Effect of Molasses, Corn Meal, or a Combination of Molasses plus Corn Meal on Ruminal Fermentation of Orchardgrass Pasture During Continuous Culture Fermentation

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ABSTRACT

Although molasses is being used by dairy farmers, particularly certified organic dairies, as a lower cost energy alternative to corn, little research currently exists evaluating the effects of molasses as the sole supplement on the ruminal fermentation of grazing dairy cows. This study evaluated the effects of pasture supplementation with molasses, corn meal, or a combination of molasses and corn meal, on ruminal nutrient digestibility and bacterial N synthesis in continuous culture fermenters. Experimental treatments were 1) orchardgrass (*Dactylis glomerata L.) pasture only (control; 70 g DM/d); 2) molasses plus orchardgrass pasture (MOL; 3.5 g DM/d of molasses plus 66.5 g DM/d of pasture); 3) corn meal plus orchardgrass pasture (CM; 4.9 g DM/d of corn meal plus 65.1 g DM/d of pasture); and 4) molasses plus corn meal plus orchardgrass pasture (MOL+CM; 3.5 g DM/d of molasses plus 4.9 g DM/d of corn meal plus 61.6 g DM/d of pasture). Treatment did not affect (P > 0.05) apparent DM, OM, and NDF digestibility values; true DM and OM digestibility values; molar proportions of VFA; or acetate-to-propionate ratio. Mean ruminal pH tended (P = 0.071) to be greater for MOL. Maximum ruminal pH was greatest (P < 0.05) for MOL. Ruminal NH₃-N was lowest (P < 0.05) for MOL+CM. Crude protein digestibility was greatest (P < 0.05) for MOL and lowest for MOL+CM. Bacterial N flow (g/d) and efficiency of bacterial N synthesis were not affected (P > 0.05). At low levels of inclusion, molasses showed results similar to corn meal in improving ruminal fermentation and N utilization, with both supplements showing only minimal improvement compared with a pasture-only diet.

Key words: molasses, pasture, ruminal fermentation, supplementation

INTRODUCTION

In the current economy of decreased milk prices and increased input costs, commercial dairy operations are seeking lower cost feed alternatives to maintain or improve productivity while reducing feed costs. Although unstable milk prices are not uncommon for the mainstream dairy industry, the organic dairy sector of the industry has recently had unprecedented changes. The price of organic corn has more than doubled in the last 18 mo (USDA-Agricultural Marketing Service; http://www.ams.usda.gov/mnreports/gx_gr120.txt). Additionally, organic milk processors announced an unprecedented reduction in organic milk pay price and other significant changes in milk contracts in early 2009.
Sugarcane molasses, a rich source of sucrose, seems to be a viable option as a source of energy and minerals. Molasses frequently costs less per kilogram of DM, is energy dense, has high palatability (Morales et al., 1989), and is available in organic form, so could be used in all sectors of the industry. Although research is available that has evaluated molasses as an energy supplement in confined dairy cows, no specific data exist regarding the impact of using molasses as the only supplemental source of feed to grazing dairy cows. Existing studies have reported mixed results in productivity and ruminal fermentation when supplementing molasses to grazing beef cows (Hart et al., 1971; Langlands and Donald, 1978; Kalmbacher et al., 1995), dairy cows fed conserved feeds (Morales et al., 1989; Murphy, 1999; Broderick and Radloff, 2004; Oelker et al., 2009), or dairy cows fed molasses with another supplement such as urea (Oelker et al., 2009) or concentrate (Gehman et al., 2006). However, although molasses is currently being used as an alternative feeding strategy by grazing and organic dairy producers, it is not known how molasses alone affects the ruminal fermentation of pasture-based dairy cows. Supplementing grazing dairy cows with molasses or corn meal, either alone or in combination, at levels similar to those currently fed in commercial and organic herds may affect N utilization and ruminal fermentation. The objective of this study was to evaluate, using continuous culture fermentation, the effect of molasses supplementation of a pasture-based diet on ruminal nutrient digestibility and bacterial N synthesis.

MATERIALS AND METHODS

Experimental Design and Treatments

A dual-flow continuous culture system designed to simulate ruminal digestion and solid and liquid outflow to the small intestine was used in this experiment. Three supplementation strategies and a pasture control diet were compared in a 4 × 4 Latin square design. The 4 diets used in this study were 1) orchardgrass (Dactylis glomerata L.) pasture only (control; PAST: 70 g DM/d); 2) molasses plus orchardgrass pasture (MOL: 3.5 g DM/d of molasses plus 66.5 g DM/d of pasture); 3) corn meal plus orchardgrass pasture (CM: 4.9 g DM/d of corn meal plus 65.1 g DM/d of pasture); and 4) molasses plus corn meal plus orchardgrass pasture (MOL+CM: 3.5 g DM/d of molasses plus 4.9 g DM/d of corn meal plus 61.6 g DM/d of pasture). These levels and type of supplementation were chosen based on data collected from organic dairy farms currently using these feeding strategies (K. Hoffman and K. Soder, unpublished data). Fermenters were fed in equal portions at 0700, 1030, 1430, and 1900 h to simulate a typical grazing pattern (Bargo et al., 2003; Gregorini et al., 2006).

Pasture was collected using a forage plot harvester (HEGE 212, Wintersteiger AG, Waldenburg, Germany; 1.5-m-wide swath) at a 10-cm stubble height (typical stubble height for northeastern US cool-season grass pastures) on June 20, 2007, in Rock Springs, Pennsylvania (40°48' N, 77°52' W; 330 m above sea level). Herbage samples were frozen at −4°C and freeze-dried. Herbage and corn meal samples were ground through a 2-mm mesh screen (Wiley Mill, Thompson Scientific, Philadelphia, PA).

Continuous Culture Operation

A 4-unit dual-flow continuous culture fermenter system, similar to that described by Hoover et al. (1989), was used in the present experiment with the following modifications: pH was not controlled, neither herbage nor supplement was pelleted, and urea was added to the mineral buffer solution (Weller and Pilgrim, 1974) at a rate of 0.4 g/L. Fermenter volumes ranged from 1,120 to 1,140 mL. Fermenter operation was similar to that described by Soder et al. (2007). Six liters of ruminal fluid and 3 handfuls of whole ruminal digesta were collected approximately 3 h after the morning feeding from one ruminally fistulated multiparous lactating Holstein cow consuming a TMR ad libitum (60% forage:40% concentrate). The ruminal fluid donor animal was cared for according to the guidelines stipulated by The Pennsylvania State University Animal Care and Use Committee. Liquid samples were collected from the dorsal and ventral rumen using a hand pump, whereas digesta samples were collected by hand from the ventral, central, and dorsal areas of the rumen. To maintain the sample temperature at 39°C, liquid and digesta samples were placed in separate insulated containers for transport to the USDA-ARS facility. Within 15 min of collection, ruminal fluid was strained through 4 layers of cheesecloth and fermenters were inoculated with 1,000 mL of ruminal fluid and 25 g of whole digesta. Solid mean retention time, solid dilution rate, and liquid dilution rate of fermenters were 24 h, 4%/h, and 11%/h, respectively, by regulating buffer input and filtrate removal (Bargo et al., 2003). Fermenters were maintained at a constant temperature of 39°C and were continually purged with N2 gas to preserve anaerobiosis.

Sample Collection and Analyses

Fermenters were operated for four 10-d periods, consisting of a 7-d diet adaptation period followed by a 3-d sampling period. Fermenter pH was recorded 4 times per day at feeding times (Beckman model 360, Beckman Instruments, Fullerton, CA). Effluent was collected into 5-L plastic jugs. During the first 7 d, effluent weights were recorded daily at 1430 h and discarded. On d 8 to 10, a water bath maintained the effluent jugs (submerged approximately one-third of the way in the water bath) at 4°C, and 20 mL of 50% sulfuric acid was added to the effluent jugs daily to prevent ruminal microbial fermentation. The solid and liquid effluent samples were collected on d 8 to 10, mixed, and homogenized...
using a 3-L Waring Blender (Waring, New Hartford, CT), and a 600-mL subsample was collected and stored at 4°C. An additional 50-mL effluent sample was squeezed through 8 layers of cheesecloth and a 15-mL aliquot of fluid was preserved with 3 mL of 25% metaphosphoric acid and 3 mL of 0.6% 2-ethylbutyric acid (internal standard), swirled, and then frozen at -4°C. The NH₃-N and VFA contents of these samples were determined according to Yang and Varga (1989). The 600-mL effluent subsamples collected on each of the 3 collection days per period were composited by fermenter. The effluent composite (approximately 1,800 mL/fermenter per period) was mixed with a stir bar, and a 500-mL subsample was collected for determination of DM content. The remaining effluent was freeze-dried and ground through a 1-mm screen (Wiley Mill, Thompson Scientific). On the last day of each period, the entire fermenter contents were prepared for analysis by freeze-drying in a blender and straining through nylon cloth. Strained contents were centrifuged at 10,000 x g for 10 min at 4°C to remove feed particles (de Veth and Kolver, 2001). Microbes were isolated by centrifuging at 20,000 x g for 30 min at 4°C (Beckman J2-21, Beckman Instruments, Palo Alto, CA) and prepared for analysis by freeze-drying and grinding through a 1-mm screen (Wiley Mill, Thompson Scientific; Kolver et al., 1998).

Samples of herbage, supplement, and effluent were analyzed for DM and OM (methods 930.15 and 942.05, respectively; AOAC, 2000). The CP contents of the diet and effluent were determined by micro-Kjeldahl digestion (method 976.06; AOAC, 2000) using 75-mL calibrated tubes with CuSO₄/K₂SO₄ as catalyst. The methods of Van Soest et al. (1991) were used in the analyses of NDF with amylase and sodium sulfite (inclusive of ash). The dietary RDP supply was determined according to the procedures of Roe et al. (1990). Purine concentrations (Zinn and Owens, 1986, as modified by Makkar and Becker, 1999) in effluent and bacterial isolates were used to partition effluent N flow into bacterial and nonbacterial fractions and to calculate true DM and OM digestibility values and flows (Stern and Hoover, 1990). Herbage and supplement starch and mineral content (P, Mg, K, Na, S, and Ca), and water-soluble carbohydrate (WSC) were analyzed via wet chemistry (Dairy One Forage Analysis Laboratory, Ithaca, NY; http://www.dairyone.com/Forage/Procedures/).

Starch was analyzed using a YSI 2700 Select Biochemistry Analyzer (YSI Inc. Life Sciences, Yellow Springs, OH). Mineral concentrations were determined using a Thermo Iris Advantage HX ICP Spectrometer (Thermo-Scientific, Waltham, MA). The WSC was analyzed via the procedures of Hall et al. (1999).

**Statistical Analyses and Calculations**

Data were analyzed as a 4 x 4 Latin square design using the GLM procedure of SAS (SAS Institute Inc., Cary, NC). The model included the fixed effects of treatment and period, the random effect of fermenter, and the residual error. Least squares means and SEM are reported for all data. Significance was declared at P < 0.05 and trends at P < 0.10.

True digestibility values of DM and OM were defined as nutrient intake minus nutrient effluent flow divided by nutrient intake, with the effluent corrected for buffer and microbial DM and OM. Apparent digestibility values of DM, OM, CP, and NDF were defined as nutrient intake minus nutrient effluent flow divided by nutrient intake, with the effluent corrected for buffer DM.

**RESULTS AND DISCUSSION**

**Diet Composition**

This study was designed in response to questions from organic dairy farmers who are currently using molasses supplementation. Their anecdotal responses have been mixed; thus, they are seeking information regarding ruminal metabolism of molasses to better understand under what feeding conditions molasses supplementation may be the most beneficial. The treatments used in this study were designed to mimic those currently being used on organic dairy farms in the northeastern United States (K. Hoffmand and K. Soder, unpublished data). At this time, no data from controlled studies are available, hence the need for such research.

The chemical composition of the ingredients and total diets is shown in Table 1. The CP concentration was numerically lower for MOL+CM (19.4% DM) than for the other diets (ranging from 20.3 to 21.3% DM) primarily because of a dilution effect of the lower protein supplements. The RDP, expressed as a proportion of dietary CP, was numerically greater for MOL (75.2%) than for the other treatments (ranging from 71.1 to 74.0%). The NDF was numerically greatest for PAST (52.6% DM) and lowest for MOL+CM (46.9%). Starch was numerically greatest for CM and MOL+CM (7.8 and 7.7% DM, respectively) because of the inclusion of corn. The WSC was numerically greatest for MOL (14.0% DM) because of the sugars in the molasses, whereas NE₅ was numerically greatest for MOL+CM (1.41 Mcal/kg) and was least for PAST (1.34 Mcal/kg). It is important to point out that blackstrap molasses, originating from sugarcane, was used in this study. Molasses originating from other sources, such as sugar beets, citrus, or wood, or from other batches from the same source can differ in sugar and mineral concentrations (Davis et al., 1955; Dumoulin et al., 1987).

**Nutrient Digestibility**

Apparent DM, OM, and NDF digestibility values, and true DM and OM digestibility values were not affected (P > 0.05) by treatments (Table 2). The response of fiber digestibility to molasses supplementation has been mixed in the literature, which may be due to wide variability in molasses sources, supplementation
levels, and forage quality. In feeding studies with dairy heifers, Davis et al. (1955) reported that in the case of poor-quality forages, molasses (supplemented at 9.7 or 19% of total DMI) has been shown to reduce fiber digestibility, possibly because ruminal bacteria utilize the easily digested soluble sugars in molasses in preference to the less available fibrous material of the forage. When molasses supplementation was decreased to 5% of total DMI (similar to the present study) in dairy heifers, no differences in nutrient digestibility were detected (Davis et al., 1955). Arias et al. (1951) found that supplementing molasses at 20 to 30% of total DM fed improved cellulose digestion in artificial rumens better than higher levels (50% of total DM fed) of molasses supplementation. The authors suggested that the energy in molasses was used to unlock the protein in the fiber component. In turn, the protein from the fiber could be used as either energy or protein; therefore, additional (>30% of total DM) energy from molasses was not beneficial. Molasses may also supply essential minerals that are needed in cellulose digestion. Additional (>30% of total DM) molasses may not have been beneficial because these mineral requirements were met at the lower supplementation levels (Arias et al., 1951; Burroughs et al., 1951).

There may be an important interaction between forage quality and digestion response to molasses supplementation, with molasses having a greater impact on digestibility of low-quality forages compared with higher quality forages (Broderick and Radloff, 2004; Titgemeyer et al., 2004). Molasses is frequently fed to cattle grazing low-quality forages, such as native range-land or hays, to enhance the protein supply to improve forage intake and digestibility (Titgemeyer et al., 2004). However, with the vegetative, relatively high-protein pastures in the northeastern United States, RDP supply is not limited. Rather, energy is the limiting nutrient to the digestibility and milk production of dairy cows grazing high-quality pastures (Kolver et al., 1998). Broderick and Radloff (2004) reported linear, quadratic, and cubic responses in performance, N utilization, and nutrient digestibility to increasing levels of molasses (dried or liquid) supplementation in 2 trials with lactating dairy cows. For instance, feeding liquid sugarcane molasses at 5% of total DMI yielded, in general, the greatest DMI, nutrient digestibility, milk yield, and milk components, and the lowest milk urea N. However, feeding higher levels or molasses (up to 9% of total DMI) tended to decrease overall digestibility and performance. It is important to point out that Broderick and Radloff (2004) fed diets with a forage-to-concentrate ratio of 52:48 containing a 40:60 ratio of corn silage to alfalfa silage. Additionally, the diet contained lower levels of CP (15.6%) and NDF (26%) than in the current study. These dietary differences, as well as the type of forage fed, may affect the response to molasses supplementation. In diets limited in energy or RDP, the nonfiber carbohydrate-fermenting bacteria may compete with fiber-digesting bacteria for available N (Lee et al., 2003). However, adequate supply of dietary RDP may prevent sucrose from depressing NDF digestibility (Lee et al., 2003), as has been noted in some studies with lower quality forages (Khalili and Huhtanen, 1991; Heldt et al., 1999). The reason for this is that the relatively high RDP from the pasture herbage results in increased levels of NH₃-N (Kolver et al., 1998) as well as preformed amino acids and peptides that can be used as substrates for cellulolytic bacterial growth (Poppi and McLennan, 1995; Atasoglu et al., 2001) to maintain fiber digestibility. Additionally, the stable ruminal pH in this study

### Table 1. Chemical composition of ingredients (molasses and corn meal) and of the pasture-only (PAST), molasses plus pasture (MOL), corn meal plus pasture (CM), or molasses plus corn meal plus pasture (MOL+CM) diets

<table>
<thead>
<tr>
<th>Item</th>
<th>Molasses</th>
<th>Corn meal</th>
<th>PAST</th>
<th>MOL</th>
<th>CM</th>
<th>MOL+CM</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM, %</td>
<td>70.9</td>
<td>88.8</td>
<td>92.8</td>
<td>91.7</td>
<td>92.5</td>
<td>91.4</td>
</tr>
<tr>
<td>OM, % of DM</td>
<td>84.8</td>
<td>98.4</td>
<td>94.0</td>
<td>93.5</td>
<td>94.3</td>
<td>93.9</td>
</tr>
<tr>
<td>CP, % of DM</td>
<td>2.8</td>
<td>6.9</td>
<td>21.3</td>
<td>20.4</td>
<td>20.3</td>
<td>19.4</td>
</tr>
<tr>
<td>RDP, % of CP</td>
<td>97.0</td>
<td>33.0</td>
<td>74.0</td>
<td>75.2</td>
<td>71.1</td>
<td>72.3</td>
</tr>
<tr>
<td>NDF, % of DM</td>
<td>0.2</td>
<td>8.5</td>
<td>52.6</td>
<td>50.0</td>
<td>49.5</td>
<td>46.9</td>
</tr>
<tr>
<td>Starch, % of DM</td>
<td>1.0</td>
<td>73.9</td>
<td>2.8</td>
<td>2.7</td>
<td>7.8</td>
<td>7.7</td>
</tr>
<tr>
<td>WSC, % of DM</td>
<td>78.9</td>
<td>4.1</td>
<td>10.6</td>
<td>14.0</td>
<td>10.2</td>
<td>13.6</td>
</tr>
<tr>
<td>NE₃, Mcal/kg</td>
<td>1.63</td>
<td>2.07</td>
<td>1.34</td>
<td>1.36</td>
<td>1.39</td>
<td>1.41</td>
</tr>
</tbody>
</table>

1Roe et al. (1990).
2WSC = water-soluble carbohydrates.
3Estimated using NRC (2001) model.
Table 2. Nutrient digestibility, pH, and VEA production of the pasture-only (PAST), molasses plus pasture (MOL), corn meal plus pasture (CM), or molasses plus corn meal plus pasture (MOL+CM) diets in continuous culture fermenters

<table>
<thead>
<tr>
<th>Item</th>
<th>PAST</th>
<th>MOL</th>
<th>CM</th>
<th>MOL+CM</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM, %</td>
<td>54.25</td>
<td>56.63</td>
<td>55.67</td>
<td>53.72</td>
<td>1.489</td>
<td>0.540</td>
</tr>
<tr>
<td>OM, %</td>
<td>57.91</td>
<td>59.51</td>
<td>59.71</td>
<td>57.33</td>
<td>1.460</td>
<td>0.612</td>
</tr>
<tr>
<td>NDF, %</td>
<td>81.20</td>
<td>78.46</td>
<td>75.84</td>
<td>77.17</td>
<td>1.715</td>
<td>0.251</td>
</tr>
<tr>
<td>True digestibility</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM, %</td>
<td>68.00</td>
<td>69.89</td>
<td>69.15</td>
<td>66.43</td>
<td>1.130</td>
<td>0.250</td>
</tr>
<tr>
<td>OM, %</td>
<td>70.70</td>
<td>71.64</td>
<td>72.29</td>
<td>69.60</td>
<td>1.152</td>
<td>0.442</td>
</tr>
<tr>
<td>Mean pH</td>
<td>6.59</td>
<td>6.68</td>
<td>6.53</td>
<td>6.50</td>
<td>0.046</td>
<td>0.071</td>
</tr>
<tr>
<td>Minimum pH</td>
<td>6.54</td>
<td>6.63</td>
<td>6.48</td>
<td>6.47</td>
<td>0.053</td>
<td>0.211</td>
</tr>
<tr>
<td>Maximum pH</td>
<td>6.65ac</td>
<td>6.74a</td>
<td>6.56e</td>
<td>6.53a</td>
<td>0.040</td>
<td>0.035</td>
</tr>
<tr>
<td>VFA, mmol/L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>75.75</td>
<td>74.30</td>
<td>75.77</td>
<td>75.06</td>
<td>0.641</td>
<td>0.398</td>
</tr>
<tr>
<td>Acetate (A)</td>
<td>52.04</td>
<td>51.13</td>
<td>52.04</td>
<td>51.59</td>
<td>0.446</td>
<td>0.473</td>
</tr>
<tr>
<td>Propionate (P)</td>
<td>14.37</td>
<td>14.17</td>
<td>14.38</td>
<td>14.18</td>
<td>0.107</td>
<td>0.378</td>
</tr>
<tr>
<td>Butyrate</td>
<td>6.96</td>
<td>6.74</td>
<td>6.97</td>
<td>6.94</td>
<td>0.111</td>
<td>0.450</td>
</tr>
<tr>
<td>Isobutyrate</td>
<td>0.51</td>
<td>0.52</td>
<td>0.50</td>
<td>0.52</td>
<td>0.025</td>
<td>0.891</td>
</tr>
<tr>
<td>Valerate</td>
<td>1.39</td>
<td>1.27</td>
<td>1.42</td>
<td>1.35</td>
<td>0.057</td>
<td>0.378</td>
</tr>
<tr>
<td>Isovalerate</td>
<td>0.49</td>
<td>0.48</td>
<td>0.46</td>
<td>0.49</td>
<td>0.031</td>
<td>0.949</td>
</tr>
<tr>
<td>A:P</td>
<td>3.62</td>
<td>3.61</td>
<td>3.62</td>
<td>3.64</td>
<td>0.0278</td>
<td>0.877</td>
</tr>
</tbody>
</table>

*Means within the same row with different superscripts differ at P < 0.05.

*In = 4.

1Acetate-to-propionate ratio.

may have prevented changes in NDF digestibility.

**Ruminal pH and Volatile Fatty Acids**

Mean ruminal pH tended to be greater (P = 0.071) for MOL (Table 2). The minimum ruminal pH was not different across treatments; however, the maximum ruminal pH was greatest (P < 0.05) for MOL, explaining the tendency toward greater mean ruminal pH. The minimum ruminal pH was greater than 6.4 for all treatments, which has been shown to be the optimal pH for cellulose digestion (Hoover, 1986; Wales et al., 2004). Supplementation levels in the current study were low enough that large variations in ruminal pH were not seen, which would support the lack of differences in nutrient digestibility. The results of other researchers support these findings; they have reported that feeding molasses up to 12% of the total DMI did not affect ruminal pH of dairy cows fed conserved forages (Broderick and Radloff, 2004; Oelker et al., 2009).

Molar proportions of individual and total VFA, as well as acetate-to-propionate ratio, were not affected by treatments (Table 2). This lack of response is in contrast to the reports of others, who found increased concentrations of ruminal butyrate in experiments conducted with cattle (Khalili and Huhtanen, 1991; Khalili, 1993; Hristov and Ropp, 2003). However, it is important to note that molasses supplementation was much greater (>9% of total DM fed) in those studies (Khalili and Huhtanen, 1991; Khalili, 1993; Hristov and Ropp, 2003) compared with data from the current trial. In studies in which molasses was supplemented at levels similar to the current study, no shifts in VFA profiles were observed (Broderick and Radloff, 2004; Firkins et al., 2008; Oelker et al., 2009). Concentrations of VFA may not capture production rates because they represent a balance between production and disappearance (Broderick and Radloff, 2004). Firkins et al. (2006) noted that butyrate concentrations may increase when lactate production is increased (thereby reducing ruminal pH) with subsequent conversion to butyrate. Because there were no significant differences in ruminal pH in the current study, shifts in proportions of butyrate may not be anticipated. Supplemented carbohydrate can depress fiber digestibility if RDP is limiting (Heldt et al., 1999; Firkins et al., 2006), which may simply be a result of the nonfiber carbohydrate microbes outcompeting fiber utilizers for scarce nutrients (Jones et al., 1998). When RDP is adequate (as in pasture-based diets), energy availability determines microbial protein synthesis, which is also tied to VFA production (Hoover and Stokes, 1991; Firkins et al., 2006). Based on the results of this study,
Table 3. Nitrogen metabolism of the pasture-only (PAST), molasses plus pasture (MOL), corn meal plus pasture (CM), or molasses plus corn meal plus pasture (MOL+CM) diets in continuous culture fermenters

<table>
<thead>
<tr>
<th>Item</th>
<th>PAST</th>
<th>MOL</th>
<th>CM</th>
<th>MOL+CM</th>
<th>SEM</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH₃-N, mg/dL</td>
<td>6.47b</td>
<td>6.32b</td>
<td>6.07b</td>
<td>5.32b</td>
<td>0.267</td>
<td>0.043</td>
</tr>
<tr>
<td>CP digestibility, %</td>
<td>67.16b</td>
<td>71.72c</td>
<td>67.16b</td>
<td>63.21a</td>
<td>1.317</td>
<td>0.022</td>
</tr>
<tr>
<td>N flow, g/d</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total N</td>
<td>1.67</td>
<td>1.50</td>
<td>1.57</td>
<td>1.62</td>
<td>0.041</td>
<td>0.081</td>
</tr>
<tr>
<td>NH₃-N</td>
<td>0.20</td>
<td>0.19</td>
<td>0.18</td>
<td>0.16</td>
<td>0.008</td>
<td>0.078</td>
</tr>
<tr>
<td>Non-NH₃-N</td>
<td>1.47</td>
<td>1.31</td>
<td>1.38</td>
<td>1.46</td>
<td>0.040</td>
<td>0.089</td>
</tr>
<tr>
<td>Bacterial N</td>
<td>0.67</td>
<td>0.65</td>
<td>0.62</td>
<td>0.64</td>
<td>0.028</td>
<td>0.688</td>
</tr>
<tr>
<td>Dietary N</td>
<td>0.80b</td>
<td>0.66a</td>
<td>0.76b</td>
<td>0.82b</td>
<td>0.029</td>
<td>0.033</td>
</tr>
<tr>
<td>N flow, % of total N flow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH₃-N</td>
<td>11.95</td>
<td>12.84</td>
<td>11.84</td>
<td>10.14</td>
<td>0.585</td>
<td>0.080</td>
</tr>
<tr>
<td>Non-NH₃-N</td>
<td>88.05</td>
<td>87.16</td>
<td>88.16</td>
<td>89.86</td>
<td>0.585</td>
<td>0.080</td>
</tr>
<tr>
<td>Bacterial N</td>
<td>45.42</td>
<td>49.37</td>
<td>44.11</td>
<td>1.428</td>
<td>0.136</td>
<td></td>
</tr>
<tr>
<td>Dietary N</td>
<td>54.58</td>
<td>50.63</td>
<td>55.89</td>
<td>1.428</td>
<td>0.071</td>
<td></td>
</tr>
<tr>
<td>Bacterial efficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OM truly digested, g N/kg</td>
<td>14.33</td>
<td>13.74</td>
<td>12.90</td>
<td>13.92</td>
<td>0.753</td>
<td>0.619</td>
</tr>
</tbody>
</table>

Means within the same row with different superscripts differ at P < 0.05.

Nitrogen Metabolism

Total N intake was numerically lowest for MOL+CM (2.79 g/d) and greatest for PAST (3.01 g/d; data not shown) primarily because of the substitution of lower protein supplements for herbage. Ruminal NH₃-N concentration was lowest (P < 0.05) for MOL+CM, possibly as a result of reduced N intake. However, the decrease in ruminal NH₃-N may be also influenced by microbial uptake of NH₃ (Kolver et al., 1998). Soluble carbohydrate supplements have been shown to reduce ruminal NH₃-N concentration by providing fermentable energy to ruminal microbes to take up greater amounts of ruminal NH₃-N (Kolver et al., 1998; Murphy, 1999). Although it might be expected that this increased NH₃-N uptake by microbes should result in increased microbial production (Kolver et al., 1998), this was not the case in the current study. The level of NH₃-N in the CM+MOL diet averaged 5.32 mg/dL, which is very close to the minimum concentration of 5 mg/dL that has been shown stimulate microbial growth (Satter and Slyter, 1974; Balcells et al., 1993). Ruminal NH₃-N may have fallen below 5 mg/dL for a period of time in all diets because of diurnal variation, which may have affected microbial growth (Brito et al., 2006).

Flow of dietary N (g/d) was lowest (P < 0.05) for MOL, whereas CP digestibility was greatest for MOL (Table 3) and least for MOL+CM, which may have been a result of the readily available sugars from molasses improving utilization of RDP (Broderick et al., 2008). Total flow of NH₃-N tended (P = 0.078) to be lower for MOL+CM. The lower CP digestibility for MOL+CM may have been due to negative associative effects resulting in digestive and metabolic interactions. The readily fermentable carbohydrate components of the corn and molasses may have reduced the rate of ruminal microbial digestion of CP, thus reducing CP digestibility (Dixon and Stockdale, 1999).

Non-NH₃-N and bacterial N flows (g/d) were not affected by treatment. When expressed as a proportion of total N flow, NH₃-N, non-NH₃-N, and dietary N followed similar trends (P > 0.05 but < 0.10) compared with total flows (Table 3). Efficiency of bacterial N synthesis (Table 3) was not affected by treatments. Strobel and Russell (1986) reported that sucrose (such as molasses) and starch (such as corn) had similar microbial protein yields when fermented at a pH of 6.7, which corroborates data from the current trial; however, at a pH of 5.5, microbial protein yield from sucrose was reduced by 34%.

Application to Pasture-Based Diets

Sugars are fermented more rapidly in the rumen than is starch (Chamberlain et al., 1993), suggesting that sugars, such as blackstrap molasses from sugarcane, could potentially serve as an effective supplement to balance the supplies of fermentable energy and RDP in diets with high levels of soluble and degradable protein, such as pasture (Kolver et al., 1998; Kim et al., 1999). This in turn could reduce the high ruminal NH₃-N concentrations commonly associated with pasture-based diets, which can decrease milk production, nutrient digestibility, and conception rates...
positively affect animal production
and health that could not be quanti-
fied in this in vitro study. Addition-
ally, if molasses is priced lower than
corn per unit of energy, molasses may
be a viable alternative to corn under
these dietary conditions. Additional
research is needed to evaluate the
level of molasses supplementation,
both alone and combined with other
supplements, on ruminal digestibility
and animal production, as well as to
evaluate varying forage quality for
grazing dairy cows.

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IMPLICATIONS

Under high-quality vegetative
pasture conditions in the northeast-
ern United States, molasses showed
results similar to corn meal in improv-
ing in vitro N utilization. However,
there was only minimal benefit in
ruminal fermentation compared with
the pasture-only diet at low levels (5% of
total DM fed) of inclusion. There
may be other benefits to molasses or
corn meal supplementation that may
also cause environmental issues as excess N is excreted
in urine into the environment (Kolver et al., 1998).

The considerable on-farm variability
in response to molasses supplementation
of grazing organic dairy cows
may be due in part to varying forage
quality (Davis et al., 1955; Rayburn,
1991). Additionally, there is wide
variability in the nutrient content of
molasses from various sources (i.e.,
sugarcane, sugar beets, etc.) as well
as between batches within a source.

These interacting factors emphasize
that results to molasses supplementation
may vary (K. Hoffman and K.
Soder, unpublished data).

Although results of studies with
confined cows showed that levels of
molasses supplementation higher (6 to
12% of total DMI) than in the current
study (5% of total DMI) may be det-
remental to nutrient digestibility (e.g.,
Broderick and Radloff, 2004), those
studies fed conserved sources of forage
as well as additional concentrate sup-
plementation. Pasture-based dairies
that feed molasses as the sole source
of supplementation energy may need
to consider supplementation rates
greater than 5% of total DMI to ob-
serve any potential benefits. Addition-
ally, potential interactions with other
feeding factors, most notably other
supplements and forage quality, must
be evaluated. Effects at the animal
level (milk production and composi-
tion, BCS, and conception rates) must
be evaluated. Effects at the animal
level of molasses supplementation,
both alone and combined with other
supplements, on ruminal digestibility
and animal production, as well as to
evaluate varying forage quality for
grazing dairy cows.


