken to avoid collection of manure and dirt. All waste was dried to approximately 15% moisture and hay remaining in the feeder at the end of the four day period was removed, dried and weighed.
<table>
<thead>
<tr>
<th>Feeder Type</th>
<th>Hay Waste</th>
<th>Hay Intake</th>
<th>Herd Weight Change</th>
<th>Payback ($100/t hay)</th>
<th>Payback ($200/t hay)</th>
<th>Purchase Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste Less</td>
<td>5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>32&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8&lt;sup&gt;e&lt;/sup&gt;</td>
<td>4&lt;sup&gt;e&lt;/sup&gt;</td>
<td>1,450</td>
</tr>
<tr>
<td>Cinch Net</td>
<td>6&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>2.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>83&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>147</td>
</tr>
<tr>
<td>Hayhut</td>
<td>9&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>2.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-3&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>650</td>
</tr>
<tr>
<td>Covered Cradle</td>
<td>11&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>25&lt;sup&gt;a&lt;/sup&gt;</td>
<td>20&lt;sup&gt;f&lt;/sup&gt;</td>
<td>10&lt;sup&gt;f&lt;/sup&gt;</td>
<td>3,200</td>
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<tr>
<td>Tombstone Saver</td>
<td>13&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>2.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-16&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>4&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>2&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>650</td>
</tr>
<tr>
<td>Cone</td>
<td>19&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>26&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9&lt;sup&gt;e&lt;/sup&gt;</td>
<td>4.5&lt;sup&gt;e&lt;/sup&gt;</td>
<td>1,195</td>
</tr>
<tr>
<td>Tombstone</td>
<td>19&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>67&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>250</td>
</tr>
<tr>
<td>Ring</td>
<td>19&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>300</td>
</tr>
<tr>
<td>Hay Sleigh</td>
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<td>2.0&lt;sup&gt;f&lt;/sup&gt;</td>
<td>17&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.5&lt;sup&gt;d&lt;/sup&gt;</td>
<td>425</td>
</tr>
<tr>
<td>No-feeder</td>
<td>57&lt;sup&gt;f&lt;/sup&gt;</td>
<td>1.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-102&lt;sup&gt;b&lt;/sup&gt;</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

Within a column, means without a common superscript letter are statically different. Purchase prices of feeders is quoted from the time of research; July 2010. Mention of trade names is solely to provide specific information and does not imply recommendation or endorsement by the University of Minnesota.

Hay disappearance was calculated as the amount of hay delivered to each paddock, less the remaining amount of hay in the feeder at the end of the four day period. Percent waste was calculated as the amount of hay waste divided by hay disappearance. Dry Matter intake (DMI) was estimated as the difference between hay disappearance and hay waste and was expressed as percent body weight (BW) by dividing hay intake by average horse weight upon entering the paddock. Herd weight change was the difference between the initial herd weight minus the final herd weight after four days. Months for waste reduction to pay back feeder cost (payback) was calculated using hay valued at 100 and $200/ton and based on mean waste from the no-feeder control. The Covered Cradle had collapsible side feeding panels that rested on the bale and compressed down as the bale was eaten. The Waste Less feeder also had collapsible side feeding panels, but panels were lowered by hand every day at 9:00 am and 9:00 pm to ensure horses had constant access to hay in the feeder.

During the study, the average maximum daily temperature was 27°C with a total of 15 cm of rainfall; which likely did not affect hay intake or waste. The daily collection and drying of hay further limited the effect of rainfall on hay waste. No injuries were observed from any feeder types during the data collection period. However, cosmetic rub marks along the sides of faces were observed on many horses feeding out of the Waste Less feeder. After two days of feeding off the Cinch Net, the round-bale collapsed and horses were able to stand and defecate on the remaining hay. Thus, it is recommended that the Cinch Net be used in combination with another feeder to eliminate horse access as the round-bales collapse (Martinson et al., 2011c). The manufacturer also recommends that horses should not be shod when feeding from the Cinch Net.

The orchardgrass hay met or exceeded the horses’ nutritional requirements for digestible energy (DE), crude protein (CP), calcium (Ca) and phosphorous (P) for non-working mature horses (NRC, 2007). Feeder design did not affect hay intake; all feeders resulted in an estimated hay intake of 2.0 to 2.4% body weight (BW; Table 4). However, the no-feeder control resulted in a reduced intake of 1.3% BW. Pen weight change was not different among feeder types. However, when compared to the no-feeder control, six of the nine feeders resulted in small pen weight gains. The no-feeder control resulted in greater pen weight loss than six of the feeders, but was not different from the Hayhut, Ring or Tombstone...
Saver. At 1.3% BW of estimated hay intake, DE requirements were not met with the no-feeder control, accounting for the pen weight loss, although, CP, Ca and P requirements were still met.

**Figure 1.** Round-bale feeder designs: (A) Cinch Net, (B) Cone, (C) Covered Cradle, (D) Hayhut, (E) Hay Sleigh, (F) Ring, (G) Tombstone, (H) Tombstone Saver, and (I) Waste Less.

Mean percent hay waste and payback differed among feeders (Table 4). Although the Cinch Net paid for itself in the shortest amount of time, the net material is guaranteed to last for three years, while all other feeders claim to last indefinitely. However, feeder longevity was not measured in this study nor accounted for in the payback. The use of a round-bale feeder, regardless of design, is necessary to avoid excessive hay waste, reduced hay intake, and horse weight loss.
**Hay Soaking**

Soaking hay in water is a common strategy used to manage horses diagnosed with laminitis, Polysaccharide Storage Myopathy (PSSM), and hyperkalemic periodic paralysis (HYPP). Researchers have suggested that diets contain less than 12 and 10% NSC for horses affected with laminitis (Frank, 2009) and PSSM (Borgia et al., 2009), respectively, and previous research has confirmed removal of NSC after soaking hay in water (Martinson et al., 2011b; Longland et al., 2011; and Warr and Petch, 1992). Hay is also commonly soaked to remove potassium (K) prior to feeding horses affected by HYPP, and Reynolds et al. (1997) determined that a diet less than 1% K is necessary for these horses. Although certain water soluble nutrients (i.e. carbohydrates and K) are targeted during hay soaking, additional essential nutrients may be inadvertently lost. Therefore, the objectives of the following research were to determine the impact of water temperature and soaking duration on removal NSC, minerals and dry matter (DM) from legume and cool-season grass hays.

The experimental design was a randomized complete block with six replications. The four hay types included bud and flowering alfalfa and vegetative and flowering orchardgrass. Flakes were submerged for 15, 30 and 60 minutes in 25 liters of cold (22°C) and warm (39°C) water, and 12 hours in cold water. One flake from each bale was randomly assigned to each treatment. Mean flake weights were (mean ± SD) 1,428 ± 213 g, alfalfa bud; 1,825 ± 495 g, alfalfa flower; 1,522 ± 339 g, vegetative orchardgrass; and 1,693 ± 425 g, mature orchardgrass. Subsamples of entire flakes (were submitted for nutrient analysis at a commercial laboratory.

Prior to soaking, both alfalfa hays were below the 10 and 12% NSC threshold for horses with PSSM and laminitis, respectively, and would not have required soaking (Table 5). The orchardgrass hays were above this threshold, however, after soaking for 15 to 30 minutes were at or below 10 to 12% NSC. Hay contains a significant amount of soluble carbohydrates which when soaked, led to notable DM losses. Dry matter loss patterns were similar among all hay types after soaking for 15, 30 and 60 minutes in either warm or cold water, with the exception of soaking vegetative orchardgrass in warm water for 60 min (Table 5). Dry matter losses for all hay types after soaking for 12 hours were greater than other soaking treatments ($P < 0.001$). Failure to account for DM losses could lead to unwanted horse weight loss or stereotypic behaviors associated with low levels of forage in the diet including wood chewing and cribbing (McGreevy et al., 1995). Neither alfalfa nor orchardgrass hay is an appropriate option for horses diagnosed with HYPP due to the naturally high levels of K. Soaking both alfalfa and orchardgrass hay for 12 hour was necessary to sufficiently reduce K concentration to recommend levels prior to feeding horses diagnosed with HYPP. However, soaking hay for this length of time resulted in a shortage of P, high Ca:P ratios, and a significant loss in DM (Table 5).

Owners should rely on forage analysis as the primary method of determining the appropriate hay for horses, especially when feeding diseased horses. Hay soaking (15 to 30 minutes in duration) should only be used if acceptable hay is not available.

**Conclusions**

To optimize forage use in the horse diet, pasture grasses should be selected based on horse preference and grass persistence, hay should be baled dry ($\leq$ 15% moisture), round-bale feeders should be utilized and forage quality testing should be done prior to selecting and feeding hay for horses, especially diseases horses. Following these recommendations will lead to more efficient use of forages, healthier horses, and greater economic returns for horse owners.
**Table 5.** Concentration of NSC, Ca, P, and K in bud (AB) and flowering (AF) alfalfa hays, and vegetative (OV) and flowering (OF) orchardgrass hays, before and after soaking in cold (C; 22°C) or warm (W; 39°C) water for various lengths of time.

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Hay</th>
<th>Control</th>
<th>% DM</th>
<th>15 min</th>
<th>30 min</th>
<th>60 min</th>
<th>12 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSC</td>
<td>AB</td>
<td>9.3a</td>
<td>5.7b</td>
<td>6.3b</td>
<td>5.8b</td>
<td>5.0b</td>
<td>5.5b</td>
</tr>
<tr>
<td></td>
<td>AF</td>
<td>7.8a</td>
<td>6.1ab</td>
<td>7.2a</td>
<td>7.4a</td>
<td>5.8ab</td>
<td>6.4ab</td>
</tr>
<tr>
<td></td>
<td>OV</td>
<td>13.8a</td>
<td>10.3b</td>
<td>9.2b</td>
<td>9.5b</td>
<td>9.4b</td>
<td>9.4b</td>
</tr>
<tr>
<td></td>
<td>OF</td>
<td>14.3a</td>
<td>11.6b</td>
<td>10.7bc</td>
<td>10.2c</td>
<td>8.6d</td>
<td>8.8d</td>
</tr>
<tr>
<td>Ca</td>
<td>AB</td>
<td>1.49a</td>
<td>1.40bc</td>
<td>1.47ab</td>
<td>1.41bcd</td>
<td>1.45abc</td>
<td>1.37d</td>
</tr>
<tr>
<td></td>
<td>AF</td>
<td>1.1</td>
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<tr>
<td></td>
<td>OV</td>
<td>0.47ab</td>
<td>0.50ab</td>
<td>0.48ab</td>
<td>0.50a</td>
<td>0.48ab</td>
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</tr>
<tr>
<td>P</td>
<td>AB</td>
<td>0.31a</td>
<td>0.30a</td>
<td>0.31a</td>
<td>0.29b</td>
<td>0.28c</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>AF</td>
<td>0.29a</td>
<td>0.23b</td>
<td>0.21b</td>
<td>0.22b</td>
<td>0.19c</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>OV</td>
<td>0.42a</td>
<td>0.34b</td>
<td>0.34bc</td>
<td>0.32bc</td>
<td>0.31cd</td>
<td>0.28bc</td>
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<tr>
<td></td>
<td>OF</td>
<td>0.29a</td>
<td>0.25b</td>
<td>0.24bc</td>
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<td>0.22ed</td>
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</tr>
<tr>
<td>K</td>
<td>AB</td>
<td>2.78a</td>
<td>2.05b</td>
<td>1.84c</td>
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<td>1.84b</td>
<td>1.50f</td>
<td>1.51c</td>
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<td>1.62f</td>
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<td>5a</td>
<td>8ab</td>
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<td></td>
<td>OF</td>
<td>--</td>
<td>4a</td>
<td>6a</td>
<td>3a</td>
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<td>8a</td>
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<td>AB</td>
<td>4.8:1</td>
<td>4.7:1</td>
<td>4.7:1</td>
<td>4.9:1</td>
<td>5.1:1</td>
<td>4.9:1</td>
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<td>4.3:1</td>
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<tr>
<td></td>
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<td>1.1:1</td>
<td>1.5:1</td>
<td>1.4:1</td>
<td>1.6:1</td>
<td>1.5:1</td>
<td>1.7:1</td>
</tr>
<tr>
<td></td>
<td>OF</td>
<td>1.4:1</td>
<td>1.6:1</td>
<td>1.7:1</td>
<td>1.7:1</td>
<td>1.8:1</td>
<td>2.1:1</td>
</tr>
</tbody>
</table>

**a-g** NSC, nonstructural carbohydrates; Ca, calcium; P, phosphorus; K, potassium; and DM, dry matter.

**a-g** Least square means within a row not sharing a common superscript letter differ (P < 0.05)

**Acknowledgements**

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**References**


THE POTENTIAL OF TEFF AS AN ALTERNATIVE SUMMER FORAGE TO MANAGE DROUGHT CONDITIONS IN THE MID-ATLANTIC REGION

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Summary

Teff (Eragrostis tef (Zucc.)) is a productive, fast-growing, warm-season annual grass that is gaining the interest of forage producers throughout the southeastern United States. Teff is adapted to a wide range of climatic and soil conditions and has shown several advantages that make it a viable alternative over other summer annual forages. These advantages include its ability to thrive both in moisture-stressed and waterlogged soils and its lack of anti-quality compounds as found in sorghum-related annuals. Teff is a bunch-type grass. Despite its small seed size, it germinates within 3-5 days and is an aggressive competitor once established. In its native habitat in Ethiopia, maximum production
occurs with a growing season rainfall of 43-56 cm (17 to 22 inches) and a temperature range of 10-29°C (50 to 85°F). Historically, annual warm-season forages such as sorghum, sudangrass and pearl millet have been used to “fill in” the summer slump, because they grow well under hot, dry conditions. However, their growth and morphological characteristics often makes these species difficult to manage for grazing and hay production. Alternative summer annual crops such as teff may be preferred for livestock or hay production, because of greater management ease and high productivity. Additionally, unlike many other grasses including warm season annuals, teff can grow with minimal to no nitrogen (N) input and can have harvestable crop within 35-40 days compared to millets’ 60-75 days. Although teff has great potential for grazing and hay production, growers need more information about its management. Currently, little information is available about teff’s establishment, productivity, persistence, cultivar variation, response to cutting, and fertilization.

Introduction

Farming, in general, and grazing livestock enterprises, in particular, are risky business endeavors. Many livestock producers minimize their input costs by relying on cool-season grasses particularly tall fescue pasture, but at the same time expose themselves to risks associated with forage yields that fluctuate in response to variable environmental conditions. Use of warm-season annual forages is one simple way to diversify farming systems to help cope with drought. Producers have few choices of warm-season annual species to plant and many can be toxic. Other, non-toxic, warm-season annual species are available, but their management and suitability for both livestock and hay production can be challenging.

Origin and Adaptation

Teff, which means “lost” in Amharic (Ethiopia), is an annual, C₄, warm-season grass. Teff’s roots in history can be traced back to 3359 BC (Mengesha, 1965) and is commonly grown as a grain crop in Ethiopia. In Ethiopia, teff provides two-thirds of the human nutrition (Gressel, 2008). It is an intermediate between a tropical and temperate grass (Hunter et al., 2008; Stallknect et al., 1993). It has several advantages that make it a viable alternative over other summer annual forages, including its ability to thrive both in moisture-stressed and waterlogged soils (Seyfu, 1997; Roseberg et al., 2005). Although it can grow in a wide variety of soil moisture conditions, teff is gaining popularity due to its tolerance of drought conditions. In addition, teff grows successfully on marginal soils, including soils with high acidity and poor fertility (Seyfu, 1997; Gressel, 2008). In its native habitat, maximum production occurs with a growing season rainfall of 17 to 22 inches and a temperature range of 50°F to 85 °F (Davidson, 2004; 2005; 2006; Hunter et al., 2008).

Plant Characteristics

The plant is a fine-stemmed, bunch-grass with large crowns and many tillers (Roseberg et al., 2005) (Figure 1). It grows 10 to 50 inches tall with smooth, narrow, long leaves and slender culms (Davidson, 2004; 2005; 2006; Hunter et al., 2008; Norberg et al., 2009). The leaves are narrow and hairless and grow nearly as tall as the seedhead (Davidson, 2004; 2005; 2006). The inflorescence is an open panicle ranging from loose to compact and produces numerous small seeds (0.3-4g/1000 seeds). Teff has a very shallow, fibrous, massive growing root system (Davidson, 2004). The seed color ranges from white, red, brown and almost black, depending on variety (Davidson, 2004).
Cultural practice

Planting date and depth are very critical to a successful establishment of teff. In a study done at Kansas State University (Evert, 2009) in growth chambers, the ideal planting depth of teff was tested using five different depths along with different day/night temperatures. Seeds were planted at 0, .25, .5, 1, and 2 inch depths and at 59/66, 66/74, 74/81, 81/88 °F daytime/nighttime temperatures (Evert, 2009). The study concluded that teff grows best when planted 0.25 to 0.5 inch deep, and teff planted at 2 inch depth did not emerge (Evert, 2009). In the study focusing on day/night temperature, teff emerged slowest at the 59/66 °F daytime/nighttime temperature (Evert, 2009). Three days after planting (DAP), the two cooler temperatures (59/66 °F, 66/74 °F) had fewer plants emerge initially than in the warmer temperatures (74/81 °F, 81/88 °F) (Evert, 2009). Four days after planting, the only differences in emergence rates where measured between the coldest (59/66 °F) and warmest (81/88°F) temperatures (Evert, 2009). The differences between the coldest and warmest temperatures continued through 9 DAP. After 9 DAP the slow germination due to cooler temperatures caught up and the emergence rates showed no significant difference (Evert, 2009). Evert (2009) concluded that temperature greatly influences the rate of emergence. Due to low tolerance of cold soil temperature, teff should not be planted before the soil temperature reaches at least 50°F.

Under ideal growing conditions (adequate moisture and warm soil temperatures (60°F+), teff can germinate and emerge in 3 to 4 days after planting (Evert, 2009). However, in less ideal conditions, such as low soil temperature (nearing 50°F) or inadequate moisture, teff can take up to 12 days to germinate. On average, teff will have a germination period of 5 days (Gressel, 2008) (Table 1).
Table 1. General information on days to: germination, heading, maturity and plant height straw yield/plant and total shoot biomass/plant of Teff (Seyfu, 1993).

<table>
<thead>
<tr>
<th>Item</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days to germination</td>
<td>4</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>Days to heading</td>
<td>26</td>
<td>54</td>
<td>37</td>
</tr>
<tr>
<td>Days to heading to maturity</td>
<td>26</td>
<td>76</td>
<td>56</td>
</tr>
<tr>
<td>Plant height (cm/inches)</td>
<td>31/12</td>
<td>155/61</td>
<td>98/39</td>
</tr>
<tr>
<td>Grain yield/plant (g)</td>
<td>4</td>
<td>22</td>
<td>8</td>
</tr>
<tr>
<td>Straw yield/plant (g)</td>
<td>20</td>
<td>90</td>
<td>41</td>
</tr>
<tr>
<td>Total shoot biomass/plant (g)</td>
<td>26</td>
<td>105</td>
<td>49</td>
</tr>
</tbody>
</table>

Rainfall early in the growing season is critical to the development of teff, but after the early growth stages, the plant survives with little to no water (Gressel, 2008). Mengistu (2009) conducted an experiment to investigate the effect of water stress on growth stages of teff. The growth stages included were establishment (emergence to four leaf stage); vegetative (five leaves until booting); flag leaf-1 (stage immediately before emergence of flag leaf) and grain filling (pollination to milky ripeness). Water stress was induced by allowing the soil conditions to dry to 50% field capacity and 25% field capacity. These conditions were maintained through the growth stage (by watering accordingly). Once the growth stage was completed, the plants were watered back to field capacity and field capacity levels were maintained through the completion of the experiment. Mengistu (2009) concluded that teff was able to fully recover from the water stress during the first three growth stages, but the grain filling stage was adversely affected by water stress.

While it is often noted for its successful growth under drought conditions, teff can also tolerate water-logged soil conditions. Aside from rice, it is the grain most tolerant of these saturated soil conditions (Seyfu, 1997). Teff also grows well in a wide range of altitudes. It is grown from sea level up to 10,000 feet in the mountains of Ethiopia (Engels et al., 1991). Because of its wide range of growing conditions and versatility, it is grown across diverse ecological zones, temperature and soil regimes making it the staple food crop in Ethiopia.

Management

Planting Procedures

Establishing teff can be difficult due to small seed size, containing about 1.25 million seeds per pound (Hunter et al., 2007). Due to the extremely small seed size, a firm moist seed bed is important. Seeding rate varies from 2.2 to 8.04 lb/ac, with 4 to 7 lb/ac being the general recommendation (Hunter et al., 2009). Teff seeds can also come coated to make planting easier; seeding rates would typically double with coated seeds. Teff can germinate within 5-6 days if planted at a depth of 0.25 inches (Table 1). Because of small seed size, when drilling the seed, it is important not to drill deeper than 0.5 inch. The ideal planting depth of teff is .25 to 0.5 inch deep (Engels et al., 1991). If the seed is planted deeper than 0.5 inch deep emergence will be delayed or it will not emerge at all. For successful establishment, it is important to have a firm, weed-free seedbed (Seyfu, 1997). Once the seedbed is prepared, the seed can be either broadcasted or drilled using a Brillion or cultipacker seeder for optimum results (Davidson, 2004; 2005; 2006).

Currently, there is no herbicide labeled for teff. However, in most cases, the quick establishment of teff can provide ground canopy cover that reduces weed pressure. However, if present, weeds can reduce the potential yield of teff by 50% (Gressel, 2008). Broadleaf weeds in teff can be controlled with chemical and or mechanical mean, whereas annual grasses can cause major competition problems (Seyfu,
Since there are no labeled herbicides for teff currently, successful establishment that ensures good stand of teff is crucial. Successful establishment of teff includes variety selection, firm soil bed preparation, and timely planting.

Although teff requires significantly less N than other warm-season annuals, N fertilization has resulted in yield response (Gressel, 2008). In a study conducted in New York, N rates for teff were compared under 1, 2 and 3 cut systems, and yields monitored (Hunter et al., 2008). The cutting system was determined based on the individual location. Four rates were applied – 0, 50, 75, and 100 pounds of plant available N per acre rate (Hunter et al., 2008). From the study, they concluded the optimum rate of application to be 50 pounds per acre of plant available N with no major increases in yield as rates increased (Hunter et al., 2008). These results are in agreement with the current recommendation of N for teff which is 40 – 60 pounds per acre N. While applying N does lead to a significant increase in yields, when used excessively, teff is likely to lodge, leading to a large loss in yield (Rockstrom et al., 2008). Fertilization with P and K only increases yields in all crops when soils test is low in P and K.

As nitrogen fertilization is increased to stimulate yield, the chance of nitrate accumulation in commonly used summer annual grasses also increases, especially when growth is limited by moisture stress (Crawford et al., 1966; Emerick, 1974; Hanway and Englehorn, 1958; May et al., 1990; Murphy and Smith, 1967; Wright and Davison, 1964). Observations and limited research have implicated manure application in nitrate accumulation in both cool and warm-season annual grasses (Hanway and Englehorn, 1958; Mayo, 1895; Wright and Davison, 1964). Hanway and Englehorn (1958) found that significant amounts of nitrate accumulated in corn stalks that had been fertilized with manure. However, the nitrogen content of the manure was not documented making it hard to draw any firm conclusions as to the effect of nitrogen source and rate on the accumulation of nitrate in forages.

Readily available organic nitrogen sources such as biosolids and broiler litter could provide an economical fertilizer source for teff grown as forage. However, the tendency of teff to accumulate nitrates and the effect of supplying nitrogen as organic sources on the nitrate content of teff are unknown.

**Feed Value/Forage Quality and Biomass Yield of Teff**

Teff is growing in popularity as a forage crop not only because of its drought resistance and quick emergence, but also because it is a good quality hay crop. When harvested at vegetative/early boot stages and adequate N is supplied, crude protein of the teff is generally between 15 and 16 % on dry mater basis (Hunter et al., 2007) (Table 2). The nutritive value of teff (crude protein(CP), neutral detergent fiber (NDF) and acid detergent fiber (ADF) for livestock has been reported to be similar to most grasses used as hay or silage/haylage (Table 2). Teff is also high in amino acids and iron content (Gressel, 2008). Neutral detergent fiber (NDF) represents the total plant fiber or cell wall including hemicellulose, cellulose and lignin while ADF represents cellulose and lignin A wide range of biomass yield has been reported throughout the teff growing states.
Table 2. Sample yield and quality data throughout the United States.

<table>
<thead>
<tr>
<th>References</th>
<th>Biomass yield Ton/hectare</th>
<th>Nutritive value</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>California (Hunter et al., 2007)</td>
<td>5.56 - 6.53</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Mississippi (Lemus, 2009)</td>
<td>8.83</td>
<td>16-17</td>
<td>57-60</td>
<td>---</td>
</tr>
<tr>
<td>Montana (Hunter et al., 2007)</td>
<td>0.41 - 2.84</td>
<td>9.6-13.7</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Nevada (Davison, 2006)</td>
<td>3.9-4.6</td>
<td>16.2</td>
<td>63.7</td>
<td>34.7</td>
</tr>
<tr>
<td>New York (Hunter et al., 2007)</td>
<td>3.9 - 4.9</td>
<td>15-16</td>
<td>60.70</td>
<td>---</td>
</tr>
<tr>
<td>Oregon (Norberg, 2009)</td>
<td>4.0 - 6.0</td>
<td>11.0-13.0</td>
<td>60.1-62.0</td>
<td>36.2-42.8</td>
</tr>
<tr>
<td>Pennsylvania (Hall, 2007)</td>
<td>4.6 - 6.9</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>South Dakota (Twidwell et al. 2002)</td>
<td>1.3 - 5.3</td>
<td>10.7-17.4</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Virginia (Newman, 2010)</td>
<td>2.00 - 4.00</td>
<td>12-17</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Wisconsin (Hunter et al., 2007)</td>
<td>5.84 - 6.71</td>
<td>---</td>
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</tr>
</tbody>
</table>

Harvesting and Grazing

Teff for hay should be harvested in the late vegetative stages – pre-boot to early-boot stage (Hunter et al., 2007; 2008). The first harvest can occur approximately 50 to 55 days after planting the teff, with subsequent harvests 40 to 45 days after cutting, depending on the environmental conditions (Hunter et al., 2007). Since the re-growth of teff is highly dependent on leaf area left (aftermath), it is important to cut teff no shorter than 3 to 4 inches so re-growth will occur; any shorter cutting will stunt the crop. Teff can also be harvested as a high moisture crop and ensiled (Hunter et al., 2007, Hunter et al., 2008).

Although no grazing data is available, in addition to being used for hay and silage, teff can also be used for grazing (Figure 2). Under grazing conditions, it is important to graze teff at the pre-boot stage or earlier so that animals do not pull the teff out from the ground. It is also important to prevent forage loss from the animals trampling the plant, causing it to lodge. To prevent trampling, the first growth of teff should be cut for hay and graze the aftermath. This management practice will allow the teff plant to establish a stable root system that would help minimize being uprooted by the grazing animal. Additionally, teff fits nicely into a cool-season perennial grass-based system where the perennial grass enters dormancy during the summer months. Due to teff’s quick establishment, low water and nutrient requirements, teff can be used as an emergency crop during the summer months. This can be accomplished either by panting teff in a separate field or by inter-seeding teff into a dormant cool-season grass or legume stand.
Summary and Conclusion

Incorporating warm-season grasses into a cool season forage system offers a money saving solution, because less hay would need to be fed during the hottest part of summer. The main benefit of incorporating these forages into a system is that warm-season annual grasses are most productive during hot weather and can provide badly needed forage during times of water deficit. Teff is an annual warm-season grass from Ethiopia that has potential to help fulfill this need. Teff has several advantages that make it a viable alternative over other summer annual forages, including its ability to thrive both in moisture-stressed and waterlogged soils, and its lack of anti-quality compounds as found in sorghum-related annuals. Despite its small seed size, it germinates within 3-5 days and is an aggressive competitor once established. In its native habitat, maximum production occurs with a growing season rainfall of 11 to 22 inches and a temperature range of 50 to 85°F. During extremely dry summers such as 2007, a crop such as teff might make the difference between financial success or disaster.

Climate change in the coming decades may well require a shift from a cool-season forage base (that requires high moisture and soil fertility) to forages that use resources more efficiently and that can be grown in a wide array of soils. Although teff has great potential for grazing and hay production, more information about its cultural practice, establishment and overall management is needed before it can be widely adopted in forage production systems.

References


PHYSICALLY EFFECTIVE FIBER: ITS HISTORY IN DAIRY NUTRITION AND FUTURE IN EQUINE NUTRITION

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Summary

Physically effective NDF (peNDF) is defined as the physical characteristics of fiber (primarily particle size) that influence chewing activity and the biphasic nature of ruminal contents (Mertens, 1997). This is a characteristic of feedstuffs that has received significant attention, particularly in the area of dairy cow nutrition. The 2007 NRC Nutrient Requirements for Horses states that “Similar concepts have not been developed in horses, but research on the effect of fiber amount and type on digestion and gastrointestinal health is needed” (NRC, 2007). In the last 10 years there have been a number of important studies that examine this question of the physical form of fiber and the impact that form may have throughout the horse’s gastrointestinal tract as well as the overall health of the animal. Some excellent information can be found in these reviews (Van Weyenberg et al., 2006; Hill, 2007; Fritz et al., 2009; Santos et al., 2011). The objective of this paper is to provide some background in regard to this topic and its coverage in regard to dairy nutrition and to stimulate discussion in regard to the definition of fiber and physically effective fiber requirements for horses in the future. The first section will provide an overview of this topic from a dairy nutrition perspective meant to stimulate ideas and appreciation of the parallels in the equine industry. The second section will look more closely at the horse and some of the research that contributes to the question of fiber requirements.

Forage Particle Size and Physically Effective Fiber (Dairy)

Forage particle size (FPS), relative to the dairy industry, is a very important but also very complex topic. Dairy cows, being ruminants, require adequate fiber for proper rumen function. Fiber is required by the ruminant to maintain a healthy ruminal environment that allows ruminal microorganisms to flourish, which is necessary to achieve optimal digestion and feed efficiency. However, cattle not only have a chemical fiber requirement but also a physical fiber requirement. Cows need physical fiber to maintain the ruminal mat, stimulate chewing, and buffer the rumen. Longer particle size can decrease dry matter and energy intake and lead to sorting, a condition where cattle do not eat the ration as mixed, but rather eat certain parts of the ration and refuse others. It is thought that ration sorting can lead to subacute ruminal acidosis, a condition of abnormally low ruminal pH (< 5.5), because dairy cows generally sort against longer particles and for shorter particles. Not much is known about how cows decide what feed particles to sort for and against and also what factors influence and change feed sorting preference. It is well known that low ruminal pH has many detrimental effects on not only the rumen, but the whole animal. Acidosis can lead to decreased intake, digestion, and milk fat content and can cause diarrhea and lameness in addition to many other conditions. In addition, FPS must be short enough to allow proper fermentation during storage. Shorter particles are necessary to allow for adequate packing of the silage
which limits oxygen during storage thus preventing improper fermentation and molding. These conflicting factors make it difficult to describe the optimum particle size distribution for forages to be fed to dairy cattle.

Another important consideration regarding FPS is the method used to measure particle size distribution. Many systems currently exist to measure particle size and even more methods exist to use particle size data to calculate physically effective fiber in rations. However, since there is not a standard method for the dairy industry or dairy researchers several different systems are currently being used and their data are used interchangeably, though their results may not be comparable. Many of the systems attempting to estimate physically effective fiber are based upon the theory that there is a critical size threshold for particles leaving the rumen and that particles above this threshold are effective because they stimulate chewing to promote their particle size reduction and rumen escape. However, the research that the currently accepted critical particle size is based on is aged, and the feeding systems that were used when it was conducted were very different than the feeding systems being used in modern dairy production.

Dairy cattle nutrition has changed dramatically, even in the last 30 years. In order to take advantage of great genetic gains made in current dairy breeds, rations that are much higher in energy must be fed. Common ways to increase energy intake are to decrease the forage to concentrate ratio, which increases the energy density of the diet, and to decrease FPS, which increases dry matter intake. These factors make cows more susceptible to acidosis and studying FPS will help allow dairy nutritionists to push to the limits of energy intake while maintaining ruminal health.

**Fiber requirements (Dairy)**

The National Research Council (NRC, 2001) recommended a minimum NDF level of 25% of ration DM with a forage NDF level of 19% of ration DM for lactating dairy cows. The NRC based its recommendations on NDF as it is the fiber measure that best separates structural from nonstructural carbohydrates and is comprised of most of the compounds that are considered fiber (NRC, 2001). Forage NDF is included in these recommendations because NDF from nonforage sources is estimated to be about 50% as effective at maintaining chewing activity, and ruminal pH; therefore for every 1 percentage unit decrease in forage NDF, total NDF content should be increased by 2 percentage units (NRC, 2001). The minimum level of NDF required by dairy cows is a product of cow and ruminal health (NRC, 2001). Forages are the major supplier of NDF in rations and their slower fermentation and physical characteristics are essential for maintaining ruminal health. The decreased digestibility of forage helps to maintain an optimal ruminal environment by diluting the effects of large amounts of volatile fatty acids produced by NFC fermentation. Fiber (NDF) with adequate length is thought to increase chewing in cattle, which increases salivary secretion of NaHCO3 and buffers the ruminal digesta (Allen, 1997; Nocek, 1997; Krause et al., 2002).

Saliva production and its ability to buffer the rumen is very important to high producing dairy cows. Large amounts of saliva enter the rumen of lactating dairy cows, approximately 98 to 190 L/d (Bailey, 1961). Bailey (1961) found that saliva secretion during eating was 2 to 4 times higher than when at rest. Beauchemin *et al.* (2008) showed that rate (g/min) of salivation stayed constant during eating; however, changes in the rate of eating affected the amount of saliva secreted per unit of DMI when cows were fed barley silage, alfalfa silage, long-stemmed alfalfa hay, or barley straw, these results agree with the previous research of Bailey (1961). Particle size, DM, and NDF content of forages are factors affecting rate of eating and time spent eating; chewing rate was decreased and thus saliva secreted per unit of DMI increased when ration particle size, DM, and NDF were increased (Bailey, 1961; Beauchemin *et al.*, 2008).

Chewing was probably first suggested as a means of estimating a feed’s effectiveness at maintaining ruminal health by Balch (1971). Sudweeks *et al.* (1981) continued this work with their roughage value index system and since then several methods have been suggested to estimate the
effectiveness of fiber. Most methods relate a feed’s effectiveness to its ability to stimulate chewing activity in the cow. Mertens (1997) first defined the concept of effective NDF (eNDF) as the sum total ability of a feed to replace forage or roughage in a ration so that the percentage of fat in milk produced by cows eating the ration is effectively maintained. Another interrelated term was also introduced by Mertens (1997) to describe a slightly different characteristic of forage. Physically effective NDF (peNDF) is defined as the physical characteristics of fiber (primarily particle size) that influence chewing activity and the biphasic nature of ruminal contents (Mertens, 1997). This measure combines the physical and chemical properties of a feedstuff to predict chewing and is a product of a feed’s physical effectiveness factor (pef) and its NDF content. Physically effective NDF differs from other measures of effective fiber (Balch, 1971; Sudweeks et al., 1981) in that it is based on the relative effectiveness of NDF to promote chewing rather than being expressed as min of chewing per kg of DMI (Mertens, 1997). This eliminates animal variation from being attributed to a feed’s effectiveness because chewing per unit of feed varies with animal size, breed, and intake (Mertens, 1997). The more specific concept of peNDF is easier to measure than eNDF since peNDF is only concerned with the effect of a feed on chewing and the ruminal mat, which are mostly influenced by particle size, NDF, and DM content; although fragility and specific gravity probably have a small influence on peNDF as well. Mertens (1997) developed a pef system to calculate peNDF that ranges from 0 (feed has no effectiveness in promoting chewing) to 1 (feed has maximum effectiveness in promoting chewing); a hypothetical long grass hay with 100% NDF was defined as having a pef of 1 and an estimated 240 min of chewing per kg of DM or NDF for nonlactating cows eating 0.4 to 2.0 times maintenance. A pef table was created that classified various feedstuffs by types and physical forms and assigned each feedstuff a pef value that could be multiplied by the NDF content of a corresponding feedstuff to achieve its peNDF. This peNDF method not only includes NDF content and particle size but differences in NDF composition, specific gravity, and fragility would be partially accounted for by classifying different feedstuffs separately.

However, Mertens (1997) also developed a laboratory assessment of peNDF where feeds are separated via dry vertical shaking and the proportion of the samples retained above a 1.18-mm sieve (1.65-mm sieve diagonal) are multiplied by sample NDF content. This method is based on 3 assumptions: NDF is uniformly distributed over all particles, chewing activity is equal for all particles retained on a 1.18-mm sieve, and fragility is not different among sources of NDF (Mertens, 1997). The first assumption can be eliminated if the portion of samples retained on a 1.18-mm sieve is directly analyzed for NDF. Measurement of peNDF has become widely used in dairy cattle nutrition and research, but it is often measured differently from Mertens’ (1997) procedure. Many instead use the Penn State particle separator. Another problem is that the NRC (2001) failed to publish a requirement for peNDF because of a stated lack of a standard, validated method to measure effective fiber of feeds or to establish requirements for effective fiber. A weakness of using the latter peNDF method is that NDF fractions are not chemically identical for all forages. NDF composition (the ratio of hemicellulose:cellulose:lignin) of forage varies wildly (Van Soest et al., 1991) and is affected by species, maturity, and storage method. Using the pef system developed by Mertens (1997) that includes values that differ with type of feedstuff would partially correct for differences across NDF compositions and may improve the correlation between peNDF and chewing in the literature.

**Defining particle size**

The sieve size 1.18 mm has been widely used as the size at which feed particles retained on or above are considered physically effective for dairy cows. This number originated from research of Evans et al. (1973) and Poppi et al. (1980), where resistance of particles leaving the rumen of cattle and sheep was measured. It was determined that 1.18 mm was a threshold particle size (not mean) for both cattle and sheep for greatly increased resistance to particles leaving the rumen and < 5% of fecal particles are generally retained on a 1.18-mm sieve. It should be noted that a wet sieving technique was used in these studies to measure particle size.
Some researchers have suggested that the critical particle size for rumen escape in dairy cattle may be larger than 1.18 mm. Yang et al. (2001) discovered that when feeding cows diets composed of alfalfa silage, barley silage, alfalfa hay, and steam rolled barley their fecal mean particle length averaged 1.86 mm and that 24.8% of fecal particles were retained above a 1.18-mm sieve and 3.1% of particles were above a 3.35-mm sieve. There was no effect of FPS on fecal particle size. Oshita et al. (2004) completed a study with 4 different diets; long alfalfa hay, chopped alfalfa round bale silage, long orchard grass hay, and chopped corn silage and measured fecal particle size; their percentage of fecal particles retained on a 1.0-mm sieve were: 28.0, 25.2, 12.6, and 26.2% respectively. Other studies that reported larger fecal mean particle size than traditionally expected are Kononoff and Heinrichs (2003) where fecal mean particle size averaged 1.13 and 1.03 mm respectively; the rations fed were composed mainly of ground corn with corn silage and alfalfa haylage respectively. The authors also reported that the proportion of fecal particles > 1.18 mm was 48 and 46% of DM respectively and that FPS did not have an effect on fecal mean particle size in either study.

Maulfair et al. (2011) fed 4 diets of increasing FPS (achieved via grass hay chop length) and calculated the geometric mean particle size (Xgm) of feces 2 ways; 1. including only particles retained on the smallest sieve and above and 2. including all sample DM by calculating the amount of soluble DM lost during the sieving process. The retained Xgm procedure (using only particles retained on ≥ 0.15-mm screens) did not result in any differences among rations and retained Xgm of all rations averaged 1.13 mm. The total Xgm procedure (using all particle fractions) had much lower values than retained Xgm and also had a significant linear contrast for fecal Xgm to decrease with increasing TMR particle size, decreasing from 0.33 to 0.31 mm for the shortest to the longest ration respectively. The fecal particle distribution resulted in approximately 16% of particles > 3.35 mm and 37% > 1.18 mm as a proportion of DM retained on the 0.15-mm sieve. The distribution had approximately 7% of particles > 3.35 mm and 17% > 1.18 mm as a proportion of total sample DM. These results, and the results of the previously cited studies, are much higher than those observed by Poppi et al. (1985) where < 5% of particles were > 1.18 mm as a proportion of total sample DM in mature steers fed exclusively forage. It is clear, based upon all of this data, that 1.18 mm is not the critical threshold for rumen escape in modern lactating dairy cows; however more research is needed to determine the exact size and what factors can lead to variance in this critical size.

Grazing Evolution

Horses, like cattle, are herbivores and depend on fiber as a significant portion of their diets. Both species are well suited to their nutritional environment due to a number of different physical and behavioral adaptations. Prior to their domestication, the diet of horses and cattle consisted mainly of grass and legume forages obtained by grazing. However, these two species have adopted very different feeding strategies (Hummel et al., 2008). Making a general comparison of cattle to horses:

- Cattle are meal feeders, while horses graze more continuously over a 24 hour period.
- Cattle meals are separated by periods of rumination.
- Cattle may spend less time, at initial ingestion, chewing each gram of dry matter (Janis et al., 2010). This difference is compensated for through rumination.
- Dentition in cattle is not as effective at comminution of plant material upon initial ingestion.
- Cattle have a slower rate of passage, resulting in a higher digestive efficiency.
- Dry matter intake has a lower limit in cattle than horses due to this slower rate of passage and rumen fill.
- Cattle and horses rely on microbial digestion of dietary structural carbohydrates to provide energy and nutrients.

Neither cattle nor horses ingested diets containing the ratios of particle size seen in the diets of domesticated animals today. The increase in the amount of smaller particles and reduction of fiber in both cattle and horse diets lends a number of advantages; improved digestibility, increased energy and nutrient
density, consistency of nutrients and energy, and ease of handling and transport to name a few. However, the argument can also be made that this dietary change does not fit well with the feeding strategy and anatomy (see below) that has evolved over millions of years of evolution. From a production (milk or athletic) standpoint the cow or horse kept domestically today needs more nutrients and energy than any wild animal could obtain, but the form that that diet takes needs to be considered with the anatomical and behavioral characteristics of the animal being fed. There is evidence that the risk of many health problems in both cattle and horses could be reduced through increased attention to the amount and form of fiber included in the diet (Forbes and Kyriazakis, 1995). The dairy industry has already invested significantly in research studying the fiber requirements of the cow.

**Gastrointestinal Anatomy and Fiber**

The nutritionist would be foolish to ignore gastrointestinal anatomy when formulating the diet of any animal. However, at times it seems that equine nutritionists do not always give the horse’s gastrointestinal tract the same attention that ruminant nutritionists give to their animals. The gastrointestinal tract is the physiologic system through which the nutrients and energy provided must be processed, so that animals can make use of what is provided in the diet. For both cattle and horses, fiber is often one of the larger dietary inputs, so throughout both tracts there are obvious adaptations to handle the range of molecules that fit under the term fiber. This section will focus on the horse with comparative examples of the cow given where appropriate.

**Mouth**

The fresh or preserved forages that horses and cattle ingest must first be chewed to reduce particle size. The technical term for this is comminution, simply defined as the reduction of particle size and volume through grinding or crushing. Both species have well developed, but different, strategies to accomplish this first step in digestion of fiber. It is interesting to note that it is likely there is little reduction in lignified particle size that occurs through the gastrointestinal tract, other than that accomplished via mastication (Hummel et al., 2008). In both cattle and horses chewing stimulates saliva production. Saliva plays a number of important roles in both species, including cleansing of dentition, bolus formation, lubrication, buffering, and enzymatic digestion. The amount of saliva that is produced in both species is related to chewing activity (Alexander and Hickson, 1970; Van Soest, 1994). In addition, it has been shown in both species that the physical composition of the diet in terms of an increase in fiber length or particle size will increase the amount of chewing (Bonin et al., 2007; Fritz et al., 2009). This is not necessarily a linear relationship, so attention needs to be paid to an appropriate range of length to stimulate chewing and saliva production.

Horses chew food once while cattle have particle size separation mechanisms (rumination) that allow them to chew longer particles numerous times. To make up for the inability to chew food twice, the horse has molars that are more effective than cattle’s molars at reducing particle size on the first pass. Add this to the fact that horses chew longer and have a greater musculature in their jaws and it is clear that both species are adept at reducing long fibers to a suitable size for digestion in the very early regions of their gastrointestinal tracts. What happens if we change the physical make up of the feed in a way that reduces the need for chewing?

**Stomach**

The equine stomach has been studied extensively due to its accessibility and important health concerns such as ulcers (Merritt, 2003). Briefly, the horse’s stomach is divided into two major regions characterized by the tissue that lines the surface of those regions. The upper half of the stomach is lined by a stratified squamous epithelium, while the lower half of the stomach is lined with a glandular mucosa responsible for the secretion of hydrochloric acid, pepsin, and a protective mucous layer. In light of this paper, I quote here a few lines from Dr. Merritt’s 2003 review of equine stomach physiology. “I (Merritt) suggest that they (microbes) colonize within the coarser fibrous ingesta, which collects towards the top of
the stratified mat of gastric contents, where the pH of the contents is more to their liking because the mat has not been fully penetrated by gastric acid. This higher pH is augmented by swallowed parotid saliva, which amounts to 10-12 L/d in an adult horse and has a bicarbonate concentration about twice that of plasma (Alexander, 1972).” The parallels between this description and that of the environment within the rumen are striking. Further it highlights how fiber length may play an important role in the normal functioning of the equine stomach. As in the ruminant, if dietary particle size is reduced sufficiently, the physical dynamics described here will change. Instead of the heterogeneous layered contents there will be a more homogeneous content. This more homogeneous content in concert with less saliva production is likely to increase the risk of ulceration in the stratified squamous epithelium. How does the normal functioning of the stomach change when particle size is reduced?

**Small intestine**

The majority of fiber digestion does not occur in the equine small intestine. While it has been demonstrated that there is a microbial population present, it is much smaller than that present in the stomach or the cecum and colon (Mackie and Wilkins, 1988). What is important to note is the large influx of fluid that occurs in the equine duodenum. While there has not been an extensive amount of research on this, the review on equine salivary and pancreatic secretions presented by Alexander and Hickson (1970) indicates that the lesser salivary production of the horse when compared to the cow is somewhat compensated for by the large pancreatic secretion in the horse. It is likely that this large volume of secretion is both helpful for the digestion and absorption that occurs in the small intestine, but also creating a substrate that will be delivered to the cecum and colon that is optimal for fermentation. We could find no work that demonstrates that the physical makeup of the diet has any impact on this pancreatic outflow, but this question may be worthy of investigation. Certainly, secretions in other regions of the gastrointestinal tract are influenced by the physical makeup of the diet so it is possible here.

**Cecum, ventral colon, and dorsal colon**

The equine hindgut is often described as being analogous to the rumen and the two structures are similar particularly in regard to their function in a grazing herbivore. One of the most interesting similarities for the current discussion is the ability to separate the particulate and liquid components of digesta as well as particles of different size (Drogoul et al., 2000; Santos et al., 2011). It is for this reason that the main fermentative structures in the equine hindgut are listed separately as they are in the title of this section. Each of these regions has anatomical characteristics that make them unique, and are additionally separated by anatomical structures that help in the selective retention of particles of different size. This selective retention of larger particles has been suggested to occur at the cecocolic orifice and the pelvic flexure, while the retention of fluid may occur at the transition from the right dorsal colon to the transverse colon (Drogoul et al., 2000; Santos et al., 2011). Another important similarity of the hindgut with the rumen is the reliance on a healthy microbial ecosystem to maintain the digestive function of these structures.

The hindgut environment of the horse has not been studied nearly as closely as that of the cow’s rumen, but there are a number of recent studies that lend clues in regard to the impact that fiber and particle size may have on the hindgut environment. One study examined the impact of feeding textured concentrate meals with hay compared to feeding only hay on the consistency and characteristics of digesta removed from the right dorsal colon and feces (Lopes et al., 2004). Horses in this study consumed between 1.6 to 2.0% of their body weight/d of the grain on an as fed basis. While numerous other characteristics were described in their paper, the observational differences in the colonic digesta and feces collected are interesting. The colonic digesta from horses fed only hay had a distinct particulate and liquid phase, while the feces were well formed. This is in contrast to the digesta from the grain fed horses that was much more homogeneous, i.e. it did not have a clear separation between the liquid and particulate phases and yet the feces were described as less formed. In addition it was noted that there was a frothy appearance to the colonic contents and that they flowed more spontaneously through the fistula. Clearly
there are a number of characteristics of these two diets that may have affected these changes, but particle size and dietary fiber are logical considerations. Another recent study looked at the fiber length and quality (harvested at vegetative stage or late bloom) on mean retention time and digestibility with detail on individual regions of the gastrointestinal tract (Miyaji et al., 2011). Both fiber length and forage quality were found to have impact on retention time and digestibility in specific regions; however, these differences were often washed out when total tract characteristics were examined. This is important because without studies that can examine specific anatomical regions researchers may not be able to accurately characterize important impacts of diets with different fiber characteristics.

Fiber’s Influence on Health and Production

Dairy

The ruminant animal is unique in the animal kingdom because to achieve optimum feed intake and efficiency its ruminal environment must be maintained within certain physiological limits. These limits are required to be maintained to provide a favorable symbiotic relationship between ruminant host and ruminal microorganisms. The ruminant should provide the microorganisms an environment of limited oxygen, relatively neutral pH, constant temperature, relatively continuous influx of water and organic matter, constant removal or neutralization of waste products and indigestible matter, and mean retention time greater than microbial generation time (Van Soest, 1994). The feeding systems necessary in modern dairy cattle production have made it increasingly difficult to provide a ruminal environment that stays within all of these narrow constraints. The enormous energy requirements of high producing dairy cattle require dairy farmers to feed cattle rations of increasing DMI and levels of concentrate feeds. One of the problems associated with this type of feeding system is an increased susceptibility to ruminal acidosis.

Ruminal acidosis is a condition where ruminal pH falls below a certain physiological range of which there are 2 distinct types. The first, more severe, condition is referred to as acute ruminal acidosis and it is generally defined as such when ruminal pH drop below 5.0; the second, less severe, condition is referred to as subacute ruminal acidosis (SARA) and it is generally defined as such when ruminal pH falls in the range of 5.0 to 5.5 (Krause and Oetzel, 2006). The decreased ruminal pH that causes acute acidosis is thought to be mainly caused by an increase in ruminal lactate, while the decreased ruminal pH that causes SARA is thought to be mainly caused by an accumulation of volatile fatty acids (Britton and Stock, 1986). Clinical signs of acute acidosis include anorexia, abdominal pain, tachycardia, tachypnea, diarrhea, lethargy, staggering, recumbency, and death (Krause and Oetzel, 2006). Clinical signs of SARA can be delayed for weeks or months after the bout of depressed ruminal pH. There are many negative side effects associated with SARA, including: decreased DMI (Britton and Stock, 1986; Nocek, 1997), decreased milk production and milk fat content (Nocek, 1997), lameness (Nocek, 1997; NRC, 2001; Stone, 2004), decreased feed efficiency (Huntington, 1993; Nocek, 1997), rumenitis (Brent, 1976), and liver abscesses (Brent, 1976; Britton and Stock, 1986).

While acute acidosis is a more severe condition, the incidence of SARA is much higher in dairy cattle and thus has a greater economic impact. In a case study of a 500-cow dairy in central New York, Stone (1999) estimated that SARA could cost up to $475 per cow per year in lost production and components only. Therefore, SARA should be heavily focused on for research and prevention. Stone (2004) suggested that there are 4 types of dairy cattle that are at high risk of developing SARA, they are: transition cows, cows with high DMI, cows that experience high variability in ration composition and meal patterns, and cows fed poorly formulated rations. This is closely related to the suggestion of Krause and Oetzel (2006) that there are 3 major causes of SARA in dairy herds: excessive intake of rapidly fermentable carbohydrates, inadequate ruminal adaptation to a highly fermentable diet, and inadequate ruminal buffering caused by inadequate dietary fiber or inadequate physical fiber. Dairy cattle can consume excessive amounts of fermentable carbohydrates in 2 ways, through high levels of concentrate in the ration or moderate levels of concentrates at high DMI (Krause and Oetzel, 2006). The ruminant should be adapted slowly to ration changes, especially when going from high forage to low forage diets,
to allow the ruminal microorganism profile to adapt (Van Soest, 1994) and ruminal papillae to lengthen (NRC, 2001).

**Equine**

The horse is well adapted to a similar nutritional environment as that of the cow with some subtle differences discussed above. It is clear that the tolerance intervals of pH, temperature, water, passage rate, oxygen, and substrate availability will be as important to maintaining gastrointestinal health in the horse as they are in cattle. Acidosis in the fermentative regions of the gastrointestinal tract is one more excellent example of an important parallel between cattle and horses that are fed rapidly fermentable carbohydrates. Abnormal decreases in pH can negatively impact any region of the equine tract. Like the cow, subclinical acidosis is likely to result in decreases in production, albeit in athletic production. The two gastrointestinal regions most commonly affected by acidosis in the horse are the stomach and hindgut (Hintz, 2000; Merritt, 2003).

In his review of the equine stomach, Dr. Merritt (2003) highlights some of the diet related factors that contribute to stomach ulceration in the horse. These include rapid fermentation of nonstructural carbohydrates, the associated rapid production of VFAs, and, under grain feeding conditions, the lack of a fibrous mat that facilitates a lower pH region where more fibrolytic bacteria reside and a buffering of the acid secreted by the glandular mucosa. In addition, he highlights research that indicated that the fibrous mat facilitates a progressive drop in pH from the dorsal of ventral regions of the equine stomach (Baker and Gerring, 1993). A recent epidemiologic study of horses not in race training suggests that a lack of dietary fiber, high grain intake, and a lack of water availability are associated with an increased risk of significant ulceration in the stomach (Luthersson et al., 2009). Of course there is a high prevalence of gastric ulcers in horses in training as well (Jonsson and Egenvall, 2006), and while it has not been specifically examined, the malaise associated with ulcers is likely to have a negative impact on performance.

Carbohydrates that are not digested and absorbed in the small intestine will be fermented in the cecum and colon of the horse. Although obvious to many, this means both structural and nonstructural carbohydrates, the difference being the rate of fermentation and the associated pH. The nonstructural carbohydrates, in most cases starch, will be fermented rapidly and produce a lower pH environment. Numerous studies have demonstrated a significant decrease in the pH of both feces and cecal or colonic ingesta of horses fed a high grain diet (de Fombelle et al., 2003). It is generally accepted that an acidic environment in the equine hindgut can result in numerous negative health consequences including colitis, colic, and laminitis (Clarke et al., 1990; Kronfeld and Harris, 2003). Through more thought out addition of dietary fiber, it is likely that the risk of these health disorders could be reduced, and welfare and performance improved.

**Conclusions**

We suggest that research into fiber requirements and physically effective fiber may be as beneficial to the equine industry as it has been for the dairy industry. Most recommendations for feeding horses point out the importance of forage, and often even highlight the evolution of the horse as a grazing species. However, the point that is still missing is that most horses are no longer kept on the open plains of North America. Through intelligent design of both the chemical and physical makeup of the diets that we provide to the horse we can provide a diet that supports athletic production, is healthy, and does so in the environments that the horse is kept today. The best idea should not be to go back to feeding horses the way they ate millions of years ago, but to move forward by incorporating what we know of the past in our feeding practices of today and tomorrow. In order to this, the equine research community will need to spend a considerable amount of time and resources studying dietary fiber.
Literature Cited


FORAGE: THE OFTEN OVERLOOKED SOURCE OF OMEGA-3 FATTY ACIDS

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Summary

Over the past 10 years, there has been interest in supplementing horses with omega-3 fatty acids for their perceived anti-inflammatory and immuno-modulatory benefits. Supplementation of omega-3 fatty acids is typically accomplished with flaxseed, flax (linseed) oil, or fish oil. A very rich source of omega-3 fatty acids that is often overlooked is forage. Although low in total fat, α-linolenic acid makes up 25-65% of available fatty acids in forages. Vegetative pasture forage, particularly in the spring and fall is higher in α-linolenic acid than forage conserved as hay. However, the fatty acid composition of forages is subject to variation due to species, growth stage, climatic conditions, and harvesting and storage methods. The faster maturing warm-season grass hays generally have about half the α-linolenic acid as cool-season grass and legume hays, whereas there are relatively minor differences in fatty acid composition between cool-season grass and legume hays fed to horses. Because forages typically make up a large portion of the diet (at least 1% bodyweight), they contribute greatly to the horse's omega-3 fatty acid intake. In fact, the ratio of omega-6 to omega-3 fatty acids in typical equine diets, including those that are relatively high in fat is well below 10:1 (and in most cases, below 5:1). Omega-3 fatty acids supplied by forage, coupled with the relatively low total and saturated fat content in typical equine diets may be one reason why studies on omega-3 fatty acid supplementation have failed to show dramatic changes in inflammatory and immune responses, as have been observed in humans.

Essential Fatty Acids

Horses require a dietary source of the omega-6 fatty acid, linoleic acid (LA; 18:2\(n\)-6) and the omega-3 fatty acid α-linolenic acid (ALA; 18:3\(n\)-3). Mammals lack the Δ12- and Δ15-desaturase enzymes necessary for insertion of a double bond in an 18-carbon fatty acid at the omega-6 (or Δ12) or omega-3 (or Δ15) positions. Therefore, LA and ALA cannot be synthesized by the horse and are deemed “essential.” By comparison, plants and algae contain ample amounts of Δ12- and Δ15-desaturase and, as a result, LA and ALA are two of the most prevalent fatty acids found in plant tissues and oils.

LA and ALA can be oxidized for energy or incorporated into cell membranes (where they contribute to membrane fluidity), but otherwise have very few direct biological effects. Rather, the dietary essentiality of LA and ALA is based on their role as precursors for the biosynthesis of longer-chain omega-6 and omega-3 fatty acids that help regulate many biological processes in the body. ALA is the “parent” omega-3 fatty acid and can be elongated and desaturated by the horse to form eicosapentaenoic (EPA; 20:5\(n\)-3)) and docosahexaenoic (DHA; 22:6\(n\)-3) acids (Figure 1). In the omega-6 family, LA competes for the same elongase and desaturase enzymes to form arachidonic acid (ARA; 20:4\(n\)-6). These long-chain polyunsaturated fatty acids are known to have significant effects on inflammation and immune responses, attributed in part to their ability to give rise to various eicosanoids (prostaglandins, prostacyclins, leukotrienes, and thromboxanes) and other potent biological mediators (isoprostanes, neuroprostanes, lipoxins, resolvins, and protectins) (Figure 1). ARA, EPA and DHA can also alter cell
receptor signaling, gene expression and protein synthesis, ultimately impacting the biological response to trauma and infection.

**Why the Interest in Omega-3?**

Both omega-6 and omega-3 fatty acids contribute to normal inflammatory and immune responses, but the relative abundance of omega-6 versus omega-3 fatty acids in cell membranes can sway the final outcome. In simplistic terms, eicosanoids derived from ARA stimulate stronger pro-inflammatory responses, whereas those originating from EPA produce weaker inflammatory reactions (Figure 1). It must be emphasized, however, that it is really the balance of the different eicosanoids produced that generates the final biological response.

Research in humans and other species has demonstrated a reduction in inflammation and enhanced cell-mediated immunity with greater inclusion of omega-3 fatty acids in the diet (Calder, 2006). Research in horses has revealed variable success with either ALA (via flaxseed or linseed oil) or EPA and DHA (via fish oil or seal blubber) addition to the diet. In some studies ARA-derived eicosanoids and pro-inflammatory cytokine production from *ex vivo* stimulated immune cells have been reduced (Hall *et al.*, 2004a,b; Henry *et al.*, 1990; Morris *et al.*, 1991; Vineyard *et al.*, 2008), whereas other studies have observed no effect of omega-3 fatty acid supplementation on these inflammatory mediators (Hall *et al.*, 2004b; Henry *et al.*, 1990; Vineyard *et al.*, 2010; Woodward *et al.*, 2007). A limited amount work conducted *in vivo* in horses with osteoarthritis, recurrent airway obstruction (heaves), culicoides sensitivity, or endotoxin infection has shown little to no improvement in clinical signs of inflammation after omega-3 supplementation (Friberg and Logas, 1999; Henry *et al.*, 1991; Khol-Parisini *et al.*, 2007; Manhart *et al.*, 2009; O’Neill *et al.*, 2002). Conflicting observations have also been made in regards to the effects of omega-3 fatty acid supplementation on innate and acquired immune function in horses. Omega-3 fatty acid supplementation has been shown to increase (Vineyard *et al.*, 2008) or have no impact (Hall *et al.*, 2004b; Vineyard *et al.*, 2007) on antibody production in response to antigen or vaccination administration. Perhaps more consistently, relatively high rates of omega-3 fatty acid supplementation do not appear to enhance lymphocyte proliferation or the ability of neutrophils to phagocytize and oxidize.
bacteria in horses (Vineyard et al., 2007, 2008, 2010). Collectively, research findings in horses suggest that omega-3 fatty acids can exert some influence over the inflammatory process, but more research is needed to verify the practical value of using omega-3 fatty acids to attenuate inflammation in horses with chronic inflammatory diseases (e.g., osteoarthritis, heaves, obesity).

**Forages Can Be a Rich Source of Omega-3 Fatty Acids**

Unless an oil or high fat ingredient (e.g., rice bran, flaxseed) is added to the diet, equine rations are generally low (< 4% DM) in fat. Nonetheless, the majority of fat consumed by the horse consists of unsaturated fatty acids, even when fat-rich feedstuffs are added to the diet (Table 1). Cereal grains (e.g., oats, corn, barley), grain by-products (e.g., wheat middlings, wheat bran), and soybean meal, though low in total fat, contain a high proportion of that fat in the form of the omega-6 fatty acid, LA. Similarly, many of the vegetable oils added to equine diets (e.g., corn oil, soybean oil), as well as rice bran and whole soybeans contain a high percentage of LA. Of the oils routinely added to feeds, only soybean and canola oils contain modest amounts of ALA (omega-3). Good sources of ALA have traditionally included flaxseed and flax (linseed oil). More recently, interest in omega-3 fatty acids has led to the inclusion of marine fat sources in equine diets, including a variety of fish oils (e.g., menhaden, cod liver, salmon, herring), seal blubber, and algae supplements, which are rich in the long-chain omega-3 fatty acids EPA and DHA (Table 1).

**TABLE 1: Total fat and fatty acid composition of feedstuffs commonly used in equine diets.**

<table>
<thead>
<tr>
<th>Feed</th>
<th>Crude Fat (% DM)</th>
<th>SFA</th>
<th>MUFA</th>
<th>PUFA</th>
<th>LA</th>
<th>ALA</th>
<th>EPA &amp; DHA</th>
<th>Ratio of Omega 6:3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forages</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grass hay, cool-season</td>
<td>2.5</td>
<td>28</td>
<td>5</td>
<td>67</td>
<td>22</td>
<td>45</td>
<td>0</td>
<td>0.49 : 1</td>
</tr>
<tr>
<td>Grass hay, warm-season</td>
<td>2.0</td>
<td>41</td>
<td>5</td>
<td>52</td>
<td>24</td>
<td>28</td>
<td>0</td>
<td>0.86 : 1</td>
</tr>
<tr>
<td>Grass pasture, cool-season</td>
<td>3.0</td>
<td>20</td>
<td>6</td>
<td>72</td>
<td>18</td>
<td>54</td>
<td>0</td>
<td>0.33 : 1</td>
</tr>
<tr>
<td>Grass pasture, warm-season</td>
<td>3.0</td>
<td>22</td>
<td>3</td>
<td>76</td>
<td>16</td>
<td>60</td>
<td>0</td>
<td>0.27 : 1</td>
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<tr>
<td>Legume hay</td>
<td>5.0</td>
<td>34</td>
<td>5</td>
<td>62</td>
<td>18</td>
<td>54</td>
<td>0</td>
<td>0.55 : 1</td>
</tr>
<tr>
<td>Concentrates</td>
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<td>Oats</td>
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<td>20</td>
<td>37</td>
<td>43</td>
<td>41</td>
<td>2</td>
<td>0</td>
<td>21 : 1</td>
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<td>Corn</td>
<td>4.2</td>
<td>17</td>
<td>31</td>
<td>52</td>
<td>50</td>
<td>2</td>
<td>0</td>
<td>25 : 1</td>
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<tr>
<td>Wheat bran</td>
<td>3.5</td>
<td>18</td>
<td>18</td>
<td>63</td>
<td>58</td>
<td>5</td>
<td>0</td>
<td>12 : 1</td>
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<tr>
<td>Soybean meal</td>
<td>1.6</td>
<td>24</td>
<td>21</td>
<td>55</td>
<td>45</td>
<td>7</td>
<td>0</td>
<td>8 : 1</td>
</tr>
<tr>
<td>Fat sources</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td>Corn oil</td>
<td>100</td>
<td>15</td>
<td>30</td>
<td>55</td>
<td>53</td>
<td>1</td>
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<tr>
<td>Soybean oil</td>
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<td>25</td>
<td>58</td>
<td>50</td>
<td>7</td>
<td>0</td>
<td>7 : 1</td>
</tr>
<tr>
<td>Fish oil (menhaden)</td>
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<td>32</td>
<td>35</td>
<td>2</td>
<td>2</td>
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<td>0.13 : 1</td>
</tr>
<tr>
<td>Rice bran</td>
<td>20</td>
<td>22</td>
<td>39</td>
<td>39</td>
<td>37</td>
<td>2</td>
<td>0</td>
<td>19 : 1</td>
</tr>
<tr>
<td>Flaxseed</td>
<td>40</td>
<td>9</td>
<td>19</td>
<td>72</td>
<td>15</td>
<td>57</td>
<td>0</td>
<td>0.26 : 1</td>
</tr>
<tr>
<td>Soybeans, whole roasted</td>
<td>22</td>
<td>15</td>
<td>24</td>
<td>61</td>
<td>53</td>
<td>7</td>
<td>0</td>
<td>8 : 1</td>
</tr>
</tbody>
</table>

1 SFA=saturated fatty acids; MUFA=monounsaturated fatty acids; PUFA=polyunsaturated fatty acids; LA=linoleic acid; ALA=α-linolenic acid; EPA=eicosapentaenoic acid; DHA=docosahexaenoic acid.

Often missing from the tabulation of omega-3 fatty acid intake is the ALA provided by forages. Forages are low in total fat (< 4% DM); however, in contrast to other feedstuffs, ALA is the predominant fatty acid in forages (Boufaïed et al., 2003; Warren and Kivipelto, 2007a,b) (Table 1). Along with ALA, palmitic acid (16:0) and LA generally make up 90-95% of the fatty acids present in forages. A study evaluating the fatty acid composition of grass (timothy, *Phleum pretense*; orchard, *Dactylis glomerata*; bermuda, *Cynodon dactylon*) and legume (alfalfa, *Medicago sativa*; perennial peanut, *Arachis glabrata*) hays commonly fed to horses found that ALA made up 16-53% and LA 16-28% of the fatty acids present (Warren and Kivipelto, 2007b). Very rarely did a hay sample have more LA than ALA; in fact, in most
hay samples, the amount of ALA was 1.5–2X higher than the amount of LA. There was no difference in fatty acid composition between the cool-season grass hays evaluated nor between the legumes evaluated. However, cool-season grass and legume hays had almost twice as much ALA than the warm-season grass hay (Table 1). This is likely related to the faster rates of maturity in warm-season forages. By comparison, LA did not differ among any of the hays evaluated (Warren and Kivipelto, 2007b).

Pasture forage is generally higher in total fatty acids and ALA and lower in LA compared to forage conserved as hay or silage (Table 1). A 4-year study conducted in north-central Florida characterized the seasonal changes in the fatty acid composition in mixed bahiagrass (*Paspalum notatum*) pasture forage (Warren and Kivipelto, 2007a). Samples were obtained monthly from areas on or near where there was recent evidence of grazing by horses, as well as samples protected from grazing that were allowed to accumulate biomass throughout the year. Changes in ALA and LA during the year were of a smaller magnitude in samples of recently grazed grass than those observed in grass that was allowed continuous, uninterrupted growth (Figure 2). In grazed grass, LA was lowest in the winter and spring and highest in the summer, whereas ALA was highest in the winter and spring and lowest in the summer. The fatty acid composition of plasma and tissues in horses grazing these bahiagrass pastures mirrored their seasonal fatty acid intake (Warren and Kivipelto, 2008). Other researchers have observed similar seasonal effects on the fatty acid composition of cool-season forages, with ALA content generally being highest in the cooler months of spring and autumn and lower during the summer (Clapham *et al.*, 2005; Dewhurst *et al.*, 2001). In contrast, opposite trends were observed in the grasses that accumulated growth, where LA was highest in the winter and ALA began declining in the fall and was lowest in the winter (Warren and Kivipelto, 2007a). In fact, the rather large progressive decline in ALA from spring through the following winter resulted in an inverted omega-6 to omega-3 ratio in the accumulated grass in the months of January, February, and March (Figure 2). It is worth noting that horses would probably avoid this more mature pasture forage, as long as other more succulent forage was available.

![FIGURE 2: Seasonal changes in α-linolenic acid (dashed lines) and linoleic acid (solid lines) concentrations (g/100 g total fatty acids) in bahiagrass pasture forage. Samples represent grasses grazed by horses (circles) or grasses allowed to accumulate biomass during the year (triangles).](image_url)

The fatty acid composition, particularly the omega-3 (ALA) content is affected by forage stage of growth and harvesting conditions. Forage lipids are predominantly of leaf origin, with the highest proportion of ALA observed during vegetative growth or after a short versus a longer cutting interval.
The ALA concentration in timothy grass was shown to decrease more than 30% between stem-elongation and early flowering (Boufaïed et al., 2001, 2003). In addition, the ALA content of hay and pasture forage has been inversely associated with the fiber content (Warren and Kivipelto, 2007a,b). These factors are likely responsible for the dramatic seasonal differences in ALA noted in bahiagrass samples that represented what horses were actively grazing (leafy, vegetative) and samples that were allowed to accumulate biomass (increasing stem and fiber content) during the year (Warren and Kivipelto, 2007a). Nitrogen, but not phosphorus fertilization was shown to boost the ALA content of fresh forage by up to 40% (Boufaïed et al., 2003; Elgersma et al., 2005). Light intensity and seasonal temperature are also factors that influence the fatty acid composition of forage (Dewhurst and King, 1998). Loss of 30-50% of the ALA in forage due to extended wilting or drying have also been observed with silage and haymaking (Boufaïed et al., 2003; Dewhurst and King, 1998; Doreau and Poncet, 2000), which explains why fresh pasture forage is usually higher ALA than conserved forages (Table 1). Length and conditions of storage might also affect the fatty acid composition hay. When relative humidity was less than 50%, the ALA content of dried perennial ryegrass decreased ~15% after 13 months of storage, but decreased 50% in the same time frame when dried forage was stored under humidity above 80% (Czerkawski, 1967).

The Impact of Forage on Omega-3 Intake

The high amount of ALA in forage contributes substantially to the total omega-3 fatty acid intake by horses. However, not all horses can perform well on all-forage diets. A greater reliance on concentrates in the diets of performance horses, broodmares and growing horses generally results in a lower intake of omega-3 fatty acids from forage and, when oils are added to the diet, a higher intake of omega-6 fatty acids when compared to an all-forage diet. Nonetheless, forage still has an impact on the omega-6 to omega-3 fatty acid ratio. Recent dietary recommendations have suggested a ratio of 5:1 to 10:1 of omega-6:omega-3 fatty acids as an ideal target for human diets (NRC, 2005). Keeping these guidelines in mind, Table 2 compares the omega-6 and omega-3 fatty acids available from a variety of equine diets. The amounts in Table 2 take into account that small intestinal availability (and thus absorption of fatty acids) is approximately 50, 75, and 100% from forages, cereal grains and corn oil, respectively (Kronfeld et al., 2004). Even with this conservative assumption, most equine diets (including those that are relatively high in fat due to LA-rich corn oil inclusion) appear to fall well below the upper omega-6 to omega:3 ratio of 10:1 recommended for humans.

### TABLE 2: Estimated amounts of omega-6 and omega-3 fatty acids available to a 500-kg horse from different types of diets.

<table>
<thead>
<tr>
<th>Diet</th>
<th>Available Omega-6 (g/d)</th>
<th>Available Omega-3 (g/d)</th>
<th>Omega-6:Omega-3 Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasture</td>
<td>25</td>
<td>75</td>
<td>0.3 : 1</td>
</tr>
<tr>
<td>Hay</td>
<td>35</td>
<td>60</td>
<td>0.6 : 1</td>
</tr>
<tr>
<td>Hay + Concentrate (4% crude fat)</td>
<td>50</td>
<td>25</td>
<td>2.0 : 1</td>
</tr>
<tr>
<td>Hay + Concentrate (6% crude fat)</td>
<td>135</td>
<td>30</td>
<td>4.5 : 1</td>
</tr>
<tr>
<td>Hay + Concentrate (10% crude fat)</td>
<td>275</td>
<td>35</td>
<td>7.8 : 1</td>
</tr>
</tbody>
</table>

* Estimates were based on the following assumptions: a) 500-kg horse with a daily intake of 10 kg DM; b) hay + concentrate diets are based on total DM intake consisting of 50% hay and 50% as concentrate; c) concentrates are made up predominantly of cereal grains, grain byproducts and oil seed meals; d) corn oil, which is rich in omega-6, was used as the fat source for the concentrates with 6 and 10% crude fat; and e) 50% of the fatty acids in forages, 75% of the fatty acids in cereal grains, and 100% of the fatty acids in corn oil are available for absorption in the small intestine.

The contribution of ALA from forages, may be one of the reasons for the inconsistent anti-inflammatory or immuno-modulatory responses to omega-3 fatty acid supplementation observed in horses.
(see earlier section: “Why the Interest in Omega-3”). Compared to humans, the herbivorous diet of horses results in a relatively low total daily fat intake, of which most is mono- or polyunsaturated rather than saturated fat. This fact remains true even in horses fed so-called “high fat” or fat-added diets that are common today. Hence, while replacement of saturated and omega-6 fatty acid sources with ingredients rich in omega-3 fatty acids seems to result in improvements in humans, the same might not hold true for many horses because their diet is already close to the “ideal” (Table 2). The ratio of omega-6 to omega-3 fatty acids is thought to be important because of the competitive nature of fatty acids and their different biological roles. However, there is also evidence that the absolute quantity of omega-3 or omega-6, more than the ratio, can influence conversion of precursor fatty acids to their longer chain derivatives, as well as the overall biological response. Much more work is needed in horses before an ideal omega-6:omega-3 ratio can be recommended, and to determine whether it is the ratio between these fatty acids or the amount consumed that has the biggest influence.

The NRC (2007) has recommended a LA intake of 0.5% DM for horses, although justification for this recommendation was not described. For a 500 kg horse with a DM intake of 2% BW, the NRC recommendation would amount to a daily intake of 50 g of LA. This requirement is likely to be met in horses consuming adequate quantities of good quality forage and is easily met by diets supplemented with fat, as most high-fat feedstuffs and oils are rich in LA (Table 1). Currently there are no guidelines for minimum daily ALA intake, although a horse consuming adequate amounts of fresh forage and/or good quality hay will likely receive ample amounts of ALA in the diet (Tables 1 and 2). Supplementation with both LA and ALA should be considered in horses receiving poor quality or limited amounts of forage for prolonged periods of time. Because an ALA requirement has not been established for horses or other herbivores, provision of ALA in amounts resulting in a 5:1 to 10:1 ratio of LA:ALA might be considered adequate, as this has been recommended for other species (NRC, 2005).

In conclusion, the contribution of forage to omega-3 fatty acid intake should not be discounted. The fatty acid composition of forage resembles that of flaxseed, a common omega-3 fatty acid supplement included in equine rations. Given that forage (as either hay or pasture) is one of the biggest components of most equine rations, the daily intake of ALA from this dietary source can be considerable and, in fact, usually exceeds the level provided by popular omega-3 fatty acid supplements. Fresh growing grass, especially in the spring and fall, appears to be the richest source of ALA for the horse. Appropriate grazing and pasture management (e.g., mowing) that keeps forage in a vegetative state will increase the ALA available to the horse. When hays are fed, more ALA will be present in leafy hays harvested at early- to mid-maturity compared to stemmy, more mature hays. Warm-season hays appear to have less ALA than legume or cool-season hays. Because legumes tend to have a greater total lipid content than other forages, daily intake of ALA is likely to be slightly higher with legume forages than grass forages.

References


DIETARY MANAGEMENT OF ULCERS IN GROWING HORSES

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Summary

Equine gastric ulcer syndrome (EGUS) has been a difficult challenge to the horse industry. Horse producers and managers attempt to achieve optimal performance in the show ring or race track, and rapid growth and development in young horses without being at odds with general health and well-being. Unfortunately, some of the methods for achieving high-level performance in horses include the feeding of high-concentrate diets, the use of non-steroidal anti-inflammatory drugs, and generally stressful housing and training environments. Each of these practices has been found to lead to an increased occurrence of gastric ulcers in horses.

Nutrition research using growing horses (weanlings and yearlings) has found that feeding total mixed rations (TMR) may improve growth and feed efficiency of these young animals, but the effects on stomach ulcers may be dependent on both the concentration of grains versus forage in the TMRs and the amount of processing of the components (pelleted versus cubed). A pelleted TMR diet with 50% grain and 50% forage appears to be equally bad or slightly worse in causing endoscopically-detected stomach ulceration than a nutritionally identical diet of 50% longer-stemmed forage and 50% grain fed separately. However, a TMR diet of hay and oats in cubed form using only 25% oats was found to cause no endoscopically-detected stomach ulcers, while still providing a growth advantage over a nutritionally identical diet fed as plain hay cubes and grain fed separately.

Introduction

Gastric ulcers are a significant problem in equine populations because of their high incidence and potentially detrimental effects on performance. Horses in heavy training are particularly vulnerable, with an estimated 58% of show horses (McClure et al., 1999) and 93% of racehorses (Murray et al., 1996) being affected. Neonatal foals are also at risk, with an estimated 25% to 50% developing gastric lesions (Andrew and Buchman, 2003) either as primary disease or secondary disease (Nadeau and Andrews, 2009; Nieto et al., 2009). Equine gastric ulcer syndrome (EGUS), ulceration and lesion formation in the distal esophagus, glandular and nonglandular stomach, and proximal duodenum (Andrews et al., 1999), is a widespread condition that leads to decreased productivity and consequent economic loss. EGUS is a complicated disease process which involves many variables and can be difficult to diagnose and manage; horses may or may not show clinical signs, and typically exhibit vague negative effects such as weight loss, abdominal pain, and poor performance (Nadeau and Andrews, 2009; Nieto et al., 2009). Equine gastric ulcers are associated with low gastric pH and overproduction of stomach acids. Horses secrete hydrochloric acid continuously and several factors can influence the level of acid production and epithelial exposure to these acids, including stomach anatomy, diet, restricted feed intake, exercise, stress (stall or transport), and use of nonsteroidal anti-inflammatory drugs (Apter and Householder, 1996).

Weaning is one of the most stressful periods in a foal’s life. Separation from the mare can cause stress and predispose weanlings to disease, injury, and reduced growth rates (Hammond, 1990).
Additionally, the months after weaning are a crucial time for the producer as sales of weanlings and yearlings is a large source of income for the horse industry. Thus, optimizing growth rates and maintaining good health during this time is important, however these goals are sometimes at odds when high energy, high carbohydrate diets are used to promote rapid growth. The horses most prone to gastric ulcers, both young horses and high performance horses, are typically fed high-concentrate diets that are rich in hydrolyzable carbohydrates. These carbohydrates stimulate both HCl secretion and produce volatile fatty acids in the stomach which can damage the protective barriers of the nonglandular epithelium, allowing acid erosion of the tissue (Nadeau et al., 2000).

Horses eating hay and grain diets are often observed to bolt their grain and eat the hay more slowly, whereas those consuming total mixed rations tended to eat at a steadier rate over several hours (Flores et al., 2011). This may help moderate and neutralize gastric pH. Although one study found no difference in gastric pH eight hours after a meal of either textured grain or pelleted grain (Healy et al., 1995), no research has compared processed grain-based feeds with those which incorporate roughage into a total mixed ration. Several studies have examined the relationship between all-hay diets and hay and concentrate diets in ulcer formation (Murray, 1994; Andrews et al., 2005) and found a negative effect on the gastric health of horses being fed concentrates as opposed to those on strictly hay diets. Some research has found that exercising horses consuming alfalfa hay may experience fewer gastric ulcers when compared to horses consuming grass (Coastal Bermuda) hay (Lybbert et al., 2007). In addition to managing diet to reduce the incidence of digestive and orthopedic diseases which have been linked to high dietary soluble carbohydrate levels (Coenen, 1990; Thompson et al., 1988), producers are striving to find the feeding methods which optimize growth and performance while maintaining overall health.

Little research has focused on gastric ulceration in horses fed differently processed feeds of the same ingredient composition. Therefore, our lab has begun to investigate the differences between diets of forage and grain fed separately vs. identically composed forage/grain diets processed into either completely pelleted form or into complete cubed form, in gastric ulcer formation in young growing horses. We have hypothesized that growing horses fed completely pelleted or cubed diets may develop fewer gastric lesions and have a higher average daily gain (ADG) as opposed to growing horses fed a ration of forage and grain fed separately based. These hypotheses were based on the idea that a possibly steadier consumption rate for the total mixed rations may favor more efficient fermentation, and the additional processing may decrease feed wastage and increase digestibility.

Research Trials

Forage and grain fed separately versus complete pellets

A study evaluated the effects of two different methods of feed processing on growth and gastric ulceration in 16 weanling Standardbred horses. The two diets were composed of identical ingredients that were processed differently and fed at a rate of 3% body weight per day (Table 1). The hay and grain diet (diet HG) consisted of 50% alfalfa hay cubes and 50% commercial texturized grain mix fed as is, without any further processing, with the cubes and grain fed in separate containers. The complete pelleted diet (diet CP) consisted of the same proportion of hay cubes and grain mix, which was ground,
pelleted, and fed in a single container. The horses were divided into two groups and the study was divided into three periods of 30 days each. During period 1, all 16 horses consumed only free choice alfalfa hay (diet H). Group 1 was given diet CP during period 2 and diet HG during period 3. Group 2 was given diet HG during period 2 and diet CP during period 3. The horses were endoscopically examined for the baseline number and severity of stomach ulcers at the end of period 1, then again at the end of each treatment diet feeding period (Table 2). Table 3 shows that horses consuming the complete feed (diet CP) wasted less feed than horses fed hay and grain separately (diet HG).

Horses on diet CP in periods 2 and 3 had greater ulcer numbers (P < .0135) than diet HG. However, there was no significant difference (P < .30) in ulcer numbers when making a direct comparison between diets CP and HG (Figure 1).

Despite the gastric ulceration found in horses on diet CP, the average daily gain was significantly greater (P < .016) for diet CP than for diet HG (Figure 2). Both diets containing 50% of a commercial grain mix were observed to cause gastric ulceration.

The CP diet in fact appeared to cause a numerically slightly higher incidence of ulcers; therefore, our hypothesis that the CP diet might result in fewer lesions was rejected. It was also found that the longer the horses were on the high grain diets the more gastric ulceration occurred, reaching nearly three times the original scores after the second 4-week period on the high grain diets, suggesting that the horses did not adjust to the high concentrate diets. This suggests that the gastric ulceration seen in the young horses in this study was a progressive, active pathology extending throughout the 60 days of both high grain diet treatments. These data support previous work which found that increases in hydrolyzable carbohydrates in the diet leads to an increase in gastric ulceration (Andrews et al., 2006). The finely ground, pelleted feed required less chewing and may therefore have resulted in reduced saliva production, thereby reducing the buffering effect of the alkaline saliva on the acidic stomach, possibly contributing to increased ulcer formation. It should be noted that at no time did the horses display any clinical signs of discomfort.

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Feed wastage from wall feeders and floor mats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed wastage by period</td>
<td>Complete feed</td>
</tr>
<tr>
<td>Period 2 wastage (kg/d)</td>
<td>0.08</td>
</tr>
<tr>
<td>Period 3 wastage (kg/d)</td>
<td>0.38</td>
</tr>
<tr>
<td>Total wastage (kg/d)</td>
<td>0.23</td>
</tr>
<tr>
<td>Total wastage as % of feed offered</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Fig. 1. Number and severity ulcer scores (±SEM) for groups on hay and grain diet (diet HG) and complete pelleted diet (diet CP) in periods 1, 2, and 3. Both groups on HG and CP consumed only alfalfa hay during period 1, and then group HG switched to diet HG in period 2 and diet CP in period 3. Group CP switched to diet CP in period 2 and diet HG in period 3.

Fig. 2. Mean body weights for diet treatment groups on HG and CP during periods 2 and 3. Group HG was fed diet HG in period 2, and then switched to diet CP in period 3. Group CP was fed diet CP in period 2, and then switched to diet HG in period 3.
as a result of gastric ulceration. Despite an advantage in growth, the current study found that providing grain as complete pellets was not better at promoting gastric health. This higher ADG may be due to increased pre-ileal digestibility of the processed grain (Meyer et al., 1994).

Forage and grain fed separately versus TMR cubes

Fourteen yearling Standardbreds, seven fillies and seven colts of similar weight, sex, age, and growth potential, with an average age of 8 months, and an average initial weight of 294 kg, were used to compare differences in ADG and G/F when fed a complete cubed TMR (diet C), or a diet in which the hay cubes and oats were fed separately (diet HG). The forage in both the plain hay cubes and the complete cubes was 80% alfalfa and 20% endophyte-free tall fescue. Diets were fed for 75 days, during which horses were fed no additional feeds, and had free-choice access to water, mineral blocks, and exercise. Horses were weighed on an electronic platform scale before the study and weekly for its duration. Upper gastrointestinal tract endoscopies were performed on all horses at the start and end of the study. Seven horses were randomly assigned to each diet and fed twice daily at 7:00 and 19:00 at a rate of 1.5% body weight as-fed per feeding. Horses were housed and fed in individual pens of 500 square feet with identical feeders. At each feeding, leftover feed was recovered and weighed to determine consumption. Feed samples were continuously collected and composited. Fecal samples were collected on days 71-75. Feces were composited and stored at -4 degrees Celsius. Collections were oven-dried at 60 degrees Celsius and samples were sent to a laboratory (Equi-analytical labs, Ithaca, NY) for analysis of dry matter (DM), crude protein (CP) and acid insoluble ash (AIA) using AOAC methods (AOAC, 1984). Apparent digestibility was calculated using the equation:

\[ 100 \times \left(1 - \frac{\text{% AIA in feed}}{\text{% AIA in feces}} \times \frac{\text{% nutrient in feces}}{\text{% nutrient in feed}}\right) \]

(Pagan, 1998). Differences in digestibility, ADG, and G/F between diets were determined using T-tests.

Horses consuming the TMR (diet C) had an ADG (Kg/day ± SEM) of 1.69 ± .79 while horses consuming the separate hay and grain (diet HG) horses had an ADG of 0.95 ± .18 (Figure 3).

Diet C horses had a feed efficiency (G/F ± SEM) of .09 ± .04 while diet HG horses had a feed efficiency of .05 ± .01. ADG (P=0.046) was found to be significantly greater for diet C, while G/F (P=0.065) between the two diets was not significantly different but showed a trend in favor of diet C (Figure 4).
There were no significant differences between the two diets in DM or CP digestibility. Diet C’s DM digestibility was 64.04 ± 6.74 while diet HG’s was 66.80 ± 5.76. Diet C’s CP digestibility was 58.29 ± 3.94 while diet HG’s was 57.85 ± 2.54. Initial endoscopies found only one horse with a single grade 1 ulcer severity score. Final endoscopies found no horses with ulcers. No growth abnormalities were observed in horses on either diet. The results of this study support the hypothesis that yearling horses fed a complete cubed diet of 75% hay (80% alfalfa hay, 20% tall fescue) and 25% oats would have higher ADG than yearling horses fed a diet of 75% hay cubes and 25% oats fed separately. However, the G/F and DM and CP digestibility between diets were not found to be different although a trend for higher G/F was found for the TMR (diet C). A significant difference in G/F may have been detected had a greater number of horses been used. The significant difference in ADG may be due to consistent grain/hay intake in diet C versus alternating grain and hay intake in diet HG leading to fluctuations in gastrointestinal tract pH and/or microbial populations. It is also possible that more of the grain may have been lost into the floor for diet HG, despite using rubber mats beneath the feeders and trying to account for as much feed wastage as possible. The results support the additional hypothesis that neither diet would cause significant gastric ulceration. It is concluded that a complete cube diet of 75% hay (80% alfalfa hay, 20% tall fescue) and 25% oats does not cause stomach ulceration while achieving an acceptable growth rate in yearling horses.

Conclusions

The findings of these studies related to the effects of feeding systems and feed processing on gastric ulcers in growing horses are consistent with recommendations made by clinical experts on equine gastric ulcer syndrome (EGUS) (Reese and Andrews, 2009). These recommendations include keeping the horse eating, around the clock as much as possible, by providing at least 1 to 1.5 percent of each horse’s body weight daily as high quality forage throughout the day and night. Also, feeding forage that includes alfalfa may help to buffer stomach acid. Feeding grain mixes sparingly; only enough to maintain adequate body condition in combination with good quality forage, and feeding grain in several small meals throughout the day no less than 6 hours apart may help to minimize stomach ulcers in horses. Additionally, hay processed as cubes, sometimes called “biscuits”, including up to 25% whole oats in a TMR product has not been found to cause gastric irritation in yearling horses, and is an excellent product for promoting growth safely.

References


CURRENT KNOWLEDGE OF DIETARY NITROGEN UTILIZATION IN EQUIDS

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Summary

Nutrient management plans may be necessary to improve and maintain sustainability of the horse industry in increasingly urbanized areas. Large nitrogen (N) losses to the environment due to excessive protein intake by equids impact ground water and air quality. The design and implementation of better feeding strategies is directly contingent upon assessment and knowledge of protein quality of common feeds fed to equids, which in turn depends on the amino acid composition and digestibility. There is some evidence suggesting contribution of the equine hindgut to protein digestibility and amino acid absorption but the extent of this contribution remains to be characterized as it may impact the estimate of N and amino acid requirement, and as such post-gastrointestinal N metabolism. Uncovering the gaps in methodological assessment of N metabolism in equids will improve our understanding of dietary protein utilization.

Introduction

Feeding to precisely meet amino acid requirements has been implemented in many livestock species in order to optimize performance and, recently, to minimize nitrogen (N) losses. Paradoxically, feeding protein in excess of requirement is common in the horse industry (Lawrence et al., 2003) and leads to increased urinary N excretion, which in turn contributes to ground water contamination and decreased environmental air quality (Knowlton and Cobb, 2006). With emerging regulations limiting N losses to the environment, nutrient management plans may be necessary to ensure sustainability of horse farms in particular in increasingly urbanized areas. Strategies to mitigate the impact of equine feeding practices on the environment are contingent on knowledge of feed protein utilization. In turn, efficient utilization of dietary proteins depends on the quality of feed proteins. The following discussion addresses the characteristics of protein quality relevant to equids, including aspects of N digestibility and amino acid composition in common feeds, with an emphasis on gaps and methodological challenges. A discussion follows on the role of the hindgut in its contribution to whole tract N absorption and concludes with a brief dialogue of post-gastrointestinal N metabolism. While the interface between quality of feed proteins and the estimation of both protein and amino acid requirements of equids are not discussed per se given the scope of this proceeding, response criteria used in equids to assess protein and amino acid utilization and requirements are briefly covered.
Protein and Amino Acid Digestibility of Feeds Fed to Equids

Protein digestibility is dependent upon the amino acid profile of the protein which is intrinsic to the protein itself and upon plant constituents which are extrinsic to the protein and that are either directly associated with the proteins or affecting the intestinal luminal flow (or passage rate) and absorption of amino acids. Such information remains exceptionally limited for many common feedstuffs fed to horses.

Forages

Forage dry matter and protein digestibility is a function of cellular contents and cell wall constituents. Cellular contents, with the exception of sugars which are completely digestible by non-ruminants and ruminants, are highly digestible (Van Soest, 1967). In contrast, cell wall constituents cellulose, hemicelluloses and fiber-bound proteins are partially digestible upon fermentation (Van Soest, 1965; Van Soest, 1994), while lignin and lignified nitrogenous compounds are completely indigestible (Van Soest, 1967) in both hindgut fermenter and ruminant animals. Differences in apparent N digestibility between grass and legume hays is related to differences in fiber composition, as reported in sheep, swine, rats (Keys et al., 1969) and horses (Glade, 1984). Digestibility of the cellulose component of fiber is directly related to lignification, which in turn decreases plant cell-wall protein digestibility (Van Soest, 1994). Further, hemicellulose is also associated with lignin content (Van Soest, 1994) and is considered a limiting factor to fiber digestibility in horses (Glade, 1984).

Several studies have measured N digestibility in various forages. However, large differences in apparent N digestibility of grass hay in particular are reported both between and within cultivars (Fonnesbeck et al., 1967; Darlington and Hershberger, 1968; Crozier et al., 1997; Takagi et al., 2002; Takagi et al., 2003). Some examples for both grass and alfalfa hay are provided herein. Between grass forages, lowest apparent N digestibility reported was 32% in bermudagrass (Fonnesbeck et al., 1967), while highest apparent N digestibility was 68% in orchardgrass (Darlington and Hershberger, 1968). Timothy grass hay ranges from 36% (Cuddeford et al., 1992) to 65% (Darlington and Hershberger, 1968). Woodward et al. (2001), Hintz et al. (1971) and Ordakowski-Burk et al. (2006) reported whole tract N digestibility values for first cut timothy hay of 38, 42, and 48%, respectively. Tall fescue ranges from 38% (Fonnesbeck et al., 1967) to 67% (Crozier et al., 1997), canarygrass ranges from 48% to 62% (Fonnesbeck et al., 1967), and orchardgrass ranges from 40% (Takagi et al., 2003) to 68% (Darlington and Hershberger, 1968).

Alfalfa is fed extensively due to its high CP concentration (Ralston et al., 1989) and superior nutrient digestibility (Cymbaluk and Christensen, 1986), both of which are affected by plant maturity (Darlington and Hershberger, 1968). Whole tract apparent N digestibility of first cutting (mid bloom) alfalfa in the study of Woodward et al. (2011) was 73%, which is considerably greater than reported values of 65% in first cut alfalfa fed to Standardbred geldings (Fonnesbeck et al., 1967). Darlington and Hershberger (1969) reported whole tract apparent N digestibility as low as 55% in their most mature alfalfa. The apparent N digestibility of second (early bloom) and third cutting (early bud) alfalfa hay reported by Woodward et al. (2011) was 75 and 78%, respectively, in agreement with those of Darlington and Hershberger (1968), i.e., 72 and 75% for mid-mature and immature alfalfa, respectively. Others have reported comparable values of 73% in ponies (Gibbs et al., 1988) and Arabian geldings (Crozier et al., 1997), 74% in Thoroughbred geldings (Cuddeford et al., 1992), and 76% in stock-type geldings (Sturgeon et al., 1999).

Consequently, the low hemicellulose of legumes compared to high hemicellulose of grass hay is likely to be an important contributing factor to the greater whole tract apparent N digestibility of legumes compared to grass hays. It is critical however to recognize that apparent N digestibility underestimates the true digestibility of low relative to high protein-containing feeds. Endogenous losses associated with
feeding grass hay are likely to be significant compared to legume hay, and correcting for endogenous losses would allow for a better assessment of grass hay protein digestibility (Woodward et al., 2011). Endogenous losses specific to feeding grass vs. legume hay have yet to be determined by regressing fecal N output against increasing levels of protein from a single grass or legume hay, respectively, but maintaining equal DM intake across diets. Such methodology remains to be designed and tested for equids.

**Cereal grains and pulses**

Cereal grains and pulses are commonly fed to horses as a source of dietary energy due to their higher energy density and high protein quality, respectively. Whole oats is a common grain used in many mixed equine diets because they are readily digestible pre-cecally and very palatable (Hussein et al., 2004; Sarkijarvi and Saastamoinen, 2006). Addition of oats enhances apparent whole tract N digestibility of low protein forages. Kienzle et al. (2002) reported an increase in CP digestibility from 50 to 66% when feeding oats with straw. We showed that addition of oats at 0.2 and 0.4% BW to a low-protein timothy hay improved apparent N digestibility by 9.1 and 14.6%, respectively, with no increase in urinary N excretion, thus indicating improved post-gut N utilization (Woodward et al., 2011). Similarly, Palmgren Karlsson et al. (2000) reported a 17 and 25% increase in whole tract apparent N digestibility when oats were provided in addition to grass hay at 0.3 and 0.6% BW compared to grass hay fed alone.

Limited published information regarding whole tract apparent N digestibility of single ingredients is available. The lack of digestibility values for individual grains and pulses stems in part from methodological obstacles. Because of horses’ obligate reliance on forages, the estimation of single feed ingredient N digestibility with the direct approach is difficult. Thus is non-physiological to feed a cereal grain or pulse as a single feed ingredient to assess its protein digestibility, limiting the digestibility data base to grain-forage mixture. The most biologically relevant way to estimate grain N digestibility is the substitution approach and the difference approach. The substitution approach entails feeding increasing graded levels of the grain of interest in substitution for forage of similar or lower crude protein concentration while maintaining dry matter intake as uniform as possible between diets. The maximum level of grain inclusion must take into consideration the safe allowable level of non-structural polysaccharides. Crude protein digestibility is regressed against the ratios of forage protein to grain protein and the grain protein digestibility is thus estimated by solving for x when x = 100% grams of N from grain. With this approach, any increase in N digestibility of the grain-forage mix with increasing protein contribution from the grain is due to the grain’s higher N digestibility. We have recently used such approach to estimate N digestibility in oats using a grass hay of similar protein concentration (Woodward et al., 2010). Regression of apparent whole tract N digestibility against the contribution level of N from oats to the total diet led to a relationship defined as y = 0.15x + 51.90 (Figure 1). When solving for x at 100, we determined apparent whole tract N digestibility of oats to be 67%. Utilizing the substitution method and feeding oats at up to 60% of the diet, Palmgren Karlsson et al. (2000) determined true oat N digestibility to be 83%. This number falls in the range of true oat N digestibility reported by Takagi et al. (2003), who used the difference method to estimate digestibility of three species of oats commonly used in diets of horses in Japan. The

![Figure 1](image-url)  
**Figure 1.** Relationship between N digestibility and dietary contribution of N from oats in a mixed forage-oats diet. The relationship is defined as $y = 0.15 \pm 0.05 x + 51.90 \pm 1.45$ and $r^2 = 0.72$. 

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difference method is more simple as it involves composition of a basal diet and addition of one test feed to a separate assay diet, but yields more variable results. In the difference approach, the two diets are provided, digestibility measures are recorded, and differences in digestibility coefficients of assay diet compared to basal diet are used to determine the test ingredient true digestibility (Fan and Sauer, 1995). While Palmgren Karlsson et al. (2000) and Takagi et al. (2003) estimated true N digestibility of oats, while our study assessed its apparent N digestibility.

Amino acid digestibility

Apart from fiber content, Muscato et al. (1983) examined the AA profile of timothy grass hay fiber components and found over 65% of the total plant AA within the neutral detergent insoluble N fraction. Thus, over half of the amino-N in timothy hay is likely available to the large intestinal microflora of hindgut fermenters but the metabolic fates of large intestinal AA utilization is unknown. Indeed, whole tract amino acid digestibility estimates in equids are not readily available and there is a gap in our understanding of the relative utilization of pre- and post-cecal luminal AA. A consensus is needed among scientists as to whether or not whole tract AA digestibility estimates in equids represent an acceptable assessment of feed ingredient quality for equids. Some of our preliminary estimates of whole tract AA digestibility would suggest that there is an advantage in using whole tract lysine digestibility compared to N digestibility values. When increasing dietary CP and quality, with supplementation of oats and soybean meal, to a low-protein grass forage corn mix-based diet, the whole tract N digestibility increased from 59 to 69% while that of lysine increased from 57 to 74%. The increase in lysine digestibility was paralleled to post-prandial lysine concentration which increased from 61 to 102 µmolar. While the contribution of fecal N from fecal AA-N remained constant at approximately 66%, that of non AA-N increased from 33 to 38%, thus resulting in an underestimation of apparent N digestibility. Whole tract AA digestibility estimates may seem erroneous for instance to swine nutritionists who exclusively use AA digestibility estimated using digesta surgically recovered at the ileum (i.e., pre-cecally), it may be perhaps as erroneous to ignore the cecum and large colon as segments of physiological importance in protein nutrition of equids until additional data are generated.

Nitrogen and Amino acid Absorption

There is very little information is available on serum AA response to forage feeding alone in horses (Graham-Thiers and Bowen, 2009). Consistent with the higher AA concentration and N digestibility of alfalfa compared to timothy hay, serum AA concentrations increased postprandially in horses fed alfalfa, reaching a peak at approximately 2 h post-feeding. Johnson and Hart (1974) also reported AA concentrations increase for 2 h and to return to basal 4 h after feeding a pelleted diet consisting of alfalfa, orchardgrass hay, wheat straw, barley, oats, and soybean. With timothy hay, serum AA concentrations also appeared to peak 2 h post-feeding. Because passage rate through the small intestine ranges from 2 to 4 h for grains and forages, respectively, our results and those of Reitnour et al. (1970) indicate that there is considerable absorption of AA from both grass and legume forage proteins in the small intestine of the horse. However, DePew et al. (1994) reported a secondary spike in plasma indispensable AA concentrations 6 h after feeding a diet consisting of bermudagrass hay and grain concentrate, indicating AA absorption from the hindgut as well. Valine and isoleucine concentrations increased 12 hours post-feeding, indicating contribution from post-cecal AA metabolism (Wickens et al. unpublished).

Horses are hind-gut fermenters, thus they rely on microbial degradation of fibrous dietary components in order to synthesize proteins and VFA (Hintz et al., 1978). Unlike ruminants, where fermentation of structural polysaccharides occurs prior to passage through the stomach and small intestine, fermentation in equids mainly occurs distal to the small intestine in the cecum and proximal large intestine (Argenzio et al., 1974; Wootton and Argenzio, 1975). While there is no question the small
intestine absorbs digested nutrients such as carbohydrates, proteins, and VFA (Reitnour et al., 1969; Reitnour and Salsbury, 1972), the site and extent of absorption of VFA and nitrogenous compounds released through fermentation in the large intestine remains unclear (Argenzio et al., 1974; Wootton and Argenzio, 1975). In addition, there is very limited information regarding the form in which N is absorbed, i.e., ammonia, urea, AA, or peptides.

Nitrogen utilization by the equine hindgut microflora and absorption was first reported by Slade et al. (1970), whereby dietary supplementation of urea improved N digestibility, presumably via cecal microbial breakdown of urea and ammonia utilization into free AA synthesis. Results of Slade et al. (1970) were substantiated by Nelson and Tynzak (1971), who demonstrated using cecally-cannulated ponies that urea, fed as the major dietary protein source, entered the cecum where it stimulated microbial protein synthesis. Similarly, Reitnour and Treece (1971) reported that although urea fed to ponies was absorbed largely from the small intestine, urea that reached the large intestine increased cellulose digestion of the basal diet. In a subsequent study, Reitnour and Salsbury (1972) infused cecally-fistulated ponies with three sources of protein, including fishmeal, soybean meal and linseed meal, and demonstrated increased plasma urea concentration and urinary N excretion following infusions. While those results indicate that N was absorbed by the large intestine, the form in which N is absorbed was not investigated.

In cecally fistulated ponies fed three different pelleted diets based on corn (89.8% corn, 8.7% purified cellulose), oat (59.8% oat, 33.1% corn starch, 5.5% purified cellulose), and barley (69.2% barley, 22.7% corn starch, 6.6% purified cellulose), only 11% of the whole GI tract (i.e., from mouth to the feces) protein digestion was attributed to the small intestine in contrast to 40% contribution from the large intestine alone based on a dietary indicator dilution approach (Reitnour et al., 1969). Poor protein digestibility rates (only 51%) were attributed to incomplete indicator recovery, as well as the contribution of metabolic N to apparent N digestibility (Reitnour et al., 1969). Similarly, in ponies solely offered Coastal Bermudagrass, low-protein alfalfa hay, or high-protein alfalfa hay, only 9.6%, 1.3%, and 21.0%, respectively, of N digestibility occurred pre-cecally, while 52.5%, 65.7%, and 66.9%, respectively, of N digestibility was post-ileal. Fitting the data to a linear regression indicated that 37% of true N digestibility occurred pre-cecally, while true post-ileal N digestibility calculated from total N presented to the large intestine was 96.3% (Gibbs et al., 1988). The high true post-ileal digestibility may also represent an artifact of metabolic N overestimation. Nonetheless, the relatively short time of passage through the small intestine (< 120 min) appears to contribute to the lower digestive efficiency in that segment of the equine GI tract, and thus digestive compensation of lower quality protein (i.e., less soluble) feeds may occur through post-cecal absorption (Reitnour et al., 1969; Gibbs et al., 1988).

Passage of digesta through the compartments of the equine large intestine, namely the cecum, ventral colon, and dorsal colon, may also play a role in post-ileal N absorption. Argenzio et al. (1974) and Wootton and Argenzio (1975) demonstrated that there was no retrograde flow between the hindgut compartments, and that each compartment independently absorbed VFA and N. This observation led Wootton and Argenzio (1975) to examine the equine large intestine as a site of active protein appearance and disappearance. They noted that as much as 80 mg total protein N atoms · h⁻¹ disappeared and appeared in different sections of the colon, yet less than 20 mg atoms N · h⁻¹ was attributed to ammonia plus urea N, leaving 60 mg total protein N atoms · h⁻¹ unaccounted (Wootton and Argenzio, 1975). The authors suggested AA may be generated and absorbed by the large intestine (Wootton and Argenzio, 1975), thusly accounting for the discrepancy in total protein N disappearance.

Compartmentalization of the equine large intestine was also observed by Glade (1983). Digesta from twelve mature horses fed a mixed diet composed of 30% corn, 30% oats, and 40% timothy grass hay was removed from 10 sections of the GI tract to determine N partitioning of neutral detergent soluble N, soluble N, and neutral detergent fiber (Glade, 1983). Only 20% of N disappearance was observed from
the small intestine, with most absorption from the jejunum and ileum; the cecum and small colon accounted for the remaining N disappearance (Glade, 1983). In that study, Glade (1983) suggested that identifying colonic N transporters would allow separation of the true nature of N uptake by accounting for absorption of AA, peptides, and N-end products derived from microbial degradation. Recently, we have shown that the transcript abundance of one of the genes encoding for a transporter protein specific for lysine uptake, i.e., b_{0}^{b}AT, did not differ between the large and small intestine of the horse, and that encoding for large neutral amino acids, i.e., LAT3, was increased in the large compared to the small intestine (Woodward et al., 2010). Lysine uptake across brush border membrane vesicles designed from small and large colonic mucosa of the pony was recently measured (Woodward et al., accepted). Lysine was taken up by the large colonic BBMV with higher capacity and lower affinity compared to that measured across the small intestinal BBMV.

The above experimental data suggest that the large intestine appears to be an important site of N absorption. Earlier research indicates significant portion of N absorption from the large intestine that cannot be accounted for by ammonia and urea (Wootton and Argenzio, 1975), and microbial protein-derived AA, specifically lysine and other essential AA, can be absorbed from the large intestine (Slade et al., 1971). If the horse does have the ability to synthesize and absorb essential AA from the hindgut, then it may be reasonable to suggest that equids would have a relatively low dietary requirement for indispensable AA, or those which cannot be derived from the host and must be synthesized by microbes.

Amino Acid Composition of Feed Ingredients Fed to Equids

Values of amino acid composition is widely available for numerous feed ingredients including grains, pulses, dairy by-products and other by-products of the feed milling and food industries (NRC, 2012). Although such feed ingredients are used in the formulation of equid diets, there are very little AA composition values available for the most common and obligatory feeds such as forages. For instance it remains unclear as whether a difference in protein quality between forages is a function of the protein digestibility as determined by extrinsic factors alone or whether it is also related to the AA composition of the protein itself. Earlier, we briefly attributed the differences between grasses and legumes digestibility to the higher NDF and hemicellulose content of grasses, and differences between maturities to the change in lignification, factors that are extrinsic to the proteins themselves. What about the amino acid composition of forage proteins?

We recently reported AA concentrations for timothy and alfalfa hay harvested at 3 distinct maturity stages (Woodward et al., 2011). Values are in close agreement to previously reported values of timothy hay AA composition expressed as % DM (Muscato et al., 1983), and of timothy and alfalfa hay expressed as % CP (Teceschi et al., 2001). When compared to these published values (Teceschi et al., 2001; Muscato et al., 2003; Woodward et al., 2011) however amino acid concentration values for timothy and alfalfa reported in NRC (2007) appear to be grossly underestimated. Thus it is clear that additional data on AA composition of forages are critically needed to improve our understanding of N and AA utilization in horses. As expected, Woodward et al. (2011) showed that timothy AA concentrations were lower than those of alfalfa across all maturities, and alfalfa AA concentrations increased with decreasing harvest maturity (mid bloom to early bud). In contrast, AA composition of the protein itself (% CP) in timothy and alfalfa hay was remarkably constant across forages and stages of maturity, which indicates that the protein quality of forages of differing maturity, at least based on those data, is less a function of the protein AA composition but rather more of extrinsic factors of N digestibility such as hemicelluloses and lignifications, as pointed out above.
Post-Gastrointestinal Nitrogen Utilization

Very few studies (Farley et al., 1995; Rey et al., 2001; Olsman et al., 2003) have predicted N metabolic responses in horses fed a wide range (4 to 6 levels) of dietary CP or amino acid levels. Factors known to affect the flow and pattern of ingested N and amino acids to metabolic pools in other animal species, such as dietary protein and amino acid level and source, fiber fractions, DM intake, and physiological phase including growth, workload, lactation and gestation are less well documented in equids (Gibbs et al., 1988; Farley et al., 1995). Therefore, deficits remain in our understanding of and ability to predict N and amino acid utilization. Response criteria used to assess N utilization in equids include urinary N excretion relative to N balance (retention), serum urea nitrogen and three-methyl histidine concentrations. To some extent, serum amino acid concentrations may be useful when used in conjunction with the response criteria listed above. We have recently looked at the impact of feeding alfalfa of differing maturity relative to timothy on N utilization, and whether feeding grass hay alone or in conjunction with oats would result in a better N utilization and as such a more environmentally sustainable feeding practice than that of feeding alfalfa (Woodward et al., 2011). Urinary volume, and in particular urinary N excretion and total N excretion, were remarkably increased in horses fed alfalfa relative to horses fed timothy hay and oat-supplemented timothy hay diets. In an attempt to maintaining similar dry matter intake across diets, feeding alfalfa (2nd and 3rd cuttings) as low as 1.8% of the horse’s BW, lead to a remarkable increase in urinary N excretion with a 3- to 4-fold higher urinary volume. While N equilibrium was maintained across diets, i.e., timothy hay, timothy hay with oats and alfalfa hay (1st, 2nd, and 3rd cuttings), the large increase in urinary N in horses fed the 2nd and 3rd cuttings of alfalfa indicated that post-gut N utilization was decreased.

The use of serum urea-N as response criteria in the evaluation of dietary protein utilization for growth and lactation has been used extensively and successfully in pigs (NRC, 2012). We have used serum urea-N in horses in an attempt to determine dietary protein utilization and requirement of the working Arabian gelding in response to feeding a wide range of graded levels of CP intake, from 2 to 3 levels below to 2 levels above the established CP requirements by NRC (2007) with a grain concentrate in one study and with different forage sources in another. The response was a linear increase rather than a quadratic response, which is an essential criterion to applying a broken-line model. The response also differed depending on whether the incremental increase in dietary CP originated from forages or grains, with a better fit and significant slope when N originated from a grain concentrate. The latter indicate that there is extensive metabolism of N in the large intestine and likely recycling of serum urea-N in horses fed forages.

In that same study, N balance and 3-methyl histidine was also measured (Wickens et al., 2005). While N retention failed to respond in a clear quadratic relationship, the 3-

Figure 2. Relationship dietary crude protein intake on serum 3-methylhistidine (3-MH) concentrations. Data represent actual (closed circle; sample) and model-derived (opened square; estimate) values. The knot occurred at 953.72 g ± 131 g of daily CP intake. The CP intake of 953.72 g is indicated (close square), along with the variation around the mean of 131 g (shaded rectangle). The estimated requirement is thus distributed between 823 and 1085 g CP. The segmented curve (P < 0.001) has an adjusted $r^2$ of 0.49 and a MSE of 199.5.
methyl histine yielding a clear quadratic response allowing to fit a broken-line model (Figure 2) and estimate CP requirement. We suggest that 3-methyl histidine offers potential advantage as a marker of N utilization in working equids. Other response criteria including the indirect amino acid oxidation for maintenance and lactation will be discussed.

Conclusion

Knowledge of feed ingredient protein quality and post-gut N utilization is important for implementing successful sustainable feeding strategies for the horse industry, i.e., designing dietary plans aimed at meeting the dietary N requirements while minimizing N excretion. Deficits remain in our understanding of and ability to predict N utilization, thus limiting construction of comprehensive models of N metabolism. Protein quality and digestibility of forages are inherently connected, with quality determined in great part by factors that are extrinsic to the proteins themselves. Additional data are however critically needed to verify this suggestion. Furthermore, contribution from endogenous losses likely grossly underestimates the true digestibility of grass compared to legume forages, and the impact of endogenous losses on the horse’s N and amino acid maintenance requirement are unknown. In addition to the endogenous losses, there is likely to be significant contribution of N metabolism in the hindgut to N and amino acid absorption and post-gastrointestinal homeostasis of the host. Assessment of post-gastrointestinal N metabolism under different physiological demands based on nitrogen balance and blood urea-N alone is limited and other response criteria, including 3-methyl histidine and the indirect amino acid oxidation should receive more attention.

Literature Cited


EVALUATING THE FEEDING PROGRAM IN A VOLATILE MARKET

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Summary

What will corn price be next year? Can we survive if it reaches $10? Some in the dairy industry are concerned that high corn prices will bankrupt many dairies. History suggests otherwise. The year 2011 has been one of the best the dairy industry has ever experienced despite high corn prices. Focusing on the proper metrics to evaluate the feeding program is necessary to make sound decisions in a changing and volatile market.

Metrics to Gauge Success of the Feeding Program

There are many metrics available to measure success of the feeding program. Most have little utility for the dairy. Those include feed cost per ton, feed cost per cow per day, feed conversions, feed cost per pound of dry matter, and feed cost/cwt. Any measure that involves a ratio is typically suspect; measures that involve margins are typically useful. As markets become more and more volatile, ratios become problematic and margins become a necessity. Useful margins include income over feed cost and static income over feed cost. These metrics fall into one of two categories: report cards and decision makers.

Report cards are typically of limited use, but do tell how the business has performed in the past. Report card metrics of limited to no use include feed cost/cwt calculated the wrong way (on a milk cow basis only), feed conversions, feed cost per day or per ton, and feed cost per lb of dry matter. Feed cost per cwt, calculated correctly, is a useful ld report card for the feeding program. It is derived from the financial statements and includes milking and dry cows but no heifers. Feed cost per cwt is a useful big picture metric to look at dairy performance in the recent past. It should not be used as a decision maker.

Decision makers include income over feed cost and static income over feed cost. These measures are useful to evaluate day-to-day feeding and management decisions such as ration changes, grouping changes, milking frequency changes, etc. Income over feed cost is the premier margin that has great utility in making dairy day-to-day decisions. It not useful as a report card as market changes largely impact the result.

Only static income over feed cost can be used as a report card and a decision maker. It is simply income over feed cost with static component values and feed cost. It is the premier measure of dairy performance and considers components and feed costs. The resulting margin is the best measure of dairy performance available to dairy producers.

Components are Critical

Dairy producers and their advisors typically monitor milk production per cow to access herd performance. We are accustomed to bragging or lamenting the “tank average” for the dairy. A good tank average can yield bragging rights and make all involved feel good about the success of the dairy, much like Rolling Herd Average did a generation before. But, just as the use of Rolling Herd Average has receded over time, so should tank average in today’s economic climate.
Today most dairy farms in the United States are not paid solely for their tank average. In most markets the milk check is determined from total pounds of components (fat, protein, and other solids), adjusted for quality premiums, marketing assessments, fluid adjustments, hauling, and basis (often called PPD). The components are paid on pounds produced, so a combination of volume and concentration (fat\%, protein\%, other solids\%) determine their contribution to the milk check. The adjustments are typically on a cwt basis, so milk volume directly impacts their milk check contribution. Thus, a combination of volume and component concentrations determine final pay price. Today components are worth twice what they were just a few years ago. More than ever, our milk is being used for manufactured products, so the value of components is greater than ever.

Given how most dairies are paid for their milk, it doesn’t make sense to use milk/cow as a measure of performance. For instance, most would agree that a 60 lb cow with 4.8% fat and 3.6% protein is better than a 65 lb cow with a 3.5% fat and 2.8% protein. This seems obvious by looking at the raw numbers and knowing what components are worth. But what about a 71 lb herd with 3.95% fat and 3.26% protein, compared to an 80 lb herd with 3.40% fat and 2.90% protein? Which is better? This comparison is not so simple.

To make comparisons more equitable, we have traditionally used Fat Corrected Milk (FCM) or Energy Corrected Milk (ECM). Both FCM and ECM are designed to relate the energy expended by the cow to produce milk with different fat or protein levels. They are strictly based on biology, and have no economic basis. The formulas work the same when protein is $1.00 per pound or $4.00 per pound.

A new measure called Money Corrected Milk\textsuperscript{TM} (MCM) considers the economic value of milk components, and the impact of milk check assessments. Similar to ECM or FCM, it is expressed as pounds of milk per cow per day. Instead of relating to the energy expended by the cow to produce the milk, MCM relates to the income derived from the milk produced. The inputs needed include all items that impact the milk check, such as value of fat and protein, quality premiums, hauling, and other assessments.
CAN WE IMPROVE PREDICTION OF PHOSPHORUS BIOAVAILABILITY FOR COWS?

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Summary

Phosphorus (P) is an instrumental nutrient in numerous physiological processes, but can have detrimental environmental impact if fed in excess. Increased P intake in dairy cows leads to increased fecal excretion of P and a reduction in efficiency of use. Variability in P concentration or availability in feedstuffs can exacerbate P excretion. Our research group is conducting several experiments to work to improve prediction of P availability to cows. To investigate variability in P between and within feedstuffs, 170 feed samples (forages, concentrates, and by-products), were collected from across the U.S. and analyzed for total P, inorganic P, and phytate. Forages contained a greater proportion of P in the inorganic form and less total P and phytate as compared to concentrates and by-products. The majority of total P was associated with inorganic P and phytate.

To assess large intestinal digestibility of phytate, an experiment was conducted in dairy heifers using ileally infused phytate, followed by collection of feces. These data indicate that there are biologically important implications of digested phytate species and furthermore some absorption of P from the large intestines. A third experiment was conducted in lactating dairy cows to investigate the effect of phytase use and forage particle length on P availability. Total P intake of the four diets was similar. Total tract digestibility of total P tended to be reduced and total P excretion was increased with phytase supplementation. There was no effect of phytase supplementation or forage particle length on milk yield or components. Variation in P compounds between feeds, and the P flow data generated in these experiments suggest opportunity for improvement in prediction of P availability from feeds for dairy cows.

Introduction

Nutrient losses from concentrated animal feeding operations (CAFO) are becoming a point of interest in legislation and regulation. Phosphorus (P) discharged to the surrounding environment negatively impact lakes and streams. Eutrophication of these water bodies lead to fish kills, odor, and an overall decline in their recreational value.

Managing P resources on a farm is a key aspect of minimizing P losses to the surrounding environment; however, recognizing the components contributing to the loss may prove to be challenging. Recent work has indicated P variability in by-product feeds is high. Last year a survey of dairy nutritionists was conducted. The survey revealed that use of by-product feeds is on the rise, and that farmers and nutritionists lack confidence in the full availability of the P in these feedstuffs.
To better describe availability of P in feedstuffs, including by-product feeds, the form of P in these feedstuffs must be determined and quantified. For instance, phytate-P may not undergo complete hydrolysis in the rumen. Any undigested or unabsorbed P increases P excretion from the animal. Quantification of the extent of phytate hydrolysis in the rumen and lower digestive tract will support improved ration formulation in dairy cattle to reduce P excretion. Defining these P-containing compounds in feeds will support the improved estimates of bioavailability of P in feedstuffs necessary to advance “precision P feeding” techniques. By understanding P-containing compounds and their bioavailability, we can have more confidence in dietary P from feeds meeting the cow’s requirement.

**Phytate phosphorus**

About 70% of the P in cereal grains is found in phytate (Nelson *et al*., 1968; Morse *et al*., 1992). Phytate, inositol phosphate (IP) -6, can be degraded into varying lower inositol species and release inorganic P, which can be absorbed by the animal.

Mammalian enzymes do not have the capacity to degrade phytate, which renders that P source unavailable for absorption by monogastrics. Inclusion of exogenous phytase and incorporation of feedstuffs containing endogenous phytase in poultry and swine diets have been extensively investigated and reflected positively for growth performance and feed efficiency in addition to reducing P excretion (e.g. Cromwell *et al*., 1993; Lei *et al*., 1993; Harper *et al*., 1997). However, ruminants have the capacity to utilize the P bound in the phytate molecule because microorganisms in the rumen possess phytase (Yanke *et al*., 1998). The extent of this degradation can vary and may be influenced by dietary factors (Yanke *et al*., 1998).

Regardless of the high content of phytate present in grains, in theory, phytate in the rumen should be completely hydrolyzed because of phytase activity of ruminal bacteria. In high producing dairy cows, the ruminal retention time of grain may be too short to provide microorganisms sufficient time to completely hydrolyze phytate bonds. Passage rate and physical properties of the feed may keep the animal from maximizing P availability (Kincaid *et al*., 2005) despite the presence of ruminal phytase activity. Therefore, phytate may exit the rumen and be excreted (Park *et al*., 2002).

**Current research regarding P requirements**

Research regarding P requirements over the past ten years has focused on more precise evaluation of the true P requirement in dairy cattle to minimize P excretion in efforts to lessen environmental impact. It is a common misconception that low P diets negatively affect reproductive performance and milk production. During a 308 day lactation, Wu *et al*. (2000) fed cows one of three concentrations of dietary P (0.31%, 0.40%, or 0.49%) and concluded that there were fewer days to first estrus for cows being fed 0.31% and 0.49% P ration. Cows fed the 0.31% P ration tended to be open fewer days (P < 0.12) and had lower services per conception (P < 0.10). For this same experiment, milk production was monitored and there was no effect on milk production over the entire lactation. For cows fed the 0.31% P ration, a decrease in milk production was observed beginning at week 25 as compared to cows fed 0.40% and 0.49% P rations. Kincaid *et al*. (1981) saw similar results during a shorter term study when cows were fed 0.30% to 0.54% dietary P. This research and other work indicates that dietary P of ~0.30% may not sustain milk production in high producing cows throughout the entire lactation but that diets above ~0.34 %P do meet requirements.
Phosphorus digestion and absorption in ruminants

Phosphorus is a very important component in ruminal digestion. Microorganisms in the rumen require P for cellulose digestion (Burroughs et al., 1951) and to synthesize microbial protein (Breves and Schroder, 1991; Bravo et al., 2000). Five g of P/kg of digested organic matter are necessary for ruminal microbes to obtain optimal fiber digestibility (Durand and Komisarzuk, 1987). Assuming 9 kg of OM digested in the rumen, then 45 g of P/day is required to meet microbial P requirements. Compared to Hill et al. (2008) (Figure 1), which indicates 53 g of P being recycled via saliva in a ‘typical’ diet, suggesting the microbial requirement for P is met by salivary contributions.

The duodenum (Wasserman, 1981) and the jejunum (Ben-Ghedalia et al., 1975) are the main sites of P absorption. There are two pathways in the small intestine that are responsible for P uptake; active transport and passive absorption. The active transport system predominates when low blood P stimulates the production of 1, 25-dihydroxy vitamin D, which initiates P absorption (Horst, 1986). Passive absorption is paramount when P consumption is in the normal to high range and is influenced by P concentration in the blood and luminal presence in the small intestine (Wasserman and Taylor, 1976). Efficiency of P absorption is reduced with high P concentrations in the digestive tract (Bravo et al., 2003).

The large intestine is not generally considered a site of P absorption; however, recent research in small ruminants suggests varying degrees of P absorption in the large intestine (Park et al., 2002; Bravo et al., 2003). Park et al. (2002) reported an increase in IP$_3$ (the partial degrade of phytate with an intact inositol ring with three phosphate groups remaining) in the lower large intestine of sheep when compared to the upper large intestines. Synonymously, a reduction of IP$_6$, IP$_5$, and IP$_4$ in digesta occurred. These findings also indicate a preference in degrading high IP structures over lower IP structures. Additionally, mass balance calculation from these data, including phytate, its partial degradates, and orthophosphates, suggest P absorption in the large intestine occurred.

Model prediction of phosphorus digestion, absorption, and excretion

The vast majority of P metabolism models in ruminant animals are in small ruminants (e.g. Vitti et al., 2000; Dias et al., 2006) and aim to describe P metabolism in regard to bone metabolism, urinary excretion, serum concentration, soft tissue content, and fecal excretion. However, these models lack description of degradation of P forms and where the P is absorbed in the gastrointestinal tract.

The model of Hill et al. (2008) describes P forms and how those forms of P are digested and absorbed throughout the gastrointestinal tract in large ruminants, most specifically lactating cows. This

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**Figure 1. Model of P digestion and absorption in the lactating cow (Hill et al., 2008).**
model also expresses how different forms of P eventually contribute to the overall P balance of the animal (Figure 1). Hill et al. (2008) was created using all of the P digestion and flow data available at that time. Therefore, some limitations to the model do exist.

Phosphorus in feedstuffs

Phosphorus concentrations in traditional feedstuffs are inconsistent and can vary with forage type, genetic strain, maturity, and soil test P. For instance, as forage matures, the mineral content decreases because of a decrease in the leaf: stem ratio and a subsequent increase in forage fiber content (Fleming, 1973; Little, 1982). Commonly fed grains also vary in P content. For example, the NRC (2001) reported dried, ground corn grain contains 0.30% P, with a standard deviation of 0.05 (16.5% variation) and 48% SBM containing 0.70% P with 11% variation (NRC, 2001). Kertz (1998) reported variability of approximately 20% in P concentrations of forages (~64,000 samples from one commercial laboratory) and concentrates (~37,000 samples from another laboratory). These values display significant variation in commonly fed products. Inaccurate ration formulation based on incorrect forage maturity or grain book values can exacerbate deficiencies or excesses.

The growing ethanol industry has made by-product feeds in dairy rations increasingly prevalent. By-product feeds tend to be higher in P than their unprocessed counterparts due to removal of the value added nutrient during processing i.e. starch. For instance, dried distillers grains with solubles (DDGS) contain 0.83% P, whereas corn grain contains 0.30% P (NRC, 2001). During fermentation for ethanol production, phytate in corn is hydrolyzed (Pedersen et al., 2007) and therefore, the P in DDGS should be more available than it is in corn (Mjoun et al., 2008). Morse et al. (1992) reported that 12 hours in vitro digestion results in 71.5% phytate hydrolysis in corn compared to a minimum of 90% phytate hydrolysis wheat middlings and dried distillers grains.

There are two different processes of corn ethanol production; wet milling and dry grinding (Rausch and Belyea, 2005), yielding the by-products of corn gluten feed and distillers grains, respectively. Variability in processing techniques vastly impacts the P concentration of these by-product feeds. To make corn gluten feed, steep water is incorporated back in with bran. Proportion of steep water to bran will immensely impact P concentration of the final product because steep water contains 34.4 mg of P/ g of DM as compared to 8.8 mg of P/ g of DM for whole stillage (Noureddini et al., 2009). Additionally, 80% of the P in steep water is in the phytate form. These data indicate the assumption of complete phytate hydrolysis during ethanol production is incorrect.

Research trials

Classification of P form in feedstuffs

The objective of this investigation was to describe the P in an array of forages, concentrates, and by-products (n = 170) by quantifying total P, inorganic P, and phytate in these feeds.

Total P concentration of forages was less than that of concentrates and by-products (Table 1). Inorganic P content of concentrates was lower than inorganic P in forages, but not different from by-products. Phytate concentration was the lowest in forages, followed by by-products, and then concentrates. When comparing inorganic P as a percentage of total P, forages have the greatest proportion in inorganic P followed by by-products and then concentrates. Phosphorus composition of concentrates and by-products do not differ.
In forages, 71.2% of the total P was associated with inorganic P and phytate; these fractions accounted for greater than 80% of total P for concentrates and by-products (Table 1). The 20 - 30% of total P unaccounted for may be associated with phospholipids, DNA, RNA, or degradates of phytate hydrolysis (IP, IP, IP, and IP).

Table 1. Effect of feed class on total phosphorus (TP), inorganic phosphorus (Pi), and phytate phosphorus (Pp) content.

<table>
<thead>
<tr>
<th>Feed class</th>
<th>TP (µg/g DM)</th>
<th>Pi (µg/g DM)</th>
<th>Pp (µg/g DM)</th>
<th>Pi (%)</th>
<th>Pi + Pp (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SEM</td>
<td>Mean</td>
<td>SEM</td>
<td>Mean</td>
</tr>
<tr>
<td>Forage</td>
<td>2,652</td>
<td>261</td>
<td>1,970</td>
<td>376</td>
<td>BDL</td>
</tr>
<tr>
<td>Concentrate</td>
<td>6,380</td>
<td>180</td>
<td>791</td>
<td>260</td>
<td>4,625</td>
</tr>
<tr>
<td>By-product</td>
<td>6,529</td>
<td>193</td>
<td>1,543</td>
<td>278</td>
<td>4,192</td>
</tr>
</tbody>
</table>

Means within columns with different superscripts are significantly different. Below detection limit

Effect of phytase and forage particle length on P digestion

Five ruminally-and ileally-cannulated first lactation crossbred cows were utilized in two incomplete 4 x 4 Latin squares. The treatments were inclusion of phytase (1,500FTU/kg diet DM) and forage particle length (short vs. long), in a 2 x 2 factorial arrangement. Diets were otherwise identical in composition and formulated to meet or exceed NRC (2001) requirements. Cows were fed once daily in the Calan door system for 14 of the 21 days per period. The last 7 days of each period, cows were fed in a metabolism barn four times daily. For the last 4 days of each period, total collection of feces and urine was conducted. During this time, omasal, ileal, and blood samples were taken in addition to milk samples. Rumen evacuations were conducted at the end of each collection period to obtain samples and quantify rumen contents.

Neither forage particle length or phytase supplementation had an effect on milk yield, milk components, or SCS (Table 2).

Table 2. Effect of particle size and phytase on milk production and composition.

<table>
<thead>
<tr>
<th></th>
<th>No phytase</th>
<th>Phytase</th>
<th>P &lt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Short</td>
<td>Long</td>
<td>Short</td>
</tr>
<tr>
<td>Milk, kg/d</td>
<td>19.5</td>
<td>20.3</td>
<td>20.2</td>
</tr>
<tr>
<td>3.5% FCM, kg/d</td>
<td>24.7</td>
<td>25.1</td>
<td>25.8</td>
</tr>
<tr>
<td>Fat, kg/d</td>
<td>1.00</td>
<td>1.00</td>
<td>1.05</td>
</tr>
<tr>
<td>Protein, kg/d</td>
<td>0.77</td>
<td>0.79</td>
<td>0.82</td>
</tr>
<tr>
<td>SNF, kg/d</td>
<td>1.89</td>
<td>1.97</td>
<td>1.99</td>
</tr>
<tr>
<td>Lactose, kg/d</td>
<td>0.96</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>MUN, mg/dL</td>
<td>11.5</td>
<td>11.0</td>
<td>10.8</td>
</tr>
<tr>
<td>SCS, mg/dL</td>
<td>1.76</td>
<td>1.68</td>
<td>1.65</td>
</tr>
</tbody>
</table>

Forage particle length

Short forage tended to decrease DM digestibility likely due to a more rapid passage rate. As designed, there was no effect of diet on total P intake (Table 3). Phytase addition to the diet reduced
phytate intake and consequently increase inorganic P intake. Forage particle length did not affect intake or omasal flow of total P or inorganic P. Ileal flow of total P and inorganic P increased as a result of short forage. Flow of total P and inorganic P at the ileum was increased with SF but flow of phytate was unaffected by forage particle length. A slight increase in fecal excretion of total P was observed with phytase supplementation. Flow of inorganic P at the omasum was reduced with phytase inclusion, but inorganic P at the ileum and in the feces was not affected. These data indicate approximately 70 to 80% of the inorganic P that was present at the omasum, was absorbed in the small intestine. Phytate flow at the omasum was approximately 1 gram/day. Total tract digestibility of phytate was greater than 95% regardless of dietary treatment. Disappearance of phytate from the large intestine was observed as well as a net reduction in total P in the feces as compared to the ileum revealing net absorption of P in the large intestine.

Table 3. Effect of forage particle length and phytase on intake, omasal flow, ileal flow, and fecal excretion of total phosphorus (P), inorganic phosphorus, and phytate.

<table>
<thead>
<tr>
<th></th>
<th>No phytase</th>
<th>Phytase</th>
<th>SEM</th>
<th>P &lt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Short</td>
<td>Long</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Short</td>
<td>Long</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Intake</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total P, g/d</td>
<td>74.5</td>
<td>76.7</td>
<td>77.8</td>
<td>74.1</td>
</tr>
<tr>
<td>Inorganic P, g/d</td>
<td>32.8</td>
<td>35.5</td>
<td>49.2</td>
<td>43.5</td>
</tr>
<tr>
<td>Phytate P, g/d</td>
<td>44.0</td>
<td>37.3</td>
<td>13.8</td>
<td>23.1</td>
</tr>
<tr>
<td><strong>Omasal flow</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total P, g/d</td>
<td>195.9</td>
<td>181.9</td>
<td>173.7</td>
<td>157.8</td>
</tr>
<tr>
<td>Inorganic P, g/d</td>
<td>181.4</td>
<td>174.5</td>
<td>159.9</td>
<td>136.7</td>
</tr>
<tr>
<td>Phytate P, g/d</td>
<td>0.87</td>
<td>0.94</td>
<td>0.99</td>
<td>1.10</td>
</tr>
<tr>
<td><strong>Ileal flow</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total P, g/d</td>
<td>72.6</td>
<td>53.6</td>
<td>74.0</td>
<td>61.4</td>
</tr>
<tr>
<td>Inorganic P, g/d</td>
<td>43.4</td>
<td>33.4</td>
<td>49.0</td>
<td>36.3</td>
</tr>
<tr>
<td>Phytate P, g/d</td>
<td>2.03</td>
<td>1.58</td>
<td>1.67</td>
<td>1.54</td>
</tr>
<tr>
<td><strong>Fecal excretion</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total P, g/d</td>
<td>54.7</td>
<td>50.4</td>
<td>59.4</td>
<td>55.3</td>
</tr>
<tr>
<td>Inorganic P, g/d</td>
<td>41.4</td>
<td>34.2</td>
<td>41.3</td>
<td>42.0</td>
</tr>
<tr>
<td>Phytate P, g/d</td>
<td>1.49</td>
<td>1.16</td>
<td>0.97</td>
<td>0.99</td>
</tr>
</tbody>
</table>

1Forage particle length

**Large intestine digestion of phytate**

Eight ruminally- and ileally- cannulated crossbred heifers were used in two 4x4 Latin squares and were randomly assigned to 1 of 4 treatments within each square. Treatments were ileal infusion of phytate; 0, 5, 15, or 25 g/d of phytate-P solution (0, 1.41, 4.22, and 7.04 g/d P, respectively). Each period included 4 days of infusion and 2 days of post-infusion ileal sampling and total collection of feces. Samples were analyzed for phytate and lower IP species.

The amount of phytate infused daily was different between different treatment groups as intended by experimental design. Daily fecal phytate output increased numerically with increased phytate infused at the ileum, but did not significantly differ between treatment groups. Similar phytate disappearance from the large intestine was observed (Table 4). For both IP5 and IP4, daily amount infused at the ileum was different between treatment groups and fecal output of these species increased with increasing infusion amount. Thus, large intestinal disappearance for both IP5 and IP4 did not differ between
different phytate infusion groups (Table 5). The disappearance of IP$_3$ and IP$_4$ from the large intestine averaged 34% and 64% of total supplied, respectively.

Table 4. Phytate flow at the ileum, amount infused, fecal excretion, and large intestine digestibility.

<table>
<thead>
<tr>
<th>Infusion dose, g/d of phytate –P</th>
<th>Ileal phytate flow g/d</th>
<th>Fecal phytate g/d</th>
<th>Phytate digestibility %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.13</td>
<td>0.11</td>
<td>13.8</td>
</tr>
<tr>
<td>5</td>
<td>0.16</td>
<td>0.99</td>
<td>16.8</td>
</tr>
<tr>
<td>15</td>
<td>0.21</td>
<td>2.81</td>
<td>18.4</td>
</tr>
<tr>
<td>25</td>
<td>0.16</td>
<td>4.33</td>
<td>12.9</td>
</tr>
<tr>
<td>P &lt;</td>
<td></td>
<td></td>
<td>NS</td>
</tr>
</tbody>
</table>

Table 5. Large intestine digestibility if lower inositol phosphate (IP) species.

<table>
<thead>
<tr>
<th>Infusion dose, g/d of phytate -P</th>
<th>IP$_3$ %</th>
<th>IP$_4$ %</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>29.7</td>
<td>58.6</td>
</tr>
<tr>
<td>15</td>
<td>36.1</td>
<td>65.1</td>
</tr>
<tr>
<td>25</td>
<td>36.8</td>
<td>68.8</td>
</tr>
<tr>
<td>P &lt;</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Conclusions

The P flow data presented in this experiment with the data detailing P digestion and absorption in the large intestine can improve published models of P digestion, absorption, and metabolism especially considering the lack of data available in large ruminants (Hill et al., 2008). Explanation of P forms will provide a greater understanding as to how P, in its complexities, can help meet the animal’s requirements. Cows in the lactating cow study were late in lactation and fed diets more than adequate in P. And cows in the heifer study had very low P demand as well because they were not in lactation. This leaves unanswered questions in regards to digestion and absorption of P in cows fed limited P diets or cows with a greater demand for P.

References


STARCH CONCENTRATION AND RUMINAL FERMENTABILITY IN RATIONS FOR LACTATING COWS

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Summary

Concentration and ruminal digestibility of starch in rations of lactating cows has important effects on productivity. Starch is more digestible and less filling than forage fiber and provides more glucose precursors than fiber from any source. Ruminal fermentability of starch is affected by grain and endosperm type, processing and conservation method, and diet and animal factors, and affects production of fermentation acids and microbial protein in the rumen. Excessive ruminal fermentability can decrease fiber digestibility, efficiency of microbial protein production, and alter ruminal biohydrogenation, decreasing synthesis of milk fat and increasing energy partitioned to body condition at the expense of milk.

The concentration and ruminal fermentability of starch affects feed intake, and energy partitioning of cows differently as they progress through lactation. High-producing cows in early to mid-lactation thrive on high-starch rations with highly fermentable starch sources while starch concentration and fermentability should decrease as lactation progresses to maintain yield of milk fat and prevent excessive body condition. Highly fermentable starch sources should be limited in rations for the first two weeks following parturition to avoid further depression in feed intake, and decrease risk of ruminal acidosis and displaced abomasum. Grouping cows by physiological state (fresh, early to mid, maintenance) is required to formulate diets for starch to optimize health and production.

Introduction

Starch is a highly digestible and energy dense feed component that typically ranges from less than 20% to greater than 28% in rations fed to lactating dairy cows. Forages are supplemented with cereal grains to increase energy density, provide glucose precursors, and decrease the filling effects of rations. Starch is composed of polymers of glucose (amylose and amylopectin) with bonds that are readily cleaved by mammalian enzymes. However, starch is packaged in granules that are embedded in a protein matrix in the seed endosperm, which varies in solubility and resistance to digestion (Kotarski et al., 1992). These differences in endosperm type have great effects on ruminal fermentability of starch, which ranges widely; ruminal fermentability of starch from various cereal grains ranges from less than 30% to more than 90% (Nocek and Tamminga, 1991; Firkins et al., 2001). Altering the concentration and ruminal fermentability of starch in rations affects digestibility of starch (Ngonyamo-Majee et al., 2008), ruminal pH and fiber digestibility (Firkins et al., 2001), and the type, amount, and temporal absorption of fuels (e.g. acetate, propionate, lactate, glucose) available to the cow (Allen, 2000). This has great effects on lactational performance by affecting energy intake and partitioning as well as absorbed protein (Allen et al., 2009). In addition, effects on animal performance depend upon physiological state of cows, which varies greatly through lactation (Allen et al., 2005). Therefore the optimum concentration and ruminal fermentability of starch in rations of lactating cows vary through lactation. The objective of this paper is to discuss what determines site of digestion and total tract digestibility of starch, effects of concentration.
and ruminal fermentability of starch on animal performance, and considerations related to starch for formulating diets for lactating dairy cows.

**Starch Fermentability**

Ruminal fermentability of starch is highly variable and affected by grain type, vitreousness, processing (e.g. rolling, grinding, steam flaking), conservation method (dry or ensiled), ration composition, and animal characteristics. Starch in wheat, barley and oats is generally more readily fermented than starch in corn, and starch in sorghum is most resistant to fermentation in the rumen and digestion by the animal (Huntington, 1997). These differences are largely because of differences in endosperm type rather than differences in starch composition (amylose vs. amylopectin) per se. Floury endosperm contains proteins that are readily solubilized, allowing greater access of enzymes to starch granules while vitreous endosperm contains prolamin proteins that are insoluble and resistant to digestion, decreasing access of enzymes to starch granules (Hoffman and Shaver, 2010). Starch sources vary in amount and proportion of the two types of endosperm and there is large variation in vitreousness of the endosperm (percent of the total endosperm that is vitreous) among varieties within certain grain types. Endosperm vitreousness in corn harvested dry ranges from 0% to greater than 75% and corn with more vitreous endosperm is more resistant to both particle size reduction by grinding and digestion (Hoffman et al., 2010) than corn with more-floury endosperm. Vitreousness increases with increasing maturity at harvest (Phillipeau and Michalet-Doreau, 1997), so differences among corn hybrids are greatest when field dried. Because corn silage is harvested earlier than high moisture corn, the grain will have less vitreous endosperm and more moisture when harvested from the same field as whole plant silage compared with high-moisture corn. However, there can be large differences in vitreousness within corn silage harvested between 30% and 40% dry matter and within high moisture corn harvested between 60% and 75% dry matter (40 and 25% moisture) from the same field.

When grains are ensiled, ruminal fermentability of starch can be greatly affected by both grain moisture concentration and storage time. This is because ensiling solubilizes endosperm proteins over time, increasing starch fermentability. The increase in protein solubility and starch fermentability over time is greatest for grains with higher moisture concentration (Figure 1; Allen et al., 2003). Therefore, the change is greatest for wetter corn silage and least for drier, high-moisture corn. This change is greatest over the first few months of ensiling and must be anticipated and accounted for when formulating rations. Because of this, it is recommended to wait several months after ensiling before feeding corn silage (Allen, 1998). However, the change continues for months at a slower rate and corn silage and high moisture corn stored for long periods (one or two years or more) can be difficult to feed in high concentrations because it is so readily fermented.

Processing increases rate of starch digestion and the effects are greater for grains with more vitreous endosperm such as sorghum and corn (Huntington, 1997). Access of enzymes to starch granules is increased by steam flaking, which causes swelling and disruption of kernel structure, and reducing particle size by rolling or grinding whole grains, or processing silage to

![Figure 1](image-url). Effects of kernel moisture concentration and days ensiled on in vitro starch digestibility (7 h) for 6 corn hybrids grown in Michigan, Nebraska, and Pennsylvania (Allen et al., 2003).
crush kernels, which greatly increases surface area. Dry grains can be finely ground, greatly decreasing effects of endosperm vitreousness on ruminal fermentability. Processing (rolling) corn silage is not as effective at increasing surface area as fine grinding; processing can reduce, but not eliminate, differences in digestibility of sources varying in vitreousness.

**Measuring Starch Concentration and Fermentability**

Starch concentration is relatively consistent within cereal grain types but varies greatly within forages containing starch such as corn silage and small grain silages. Therefore, book values for starch concentration may be acceptable for cereal grains but starch concentration must be measured for forages from grain crops. For instance, the starch concentration of corn silage varies from less than 20 to over 50% of DM depending upon grain concentration, which, in turn, is dependent upon genetics, environment and maturity at harvest. The starch concentration of corn silage is inversely related to concentration of NDF; fibrous stover fraction of the plant is enriched if kernels don’t fill.

The non-fiber carbohydrate (NFC) concentration of diets should not be relied upon as a measure of starch concentration. The NFC fraction is calculated by subtracting measured components (NDF, CP, ether extract, ash) from total DM. It contains other carbohydrates such as sugars and pectin and can be underestimated to the extent that non-protein nitrogen is present. While starch, sugars and pectin are generally highly digestible, their effects on rumen microbial populations and fuels available to the animal differ greatly. Starch that is ruminally-fermented increases propionate production in the rumen (Sutton et al., 2003) and starch that escapes ruminal fermentation provides glucose that is absorbed or metabolized to lactate in the small intestine (Reynolds et al., 2003). Sugars are nearly completely fermented in the rumen and generally increase butyrate production (Oba, 2011). Most strains of pectin-degrading rumen bacteria produce acetic and formic acids and relatively little propionic acid (Dehority, 1969). Propionic and lactic acids are glucose precursors while formic, acetic, and butyric acids are not. In addition, propionate can decrease feed intake under some conditions (Allen, 2000) and starch, sugars, and pectin have different effects on microbial populations in the rumen that can affect fiber digestion and ruminal biohydrogenation of fatty acids. Therefore, NFC is not a useful proxy for starch when formulating rations for lactating cows.

Relative differences in rate of starch digestion can be determined by *in vitro* starch digestion (IVSD) with ruminal microbes. This can be done by incubating samples over time in rumen fluid with buffered media and evaluating the rate of starch disappearance or, less costly and equally informative, by evaluating starch disappearance over a period of time (e.g. 7 hours). We began using a 7-h incubation time over 20 years ago when our objective was to predict *in vivo* ruminal digestibility of starch because we thought it was a reasonable mean residence time of starch in rumens of lactating cows. However, we subsequently realized that was naïve because ruminal digestibility of starch *in vivo* is highly affected by the enzyme activity of the rumen fluid and particle size of the starch source, and that residence time of starch in the rumen is extremely variable, not only across cows, but also across sources of starch (Table 1). We continue to use IVSD with a 7 h retention time because we think it provides useful information about relative rates of fermentation among starch sources. However, it is very important to know that 7-h IVSD is a relative measure of rate of starch digestion among sources only. Samples must be ground before analysis, which removes important variation for many comparisons (e.g. processed vs. unprocessed corn silage). Comparisons must be done in the same *in vitro* run (at the same time) because IVSD of the same sources is highly variable across runs. This is because enzyme activities (amylases and proteases) of rumen fluid are highly variable from cow to cow, time relative to feeding, and diet consumed. In our laboratory, the coefficient of variation for 7-h IVSD across runs can be as high as 25% even after attempting to minimize variation by taking rumen fluid from several cows fed a specific diet at the same time of day relative to feeding. This is much higher than our coefficient of variation for 30-h *in vitro* NDF digestibility of less than 3%.
Because starch digestion is inhibited by insoluble proteins in the endosperm, the solubility of protein has been measured as an indicator of relative differences in starch digestibility. Like IVSD, determination of protein solubility requires grinding samples, removing variation among sources. Because it is a chemical rather than biological measure, it is less variable across runs than IVSD. Accuracy of ruminal starch digestibility prediction from protein solubility is limited by the relationship between protein solubility and rate of starch digestion as well as limited knowledge of passage rate of starch from the rumen. Therefore, like IVSD, measures of protein solubility provide some information related to ruminal starch digestion but cannot be used to measure ruminal starch digestibility accurately.

Table 1. Effects of dietary treatment on passage rate (kp) of starch from the rumen.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Treatment</th>
<th>kp, %/h</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oba and Allen, 2000b</td>
<td>bm3 corn silage</td>
<td>12.9</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>control corn silage</td>
<td>10.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>29% diet NDF</td>
<td>14.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>38% diet NDF</td>
<td>9.0</td>
<td></td>
</tr>
<tr>
<td>Oba and Allen, 2003a</td>
<td>high-moisture corn</td>
<td>15.4</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>dry ground corn</td>
<td>19.7</td>
<td></td>
</tr>
<tr>
<td>Voelker and Allen, 2003b</td>
<td>high-moisture corn</td>
<td>15.9</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>24% beet pulp</td>
<td>23.5</td>
<td></td>
</tr>
<tr>
<td>Ying and Allen, 2005</td>
<td>high-moisture corn</td>
<td>7.1</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>dry ground corn</td>
<td>16.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>vitreous endosperm</td>
<td>16.0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>floury endosperm</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>Taylor and Allen, 2005</td>
<td>vitreous endosperm</td>
<td>21.2</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>floury endosperm</td>
<td>16.2</td>
<td></td>
</tr>
<tr>
<td>Allen et al., 2008</td>
<td>vitreous endosperm</td>
<td>25.7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>floury endosperm</td>
<td>16.0</td>
<td></td>
</tr>
</tbody>
</table>

1 Determined by dividing duodenal flux (g/h) by rumen pool size (g) and multiplying by 100.

**Prediction by models**

Although measurement of digestion rate of feed fractions in vitro and in situ can provide relevant information regarding relative differences among feeds, absolute, not relative, values are required by models to predict ruminal digestibility. Therefore, despite their promise, ration formulation models that include rumen sub-models such as CNCPS do not predict ruminal starch digestibility accurately even if in vitro rates of starch digestion are used as inputs (Allen, 2011). Accuracy and precision of prediction of ruminal starch digestibility was poor for several models including CPM and AMTS in a recent evaluation; AMTS and CPM over-predicted ruminal starch digestibility for corn grain by over 25 percentage units (~80% vs. 55%), leading the authors to conclude that the model estimates were not useful (Patton et al., 2012). The primary factors limiting accurate determinations of digestion rate in vitro or in situ are 1) the inability to mimic the increase in surface area and breakdown of particle size by rumination, 2) variation in enzyme activity and ratio of enzyme to substrate in the rumen over time, and 3) lack of understanding and data on passage rates of starch.

Rates of starch digestion determined in vitro are much different than actual rates of digestion because feed particles containing starch that are consumed by cows are larger than what is required for in vitro analysis and because enzyme activity in the rumen is extremely variable depending upon diet, time since eating, and the cow. Grinding feeds is necessary to obtain uniform samples for analysis in the laboratory but grinding increases surface area accessible to microbes, increasing rate of digestion.
compared to intact feeds *in vivo*. On the other hand, not grinding at all will underestimate rate of digestion because feeds are crushed and ground by chewing over time, before they pass from the rumen. This is an unsolvable problem because simulation of the effects of chewing over time of incubation *in vitro* or *in situ* is infeasible.

The high variation in IVSD across runs prompted us to evaluate the effect of rumen fluid sampled before and after feeding on IVSD-7h which was 33% greater after feeding compared to before feeding (41.2 vs. 30.9%, P < 0.01; Fickett and Allen, 2002). Enzyme activity related to starch fermentation is also increased with higher starch diets; we reported that the fractional rate of starch digestion determined *in vivo* with the pool and flux method was greater for diets with higher starch concentration and lower NDF from forage (Oba and Allen, 2003a) or beet pulp (Voelker and Allen, 2003b). Therefore, at least for starch, digestion is a second-order process dependent upon both substrate and enzyme activity. This is a problem for utilization of current data with most existing models in which digestion is modeled as a first-order process dependent on feed characteristics only.

Passage rate of starch was greatly affected by particle size, conservation method, and endosperm type for corn (Table 1; Ying and Allen, 2005; Allen *et al.*, 2008). However, little data exists for passage rates of starch and how it is affected by diet and level of intake. Because passage rate is as important as digestion rate for determining ruminal starch digestibility, accurate predictions by models that use digestion kinetics to predict starch digestibility are not currently possible. In addition, models such as CNCPS that use digestion rates for carbohydrate fractions but passage rates for entire feeds result in even greater inaccuracies for determination of ruminal starch digestion.

**Production Response**

The filling effects and fermentability of rations are affected by the concentration and ruminal fermentability of starch and can affect DMI, nutrient partitioning, microbial protein production, and total-tract digestibility. Increasing the starch concentration of the ration offered to lactating cows from ~23 to ~34% (~24 to 16% forage NDF, respectively) resulted in variable effects on DMI and FCM yield depending upon the milk yield of cows (range in FCM: ~50 to ~130 lb/d); DMI response to the high-starch, low forage NDF ration increased linearly with increasing milk yield of cows throughout the range while FCM response increased only for cows above ~90 lb/d of FCM (Voelker and Allen, 2003a; Figure 2). Response for DMI was likely because the higher starch diet was less filling.
(16% forage NDF) and rumen fill is a greater limitation to feed intake as milk yield increases (Allen, 1996), while response for FCM likely depended upon effects of the ration on digestibility and energy partitioning among cows.

The physiological state of animals determines the effects of starch fermentability on DMI (Bradford and Allen, 2007) and production (Bradford and Allen, 2004) responses. High moisture corn compared to dry ground corn had opposite effects on milk yield for cows depending on initial milk yield, with no change for the group overall; high moisture corn increased concentration of milk fat and yield of FCM for cows producing over ~90 lb/day but decreased both for cows producing less than that amount (Bradford and Allen, 2004). Effect of treatment on DMI was not related to milk yield but was affected by physiological state of cows; depression in DMI by the high moisture corn compared with the dry corn treatment was related to plasma insulin concentration and insulin response to a glucose challenge (Bradford and Allen, 2007). Feed intake of cows with greater insulin concentration, and lower insulin response to a glucose challenge, was depressed to a greater extent by high moisture corn compared with dry ground corn. As lactation proceeds and milk yield declines, feed intake is increasingly dominated by metabolic signals. Highly fermentable diets often decrease feed intake in mid to late lactation, likely from stimulation of hepatic oxidation by propionate (Allen et al., 2009). Reducing ruminal fermentability of starch by substituting dry corn for high moisture corn in rations often increases energy intake and partitioning to milk for these cows.

Energy partitioning between milk production and body condition varies depending upon fuels available and as physiological state changes throughout lactation. Substitution of fiber for starch greatly alters fuels available for intermediary processes and often results in greater partitioning of energy to milk rather than body condition. Substitution of soyhulls for dry ground corn up to 40% of diet DM increased milk fat percent (linearly from 3.60 to 3.91%) and decreased body weight gain (linearly from 1.02 to -0.14 kg/d) with no effect on milk yield (~29 kg/d) and a slight decrease in DMI (tendency, linearly from 23.8 to 22.7 kg/g, Ipharraguerre et al., 2002). We showed that beet pulp decreased BCS without decreasing yields of milk or milk fat when substituted for high-moisture corn up to 12% of diet DM (Voelker and Allen, 2003a). Furthermore, we showed that a 69% forage diet (0% corn grain) containing brown midrib corn silage increased energy partitioned to milk, decreasing body weight gain while numerically increasing FCM yield compared with a 40% forage diet (29 % corn grain) containing control corn silage (Oba and Allen, 2000a). In contrast, DMI and milk yield was reduced when the control corn silage, which had ~20% lower in vitro NDF digestibility (46.5% vs. 55.9) than the brown midrib corn silage, was fed in the higher forage diets.

As lactation proceeds, insulin concentration and sensitivity of tissues increase and energy is increasingly partitioned to body condition. Intravenous glucose infusion of up to 30% of net energy requirement linearly increased plasma insulin, energy balance, body weight and back fat thickness, without affecting DMI or milk yield of mid-lactation cows (Al-Trad et al., 2009). An experiment conducted with cows in the last 2 months of lactation showed that substitution of beet pulp for barley grain linearly decreased body condition score and back fat thickness, maintained milk yield and linearly increased milk fat yield and milk energy output (Mahjoubi et al., 2009). Decreased body condition score and increased milk fat yield might have been because of a linear decrease in plasma insulin concentration which linearly increased plasma NEFA concentration.

High starch diets might result in greater insulin concentration, partitioning energy to adipose at the expense of milk, but they also often result in lower ruminal pH resulting in milk fat depression from altered biohydrogenation of polyunsaturated fatty acids in the rumen reducing milk energy output. While increased energy retention as body condition might be because of increased insulin as observed by Ipharraguerre et al. (2002) and Mahjoubi et al., (2009), it might also be a result of altered gene expression in adipose tissue. Harvatine et al. (2009) reported that CLA-induced milk fat depression increased gene
expression for enzymes and regulators of fat synthesis in adipose tissue. The energy spared from the reduction in milk fat synthesis was likely partitioned toward adipose tissue fat stores. Reducing ration starch concentration by increasing fiber from forages or non-forage fiber sources can maintain milk yield while decreasing gain in body condition.

Increasing ruminal degradability of starch generally increases microbial nitrogen flow to the duodenum but excessive ruminal starch digestion might decrease ruminal fiber digestibility, offsetting its effects (Firkins et al., 2001). In addition, starch sources with faster rates of fermentation might decrease efficiency of microbial protein production; microbial growth can be uncoupled from OM fermentation under some conditions (Russell and Cook, 1995). Greater concentration of starch in rations (32 vs. 21% of DM) increased flow of microbial nitrogen from the rumen with no effect on efficiency of microbial nitrogen production in a study from our laboratory with lactating cows (Oba and Allen, 2003b). However, although ruminal starch digestibility was increased by high moisture corn compared with dry ground in that experiment, high moisture corn decreased efficiency of microbial nitrogen production compared with dry corn and did not affect flow of microbial nitrogen from the rumen. While flow of microbial nitrogen was positively related to true ruminal OM digestibility in that experiment, it was negatively related to rate of starch digestion across all cow period means. Microbial growth might be limited when rate of starch digestion is very fast (Oba and Allen, 2003b). Therefore, increasing ruminal starch degradation by increasing starch concentration of diets might improve flow of microbial nitrogen to the duodenum to a greater extent than increasing ruminal fermentability of starch.

**Formulating Rations for Starch**

We know a great deal about what factors affect ruminal digestibility of starch that can be routinely used for ration formulation even if we cannot accurately measure rates of digestion and passage of starch. Starch concentration and ruminal digestibility is so variable across feeds that we can measure starch concentration and use literature values for ruminal digestibility for initial formulation which can be adjusted using qualitative knowledge of factors that affect ruminal starch digestibility discussed above. Although we should strive to increase accuracy of prediction over time, we are not able to accurately predict animal responses to starch concentration and fermentability because of the many interactions that ultimately affect response such a stocking density, effective fiber concentration, milk yield, physiological state, etc. However, ration formulation should be an iterative process that includes cows in the loop; evaluation of cow response will provide feedback to optimize diets. Cow responses include DMI; yields of milk, fat, and protein; milk urea nitrogen; body condition; manure consistency; ketones; etc. Grains that differ in ruminal starch fermentability, but have high whole tract digestibility (e.g. high moisture corn and ground dry corn), allow evaluation of optimal ruminal starch digestibility without other confounding effects (e.g. effects of changing forage NDF concentration on feed intake) and diet starch concentration can be reduced by substitution of a non-forage fiber source, such as beet pulp, soyhulls, or corn gluten feed, for grains.

Group feeding complicates interpretation of responses for DMI and milk yield. Mean milk yield for the group masks effects of diets because large changes in milk yield of individual cows within the group might occur with no change in milk yield for the group overall. This is most evident when all lactating cows (with great differences in physiological state) are offered the same diet. Individual milk meters provide timely feedback regarding response of individuals within the group and are an important tool for diet formulation and grouping. The same is true for individual DMI response, but this is not feasible economically for group-housed cows. While that limits the usefulness of DMI determination for the group, it is still a very useful measurement, particularly in combination with milk yield to provide important clues for the effects of the diet change. Evaluation of cow response requires more attention by nutritionists and coordination with the management teams on farms. The extent to which nutritionists and the management team interact will vary from farm-to-farm, but this is an important determinant of the
success of the nutrition program. The following recommendations for ration starch concentration and ruminal fermentability for cows as they progress through lactation should be adjusted as indicated by cow response.

**Fresh cow ration (10 days to 3 weeks following parturition)**

Fresh cows are in a lipolytic state, are at increased risk for metabolic disorders, and feed intake is likely controlled by oxidation of fuels in the liver (Allen et al., 2009). These cows require glucose precursors and rations should contain higher starch concentrations to the extent possible. However, they also have lower rumen digesta mass, which increases risk for ruminal acidosis and displaced abomasum. Highly fermentable starch sources increase fermentation acid production including propionate, which can stimulate oxidation of fuels in the liver, suppressing feed intake (Allen et al., 2009). Therefore, highly fermentable starch sources should be limited during this period which lasts up to two weeks for most cows but even longer for cows with excessive body condition at parturition. Highly fermentable starch sources such as wheat, barley, low-density steam-flaked corn, and aged (greater than 1 year old) high moisture corn and corn silage, should be limited to allow greater starch concentrations (and glucose precursors) with less risk of acidosis or displaced abomasum. Supplementing corn silage based diets with dry ground corn works well for this ration with a total starch concentration of 22 to 25% (DM basis). Because feed intake is less limited by ruminal distention during this period, and greater rumen digesta mass is desirable, forage NDF concentration should be greater than 23% and use of non-forage fiber sources should be limited to diluting starch concentration, if necessary. Starch concentrations must be decreased when feeding highly fermentable starch sources.

**Early to mid-lactation ration**

Cows in early to mid-lactation have high glucose requirement for milk production and partition relatively little energy to body reserves. They respond well to rations with lower forage NDF concentration (low fill) and highly fermentable starch. Starch concentration of rations should be in the range of 25 to 30% (DM basis) although the optimum concentration is dependent upon competition for bunk space, forage/effective NDF concentration, and starch fermentability. Higher starch, lower fill rations generally increase peak milk yield and decrease loss of body condition in early lactation. However, once cows replenish body condition lost in early lactation, they should be switched to a maintenance diet with lower starch concentration and ruminal fermentability.

**Maintenance ration (> 150 DIM and BCS of 3)**

The maintenance ration is the key component of a ration formulation/ grouping system to increase health and production of cows. The goal of the maintenance ration is to maintain milk yield and body condition through the rest of lactation. Cows should be offered the maintenance ration when they are regaining BCS and reach a BCS of 3. If they continue receiving a high starch diet, BCS will continue to increase and they will be at increased risk for metabolic disease following parturition. Evidence presented above suggests that they are gaining condition because they are being fed rations with greater starch concentrations needed for their current requirement for milk production, increasing plasma glucose and insulin concentrations. Lowering ration starch concentration should limit body condition gain while maintaining and possibly improving feed intake and yields of milk and milk fat. The optimal concentration of starch is dependent upon the milk yield of the herd and physical groups possible but will likely be in the range of 18 to 22% (DM basis). Starch sources that are high fermentable (high-moisture corn, bakery waste, aged corn silage, etc.) should be avoided. Dried ground corn is an excellent starch source because it has lower ruminal digestibility (~60%) but high total tract digestibility (< 90%). The starch concentration of the maintenance ration should contain adequate, but not excessive forage NDF concentration to maintain DMI, and non-forage fiber sources (beet pulp, corn gluten feed, soyhulls, etc.)
can be used to dilute starch to the target concentration. Monitoring BCS at dry-off is essential to adjust the starch concentration of the maintenance diet over time.

Conclusions
Concentration and ruminal fermentability of starch are highly variable among rations fed to lactating cows and have great effects on feed intake, energy partitioning, milk production, and health. The optimal starch concentration and starch source in rations varies by physiological state of cows, which changes through lactation. Cows should be fed different rations through lactation to maximize use of existing knowledge regarding starch nutrition.

References
Hoffman, P.C., and R.D. Shaver. 2010. The nutritional chemistry of dry and high moisture corn. Pages 179-192. Proc. 10th Western Dairy Management Conference, Department of Animal Science, Kansas State University, Manhattan, KS.


NUTRITION AND MANAGEMENT OF AUTOMATIC CALF FEEDING SYSTEMS

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Summary

As calves of today are the future of the dairy industry, researchers have taken a keen interest in how producers can best raise dairy calves. A look back at the evolution of the dairy cow shows that at one point in time calves were allowed to stay at their dam’s side to nurse to receive their nutrition. As the dairy industry evolved to produce milk and provide nutrition to the general population calves were separated from their dams and raised with milk or milk replacer. There are many benefits to this practice if done properly but unfortunately the industry evolved to feeding calves a low level of milk two times a day on a bottle or with a bucket.

Dairy calves are the only mammalian neonates that are limit-fed milk, and dairy producers have been challenged to find ways to keep them alive, healthy and growing. Researchers have started to look back at how Mother Nature would have fed calves, providing a higher level of nutrition in multiple feedings daily.

Automatic calf feeding equipment is a tool to offer calves a higher level of nutrition through multiple feedings daily and has replaced traditional manual calf feeding on many dairy operations. Technological advancements allow the systems to more efficiently grow calves.

Though automatic calf feeding equipment has been on the market for decades, greater interest in higher levels of nutrition, improvements in computerization and collaborative management tools has increased product popularity in recent years. The latest automated calf feeding systems allow producers to customize milk volume, feedings per day and automate health treatments. Individual calves are monitored by using radio frequency identification (RFID) tags and collaborative software. Land O’Lakes Animal Milk Products has analyzed the technology for the past five years.

When coupled with research conducted at academic institutions across the world, the five years of research on more than 1,500 calves at Land O’Lakes facilities has brought the industry to a point where automated feeders can be evaluated for efficacy. The ongoing study has determined which feeding rates and management strategies best fit today’s dairy operation. The advantages of automatic calf feeding systems determined through the research include: the appearance of improved animal welfare, potential labor savings, labor flexibility, higher nutrition levels and increased meal frequency.

To realize the benefits, producers must manage risks associated with the technology. Users of automated calf feeding equipment have found success by paying close attention to maintenance, sanitation and biosecurity as well as by employing new strategies to prevent respiratory challenges.

Introduction

A key capability of an automated feeding system is its ability to conveniently deliver a higher plane of nutrition in several meals per day similar to what the dam would do. Some calf growers have mimicked this by hand feeding dairy calves three times per day – with an estimated 14 percent of U.S. dairy producers moving to three times per day feeding in the winter (Intervet – Schering Plough Market Research, 2010). Miller et al. (2010) further evaluated three time-a-day feeding and found that calves fed...
three times daily could be weaned at six weeks rather than seven weeks and still show trends for greater weaning weights, increased hip heights and significantly larger heart girth measurements than calves fed the same total amount of milk twice daily (Figures 1& 2).

In fact, the body volume gain of the calves fed three times daily was 22 liters larger than those fed twice daily in the study. Similar research conducted in 2011 (Figure 3) shows that the influence of feeding frequency continues through heifer growth and into lactation as calves fed three times daily not only had better gains in weight and hip height and improved feed efficiency but also were more likely to reach lactation than those fed the same amount twice daily and weaned at the same age (Sockett, et al., 2011). Sockett’s research study showed that when it came time for the calves to enter the lactating herd, 97.1 percent (34 of 35) of the calves in the three times a day feeding group entered the milking string. In comparison 80.0 percent (28 of 35) of calves fed two times per day entered the milking herd. This means for every six calves fed three times a day, one additional heifer entered lactation.

Dairy calves fed via automated calf feeding systems can be compared to ad libitum feeding strategies used on beef operations as both are allowed to consume high levels of dry matter in several feedings.

If you compare dairy calves fed manually to ad libitum feeding strategies used on beef operations, the advantage appears to be with the ad libitum feeding strategy. Beef calves drink four to eight times per day on average, consuming about 25 pounds or three gallons of milk daily, compared to the ¾ to one
gallon of milk typically fed to dairy calves manually. If you assume 12.5 percent solids, the beef calves consume 2.5 pounds of dry matter per day while dairy calves delivered milk manually take in 0.75 to one pound of dry matter. Fat and protein levels on a dry basis consumed by beef calves are also significantly higher; 27 percent protein and 30 percent fat in beef calves compared to 20 percent protein and 20 percent fat in traditionally-fed dairy calves. Due in part to increased milk accessibility and greater nutrition provided, the total death loss in all beef calves (heifers & bulls) from birth to weaning is 5.5 percent compared to a 14.3 percent loss in dairy heifer calves (USDA, 1997; NAHMS, 2007).

Automated calf feeding systems take the idea of increased growth from added nutrients one step further. The products work on the same basic premise as beef calves raised in cow-calf situations but allow the dam to remain in the milking herd. Several studies have been conducted to prove if the principle on paper translates to production.

### Automatic Calf Feeders Available

Numerous companies have recognized the growth and health benefits of increased milk volumes in calves by creating and modifying automatic calf feeders. Many of the automatic calf feeders currently on the market are made by Förster Technik of Germany. The company estimates that each machine can feed up to 120 calves with 25-30 calves per nipple and one to four nipples per feeder.

Many other systems are also available with a vast array of features and sophistication. The most problematic of these feeders is a system that is designed for sheep or goats but used to feed calves. Considerations prior to purchasing a machine include accuracy, cleaning process, calibration, machine size and technical support.

### Land O’Lakes Research Results

Land O’Lakes Animal Milk Products is evaluating the efficacy of the Förster Technik Vario Milk Powder Feeder through an ongoing study. Prior to 2009, one milk mixer unit with two nipples was used with 24 calves on each nipple during the study. In 2009, a second feeder was added to the operation to increase the research scope into nutrient composition comparisons.

In the five years of trials, more than 1,500 calves have been fed on the feeder in 62 treatment groups. Feeding curves, weaning methods, housing and behavior were monitored and adjusted based on previous results in various treatment groups.
On top of the appearance of improved calf comfort in group settings, the studies have found that labor is significantly reduced in automatic group feeding systems. Utilization of the feeders has resulted in excellent calf growth but best strategies were needed to secure premium results.

First, backgrounded calves transitioned into automated calf feeding systems more smoothly. Backgrounding involves hand-feeding calves individually seven to 12 days in a separate facility. This may not be necessary in home-raised calves or in situations with low stocking density but it appears at least three days is needed. In Danish work, calves that were backgrounded for 14 days prior to group feeding shifted onto the automated calf feeding system with less restlessness, needed less assistance, and had 50 percent less risk of respiratory disease than those backgrounded for six days (Rasmussen et al., 2006; Svensson and Liberg, 2006; Jensen, 2007).

Regardless of backgrounding length, respiratory problems were evident in automated calf feeding-fed calves. It is surmised that since the entire group of calves sucks from the same nipple and respiratory organisms colonize in the back of the throat, transfer from calf to calf is quite efficient.

After a 14 day manual feeding period, the best results were achieved when the automatic calf feeding system was set to feed two times per day for the first three days then after calves became adjusted to feeder use, it was set for more frequent meals. For healthy calves, the minimum feeding rate appeared to be 1.6 to 1.8 pounds of dry matter daily. The best performance in terms of growth in both body weight and body dimensions (frame) was recorded when calves consumed 2.5 pounds or greater of 28% protein milk replacer (Figures 4 & 5; Earleywine et al., 2012).

In trials at lower feeding rates, there were challenges with calves bunching at the feeder or greater feeder occupancy times (Earleywine et al., 2010a). This agrees with work in Denmark and Canada (Jensen, 2006; Borderas et al., 2009). Stocking density in terms of calves per nipple would likely need to be reduced if low feeding rates are used.

Land O’Lakes found challenges with the automated concentrate station that is available as an option with the feeder. It was found that it limited intake and realized better performance with starter feed offered in bunks with adequate feeding space and height appropriate to calf height.
Once the management strategy was fine-tuned, the research team noticed significantly lower labor required to raise calves on the automatic calf feeding system. Labor required was on par with those reported by GEA Farm Technologies (Fisher, 2007). They estimated that calf feeders required 1.09 minutes per calf daily of labor while manual feeding of the same number of calves consumes 5.9 minutes. Savings can also be tallied based on more efficient calf growth and potentially less time required on milk (Earleywine et al. 2010a&b).

**Challenges**

The increased nose-to-nose contact of group housed calves presented augmented health risks when combined with shared nipples. Hazards were amplified when young calves were housed in the same groups as older calves. Respiratory illness rates drop with improved ventilation and bedding and with smaller group sizes as well as lower stocking density.

Calf morbidity is also improved when calves were monitored in person at least twice daily rather than relying on the computer. Risk of disease is also decreased when calves entered the system on an all-in, all-out basis versus continuous entry over time.

Ventilation is also highly critical with group housing. Proper ventilation requires an air exchange, not just air movement. Group housing environments should have air exchange rates of four air changes per hour, 15 air changes per hour and 60 air changes per hour in cold, mild and hot weather, respectively. Understand that installing fans does not equate ventilation; neither does installing exhaust fans if the inlets are not engineered correctly. Adequate amounts of fresh air need to be delivered uniformly throughout the barn to every calf at a speed that does not get felt as a draft. Adequate space and bedding are also critical for complete functionality with minimal stress.

The majority of the researchers who have focused on automatic calf feeding systems and the producers who have utilized the technology have found that the biosecurity risks associated with the feeders can be minimized by segregating calves by age, backgrounding calves, maximizing space available, minimizing group size and utilizing an all-in, all-out approach.

**Conclusion**

Though automatic calf feeding systems are not the best fit on all calf raising operations, benefits of the technology can be achieved if the correct strategies are utilized. Automated calf feeding systems are not the answer to poor calf management, so producers who employ the technology must continue to provide constant calf and equipment monitoring as well as an excellent colostrum program and follow a vaccine/treatment protocol created with a veterinarian.

Less manual labor is required to raise calves on automated calf feeders but additional management is required. Clean, dry bedding, adequate ventilation and a better plane of nutrition will help to meet performance goals while splitting calves into small groups based on age, properly sanitizing pens after groups leave and disinfecting automated calf feeding systems daily can allow producers to secure increased growth rates. When used properly, automated calf feeding systems can prove to benefit the herd into future lactations.

**References**


Miller, B.L., T.J. Earleywine and T.E. Johnson. 2010. Strategies for feeding full potential rates of calf milk replacer: Two feedings daily and weaned at seven weeks vs. three feedings daily and weaned at six weeks. J. Dairy Sci. Vol. 93 (Supp. 1) 637.


FEEDING DAIRY HERDS USING ROBOTIC MILKING SYSTEMS

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FEEDING COMPROMISED CROPS / FLOODS AND DROUGHTS

PANEL DISCUSSION

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NUTRITIONAL CHALLENGES AND PERCEPTIONS OF ORGANIC POULTRY PRODUCTION

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Summary

Organic meat production is the fastest growing segment of total organic production and poultry products are often the entry point by new organic customers into organic meat purchases (Crandall et al., 2009). These authors described the demographics of organic poultry consumption and it is interesting that the two largest consumer groups are those in the early 20’s and older baby boomers. The cost of organic poultry diets has been a limiting factor with respect to the growth of this segment of the industry because in many instances organic producers will still raise and market “pasture reared” but not organic broilers and eggs. Organic poultry producers, particularly those raising broilers, need to develop a new paradigm with respect to their approach to raising organic poultry. The published nutritional requirements of meat strains of poultry are designed to maximize growth and carcass yield and this is not necessarily the goal of organic producers nor the route for maximizing profitability. The objective our research and the following paper is to discuss alternative approaches to rearing quality and cost effective organic broilers.

Introduction

In 1990, Congress passed the Organic Foods Production Act and established a framework for the production and marketing of certified organic foods. Over the last decade, Europe and the U.S. have accounted for the largest proportion of the approximate $38 billion in total international organic sales (Willer et al., 2008). Wholesomeness of organic products, both in terms of nutrient content and the production standards required for organic certification, are the two primary factors driving organic sales in the U.S. (Knudson, 2007). The results of a 2007 Mintel survey cited by Mogelonsky (2008) suggest that almost half (48%) of the respondents agreed with the idea that organic products were healthier. The demand for organic products in 2008 was approximately $23 billion which represents a considerable increase in sales compared with previous estimates (Laux, M., 2009). The cliché “perception becomes reality” is appropriate for consumers purchasing organic products, particularly poultry products. The absence of subtherapeutic dietary antibiotics and other medications combined with diets composed of grains produced without the use of herbicides and pesticides are drivers behind organic poultry sales.

The rearing of organic poultry for meat production is often done on pasture using some type of movable range unit such as the Salatin “chicken tractor” (Joel Salatin, Pastured Poultry Profits, 1996). Each unit is moved frequently to a new section of pasture although there is only a minimal contribution of the pasture to the overall plane of nutrition (Walker and Gordon, 2003). The pasture, however, can be a source of selective nutrients that may enhance the nutritional quality of the finished product. It has long been recognized that egg and tissue lipids of poultry are largely a reflection of the pattern of dietary fatty acid intake (Marion and Woodruff, 1963). A unique experiment conducted by Ponte et al. (2008) showed that pasture dry matter intake could be increased from 1.5% to 5% by restricting consumption of a cereal based diet. As would be expected, feed restriction reduced body weight but the increase in pasture consumption significantly improved breast skin pigmentation and the levels of polyunsaturated, omega-3 fatty acids in breast meat. This supported previous observations by Castellini et al. (2002) who also...
compared organic versus conventionally reared broiler chicks. It is this potential for improving the omega-3 fatty acid profile and other nutritional characteristics that can add additional value to organic poultry products.

In a survey conducted by Batte et al. (2003), organic meat (including seafood and poultry) is purchased by approximately half of all consumers who purchase organic products and 82% of those who do not purchase organic products cite cost as the reason. Organic cereal grains are readily available as dietary energy sources for poultry but formulating diets with acceptable levels of protein and essential amino acids at a reasonable cost can be problematic, particularly if the objective is to “optimize” growth. Market surveys have reported that many consumers do not differentiate between pasture reared and certified organic poultry, hence there is often reduced economic incentive for producers with access to organic pasture to assume the added cost of sourcing organic ingredients/diets.

If organic poultry production is viewed in terms of an overreaching organic enterprise, the balance between economic and biological “sustainability” is more easily attained if purchased inputs (i.e. feed) are balanced by the combination of product sales and the environmental value of the outputs (i.e. manure, soil fertility). While the latter statement is obviously intuitive, the extensive marketing of organic products often overshadows the original intent of the organic movement which is sustainable agricultural practices. The question remains therefore, what are the niches that can be filled by poultry within an overall organic farm enterprise. If one considers “poultry” to be one component of a multi-year rotation system, poultry products could be a source of income and other inputs (i.e. nitrogen, phosphorus) during the year in which they serve as a designated rotation crop. The frequent moving of mobile rearing units or chicken tractors would lead to the uniform deposition of nitrogen and phosphorus whereas free-range rearing would result in a more scattered distribution of nutrients (Kratz et al., 2004). The flexible nature of pastured poultry could also allow for an initial hay crop to be harvested from a plot prior to the placement of that years’ initial crop of broilers, thus further diversifying the income from a plot during a given year.

In Europe, organic production standards are concerned with both the welfare of the animal and the source of inputs (i.e. organic ingredients). In this regard, European organic standards take into consideration the welfare consequences of maximizing growth in commercial cross broilers and this has allowed for the development of alternative, slower growing genotypes that adapt better to the rearing and dietary constraints of organic agricultural practices (Castellini et al., 2002; 2005). While it is accepted that slower growth will minimize growth associated anomalies and increase the production period, there are also reported improvements in the “quality” of the carcass in slower growing genotypes (i.e. increased antioxidant status and serum tocopherol) and these observations go hand in glove with the aforementioned increase in carcass omega-3 fatty acid content (Castellini et al., 2005).

A major goal of our organic research program is to better understand the dietary and genetic opportunities and constraints underlying cost effective organic poultry production. To this end we identified a group of organic producers for input. A study was conducted in our lab using commercial broilers fed conventional or organic diets ad libitum, heritage strain broilers (Barred Rocks) fed the conventional diet ad libitum, and commercial broilers fed the conventional diet but restrict fed to the same growth curve as the Barred Rocks. There has been much public press about the benefits of heritage strains due to their inherent slower rates of gain so the latter treatment was designed to ascertain if growth rate alone, independent of genetics and diet, influenced processing traits. All birds were reared in conventional floor pens with pine shavings. A sample of birds from each treatment were processed within the same body weight range, approximately 5.5 to 6.5 lbs live weight to obtain a typical “farmers market” dressed weight of approximately 4.5 lbs. It is important to note that the samples represented up to 10 days difference in age due to the aforementioned genetic (Barred Rock, Commercial) and feed management (ad libitum, restrict fed) differences.
As can be seen in Table 1, there were some differences in live weight among the treatment groups, the result of trying to equalize body weights among treatments differing in age, genotype, and diet management. The trends in carcass weight, both fresh and chilled, followed the differences in body weight. The increased carcass moisture uptake in the Barred Rock broilers is likely a reflection of a leaner carcass and may represent the potential for increased cooking loss. The fact that restricted feeding resulted in similar carcass and breast traits in the commercial broilers suggests that this genotype will respond best to organic pasture treatments designed to stimulate appetite through restriction and thus enhance pasture consumption.

Table 1. The effect of strain and diet on body weight and carcass traits.

<table>
<thead>
<tr>
<th></th>
<th>Commercial</th>
<th>RF-Commercial</th>
<th>Barred Rock</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Live Wt (lbs)</td>
<td>5.61 b</td>
<td>6.09 a</td>
<td>5.63 b</td>
<td>.08</td>
</tr>
<tr>
<td>Carcass Wt (lbs)</td>
<td>4.09 b</td>
<td>4.48 a</td>
<td>3.98 b</td>
<td>.06</td>
</tr>
<tr>
<td>Chilled Carc. (lbs)</td>
<td>4.48 b</td>
<td>4.91 a</td>
<td>4.42 b</td>
<td>.07</td>
</tr>
<tr>
<td>% Moisture (3 hr)1</td>
<td>9.45 b</td>
<td>9.44 b</td>
<td>11.06 a</td>
<td>.29</td>
</tr>
<tr>
<td>Breast Muscle (%)2</td>
<td>9.49 a</td>
<td>9.34 a</td>
<td>7.63 b</td>
<td>.16</td>
</tr>
<tr>
<td>Breast Muscle Drip (%)3</td>
<td>0.74</td>
<td>0.76</td>
<td>1.12</td>
<td>.16</td>
</tr>
</tbody>
</table>

1 All processed carcasses were weighed before and after a 3 hr immersion in an ice water bath.
2 This represents one-half of the Pectoralis major breast muscle which was weighed post-ice water immersion, placed individually in a plastic bag, refrigerated for 24 hr, and reweighed.
3 Analysis of variance drip loss percent – P < .101

The real answer to cost effective organic production will be adapting non-traditional cereal grains to organic production systems. There is a novel variety of oats in which the husk threshes free of the grain during harvest (Naked oats; *Avena sativa* ssp. *Nuda* L.). This cereal has a long history of being incorporated into agricultural cropping systems going back several centuries (see Peltonen-Sainio et al., 2004) and has long been recognized as a suitable ingredient in poultry diets (Gerry, 1958). When compared with conventional husked oats, the naked variety has significantly less crude fiber and a significant increase in both protein and lipid (Biel et al., 2009). Numerous feeding studies with broilers have suggested that growing and finishing diets containing up to 72% naked oats can largely replace corn with no effect on growth and similar results have been observed in growing and finishing swine (Cave and Burrows, 1985; Maurice et al., 1985; MacLean et al., 1994; Brand and van der Merwe, 1996). It is the relatively high protein and lysine levels that make naked oats such an attractive ingredient for organic poultry diets. It is well documented that achieving an adequate level of protein and amino acids is problematic and often results in diet formulations that are excessively high in total protein in an attempt to meet certain essential amino acid requirements (Moritz et al., 2005). Our own preliminary data using locally grown naked oats supports the hypothesis that up to 80% naked oats, when combined with extruded full-fat soybeans can support consistent, though not maximal growth rates in broilers and will also influence carcass composition and breast muscle moisture characteristics. Within an organic whole farm system, naked oats could be produced on the farm so the purchased dietary inputs would be greatly reduced. In addition, there is an increasing body of data describing the unique role that oats and their soluble fiber fraction could play in alleviating a host of current human health concerns (Wood, 2007; Sadiq Butt et al., 2008). Thus, naked oats could serve as a product for both organic poultry production and as an input into organic cereal/granola products for human consumption.
References


REGULATION OF ANTIBIOTIC USE IN POULTRY PRODUCTION: IMPACT ON BROILER NUTRITION AND PRODUCTION

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Summary

The ban on in-feed antibiotics (as antimicrobial growth promoters, AGPs) in poultry production stimulated therapeutic use of antibiotics in many European countries with intensive broiler industry. The fact total use of antibiotics in livestock production did not automatically decrease after the ban on AGPs and the public debate on increasing antimicrobial resistance urged national authorities to take further action. Registration and benchmarking of therapeutic use of antibiotics based on active compounds per live weight seems to be an effective tool to lower its use. In this paper alternative nutritional strategies are briefly discussed based on the anticipated modes of action of AGPs. Although economic considerations not always show clear adverse effects of the ban on AGPs, it should be realized that the outcome of such evaluations will be highly dependent on the intensity of regional poultry production.

History

Soon after the introduction of antibiotics in human medicine in the 1940s, it was observed that these drugs also had growth-promoting effects in animals, via improved weight gain and feed efficiency. As a result, antimicrobial drugs were implemented in all types of livestock production, and were referred to with the familiar term “antimicrobial growth promoters” (AGPs).

The mode of action of AGPs is not completely understood, although the relationship with the host intestinal microbiota seems to be unequivocal. This was confirmed by the absence of growth promoting effects when AGPs were used in germ-free animals. As these animals do not possess an intestinal microflora, it became clear that the mode of action of AGPs had to be related to the presence of gut bacteria. The most common explanation for the growth promoting effect of AGPs is that they directly or indirectly inhibit the commensal flora that is competing for nutrients with the host animal. AGPs are also claimed to reduce subclinical infection and the metabolic costs of the immune system, especially in case of an inflammatory response. Moreover, due to lower intestinal immune challenges, the gut wall is thinner, reducing its maintenance nutrient requirements and enhancing nutrient uptake. AGPs would also reduce bile degradation via reduced microbial activity and reduce the production of biogenic amines produced by commensal bacteria (Niewold, 2007). However, AGPs were used in sub-therapeutic doses below the Minimal Inhibitory Concentration, so it is unlikely that it was just a direct antimicrobial effect that was solely responsible for the growth promoting effect. Niewold (2007) proposed therefore a non-antibiotic anti-inflammatory effect of AGPs, being responsible for their growth promoting effects.

Ban on AGPs in the EU

In the early 1980s, a social debate on the use of antibiotics in otherwise healthy animals was raised in Sweden, leading to the formulation of a new feed law. The legislation came into force on January
1st 1986: the use of antibiotics and chemotherapeutics in feeds was only allowed for preventing, relieving, or curing illness, and the drugs could only be used on prescription by a veterinarian (Inborr, 2000). The “Swedish model” was a starting-point for the EU-wide ban on AGPs; most of them were already banned in 1999, and from January 1st 2006, a complete ban on all AGPs came into force. The Scandinavian countries (Norway, Sweden, Denmark, and Finland) played a strong pioneering role in this development.

Although in the Netherlands, the amount of AGPs already gradually declined between 1998 and 2005, the total net amount of antibiotics used, expressed in kg, remained almost the same between 1998 and 2008. This was due to the increased therapeutic use of antibiotics that completely outweighed the removal of AGPs. Until then, the only information available was based on sales figures of antibiotics, but these do not take into account the dosage of the active compounds. Nowadays, a different and more accurate methodology is used. Antibiotic use per farm is calculated based on the amount of antibiotics used, the concentration of active substance and the dosage to treat one kg of animal. It is comparable to the system used in Denmark, where they use Defined Animal Daily Doses (ADDkg), defined as the assumed average maintenance dose per day for treatment of one kg animal for the main indication in a specified species (DANMAP, 2011). Although this method describes the actual exposure to antibiotics better than just the amount of antibiotics used, DANMAP even prefers an additional refinement, by taking production as denominator in the ADD calculation, so antibiotic exposure is measured as ADDkg per kg of meat produced (including export of live animals) or per number of animals produced (i.e. slaughtered or exported; DANMAP, 2011). Despite some increase in therapeutic use of antibiotics, there has been a tremendous overall reduction (90%) in total use of antibiotics in poultry production in Denmark (Cogliani et al., 2011).

The fact that total use of antibiotics in the Netherlands did not decrease despite the ban on AGPs, as well as the public debate on increasing antimicrobial resistance, urged the Dutch authorities for further action and led to a master plan to reduce total antibiotic use. This will be briefly discussed later. It illustrates the need to take additional measures, such as monitoring and disease control programs, for a ban on AGPs to be effective (Cogliani et al., 2011).

Emerging problems and measures

The key problem after the ban on in-feed antibiotics in broilers in Sweden was the increased frequency of outbreaks of necrotic enteritis (NE) (Inborr, 2000). This problem was tackled by improving broiler management such as climate and hygiene procedures, and the use of in-feed ionophore coccidiostats. Also development and use of in-feed carbohydrases clearly decreased the risk of NE. Management practices to prevent the introduction of the *Eimeria* parasite include biosecurity measures, such as rodent control, traffic control, cleaning and disinfection of poultry houses, and maximizing downtime (Peek, 2010), although the latter may not always be the most economical approach.

Remarkably, production performance in Sweden was not severely affected by the ban on antibiotics (Inborr, 2000); however, it must be noted that production was very extensive in Sweden at that time (max. 25 kg/m²), especially when compared with the Dutch highly intensive boiler industry with high animal densities (currently: up to 42 kg/m²) in combination with high density of poultry farms. As in Sweden, also the poultry industry in Denmark voluntarily removed all AGPs in broiler feeds from 1998 onwards, already before the EU-wide ban. The effects on production performance were studied using data from the period November 1995 until July 1999. The results showed that kg broilers per m² and percentage dead birds were not affected by the ban on AGPs, but feed conversion ratio had increased by only 0.016 kg/kg (Emborg et al., 2001).

Apart from improved management procedures, the role of nutrition was extensively examined. Regarding feed composition, broilers in Western-European countries are commonly fed wheat-based diets.
The soluble non-starch polysaccharides (NSP) fraction in these diets results in increased viscosity, which may lead to digestive disorders, such as NE. The control of NE can thus be considered a key strategy following AGP-free or total antibiotic-free production. Measures that could be taken consist of introducing or maintaining coccidiostat programs, considering characteristics of raw materials and feed processing, whole wheat supplementation, protein digestibility, gut conditioners, alternative additives, like in-feed enzymes, and management practices (Ratcliff, 2001).

**Coccidiosis**

As coccidiosis is a risk factor for the occurrence of NE, the use of coccidiostats can be encouraged to control NE. Especially ionophore coccidiostats appear to be very effective. Currently, the only permitted in-feed antimicrobials in the EU are the approved ionophore coccidiostats monensin, lasalocid, maduramicin, narasin, salinomycin, and semduramicin, and the chemical coccidiostats decoquinate, robenidine, halofuginone, diclazuril, and nicarbazin (COM, 2008). Vaccination against coccidiosis with live (attenuated and non-attenuated) vaccines is not yet adopted on a large scale, because of the high production costs of the vaccines, loss of infectivity with time, potential reversal of virulence, and management concerns such as dosage errors, but it may be a useful alternative in future (Peek, 2010). Also risk of reduced production performance compared to coccidiostat programs plays an important role. Coccidiosis vaccination, however, is used in commercial practice in case of complete antibiotic free production.

**Feed composition**

Characteristics of raw materials were mentioned before, and deal mainly with the fraction of soluble NSP and their viscosity-increasing properties. Diets rich in wheat are a particular example of situations where broilers are at risk for developing NE. A clear demonstration of this relationship was shown by Kaldhusdal and Skjerve (1996). They evaluated cereal grain composition of the feed and incidence of NE in retrospect of a 20-year period. Years with high barley-plus-wheat to corn ratio were associated with higher incidences of NE. Since the commercial use of in-feed NSP enzymes (xylanases and glucanases) the risk of wheat and barley use on NE will no longer be as clear. Coarse grinding of raw materials or whole wheat feeding programs help in a better development of the gizzard, thus leading to better peristalsis and reverse peristalsis, better mixing of digesta and digestive enzymes, and better absorption of nutrients. Especially when protein is well digested and absorbed, it reduces the risk of protein entering the hindgut, where it would be fermented by proteolytic bacteria. Fermentation products can damage the intestinal wall and are thus a risk factor for NE.

Due to the BSE crisis that started in 1996, animal meat and bone meal were prohibited in animal feeds in the EU from January 1st, 2001 onwards. At first, it was a temporary measure for only six months; however, the regulation is still in place today. Although poultry can handle a plant-based diet, they are insectivores and not strict herbivores. In order to compensate for the lack of animal protein, soybean meal inclusion levels increased. However, its carbohydrate fraction has a poorer digestibility than cereal carbohydrates; moreover, soybean meal contains higher levels of potassium, which could increase water intake, resulting in wet litter (Vieira and Lima, 2005). Results from a trial with isocaloric and isonitrogenous corn/soybean meal based diets, with or without animal byproducts, showed that growth, feed intake, and feed conversion ratio were similar for both diets. However, water intake and excreta moisture were significantly higher, and feed digestibility was significantly lower in the all-vegetable diet than in the regular diet containing animal byproducts (Vieira and Lima, 2005). Poor litter quality due to high excreta moisture may add to the microbial challenge, especially in the absence of antibiotics. Not in the least, all-vegetable diets are also more expensive than diets containing animal byproducts (Smith, 2011). Vieira and Lima (2005) estimated that feeds without any animal byproducts are 10% more expensive than regular corn/soybean meal diets.
**Alternative additives**

Gut conditioners and alternative additives can be separated into several product types. The most important ones in this respect are in-feed enzymes, probiotics, prebiotics, organic acids, essential oils and anti-oxidants. They will be briefly dealt with in this section.

Organic acids are commonly used as acidifiers in poultry nutrition. They act directly against bacteria in the feed (e.g. to decontaminate the feed in case of salmonella infections) and in the animal (Canibe et al., 2001). Their mode of action is that they are lipid-soluble in undissociated form and are thus able to enter the bacterial cell. Inside the cells, they dissociate and decrease the intracellular pH, causing the bacterial cell to die; moreover, also the anion itself may cause damage to the cell (Van der Wielen et al., 2000). Organic acids can also act indirectly by reducing the pH in the gut. An acid intestinal environment is less favorable for undesired bacteria (Grashorn, 2010). Apart from being used as in-feed treatments, acidifiers can also be used as water treatments, where they are usually more effective than as in-feed treatments. Organic acids are absorbed very rapidly in the upper parts of the intestinal tract. In order to take effect in the lower parts of the intestines, where they are most wanted, they have to be encapsulated.

Prebiotics are non-digestible carbohydrates that act as substrates for fermentation by beneficial intestinal bacteria, such as Lactobacilli. The fermentation products consist of fatty acids, among which lactate and butyrate. Apart from the pH-decreasing properties of the acids, butyrate has an additional favorable effect, because it is an energy source for enterocytes (Leeson et al., 2005).

Probiotics are spores or live bacteria or yeasts that act through competitive exclusion, stimulation of the immune system, and production of antibacterial substances such as bacteriocins and peroxides. Probiotics usually consist of Bifidobacteria, Lactobacilli, Bacilli, or Saccharomyces species (Grashorn, 2010), although the exact composition is usually not well-defined.

Some essential oils, such as carvacrol, thymol, eugenol and cinnamaldehyde have clear antibacterial properties in vitro (Pei et al., 2009), either disturbing the outer membrane bacterial cell walls (carvacrol, thymol) or preventing enzyme action through interaction with bacterial proteins (eugenol, cinnamaldehyde). There is a synergistic antibacterial effect between essential oils (Pei et al., 2009) and in combination with organic acids. Like organic acids, essential oils are absorbed very efficiently from the intestinal tract and they therefore need proper coating to reach the small intestinal lumen.

Based in the concept of non-antibiotic, anti-inflammatory effects of AGPs, also feed components with an antioxidant, anti-inflammatory effects will be of benefit to develop alternatives to AGPs, like was shown for grape pomace (McDougald et al. 2008). Effects of flavonols clearly differ despite structural similarities (Wang et al., 2006). Effects therefore cannot be generalized.

**Economic considerations**

Many of the aforementioned strategies to sustain broiler production in the absence of antibiotics have been tested in small-scale settings, but also in long-term and large-scale trials. The results are usually not unambiguously. An extensive overview of several measures to support drug-free and animal-byproduct-free broiler production, carried out under practical-scale conditions, is provided by Smith (2011). Measures, mainly to control NE, included NE toxoid vaccination of breeder pullets, vaccination of broilers with a live E. coli vaccine, applying organic acids in drinking water, probiotic treatment (containing Enterococcus faecium and Saccharomyces yeast), in-ovo application of a β-glucan immunostimulant, in-feed oregano treatment, multi-species probiotic application in hatchlings, and in-ovo
application of *Lactobacillus reuteri*. Apart from some successful interventions, none of the measures achieved a return on investment. It was concluded that in the absence of cost-effective alternatives to antibiotics, the drug-free program could only be maintained by management-related procedures (Smith, 2011). Still, as there were no explicit challenges and bird density in this program was restricted to only 30 kg/m² at slaughter, the outcome could have been different in more challenging conditions and/or with higher bird densities. Noteworthy in this respect is also the remark of Smith (2011) that looser bird density may help decreasing the problems associated with drug-free broiler production.

A three-year study conducted in North America by Engster *et al.* (2002) on 158 paired-houses investigated the effects of removing AGPs from broiler production. Average stocking density varied from 14.4 to 15.2 birds per m². In this study, no additional measures to compensate for the removal of AGPs were taken. Mortality rate was slightly higher (0.2%), weight gain slightly less (-0.04 lb), and feed conversion ratio slightly higher (0.016) in broilers without AGPs compared with broilers on a standard AGP-containing feed. However, removal of AGPs resulted in a consistent decrease in weight uniformity (coefficient of variation increased from 8.5 to 10.4% in male broilers and from 9.7 to 10.9% in female broilers). More importantly, there were differential responses between both geographic different locations. No outbreaks of necrotic enteritis had occurred during this trial. There were no differences in condemnation rate. Based on the small but consistent decline in production performance, it could be assumed that removing AGPs from broiler diets will lead to increased production costs. However, an economic analysis using these data (Graham *et al.*, 2007) showed that this was not the case. On the contrary, it was concluded that improvement in feed conversion ratio was not sufficient to outweigh the costs of the AGPs (assuming feed costs per ton of feed $190.00 and costs of AGPs per ton of feed $1.25–3.00; Graham *et al.*, 2007). It should be realized that the outcome of such economical evaluations of the ban on AGPs will depend on differences in regional intensity of the broiler industry with respect to bird stocking density and poultry farm density.

**Resistance**

When using antibiotics, it is almost inevitable that the target microbes develop escape mechanisms. This becomes apparent as antimicrobial resistance. It is important to stress that development of resistance is a natural phenomenon. It was already recognized by Alexander Fleming that bacteria developed resistance when a too low dosage of penicillin was used or for too short a period of time.

Development of resistance has now become a growing public health threat, illustrated by the fact that according to WHO (2011) more than 25,000 people in the EU die from infections caused by antibiotic resistant bacteria. Although there is still a debate whether this development is (mainly) due to veterinary use of antibiotics, the WHO calls for action.

The veterinary use of antibiotics exceeds the use for human medicine in some countries, among which the Netherlands. There is a remarkable paradox: whereas antibiotic use in humans in the Netherlands is amongst the lowest in Europe, the veterinary use of antibiotics is among the highest. One of the reasons is that in highly intensive systems, such as the broiler industry, it is not feasible to treat sick animals individually. Therefore, mass oral medication, usually in drinking water, is the only practical method; thus, leading to a relatively high exposure to antibiotics.

**Current situation in the Netherlands**

There is increasing concern about ESBL-producing bacteria. ESBL stands for Extended Spectrum Beta-Lactamase. Beta-lactamase is an enzyme produced by bacteria that hydrolyzes certain types of antibiotics, thus rendering them ineffective. “Extended spectrum” means that the enzyme deactivates almost all current antibiotics: not only β-lactam antibiotics, such as penicillins, but also antibiotics from...
other groups. Therefore, ESBL-producing bacteria produce β-lactamases that not only deactivate β-lactamase-sensitive antibiotics, but also antibiotics that are usually β-lactamase-insensitive. The genes encoding for resistance are located on plasmids and can easily be transferred between and within bacterial species. Particularly resistance to cephalosporines is a major concern. Cephalosporines are beta-lactam antibiotics, some of which are used as a last resort in human medicine.

In 2010, it was discovered that ceftiofur was used illegally in a hatchery in the Netherlands. Ceftiofur is a 3rd generation cephalosporin. Its use in poultry is not allowed, because since 2001 no final MRL was established. Still, veterinarians could prescribe ceftiofur as off-label drug in case of a veterinary emergency, but that was not the case here. The hatchery was prosecuted and the Veterinary Medical Association made a covenant that 3rd and 4th generation cephalosporines are no longer prescribed to poultry. Also in other countries (like shown in Belgium soon after this case was reported in The Netherlands) ceftiofur was used in hatcheries to control E. coli infections and reduce early chick mortality. The lively public debate on ESBLs as well as the use of veterinary antibiotics that had not decreased despite the ban on AGPs, pressured the Dutch government to take additional steps. It was mandated that the total use of antibiotics (prophylactic as well as therapeutic) in the total livestock production in the Netherlands should be reduced by 20% in 2011 up until 50% in 2013, with the year 2009 as a reference and Animal Daily Doses as a read-out parameter.

The steps to come to this strong reduction were laid down in a master plan. An important tool is central registration by the veterinarian of the amount of antibiotics prescribed, type of antibiotic that was prescribed, reason for which it was prescribed, and week of the growing phase (in broiler production) for which it was prescribed. Also a valid veterinarian-client relationship must be registered. The ultimate goal is to come to a reduction in the use of antibiotics, but first it is necessary to gain insight in broiler producers that are heavy users of antibiotics, but also in “heavy-prescribing” veterinarians. These data were used for benchmarking: all broiler producers and veterinary practices got an overview of their own data, related to the average use in the Netherlands. Presenting these data should increase awareness about the use of antibiotics on individual farms. Two critical values are established: a signaling value (target for 2011 plus one standard deviation) and an action values (target value for 2011 plus two standard deviations). Farmers and veterinarians with antibiotic use higher than the action value are mandated to install improvements.

Data so far show that total reduction in antibiotics in the livestock production sector was decreased by 28% in 2011. Therefore, the goal for 2011, i.e. overall reduction of 20% compared to 2009, is achieved.

References

DANMAP 2010. 2011. Use of antimicrobial agents and occurrence of antimicrobial resistance in bacteria from food animals, food and humans in Denmark. ISSN 1600-2032.


CURRENT BROILER FORMULATION PRACTICES UTILIZING FEWER, LESS AND/OR NO DRUGS

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Summary

3Nitro (roxarsone) has been around for a long time in broiler diets being used for E. Tenella control late in life and as a performance enhancer. The drug was pulled from the market in July 2011. This Pfizer action left broiler companies with some decisions to make regarding several ionophore coccidiostat programs and all coccidial vaccine programs. 3Nitro had been successfully used in the first 30 day feeds supporting weaker ionophore programs. It had also been used in day 15-35 day feeds supporting gut health in all coccidial vaccine programs. Neither of these programs can run without the 3Nitro effect. There are several ingredients being used in ABF and DFV diets that have been effective in gut health control much like 3Nitro in regular birds. Bacillus, phenol compounds and macro trace minerals among others do have some 3Nitro replacement capabilities allowing for a successful creation of a coccidial control program in regular birds. The drug program of the future includes six months of these ingredients combined with a good ionophore or chemial coccidiostat followed by six months of a coccidial vaccine supported by the same ingredients. Coccidiosis control programs like this successfully work in all size birds as long as the 3Nitro effect has been duplicated. 3Nitro is like any other drug. It is difficult to remove from daily use but not impossible. Over time broiler diets will be successful without 3Nitro.
CORN OIL EXTRACTION IN THE ETHANOL INDUSTRY

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Summary

In the beginning dry-grind ethanol production resulted in three basic products; ethanol, carbon dioxide and distillers dried grains with solubles (DDG/S). As the industry matures ethanol producers have found ways to produce other co-products to serve other markets and also to increase profitability. One of these co-products is corn oil. Corn oil can be extracted more than one way and either before the fermentation process or after the fermentation process. Traditional methods most generally involved solvent-based extraction of the oil from corn germ, and this was done with corn germ obtained from the wet milling industry. There are also methods to remove the oil from the final DDG/S product using solvent based extraction. More recently, there has been an increase in dry-grind ethanol producers removing oil from the stillage portion of the ethanol process, which is what is left after the ethanol has been removed via distillation. More specifically, the oil is removed from the condensed distillers solubles. This is a more mechanical process and involves the use of centrifuges to remove the oil and the exact process can vary depending on the overall ethanol production process used at each facility. Regardless of how or why the oil is removed the obvious result will be a DDG/S product with a lower crude fat value, while values for other nutrients (i.e. protein, fiber, etc.) tend to increase.

The obvious question that accompanies the removal of corn oil from DDG/S is the change in energy value of the resultant DDG/S. Recent reports have placed energy changes for poultry in the area of 100kcal/kg for each percent of fat, although there appears to be up to 20% or more variation around that estimate. Quality of the oil extracted most likely plays a role in the extent of the energy change. Currently, a significant portion of the US ethanol industry is producing a de-oiled DDG/S product, and as that number continues to increase it is going to be necessary to “re-learn” how to feed DDG/S and some producers have already begun that process. Depending on a producer’s location, and their DDG/S supplier’s technology/method used to remove corn oil, they could be presented with DDG/S ranging anywhere from 5 to 11% crude fat on average, although some solvent extraction methods can produce a product with even lower crude fat levels.

With this major change in the ethanol industry it becomes necessary for nutritionists to reassess DDG/S as an ingredient in their rations as a result of the energy change of the product. It should also be noted that while currently the bulk of the extracted corn oil is being sold to be utilized for biodiesel production it would certainly be a suitable fat source for inclusion in animal rations. This could especially hold true for the production of “All-Vegetable” diets that some broiler producers feed. Depending on price and availability the corn oil could be an economical choice as it sometimes assigned a higher energy value than soybean meal.
Introduction

To say the ethanol industry has experienced significant change over recent years is an understatement. As the industry has had ups and downs many things have changed, and during the low times many ethanol producers have disappeared or been acquired by a bigger company. The ones that have survived were the ones that had made smart business decisions and knew how to survive the tough times. One of the biggest keys to survival in the future will not only be efficient and cost effective ethanol production, but also diversification and the ability to understand that more than ethanol can come from a kernel of corn. The prime example of this idea is the increasing practice of corn oil extraction in the ethanol industry. In typical ethanol production the 190 proof ethanol and the whole stillage are separated via the distillation system. The whole stillage continues to a centrifugation step where the wet grains are separated from the thin stillage. The wet grains then enter the dryers and the thin stillage goes to an evaporator where it condensed down to what is commonly referred to as syrup, but is officially defined as condensed distillers solubles. Typically the syrup would be sprayed back onto the wet grains in the dryer to produce DDG/S. However, with a lot of newer de-oiling setups the syrup now undergoes a centrifugation step to remove a portion of the corn oil present. This is depicted in figure 1, a basic schematic of ethanol production.

Currently, industry predictions are close to fifty percent of the ethanol plants in the U.S. are extracting oil from DDG/S. Obviously, to what extent the DDG/S are low fat will vary depending on the extraction rate. Extraction rates currently can vary from .2 to .9 lbs of corn oil per bushel of corn. When oil is being extracted at the higher rate of .9 lbs per bushel of corn the resultant DDG/S product will have a crude fat value of roughly 5% while product at the lower end of the extraction spectrum could still have a crude fat level of 7 to 8%. It is expected that a majority of the ethanol plants in the U.S. will be extracting oil before the end of 2012 and as a result this is something that will affect many livestock and poultry producers. The decision will then have to be made as to what the value is of a lower fat DDG/S product in the ration. The value would obviously differ significantly if you were to look at it from the standpoint of a dairy ration versus a broiler grower. The bulk of the oil being produced from the ethanol industry is currently being utilized for the production of biodiesel but it is also reasonable to look at it as a fat source for rations as well. As is the case with DDG/S though, it would be expected that the quality of corn oil will vary among different sources due to differences in technology and plant process.

Even though the practice of removing corn oil from the whole stillage stream has just recently started to expand at a rapid pace, the basic technology has been available for several years (GS Agrifuels, 2012).
There can be significant time involved however, in the manufacture of the equipment necessary for this kind of oil removal and only a few companies produce the equipment so that has also limited the rate at which this practice has expanded. As is always the case in the ethanol industry, the technology has also been expanded upon continuously. Plus, from an economic standpoint, the removal of corn oil became much more attractive with the increase in price of the oil over the last few years primarily as a result of biodiesel production, but also due in part to the world market being short on oils/energy. Couple that, with the fact that currently full fat DDG/S aren’t selling at much of a premium, if any, to product that has been de-oiled to 7% crude fat. Simply put, the oil is now worth more out of the DDG/S than in the DDG/S. This is the result of many producers placing a 7 or 8% crude fat minimum for any DDG/S they buy, along with some other specifications of course, and thus a facility that routinely produces DDGS in excess of 10% crude fat is given no additional value over product from a facility with 2 or 3% less fat.

The future of de-oiling clearly depends on the production of biodiesel as well as the future market trends for both corn oil and high fat DDG/S. If the economics driving de-oiling change and corn oil prices drop dramatically, for whatever reason, and high fat DDG/S are more highly valued than the lower fat DDG/S products we could see some companies slowing down oil extraction.

Low-Fat DDG/S

Nutritional Aspects

As de-oiling is just recently making a large impact on the ethanol industry, data concerning the use of de-oiled DDG/S in animal rations is minimal. However, some initial work has been done by POET Nutrition in an attempt to quantify the change in energy seen as oil is removed and the crude fat content of the DDG/S decreases. Figure 2 gives a graphical representation of the change in TME\textsubscript{n} seen as the crude fat level of DDG/S changes as a result of de-oiling. An accepted method for determination of TME\textsubscript{n} (Sibbald, 1976) was used to determine the values in all instances. A line has been fitted to the points to show the linearity of the measurements. Based on this data it was concluded that for each percent of fat that is removed via de-oiling, the TME\textsubscript{n} of the DDG/S will decline roughly 105 kcal/kg. However, as has been the case for some time, there is room for discussion concerning the use of TME\textsubscript{n} versus AME\textsubscript{n} when it comes to growing broilers as TME\textsubscript{n} is of course done using mature white leghorn roosters. A significant difference in energy values for de-oiled DDG/S, depending on the method used to quantify the energy content, would not be a surprise though as it has long been known that ME\textsubscript{n} and TME\textsubscript{n} can vary significantly for certain ingredients, especially DDG/S (Council, 1994). Also, while this current work to quantify the change in TME\textsubscript{n} as the crude fat is reduced appears to show a very linear...
relationship, that might not always be the case. Researchers tested 17 different DDG/S samples from 6 different Midwestern ethanol plants and in their study they showed that a sample containing 7.1% crude fat yielded a TME<sub>n</sub> value 50 kcal/kg greater than another sample that contained 10.6% crude fat (Batal and Dale, 2006). Unquestionably, other nutritional factors can play a significant role in determining how much energy a bird will be able to extract from a DDG/S product and as nutritionists, we should look at the big picture when assessing different sources of DDG/S. That being said, as there becomes a greater prevalence of de-oiled DDG/S in the market the analyses and research available on the product will increase, giving producers a better idea of how to best utilize the product in their rations. Figure 3 shows average nutrient profiles for two different Dakota Gold products from POET Nutrition. One is Dakota Gold low fat and the other is Dakota Gold high fat, and this figure gives a good idea of the differences seen between de-oiled and non-de-oiled DDG/S products from one major ethanol producer.

| Figure 3. Average Nutrient Profiles for Low Fat and High Fat Dakota Gold DDG/S |
|---------------------------------|-----------------|-----------------|
| Parameter (%)                  | Dakota Gold Low Fat | Dakota Gold High Fat |
| Dry Matter                     | 89.38            | 90.07            |
| Crude Protein                  | 27.79            | 26.79            |
| Crude Fat                      | 5.49             | 10.48            |
| Crude Fiber                    | 6.64             | 6.30             |
| ADF                            | 8.63             | 8.40             |
| NDF                            | 24.22            | 22.83            |
| Ash                            | 5.02             | 4.54             |
| Ca                             | 0.05             | 0.05             |
| P                              | 0.97             | 0.92             |
| Na                             | 0.20             | 0.14             |
| K                              | 1.24             | 1.15             |
| Mg                             | 0.38             | 0.36             |
| S                              | 0.84             | 0.84             |
| Met                            | 0.52             | 0.52             |
| Cys                            | 0.58             | 0.58             |
| Lys                            | 0.95             | 0.97             |
| Thr                            | 1.00             | 1.00             |
| Val                            | 1.05             | 1.03             |

It has long been reported that nutritional variability among DDG/S from different sources can be a major concern when it comes to formulating rations (Cromwell et al., 1993, Batal and Dale, 2006, Fastinger et al., 2006). With the advent of de-oiling on such a large scale this should now be a renewed concern. With differences in equipment, personnel, technology, technique, etc. there will be significant variation in crude fat levels among different sources. It could also be possible for there to be significant variation in crude fat levels within a single facility, especially during the startup period and when maintenance work is necessary. An ethanol facility will need to be aware of changes in how the de-oiling equipment is running at all times to prevent mixing of product with different levels of crude fat in storage. Also, an ideal facility would have enough space to segregate product that deviates from its’ target crude fat range, but otherwise is totally acceptable. It could represent a significant economic loss for the plant if every time product strayed out of the target fat range it was simply piled in with other “off-spec” product that was being sold for a significant discount as a result of what made it unable to meet product specifications. Obviously, it will be important to a livestock or poultry producer that their DDG/S supplier produce a very consistent fat level so that when their nutritionist formulates they will be able to effectively utilize the energy content of the DDG/S, but not over estimate and cause a decrease in performance. As a result it is going to be more important than ever to have a source with the ability to provide a reliable and nutritionally consistent supply of DDG/S.

**Physical properties**

When dealing with the physical properties of de-oiled DDG/S it has been reported that the water activity, bulk density, angle of repose and thermal properties of the low fat DDG/S were similar to those of conventional DDG/S (Saunders and Rosentrater, 2009). This research was done on low fat DDG/S that was produced via a solvent extraction method, and the resultant product had a crude fat level of 2.7% on a dry matter basis. This is a lower crude fat value than would be expected from product that was produced
via centrifugation of the solubles stream. The same researchers also noted lighter color and increased protein and fiber concentrations in the low fat DDG/S. There is additional peer reviewed research available that discusses the physical properties of de-oiled DDG/S but the vast majority of the research has been done on DDG/S from a solvent extraction process.

**Poultry Research**

**Layers**

Simply from an energy perspective one would expect that a de-oiled DDG/S product would work into a layer ration a bit easier than a broiler ration given that layer diets are formulated to lower energy content in general. A trial sponsored by POET Nutrition looked to get some preliminary data on the use of de-oiled Dakota Gold DDG/S in layer rations. This work was done before there were any results for the energy work that has since been completed, and as a result all diets were formulated using a single matrix for the DDG/S, regardless of the crude fat level. First cycle Bovan White hens were fed from 20 to 33 weeks of age on the test diets. There were 4 test diets, a corn and soybean meal based control along with three DDG/S containing diets with DDG/S included at 20% of the ration. The three DDG/S products utilized consisted of a full fat sample that had undergone no de-oiling (roughly 10 to 11% crude fat), a sample that had been de-oiled to roughly 7.3% crude fat and a sample that was de-oiled to roughly 5.6% crude fat. All DDG/S was manufactured at a single facility. Results for egg production can be seen in figure 3. As is evident from figure 3, there were no significant differences reported for the parameter of egg production. The researchers also reported no significant differences in any of the other parameters measured, which included egg weight, feed intake and hen body weight. This is of course a single study with de-oiled DDG/S looking at a single phase of a layer cycle in what is sure to be a long line of research aimed at determining the value of varying crude fat levels of DDG/S in commercial poultry rations, as more work is needed in all poultry species.

**Corn oil**

As was previously mentioned, the bulk of de-oiling in the ethanol industry is currently being done to supply the biodiesel industry with corn oil for production of their fuel. However, with a large amount of this oil entering the market there is nothing preventing a poultry producer from utilizing this product as a supplemental fat source in their rations. With that in mind POET Nutrition sponsored a study to look at the use of this new DDGS-derived corn oil (CO) versus poultry oil (PO) in the ration of growing broilers. Four separate treatment diets were fed. One diet contained pure PO as the supplemental fat source and portions of the PO were replaced with 25%, 75% and 100% CO to create the other three treatments. All diets were formulated using the nutritional matrix for PO, regardless of which fat treatment was applied. Birds were grown to 49 days and treatments were carried throughout. There were no differences observed.
in the starter phase for any parameters measured. At the end of the grower phase the 75:25 (PO:CO) blend and 100% CO treatments showed significantly improved BW and BWG versus the other treatments, while the 75:25 blend also showed significantly improved FCR over all other treatments. At the end of the finisher phase there were no significant differences for the above mentioned parameters, however the 75:25 (PO:CO) blend exhibited a trend towards improvement in live production parameters (Kim et al., 2012). No sensory analysis was done on the breast meat to determine if there is any effect of the oil on consumer perception and/or meat quality. The positive effects of blending sources of animal and vegetable fats is nothing new and has been documented previously on multiple occasions (Lall and Slinger, 1973; Sibbald, 1978). So, provided the price of corn oil is competitive with the other options available, corn oil produced via de-oiling in the ethanol industry could be a viable option as a fat source for producers.

Conclusions

The fuel ethanol industry has experienced its’ fair share of changes and it is safe to say that it will continue to change on an almost constant basis. These changes are reflective of technological growth within the ethanol industry. The fuel ethanol industry as we know it is a young industry, as there were less than 10 facilities in 1980 producing roughly 50 million gallons of total ethanol. In 2010 there were roughly 200 ethanol plants that produced in excess of 13 billion gallons of ethanol and 32 million metric tons of DDG/S. Along the way several advances were made in technology that have allowed for more efficient production of ethanol, as well as other co-products of the process. The process of extracting corn oil for biodiesel production, as well as use in animal rations, is simply another step in the process of creating a more diverse industry. De-oiling may have been occurring for some time within the ethanol industry but it hasn’t been occurring in a manner that was widespread enough to really affect many poultry and livestock producers. That is to say, many producers would prefer to feed full fat DDG/S if and when they did include DDG/S in their rations and in general there has always been enough full fat DDG/S to meet domestic demand. There has actually been an excess for several years which has led to a growing DDG/S export market for many U.S. ethanol producers. As de-oiling continues to spread in the ethanol industry and research with the resultant products of de-oiling is generated, these ingredients will find their place in animal rations.

There have been advances in the ethanol industry that have proven beneficial to monogastric producers such as raw starch hydrolysis and the fractionation process. Currently, the process of extracting corn oil is yet to be classified as there is still much to be learned regarding the use of products from the de-oiling process in animal rations. However, we do know that we have new co-products from the ethanol industry and the DDG/S many producers have been effectively feeding for past several years will become much less available, and possibly disappear altogether. Perhaps for the sake of economical animal production producers should begin to tie more closely together the economic value of DDG/S as a dietary constituent and the nutritional value of the DDG/S. Depending on the ever-changing commodity markets it may be more economical to pay extra for full fat DDG/S that has not undergone any de-oiling and thus has a crude fat level of 9 or 10%, as opposed to buying a lower fat DDG/S and having to add calories elsewhere. Maybe just the opposite is true. It will all depend on several factors including the market and each producer’s unique situation among others. The corn oil extraction process appears to be well on the way to becoming the “norm” in the majority of the ethanol industry so it would be in the best interest of the livestock and poultry producers to learn how to best utilize the resultant co-products in their operations.

References

NUTRIENT REQUIREMENTS OF POULTRY- WHAT IS THE TIMELINE FOR VALIDITY OF PUBLISHED RECOMMENDATIONS

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Summary

Although the classical nutrient requirements of poultry have changed very little over the last 50 years, feeding practices of both broilers and layers have evolved with change in genetic potential and market demands. Eggs and meat are remarkably consistent in composition and so knowing a bird’s weight and its production output give a sound basis for prediction of requirements. Likewise there is no evidence for meaningful change in digestibility or metabolizability of major nutrients. Birds do not recognize the complexities of our formulations and perform adequately when confronted with an array of feeding scenarios since as long as their needs can be met within the confines of their physical capacity to eat feed, performance will be unaffected. Although requirements have changed little for maintenance or per unit of production, our emphasis on the need for various nutrients are in constant flux. In many instances, such changes relate to minimizing as well as maximizing the supply of a nutrient. Over the last 15 years, there has been a re-evaluation of the requirements for certain nutrients as it impacts the environment, rather than the bird per se. Societal issues now represent a major constraint during feed formulation that impact nutrient supply and feed formulation and again somewhat disregard the absolute needs of the bird. In essence the nutrient requirements of the bird, as epitomized by NRC (1994) are now only a component of our decision making in establishing diet specifications.

Historical Perspective

There is considerable information available on the nutrient needs of broilers, and layers. In many instances the basis for such information has been the series of publications of the National Research Council (NRC). Over the years, the NRC has reviewed published information on needs for the major nutrients and presented these in their own publications each 6-10 years. The most recent such publication is Nutrient Requirements of Poultry, 9th Revised Edition was released in 1994. Many nutritionists criticize the NRC (1994) recommendation as not representing the needs of poultry that are housed and managed under modern commercial conditions.

The 1994 NRC poultry subcommittee were given one straightforward, although somewhat restrictive mandate, namely to establish nutrient requirements based solely on data from peer-reviewed journals. This directive is particularly restrictive to estimating certain nutrient needs, since there has been a lack of scientific research and publication on many topics over the last 40 years. This situation often dictated the reliance on very dated literature estimates for certain nutrients. On the other hand, everyone recognizes the increase in growth rate of broilers and egg production of layers that has occurred over the last 40 years. For this reason, the NRC estimates are often criticized as not representing the needs of modern strains of commercial poultry.

Another concern is that many of the older research studies involved purified diets. These diets often contain isolated soybean protein or casein as a source of protein and amino acids, and dextrose,
starch and sucrose as a source of energy. Cellulose was often used as non-nutritive filler in these purified diets. Such diets are highly digestible, and were not encumbered with facets of variable nutrient availability, and so can be criticized as not being of relevance to commercial feeding using conventional ingredients. It is very difficult to pellet diets with these purified ingredients, and today mash diets are obviously of little relevance to the broiler industry.

Nutritionists today are often more specialized in certain areas, and broiler nutritionists for example, may rarely need to be concerned about the nutrient needs of laying hens. Our degree of specialization leads us to source more specific material, while NRC provides a general overview of all species. In research, specialization tends to be even more extreme, where researchers in amino acid metabolism, for example, at best pay cursory attention to trace mineral levels in their diets. In fact, the complexity of research today dictates that we can answer questions on at best a very limited number of nutrients at any one time.

In reviewing the more dated research, it is now obvious that there has been a gradual change in our assessment criteria. In NRC (1994) virtually all nutrient needs for broilers are assessed in terms of growth rate, and perhaps feed utilization. For layers, the measurement criteria are most usually egg production and egg weight. Over the last 40 years, commercial goals have evolved, and these impact nutrient requirements and feeding programs. For the broiler chicken, the needs for lysine now relate to not merely growth and feed utilization, but also breast meat-yield and carcass quality per se. Broiler chickens today are marketed over a vast range of weights/ages and in some instance these may be as mixed-sex or separate-sex flocks.

An interesting scenario has occurred with broilers since 1994, and that highlights the importance of continual need for reappraisal of feeding systems. In the mid-90’s, metabolic disorders such as ascites, sudden death syndrome, and leg disorders together accounted for 3-5% mortality in male broilers. In order to counteract such problems, it was common to feed lower nutrient- dense diets, at least for part of the grow-out period. Today such disorders are much less problematic, due to genetic selection, and consequently there is little need for any period of undernutrition. Consequently, over a period of 15 years, we have gone from a situation of selecting nutrients for maximum growth followed by a 5-6 year period of consideration for tempering growth, back to today’s goal of maximum growth rate. Concurrently the ever -changing cost of feed ingredients now means that broilers are being fed a much wider range of feeding scenarios that impact the balance of performance of the individual bird vs. overall economics of meat or egg production. These evolving on-farm conditions, together with advances in feed processing, mean that nutritionists cannot expect that single nutrient values, whatever the source, will be applicable to feeding birds under all farm conditions.

**Nutrient Requirements vs. Diet Specifications**

Diet specifications are the practical end point of our consideration for the bird’s nutrient requirements together with the influence of individual corporate needs. Even though the requirements per se may not change, or change very little, continuous improvement in production output as eggs and meat dictate the need to continually re-evaluate diet descriptors. Since 1956, the University of Guelph has, each 5-8 years, detailed diet specifications for most poultry species. Table 1 summarizes five such specifications published over the last 50 years for broiler starter and phase I layer diets. The most noticeable change over time is the greater detail and recognition of more nutrients. For broiler chickens, there is surprisingly little change in energy and crude protein, which is perhaps happenstance in terms of the industry using diets manufactured predominantly from corn and soybean meal since inception of the broiler industry in the late 1950’s. For boilers, the most noticeable change is an increase in the concentration of the essential amino acids. For layers, there is a dramatic increase in energy level as well
as an increase in the levels of calcium and the essential amino acids. Interestingly, with layers, the levels of calcium and methionine + cystine increase more moderately when expressed per unit of energy.

Table 1. Diet specifications for broiler starter and layer diets, 1956-2009

<table>
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<tr>
<th></th>
<th>1956 (0-6 wks)</th>
<th>1964 (0-5 wks)</th>
<th>1970</th>
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<td>Crude protein (%)</td>
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<td>ME (MJ/kg)</td>
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<td>0.83</td>
<td>0.86</td>
<td>0.95</td>
</tr>
<tr>
<td>Lysine (%)</td>
<td>-</td>
<td>-</td>
<td>1.36</td>
<td>1.15</td>
<td>1.30</td>
</tr>
<tr>
<td><strong>Layer:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crude Protein (%)</td>
<td>20.1</td>
<td>15.0</td>
<td>17.0</td>
<td>17.0</td>
<td>19.0</td>
</tr>
<tr>
<td>Energy PE (MJ/kg)</td>
<td>7.40</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ME (MJ/kg)</td>
<td>-</td>
<td>10.50</td>
<td>11.90</td>
<td>11.70</td>
<td>12.10</td>
</tr>
<tr>
<td>Calcium (%)</td>
<td>2.10</td>
<td>3.20</td>
<td>3.20</td>
<td>3.50</td>
<td>4.00</td>
</tr>
<tr>
<td>Av. Phosphorus (%)</td>
<td>-</td>
<td>0.50</td>
<td>0.57</td>
<td>0.40</td>
<td>0.48</td>
</tr>
<tr>
<td>Sodium (%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.20</td>
<td>0.17</td>
</tr>
<tr>
<td>Methionine+Cystine (%)</td>
<td>-</td>
<td>0.55</td>
<td>0.58</td>
<td>0.64</td>
<td>0.71</td>
</tr>
<tr>
<td>Lysine (%)</td>
<td>-</td>
<td>-</td>
<td>0.86</td>
<td>0.70</td>
<td>0.82</td>
</tr>
</tbody>
</table>

Unfortunately, birds do not recognize the complexities of our formulations, and to a large extent, perform reasonably well when confronted with an array of feeding scenarios. As long as their needs can be met within the confines of their physical capacity to eat feed, then their performance will be unaffected. Birds have needs for µg’s, IU’s etc. of various nutrients each day, and our formulation exercise is merely to provide the most judicious way of meeting such needs, at a minimal cost.

As previously suggested, the need for a nutrient such as lysine, described per unit of gain in meat birds is unlikely to have changed in recent history. Over the last 20 years, there have been repeated suggestions that for example, the lysine needs of modern high-meat yield broilers has increased. In 1970, we were advocating 1.36% total lysine in diets for young broilers and it is unlikely that needs today are much greater than this historical assumption. It is difficult to accept that a bird with increased breast meat yield has a higher requirement for a target amino acid when the amino acid composition of all avian muscles, are remarkably similar. It is difficult to appreciate that the disproportionate growth of one
particular muscle would impact the nutrient needs when the amino acid composition of all the muscles are similar. NRC (1994) fueled this debate in reducing the nutrient requirement of total lysine in the starter diet of broilers suggesting 1.10% compared to the NRC (1984) estimate of 1.20%. The rational behind the apparently heretical trend was simply that the unbiased, refereed publications on this topic justified less, and not more of this amino acid. This single number probably had most negative impact on those reading NRC (1994)

**Changing Requirements for Maintenance vs. Production**

Numerous metrics are available to quantitate the phenomenal increase in the growth rate of the broiler chicken over the last 50 years. Whether such increase in genetic potential has changed the bird’s nutrient requirements is open to debate. Certainly the maintenance energy needs of broilers to a specific weight have declined simply due to faster growth rate. The improvement in feed utilization in broilers seen over time is not a reflection of increased metabolizability of energy, but rather a reduction in maintenance needs. With diets composed of conventional ingredients such as corn, soybean meal and animal proteins, the maintenance needs are predictable based on the bird’s weight and the environmental temperature. Such predictability of maintenance needs, because of standardized conditions, is the basis for the potential to model nutrient requirements for production, and then by extrapolation, establishment of total nutrient requirements and feed specifications.

**Impact of Evolving Genetics and Societal Issues**

Even though classical nutrient requirements have not changed for either maintenance or per unit of production, feed specifications are in constant flux.

**Evolving bird genetics**

Everyone assumes that “modern” strains of broiler and layer must have different requirements than in the past because of their evolving genetic potential. Although there is little evidence for a genetic basis across strains, or over time within a strain, for differentiation of nutrient needs, there are often associated transient issues that need accommodating during feed formulation. Perhaps the classic example is the “relaxation” of nutrient density of broiler diets in the mid 1980's for a 10-12 year period. During this time, metabolic disorders such as Ascites, Sudden Death Syndrome and skeletal defects were of sufficient magnitude to warrant change in the nutrient supply. Over time such metabolic disorders were resolved by the geneticists and so today it is usually not economical to consider feed restriction and nutrient supply has invariably reverted to fuel maximum growth.

In the 1990's, certain strains of laying hens were prone to Cage Layer Fatigue, a situation that could only be resolved by feeding higher than normal levels of phosphorus in pre-lay and early-lay diets. Today, the problem has been resolved through genetic selection, and so it is not necessary to utilize such specialized diets, and the bird is able to perform adequately on more normal and more economical levels of phosphorus.

**Environmental issues**

Over the last 15 years, there has been a re-evaluation of the requirements for certain nutrients as it impacts the environment. Currently such concerns centre around mineral nutrition, although in the near future, the need to limit ammonia loss from animal feeding operations may impose limits on the supply of dietary nitrogen.
For phosphorus and certain trace minerals such as zinc and copper, the issue is accumulation in manure. Modeling output is fairly straightforward, with the overwhelming influence being dietary supply. The advent of exogenous phytase enzyme has allowed for adequate performance on diets with less total phosphorus. Likewise, in order to meet environmental regulations we have generally revised phosphorus requirement values so as to minimize excess. This latter scenario highlights the significance of mineral interaction, since the supply of calcium has been re-evaluated in concert with new systems of providing less phosphorus and/or phytase enzyme.

The excretion of copper and zinc in manure is now leading to the re-evaluation of requirement for these nutrients. Studies on requirement for trace minerals are sadly lacking over the last 40 years, and in fact the basis for most of the NRC (1994) values, is estimation (Table 2). To some extent, our current diet specifications are dictated by variable availability from major ingredients, uncertainty of availability from inorganic salts, and the known interaction between minerals. Mineral proteinates are highly available sources of trace minerals, and allow for reduced inclusion level with assurance of digestible/available supply. If quotas are set for ammonia release from poultry and other intensive farm operations, then we may need to re-evaluate the requirements for nitrogen relative to needs for amino acids, so as to reduce further the supply of non-protein nitrogen.

<table>
<thead>
<tr>
<th>Table 2. NRC (1994) trace mineral specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown egg: Pullets/ Layers 100% estimates</td>
</tr>
<tr>
<td>Broiler: After 3 weeks 100% estimates</td>
</tr>
<tr>
<td>Broiler Breeder: No data</td>
</tr>
<tr>
<td>Turkey: After 4 weeks 100% estimates</td>
</tr>
</tbody>
</table>

Societal concerns

Societal or emotional issues now represent a major constraint during feed formulation and feed/ingredient quality control. An interesting issue has arisen with the voluntary removal of animal protein ingredients and in Europe of genetically modified ingredients. Many such poultry diets now contain very high levels of soybean meal, since there are few viable alternatives to provide most amino acids. In very high protein diets, this dictates the need for very high inclusion levels of soybean meal, especially in diets for young turkeys. The associated high provision of diet potassium imposes unique challenges in maintaining electrolyte balance for this bird, especially in terms of trying to limit water intake and maintain litter condition. While electrolyte balance can be achieved by the judicious use of novel salts, the problem of wet litter and foot pad lesions remains. The removal of antibiotic growth promoters, coupled with a high inclusion level of soybean meal, leads to indigestion and bacterial overgrowth. In essence, the apparent nutrient requirements of the bird are increased under these conditions.

Economics of production

Prevailing economic conditions often dictate dietary nutrient specifications independent of birds’ absolute needs for certain nutrients. Broilers, and to a lesser extent laying hens are able to perform when offered diets with a range of nutrient density. Consequently it may be economical, even within a single geographical location, to use variable energy density over time. Broilers perform remarkably well when offered diets with a range of energy density. Classical feed efficiency obviously deteriorates as energy density declines, although energy efficiency per unit of gain improves linearly with reduced energy density up to certain levels. Classically, in situations of high feed energy costs it is economical to use
diets of higher energy concentration and vice versa. We are now questioning this concept with a general move world-wide to diets of lower nutrient density even with unprecedented high feed prices. As long as birds can physically eat sufficient feed then performance is little affected within a wide range of diet nutrient densities. For broilers it is not always clear how just how much freedom they have in accessing feed. To accommodate this issue formulation is being impacted by the four-way interaction between bird stocking density, pellet quality, nutrient density and bird age/weight.

**Conclusion**

Classical nutrient requirements, as exemplified by NRC (1994) are still appropriate to today’s modern strains of broilers and layers. However we have seen and will continue to see ever evolving changes to diet specifications. Such changes are sometimes dictated by real changes in bird biology, but more often they are a factor of societal issues or changing economics of the feed, meat and egg industries. We are approaching the biological limit of egg production in commercial layers, and so there is going to be only a minor change to the feeding practices over the next 10-20 years related specifically to the birds needs. The broiler has to be approaching its low-end limit of manageable weight-for-age and ability to mechanically process a juvenile carcass. Future predictions are for only moderate change to broiler formulations relative to current practice.

**References**

NUTRIGENOMICS: NEW TOOLS TO ESTIMATE REQUIREMENTS FOR VITAMINS AND ANTIOXIDANTS

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F.W. Edens, North Carolina State University, Raleigh, NC

Introduction

Nutrigenomics is the latest tool that we have as nutritionists to better understand the effects of nutrients on the health, growth, and reproduction of animals. The complete chicken genome was announced in 2004 in a landmark article by Hillier et al. (2004). Since then, the use of microarray technology has ushered in a new era in poultry nutrition. This new method of evaluating the effects of nutrients at the genotypic level, rather than waiting for phenotypic responses will likely be looked on as one of the most important advances in nutrition since the discovery of essential nutrients.

Because of the approximately one billion base pairs of sequence and an estimated 20,000–23,000 genes in the chicken (Hillier et al., 2004) and the 13 vitamins that are recognized by the NRC, (1994) the scope of this paper will be more narrow and focus on an example from our laboratories.

Oxidants and Antioxidants

There is tremendous awareness of the term “antioxidant” in all forms of advertising media today. Unfortunately there is not a short list of enzymes and molecules that can have antioxidant properties. Fortunately antioxidants do fall into a few categories: labile and fixed, each of which contain enzymatic and non-enzymatic components. These antioxidants, whether dietary or in vivo, are there to serve the primary role of removing free radicals.

Oxygen, the most abundant free radical, is used for respiration because of its two unpaired electrons which spin in the same direction making it a biradical, thus a very effective electron receptor. Free radicals that receive the most attention, however, are oxygen-derived free radicals (reactive oxygen species or ROS), such as superoxide are produced through normal metabolism pathways, making them much stronger oxidants. Free radicals are usually portrayed in a negative light because of the damage they can cause to cell membranes and their links to many diseases. However, these molecules are necessary for normal metabolism because of their involvement in signal transduction, antimicrobial activity, and the cytotoxic activity of neutrophils (heterophils in birds) and macrophages. The overproduction or the lack of sequestration of these radicals leads to “oxidative stress”. Oxidative stress can be defined as an imbalance between the prooxidants and antioxidants in favor of prooxidants. All forms of life must constantly maintain a reducing environment within their cells. This reducing environment is preserved by enzymes and molecules that maintain the reduced state with a constant input of metabolic energy. Any imbalance in the otherwise normal redox state can cause toxic effects through the excess accumulation of peroxides and free radicals that damage all components of the cell, including proteins, lipids, and DNA (Blumberg, 2004).

In addition to ROS, much of the current research has broadened to include reactive nitrogen species (RNS). Nitric oxide (NO) is produced by nitric oxide synthase which is involved in signaling for physiological activities such as vasodilatation and brain function. When disease or injury causes inflammation NO is produced in larger amounts for protection against infection (Packer and Cadenas, 2005).
The most potentially destructive radical is formed from the superoxide anion and nitric oxide to form the highly oxidizing species peroxynitrite, which has been shown to be responsible for the oxidation of myoglobin, which is most relevant to meat quality (Connolly et al., 2002, Connolly and Decker 2004).

The effects of oxidative stress depend on the ratio of oxidants to antioxidants, which is also known as redox status. Some of these ratios include, but are not limited to:

- total antioxidant capacity or trolox equivalent (TAC)
- glutathione disulfide to glutathione ratio (GSSG:GSH)
- NADPH/NADP
- NADH/NAD
- Thioredoxin-reduced/thioredoxin-oxidized

Obviously, there is no single variable that can accurately describe the complete oxidative status of an animal. Therefore, a broader approach, such as nutrigenomics, gives us the tools to evaluate the overall redox status by comparing the genomes of affected animals to healthy animals.

### Circulating and Intracellular Antioxidants

Antioxidant systems throughout the bird must be evaluated in order to maximize the potential to overcome oxidative insult when it occurs. The first line of defense is the prevention of free radicals by removal of their substrates. This is accomplished with the mitochondrial enzymatic antioxidants, most of which are listed in Table 2. Circulating antioxidants are non-enzymatic and mostly consist of uric acid, vitamin C, E, carotenoids, and albumin and, to some degree, are considered to be a second line of defense (Surai, 2006; Cohen et al., 2007). The third and final layer of defense involves the excision and repair of damaged molecules and cells (Surai, 1999).

### Vitamin E

Vitamin E is probably the most recognized antioxidant that is routinely supplemented in poultry feeds. The Nutrient Requirements of Poultry list the dietary requirements for broilers at 10 IU/kg of vitamin E activity. However improvements in bird growth and meat quality have been demonstrated with additions of 50 and 100 IU/kg of vitamin E activity, especially in the presence of selenized yeast (Choct and Naylor, 2004).

There is a considerable amount of controversy regarding natural and synthetic forms of vitamin E. It is covered in an excellent review by Mahan (2009) and will not be discussed herein. Vitamin E is standardized with International Units (IU) by Section 5.50.10 of the United States Pharmacopeia (USP, 2010) with the goal of equalizing comparisons across the many forms available for animal diets.

<table>
<thead>
<tr>
<th>Radicals</th>
<th>Basic structure</th>
<th>Non-radicals</th>
<th>Basic structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triplet oxygen</td>
<td>O-O</td>
<td>Singlet oxygen</td>
<td>O-O</td>
</tr>
<tr>
<td>Superoxide</td>
<td>O-O</td>
<td>Water</td>
<td>H:O:H</td>
</tr>
<tr>
<td>Hydroxyl</td>
<td>H:O</td>
<td>Hydrogen peroxide</td>
<td>H:O-O:H</td>
</tr>
<tr>
<td>Peroxyl</td>
<td>R-O-O</td>
<td>Hydroxyl ion</td>
<td>H:O</td>
</tr>
<tr>
<td>Alkoxyr</td>
<td>R-O</td>
<td>Ozone</td>
<td>O=O-O</td>
</tr>
<tr>
<td>Hydroperoxyl</td>
<td>H:O-O</td>
<td>Peroxynitrile</td>
<td>O=N-O-O</td>
</tr>
<tr>
<td>Nitric oxide</td>
<td>N=O</td>
<td>Nitroxyl anion</td>
<td>N-O</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>N=O-O</td>
<td>Nitrous acid</td>
<td>H N-O-O</td>
</tr>
</tbody>
</table>

Table 1: From Edens and Gowdy (2005)
Vitamin E reduction requires oxidative decarboxylation of 6-phosphogluconate to ribulose-5-phosphate in the pentose phosphate pathway, two selenoprotein antioxidant enzymes (glutathione peroxidase [GSH-px] and thioredoxin reductase, [TrxR]), and vitamin C. TrxR reduces dehydroascorbic acid (DAA) to reduced ascorbic acid, which recycles oxidized α-tocopheroxyl back to reduced α-tocopherol (Vitamin E). Without TrxR-facilitated reduction of oxidized dehydroascorbic acid to reduced ascorbic acid, recycling of Vitamin E would be minimal.

Figure 1. Adapted from Edens and Gowdy, 2005.

Vitamin E is recycled to a large degree as shown in Figure 1. However, this is not 100% effective and some vitamin E must be obtained through the diet. The complete antioxidant protection of a cell cannot rely on vitamin E alone, but rather the recycling of the vitamin and dependence on other molecular and enzymatic systems (Table 2).

Table 2: Antioxidant Enzyme Systems and Antioxidants used by Animals

<table>
<thead>
<tr>
<th>Superoxide dismutases</th>
<th>Peroxiredoxins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper-zinc superoxide dismutase</td>
<td>Glutathione</td>
</tr>
<tr>
<td>Extracellular superoxide dismutase</td>
<td>Glutathione related systems</td>
</tr>
<tr>
<td>Catalase</td>
<td>Glutathione reductase</td>
</tr>
<tr>
<td>Glutathione peroxidases (Selenium dependent)</td>
<td>Glutathione-S transferases</td>
</tr>
<tr>
<td>GSH-Px-1 (cytosolic)</td>
<td>Other compounds used as antioxidants by animals</td>
</tr>
<tr>
<td>GSH-Px-2 (intestinal)</td>
<td>Ascorbic acid (vitamin C)</td>
</tr>
<tr>
<td>GSH-Px-4 (phospholipid hydroperoxide)</td>
<td>α-tocopherol (vitamin E)</td>
</tr>
<tr>
<td>GSH-Px-5 (spermatazoal nucleus)</td>
<td>Lipoic acid</td>
</tr>
<tr>
<td>GSH-Px6- (cytosolic homologue)</td>
<td>Ubiquinone (coenzyme Q10)</td>
</tr>
<tr>
<td>Thioredoxin reductases (Selenium dependent)</td>
<td>Uric acid</td>
</tr>
<tr>
<td>TrxR-1 (cytosolic)</td>
<td>β-carotene</td>
</tr>
<tr>
<td>Trx-2 (mitochondrial)</td>
<td>Retinol (provitamin A)</td>
</tr>
<tr>
<td>Trx-3/SpTrx (Sperm cell)</td>
<td>Various selenoproteins</td>
</tr>
<tr>
<td>Trx-4 (truncated)</td>
<td></td>
</tr>
</tbody>
</table>

Adapted from Edens and Gowdy (2005) and Surai, (2006).
The first product developed with nutrigenomic data: EconomasE® an example of combating oxidants on several fronts

As discussed, Vitamin E is one of the most important antioxidants in broiler diets and is crucial for optimizing immunity, health and production. The requirement for Vitamin E was set at 10 IU/kg by the NRC (1994). However, 5 to 10 times in excess of NRC requirements have been known to be added to commercial diets for improved growth performance and meat quality (Choc and Naylor, 2003). EconomasE® (EcoE) is a proprietary blend of ingredients that was designed to maximize antioxidant status of the animal and the synthesis, recycling and metabolic response of various antioxidants, especially Vitamin E.

A study was conducted to investigate the effects of supplementing EconomasE® in broiler diet on the performance, oxidative stability, meat quality, and storage stability of broiler chicks.

A total of 640 chicks were raised for six weeks. Eight replicate pens of 20 chicks were randomly assigned to each of four dietary treatments. Chicks were housed in floor pens with new litter in an environmentally controlled room and were given ad libitum access to feed and water.

Dietary treatments

1. Corn-soy diet + 0.3 ppm Se as selenite + no VE
2. Corn-soy diet + 0.3 ppm Se as selenite + 50 ppm VE
3. Corn-soy diet + 0.3 ppm Se as selenite + 100 ppm VE
4. Corn-soy diet + 200 g EconomasE®/Ton

Effects of EcoE and high Vitamin E on antioxidant capacity of broilers

To study the effects of high Vitamin E (VE) or EcoE supplementation on the tissue antioxidant status, the total antioxidant capacity (TAC) of the serum collected at times of 3- and 6-weeks during the experiment were measured (Fig. 2). As shown in the Figure 2, both high VE and EcoE significantly increased the value of TAC. Assays on VE content, however, showed no significant dietary differences in breast muscle, which may indicate the saturation of VE in breast muscle under current dietary conditions and imply, that in addition to tissue VE content, other components or processes related to oxidative systems were involved with the VE and EcoE treatments.

![Figure 2. Effects of dietary treatments on the total antioxidant capacity (TAC) of serum](image-url)
Gene expression profiles in the breast muscle

Out of 28,000 genes represented on the GeneChip® (Affymetrix, Santa Clara, CA) about 50% of these genes were expressed in the breast muscle. Compared with untreated controls, the expression level of 312 transcripts were altered in E100-fed chickens (179 up-regulated, 133 down-regulated); whereas E50-fed birds exhibited changes on 324 mRNA levels (166 up-regulated, 158 down-regulated). The broilers given the EcoE-supplemented diet displayed altered expression on 285 transcripts (169 up-regulated, 116 down-regulated). Effects of dietary treatment on the expression patterns of these genes were clearly shown by an unsupervised hierarchical clustering based on both treatment (array) and normalized intensity of gene expression (Figure 3). Further comparison of genes regulated by EcoE and VE indicated that different as well as common genes were included.

Figure 3. Hierarchical clustering of similar genes as affected by treatment

High VE altered genes were similarly modulated by EcoE in breast muscle

If the bio-physiological benefits related with high level VE consumption are the reflection of transcriptional changes, genes affected significantly by VE are likely to play the key roles in mediating these effects. In support of this, several VE sensitive genes reported before including heme-oxygenase 2 (Nier et al., 2006), peroxiredoxin 6 (Tolle et al., 2005), interferon gamma receptor 2 (Han et al. 2006; Crujeiras et al. 2008) and sterol carrier protein 2 (Cho et al., 2009) were among those changed by high level of dietary VE (Figure 3). Further, expression pattern analysis focusing on genes regulated by E100 (data not shown) showed a significant similarity between E100 and EcoE at gene expression intensity and their relative fold changes compared with Control.
Validation of differentially expressed genes

To confirm the microarray analysis, quantitative real-time PCR (qRT-PCR) was performed on selected genes (Figure 4). Sterol carrier protein 2 (SCP2) plays an important role in maintaining cellular morphology and lipid metabolism (Fuchs et al., 2001; Seedorf et al., 2000; Atshaves et al., 2000), suppression of this gene by either high VE or EcoE in breast muscle was manifested by qRT-PCR. Protein phosphatase 3 (PPP3CA) has been linked with growth factor stimulated cell proliferation and signaling cascades related to immune responses, cardiac hypertrophy, and neuronal and muscle development (Wang et al., 2008; Camps et al., 2000; Aramburu et al., 2004). As qRT-PCR analysis indicated, the similar pattern of expression of this gene as shown in microarray was confirmed. Expression of calpastatin (CAST), a gene that encodes for a protease inhibitor and shown increased by VE and EcoE in microarray study, however, was not significant, but a similar pattern of dietary effects was observed. This observation was probably due to the differences of the normalization methods used by the 2 approaches using different fluorescent dyes (Lee et al., 2002b).

Heme oxygenase 2 (HMOX2), together with HMOX1 and HMOX3 are HSP32 protein cognates with a known function of catalyzing the isomer-specific oxidation of the heme molecule, including that of NO synthase. These proteins play a central role in the cellular defense mechanisms.

Sterol carrier protein 2 (SCP2) is a peroxisome-associated thiolase that is involved in the oxidation of branched chain fatty acids. Over expression of SCP-2 has been related to down-regulation of proteins involved in cholesterol transport (L-FABP and SR-B1), cholesterol synthesis (SREBP2 and HMG-CoA reductase), and bile acid oxidation/transport.
Interferon gamma receptor 2 (IFNGR2) encodes the non-ligand-binding beta chain of the gamma interferon receptor. Defects in IFNGR2 are a cause of autosomal recessive Mendelian susceptibility to mycobacterial disease (MSMD). Mutations in IFNGR1 and IFNGR2 impair IFN-gamma responses and may lead to a predisposition to mycobacterial diseases.

Glycoprotein M6B (GPM6B) is an integral part of membrane, the normal expression level and function of this protein is critical to the integrity of plasma and multiple organelle membrane.

Protein phosphatase 3 (PPP3CA) modulates the VEGF- and FGF2-stimulated cell proliferation and signaling cascades through its protein phosphatase activity. Abnormal expression or activity of PPP3CA has been linked to multiple diseases such as hypertrophy, fibrosis, and hypertension etc.

Peroxiredoxin 6 (PRDX6) is a member of the thiol-specific antioxidant protein family. It may play a role in the regulation of phospholipid turnover as well as in protection against oxidative injury.

Meat Quality

Surprisingly, the vitamin E concentrations in the breast muscle from birds fed EcoE and VE were not different. This shows that EcoE-fed birds were able to facilitate the recycling of VE more effectively than birds fed the control diet (Figure 5).

Figure 5. Effects of dietary treatments on VE concentration in breast muscle

![Figure 5](image)

Birds fed EconomasE produced breast meat with the lowest Drip Loss (Fig 6). On comparison of 0.3 ppm selenite +50 IU VE/kg to 200 g EconomasE/ton there was about 0.6% less drip loss from breast meat at 7 days. Thus, a ton of breast meat would retain 12 lbs more weight, at $1.18 /lb, which would equal $14.16 per ton of saleable breast meat.

The redness (a* value) of chicken meat is largely attributed to the Fe$^{2+}$ state. The initial redness (a* value) of meat was similar for all dietary groups (a* = 12.5-13.1). During storage, the a* value dropped for all samples due to myoglobin oxidation, i.e., conversion to metmyoglobin (Fe$^{3+}$), and this deterioration/oxidation is related to peroxynitrite formation (Connolly et al., 2002). The meat from birds fed EcoE maintained the highest degree of redness (Figure 7).
In conclusion, dietary supplementation of EconomasE® had the same or better effects on performance, meat quality and total antioxidant capacity of broiler chicks compared with dietary supplementation of 0.3 ppm Se as selenite plus 50 or 100 IU/kg VE.
Table 3. Effects of dietary treatments on the performance of chicks (day 1 – 42)*

<table>
<thead>
<tr>
<th>Diet</th>
<th>Weight gain, g/bird</th>
<th>Feed intake, g/bird</th>
<th>gain to feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn-soy control + 0.3 ppm Se as selenite + no VE</td>
<td>2776</td>
<td>4343</td>
<td>0.639</td>
</tr>
<tr>
<td>Corn-soy control + 0.3 ppm Se as selenite + 50 IU VE/kg</td>
<td>2723</td>
<td>4320</td>
<td>0.630</td>
</tr>
<tr>
<td>Corn-soy control + 0.3 ppm Se as selenite + 100 IU VE/kg</td>
<td>2735</td>
<td>4287</td>
<td>0.638</td>
</tr>
<tr>
<td>Corn-soy control + 200 g EconomasE/Ton</td>
<td>2694</td>
<td>4212</td>
<td>0.640</td>
</tr>
</tbody>
</table>

*Data presented are means from eight groups of 20 birds.

References


PLANT GENETICS: WHAT CAN WE EXPECT IN THE FUTURE

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METABOLOMERIC PROFILING OF THE LIVER IN DEVELOPING CHICKEN EMBRYOS AND POST-HATCH CHICKS REVEALS UNIQUE METABOLIC DIFFERENCES

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ABSTRACT: The emerging new field of metabolomics aides in the identification and characterization of global metabolite patterns of organs and tissues. In this study, a metabolomic profiling approach was employed to investigate differences in metabolism in the liver of chicken embryos from two egg sizes and from broiler breeders of different maternal ages. Whole livers were collected on embryonic (e) days 17 and 20, and on post-hatch day 1 (n = 9-10) from embryos and chicks derived from broiler breeders of different ages (32 wk vs 51 wk, 63.2 ± 1.2 g) and from two sizes of eggs laid by 45 wk old breeders (55.8 ± 1.2 g vs 67.7 ± 1.1 g). Livers were lyophilized to dryness and freezer-milled, and the metabolites were extracted prior to chemical derivatization. Metabolites were separated by gas chromatography and under full scan mode complete ion spectra were recorded by mass spectrometry. Data files were converted using Agilent data analysis software and processed with the XCMS online server. Compound identification was determined by searching against the NIST 2008 library. Principal component analysis was employed to visualize the metabolite differences between two groups at three developmental stages. The results showed that embryos on both e17 and e20 from 32 wk old breeders clustered separately from 51 wk old breeders. However, this was not observed for embryos from small vs large eggs at these developmental stages. Concentrations of six metabolites from e17 livers differed (P < 0.05) between 32 wk and 51 wk old breeder eggs, 13 metabolites differed on e20 and five metabolites differed on post-hatch day 1. Metabolite categories included amino acids, carbohydrates, fatty acids and cholesterol esters. Comparison of small and large egg sizes revealed that 14 metabolites differed (P < 0.05) on e17, 13 metabolites differed on e20 and six metabolites differed on post-hatch day 1. In conclusion, these results reflect that the liver metabolisms of embryos during later development are distinct due to breeder age and egg size. Together, this study is the first assessment of global metabolism of developing embryo livers and our data provides the framework for further metabolic pathway analysis.
OXIDATIVE STRESS AND ANTIOXIDANT STATUS IN EQUINE SKELETAL MUSCLE AND BLOOD AFTER INTENSE EXERCISE

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ABSTRACT: The musculoskeletal system is a common area for injury in athletic horses. Oxidative stress occurring after exercise can lead to delayed onset muscle soreness (DOMS), potentially resulting in muscle damage. The objective of this pilot study was to compare markers of oxidative stress in skeletal muscle and blood of intensely exercising horses and non-exercising horses. Using a randomized crossover design, six mature, healthy unfit Standardbred mares were divided into two groups of three. Each horse served as its own control by either standing in a set of restraining stocks or completing an Interval Exercise Test (IET). Blood samples were collected at 30 min prior to exercise, immediately prior to exercise (PRE), immediately after exercise (POST), 30 min, 1, 1.5, 2, and 24H after exercise; muscle samples were collected from the middle gluteal muscle only at PRE, POST, 2H and 24H. Samples were analyzed for hematocrit (Hct), plasma total protein (TP), total muscle and erythrocyte glutathione (GSH-T) and glutathione peroxidase (GPx), and muscle and plasma nitric oxide (NO). Data was statistically analyzed using a general linear model ANOVA, and post hoc analysis was performed using the Ryan, Einot, Gabrielle, Welsch multiple-range test. Significance was set at P < 0.1. Hematocrit and TP were significant for main effects treatment and sample and a treatment by sample interaction (P < 0.0001); values peaked at POST and returned to baseline by 24H, while standing horses had no change (P > 0.1). The main effect of treatment was significant for plasma NO (P = 0.002) and erythrocyte GPx (P < 0.0001) with exercising horses being higher POST, 30 min, and 1.5H (P < 0.1) for plasma NO and higher at 1.5H for erythrocyte GPx (P = 0.019). The main effect of sample was significant for plasma NO (P = 0.026) and erythrocyte GPx (P = 0.0006) and GSH-T (P = 0.0002) with erythrocyte GPx and GSH-T peaking at 1.5H and plasma NO peaking at 24H. Muscle NO has a significant treatment by sample interaction (P = 0.080) with exercising horses being lower than standing at 2H (P = 0.089) but higher than standing at 24H (P = 0.057). There were no differences with treatment or sample for muscle GPx or GSH-T. The results suggest that increased levels of oxidative stress after exercise may contribute to DOMS. Further research is needed to determine if exercise training could lessen the effect of DOMS and prevent muscle damage.
EARLY METABOLIC IMPRINTING INCREASES MARBLING SCORES AND QUALITY GRADES OF FINISHED CATTLE

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ABSTRACT: Intramuscular fat (IMF), present and visually identifiable in a beef carcass as marbling, is the single most important physical characteristic used to determine quality grade (QG). As level of marbling increases, overall QG and carcass value increase. Weaning calves at ages much less than those typically utilized in conventional management systems has been associated with changes in growth and carcass characteristics, however researchers have failed to determine if those are carry-over effects, or the result of programming via metabolic imprinting. The objective of this study was to determine the ability of short term dietary energy supplementation early in life to metabolically imprint early weaned (EW) steers for increased IMF deposition during the finishing period. Twenty four fall-born Angus-sired steer calf progeny of primiparous dams (n=24) were stratified by sire and randomly assigned to a conventionally weaned (CW; control, n=12) or metabolically imprinted (MI; n=12) treatment group. Conventionally weaned calves remained with their dams and without supplementation until weaning at 251 ± 6 days of age. Metabolically imprinted calves were EW at 105 ± 6 days of age and quickly transitioned to ad libitum access to a concentrate-based ration in a step-wise fashion as dictated by changes in protein requirements. Metabolically imprinted calves received the ration until the end of the 150 day supplementation period, at which time treatment groups were commingled and allowed to graze a mixed cool season grass pasture for an additional 150 days, followed by transportation to a feedlot, where the cattle were stratified by treatment group within pen and adapted to a concentrate- and corn silage-based finishing ration. Cattle were harvested upon reaching a uniform target twelfth rib fat thickness of 0.4 to 0.5 inches. Average daily weight gain (ADG) was greater (p<0.0001) for MI calves between the dates of early and conventional weaning, but was greater (p<0.0001) for CW calves throughout the grazing period. Initial feedlot weight (p<0.05) and final harvest liveweight (p<0.01) were greater for MI calves, while ADG and feed efficiency throughout the finishing period did not differ (p>0.05) between treatment groups. Twelfth rib fat thickness, kidney, pelvic and heart fat, as well as yield grade did not differ (p>0.05) between treatment groups, while hot carcass weight (HCW; p<0.01), ribeye area (REA; p<0.01), marbling score (MS; p<0.01), QG (p<0.01) and percentage qualifying as certified Angus beef (p<0.05) were greater for carcasses of MI cattle. Though these results indicate that conventional weaning resulted in a higher growth rate throughout the grazing period, increased MS, QG, HCW and REA of carcasses from EW cattle not only suggest the existence of mechanisms associated with metabolic imprinting of growing beef cattle for increased IMF deposition during the finishing period, but also indicate the potential role that early metabolic imprinting could play in value-added beef production.
LIPID PEROXIDATION IN BLOOD AND SKELETAL MUSCLE AFTER INTENSE EXERCISE IN HORSES

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ABSTRACT: Oxidative stress occurs when there is an imbalance of radicals and antioxidants, where radicals attack cellular components such as lipids. This leads to the destabilization of lipid membranes, also known as lipid peroxidation. Malondialdehyde (MDA) is a common marker used in measuring lipid peroxidation. Although equine research has looked at plasma MDA, no research has studied MDA concentrations in horse skeletal muscle. The objective of this study is to account for MDA levels in blood plasma and skeletal muscle in mature horses, before and after exercise. It is hypothesized that the horses will have higher levels of MDA after exercise and these levels will be influenced by the amount of oxidative stress they endure. This cross over study used six Standardbred mares, ages 8-14, which were unfit, but accustomed to the high speed treadmill. Exercising horses will complete an Interval Exercise Test (IET). Standing controls will be restrained in stocks during the duration of the IET. Medial gluteal muscle samples will be taken immediately before exercise, immediately after, 2 h, and 24 h after exercise in alternating corners of a 5.1 x 5.1 cm square. Blood samples will be taken at the same time points as muscle samples in addition to 30 min prior to exercise, 30 min, 1h, and 1.5h post exercise. Data was analyzed using a general linear model ANOVA in SAS 9.1 and post hoc analysis was performed using the Ryan, Einot, Gabrielle, Welsch multiple-range test. Significance was set at P < 0.1. Hematocrit and total protein values for exercising horses showed a sharp increase (P < 0.0001) immediately after exercise and levels reverted back to baseline by 24 h. For standing horses, hematocrit and total protein levels remained unchanged throughout the study period (P > 0.1). There is no difference for the main effect of treatment or sample for either muscle (P = 0.89; P = 0.65, respectively) or plasma (P = 0.27; P = 0.53, respectively) MDA. Plasma MDA was significantly higher than standing horses and peaked at 1.5 h (P = 0.066; 15.96 ± 2.4 umol/mg protein), while the standing controls remained unchanged (P > 0.1) average 10.9 ± 0.84 umol/mg protein). Muscle MDA for the exercising horses numerically fluctuated; however, was not statistically significant between sample times in either exercised or standing horses. Overall, fluctuations are seen throughout the data for both exercising and standing horses with both muscle and plasma MDA. As seen by previous research, fluctuations can be caused by fitness of the subject thus having a lower response to lipid peroxidation after intense exercise for more fit animals. In conclusion, more research should be done to create data for baseline MDA measurements for fit and unfit horses, as well as their response to intense exercise.
TRAINABILITY AND REACTIVITY OF YOUNG MUSTANGS FED FORAGE-BASED TOTAL MIXED (TMR) RATIONS WITH OR WITHOUT ADDED GRAIN

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ABSTRACT: The relationship between ration and behavior in horses has not been extensively studied, though it is widely thought that the type of feed fed can influence how a horse behaves. For example rations high in sugar and starch have been documented to increase young horses' reactivity to novel stimuli. Since the temperament of a horse has been linked to the ease with which it can be trained, documenting if a horse’s behavior can be altered by its ration would be of interest to the equine industry. We hypothesized that increasing the starch intake of young mustangs by addition of corn or oats to a forage-based total mixed ration (TMR) would alter their reactivity to stimuli and responsiveness to learned commands. To test this hypothesis 8 recently tamed mustangs (4 geldings and 4 fillies, one and two years of age) were used. The mustangs were divided into two groups based on age, sex and temperament. In a series of three experiments they were fed TMR cubes with or without 10% added corn free choice (Exp. 1, Fall, 2010), or basal ration of TMR cubes free choice with morning meals of 1kg TMR cubes versus an equicaloric amount of corn (exp. 2, Spring, 2011) or oats (Exp. 3, Spring 2011) in a simple crossover design with 2 to 2.5 week adaptation periods for each trial. The horses’ trainability and reactivity to stimuli were evaluated before the treatments were initiated and after each adaptation period 60 to 90 minutes after the morning meals were fed. In the tests the horses were asked to perform a standardized series of commands (i.e.: walk on, turn, stop and stand still, back up), and were then confronted with a novel stimulus, which varied with each trial. A single handler (SLR) led each horse through the tests, which was then repeated on the next day using a student handler instead. Treatments were then switched and the horses were re-tested, so that each horse was tested on each feed type in all 3 experiments. Each horse’s performance was scored by 2 judges, who were both professional trainers who had been assigned 4 horses to train throughout the study. These judges scored the horses' performances as the tests were done. Each test was videotaped for further evaluation by a third judge (D. Ramnath) who was not familiar with the horses and who was blind to the ration being fed. The performances were scored using a numerical scale of 0-5, with 0=total noncompliance and 5=perfect execution of the tasks asked of the horse. There were no differences (p>0.1) in responses to commands or reactivity to stimuli between rations in any of the trials or with respect to which trainer had trained the horse. There were, however differences (P<0.05) among horses, handlers and judges with respect to the scores. It appears that addition of a moderate amount of starchy feed to a horse's ration has less influence on the horse's trainability and reactivity than the animal's natural temperament and handler ability.