Project Title:

Molasses as an Alternative Energy Feed Source for Organic Dairies

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Abbreviation key: **A:P** = ratio of acetate to propionate; **BUN** = blood urea nitrogen; **CM** = corn meal; **CP** = crude protein; **DM** = dry matter; **DMI** = dry matter intake; **MOL** = molasses; **MOL+CM** = molasses plus corn meal; **MUN** = milk urea nitrogen; **N** = nitrogen; **NDF** = neutral detergent fiber; **NE_L** = net energy for lactation; **NS** = not significant; **OM** = organic matter; **PAST** = pasture treatment; **RDP** = rumen degradable protein; **SEM** = standard error of the mean; total mixed ration = **TMR**; **UNH** = University of New Hampshire; **VFA** = volatile fatty acids; **WSC** = water soluble carbohydrates.

1. Project Summary

Pasture is rich in soluble protein which is rapidly converted to ammonia in the rumen. If this ammonia is not re-captured as microbial protein due to a lack of energy needed to convert ammonia to protein, the ammonia is excreted in the urine as urea, thereby decreasing N utilization in lactating dairy cows. Sucrose is more quickly degraded in the rumen than starch, suggesting that feeding molasses to balance the supplies of energy and degradable protein in the rumen can be strategically used to improve nitrogen utilization in grazing dairy cows. We hypothesize that molasses supplementation will alter nitrogen utilization and microbial protein synthesis which may be responsible for changes in milk production, milk composition, and body condition anecdotally observed by organic farmers currently utilizing molasses supplementation.

Twenty lactating organic Jersey cows housed at the University of New Hampshire's Burley-Demeritt Organic Dairy Research Farm were assigned randomly to one of two supplementation treatments: 1) certified organic liquid blackstrap molasses (**MOL**) (12% of diet dry matter; **DM**) or 2) certified organic cornmeal (**CM**; 12% of diet DM). Cows grazed for approximately 110 days from early June to mid-September. The supplements were top-dressed on a grass-legume baleage (fed at 18% of diet DM) and fed individually twice daily. Intake of supplement (baleage plus supplement) was significantly higher for cows fed MOL vs. CM possibly due to the enhanced palatability of MOL. Pasture and total DM intake were numerically higher for cows fed MOL than those fed CM. Despite enhanced total DM intake, no significant differences were observed for milk yield. Likewise, yields and contents of milk components (milk fat, protein, lactose) did not differ between MOL and CM. However, cows fed MOL had reduced milk urea nitrogen and blood urea nitrogen compared to those fed CM, which may be partially explained by the higher protein content of CM vs. MOL which resulted in greater amounts of soluble protein being converted into ammonia in the rumen and excreted in the blood and milk. In this study, MOL performed similarly to CM in terms of animal performance yet MOL improved nitrogen utilization in organic dairy cows. Liquid MOL may be an alternative energy source for CM if economically competitive.

A complementary study in the lab with continuous culture fermentation units which mimic a functioning rumen was conducted to further evaluate the effects of MOL supplementation on ruminal fermentation and nutrient digestibility of pasture. The fermentation units were fed diets of orchardgrass pasture only (**PAST**) or supplemented with MOL, CM, or molasses plus corn meal (**MOL+CM**). Treatment did not affect DM, organic matter (**OM**), fiber digestibility or molar proportions of volatile fatty acids. Mean fermenter pH tended to be greater for MOL. Fermenter ammonia-nitrogen was lowest for MOL+CM. Protein digestibility was greatest for MOL and lowest for MOL+CM. Bacterial nitrogen flow (g/d) and efficiency of bacterial nitrogen synthesis were not affected. At low levels of inclusion, molasses showed results similar to cornmeal in improving ruminal fermentation and nitrogen utilization, with both supplements showing only minimal improvement compared with a pasture-only diet.

The decision to feed MOL or CM as an energy supplement to grazing dairy cows should be based on the cost of each feed on a DM basis. Grazing management, genetics, environment, and other farm-specific characteristics are most likely to influence the success or failure of cow performance rather than energy source.

2. Introduction to Topic

As milk prices fluctuate and input costs increase, grazing dairy operations seek lower-cost feed alternatives to maintain or improve milk production while reducing feed costs to improve overall farm profitability. This has been most evident within the organic dairy sector, as organic grain prices have been traditionally high relative to conventional grain. Thus, farmers have experimented with a variety of supplemental grains and other products, such as molasses.

Sugar cane molasses is a rich source of sugars, is available in organic form, and may be a viable supplementation option to corn. However, there is little literature available that evaluates

molasses as the only supplement for grazing dairy cows. Anecdotal results, as reported by farmers, are mixed - some farms use molasses successfully while others report major milk production or body condition losses. Also, it has been anecdotally proposed that molasses has three times more energy than corn, allowing for a lower feeding rate. While there is research available that evaluated using molasses as an energy supplement in confined dairy cows, there are no specific data available in the peer-reviewed journals regarding the impact of using molasses as the only supplemental source of feed to grazing dairy cows. Additionally, there is no research data available to verify that molasses is higher in energy, as it is generally considered to be equivalent to corn.

3. Objectives Statement

The overall objective of this study was to evaluate the effects of substituting corn with molasses supplementation on organic dairy farms. We hypothesized that molasses supplementation will alter nitrogen utilization and microbial protein synthesis, which may be responsible for changes in milk production, milk composition, and body condition observed by organic farmers currently utilizing molasses supplementation.

Specific objectives included:

1. Determine the effects of molasses supplementation on milk production, milk components, and body weight of lactating dairy cows in a feeding trial.

2. Evaluate the effects of molasses supplementation on ruminal fermentation and degradability of pasture in an *in situ* study.

NOTE: In the original grant proposal, the *in situ* protocol was to occur via insertion of porous nylon bags filled with feed directly into the rumen of surgically fistulated cows. Although the organic certifier for this particular herd was willing to consider this surgical alteration of certified organic cows, we determined that the possible risk to the animals' health as they recovered from surgery without the use of antibiotics was unacceptable. Alternatively, we conducted a 40-day continuous culture fermentation study in the laboratory using the same feeds as in the pasture study. The results were reported in a peer-reviewed journal paper (Soder et al., 2010).

3. Evaluate the profitability (income over feed costs) of molasses supplementation for organic dairy farms in a feeding trial.

4. Materials and Methods

Feeding Trial Methodology

The study was conducted on the Burley-Demeritt Farm in Lee, NH (seven miles from the University of New Hampshire (**UNH**) campus), which supports the UNH Research Organic Dairy. The property consists of 215 certified organic acres of which about 40 acres are in pastures (certified 2007 by New Hampshire Department of Agriculture, Markets, and Food). Twenty multiparous, lactating organic Jersey cows were blocked by parity and milk production and assigned randomly to one of two supplementation treatments: 1) certified organic liquid blackstrap molasses (**MOL;** 12% diet DM) or 2) certified organic cornmeal (**CM**; 12% diet DM). MOL and CM averaged (% DM), respectively: 5.35% vs. 7.85% crude protein (**CP**), 68.9 vs. 0.12% starch, and 1.53 vs. 50.1% sucrose. The supplements were top-dressed on a grass-legume baleage (18% diet DM) fed individually twice daily following milking using Calan doors (American Calan, Northwood, NH) to assure each cow received the correct treatment. Cows were segregated by treatment into two grazing groups with pasture intake estimated by group using a calibrated rising plate meter to quantify pre- and post-grazing herbage biomass (Sanderson et al., 2001). Each group was provided a new paddock averaging 0.10 hectares for each of the twice daily grazing times (from about 08:00 to 14:00 and then again from 18:30 to 04:30) from early June to mid-September for a total of approximately 110 days. Group pasture intake was estimated using pre-

and post-grazing pasture height measurements using a pasture ruler and a rising plate meter. Pasture herbage samples representative of that harvested by the grazing cows were collected for nutrient analysis. Supplements were sampled weekly and composited monthly. During each of four collection periods (June, July, August and September), blood samples were collected twice (am and pm) and cows were weighed on three consecutive days, and milk samples were collected on two consecutive days (am and pm). Daily milk yield was recorded for the duration of the trial.

Milk samples were analyzed for milk fat, protein, lactose, and milk urea nitrogen (**MUN**) by mid infrared spectrophotometry. Plasma samples were analyzed for blood urea nitrogen (**BUN**) as previously described (Brito et al., 2008). Data were analyzed using the MIXED procedure of SAS for a completely randomized design with repeated measures over time.

Continuous Culture Fermentation Methodology

The continuous culture fermentation study was conducted at the USDA-ARS Pasture Systems and Watershed Management Research Unit in University Park, PA. 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. 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 total mixed ration (**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 though 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 N_2 gas to preserve anaerobiosis.

Three supplementation strategies and a pasture control diet were compared in a 4 × 4 Latin square design. The four diets used in this study were 1) orchardgrass (*Dactylis glomerata* L.) pasture only (control; **PAST**; 70 g DM/d); 2) certified organic blackstrap molasses plus orchardgrass pasture (**MOL**; 3.5 g DM/d of molasses plus 66.5 g DM/d of pasture); 3) certified organic 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 U.S. 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 CM samples were ground through a 2-mm mesh screen (Wiley Mill, Thompson Scientific, Philadelphia, PA).

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 four times per day at feeding times (Beckman model 360, Beckman Instruments, Fullerton, CA). Effluent was collected into 4-L plastic jugs. During the first 7 d, effluent weights were recorded daily at 1430h 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. Ammonia and volatile fatty acid (**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 used to harvest microbes by mixing in a blender and straining through nylon cloth. Strained contents were centrifuged at 10,000 × *g* for 10 min at 4°C to remove feed particles (de Veth and Kolver, 2001). Microbes were isolated by centrifuging at 20,000 × *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 by wet chemistry for DM and organic matter (**OM**) (methods 930.15 and 942.05, respectively, AOAC, 2006). The CP contents of the diet and effluent were determined by micro-Kjeldahl digestion (method 990.03, AOAC, 2006) using 75-mL calibrated tubes with $CuSO_4/K_2SO_4$ as catalyst. The methods of Van Soest et al. (1991) were used in the analyses of neutral detergent fiber (**NDF**) with amylase and sodium sulfite (inclusive of ash). The dietary rumen degradable protein (**RDP**) supply was determined according to the procedures of Roe et al. (1990). Purine concentrations (Zinn and Owens, 1986) 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 × 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 standard error of the mean (**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.

5. Project Results

Feeding Trial Results

Intake of supplement (baleage + MOL or CM) was significantly greater ($P < 0.001$) for cows fed MOL vs. CM (Table 1) possibly due to enhanced palatability of MOL. Pasture and total DM intake (DMI) were numerically greater for cows fed MOL than for those fed CM. Despite enhanced total DMI, no significant differences ($P > 0.05$) were observed for milk yield comparing

these two energy sources. Likewise, yields and contents of milk components did not differ ($P > 0.05$) between MOL and CM. However, cows fed MOL had lower MUN ($P = 0.03$) and BUN ($P < 0.01$) compared to those fed CM, which may be partially explained by the lower crude protein content of MOL vs. CM. There were no significant differences ($P > 0.05$) in body weight change.

Income over feed costs were within 1% of each other when comparing supplements, suggesting that MOL was competitive with CM in providing supplemental energy to organic grazing dairy cows. The lack of significant differences in milk production and milk components between MOL vs. CM suggests that MOL can replace CM if economically competitive. Concentrations of MUN and BUN were both reduced in cows fed MOL vs. CM indicating improved nitrogen utilization.

Table 1. Dry matter intake (**DMI**), milk production and composition, and body weight change of cows supplemented with molasses (**MOL**) or cornmeal (**CM**) while grazing pasture.

	Treatment		standard error of mean	*P* -value
	MOL	CM		
Pasture DMI, lb/d	25.3	22.0	-	-
Supplement DMI, lb/d	9.4	8.1	0.29	<0.01
Total DMI, lb/d	34.8	30.0	-	-
Milk yield, lb/d	28.2	26.0	3.37	NS
Milk fat, lb/d	1.3	1.2	0.31	NS
Milk protein, lb/d	1.0	0.9	0.20	NS
Milk lactose, lb/d	2.9	2.7	0.33	NS
MUN, mg/dL	13.4	14.9	0.59	0.03
BUN, mg/dL	14.8	16.7	0.56	<0.01
Body weight change, lb/d	0.90	0.51	0.37	NS

MUN = milk urea nitrogen
BUN = blood urea nitrogen

Continuous Culture Results

The chemical composition of the ingredients and total diets is shown in Table 2. The CP concentration was numerically lower for MOL + CM (19.4% DM) than the other diets (ranging from 20.3 to 21.3% DM) primarily due to a dilution effect of the lower-protein supplements. The rumen degradable protein (RDP), expressed as a proportion of dietary crude protein (CP), was numerically greater for MOL (75.2%) than for the other treatments (ranging from 71.1 to 74.0%). The neutral detergent fiber (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) due to the inclusion of corn. The water soluble carbohydrates (WSC) was numerically greatest for MOL (14.0% DM) due to the sugars in the molasses, while net energy for lactation ($\mathbf{NE_L}$) was numerically greatest for MOL+CM (0.64 Mcal/lb) and least for PAST (0.61 Mcal/lb).

It is important to point out that blackstrap molasses, originating from sugar cane, 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 concentration (Davis et al., 1955; Dumoulin et al., 1987).

Nutrient Digestibility

Apparent DM, OM, and NDF digestibilities and true DM and OM digestibilities were not affected ($P > 0.05$) by treatment (Table 3). Response of fiber digestibility to molasses supplementation has been mixed in the literature, which may be due to wide variability in molasses source, supplementation level, and forage quality. In feeding studies with dairy heifers, Davis et

Table 2. Chemical composition of ingredients molasses (**MOL**) and corn meal (**CM**).

Item	Ingredient	
	MOL	CM
DM, %	70.9	88.8
OM, % DM	84.8	98.4
CP, % DM	2.8	6.9
RDP, % CP	97.0	33.0
NDF, % DM	0.2	8.5
Starch, % DM	1.0	73.9
WSC, % DM	78.9	4.1
NE_L, Mcal/lb	0.74	0.94

DM = dry matter; **OM** = organic matter; **CP** = crude protein; **RDP** = rumen degradable protein; **NDF** = neutral detergent fiber; **WSC** = water soluble carbohydrates; **NE_L** = net energy for lactation

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 20-30% 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 to higher quality forages (Broderick and Radloff, 2004; Titgemeyer et al., 2004). Molasses is frequently fed to cattle grazing low-quality forages, such as native rangeland or hays, to enhance protein supply in order to improve forage intake and digestibility (Titgemeyer et al., 2004). However, with vegetative, relatively high-protein pastures of the northeastern USA, RDP supply is not limited. Rather, energy is the limiting nutrient to 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 two trials with lactating dairy cows.

For instance, feeding liquid sugar cane molasses at 5% of total DMI yielded, in general, the greatest DMI, nutrient digestibility, milk yield, milk components, and the lowest milk urea N. However, feeding higher levels of 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 40:60 corn silage to alfalfa silage. Additionally, the diet contained lower levels of CP (15.6%) and NDF (26%) than the current study. These dietary differences, as well as type of forage fed, may impact the response to molasses supplementation. In diets limited in energy or RDP, the non-fiber 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),

Table 3. Nutrient digestibility, pH, and volatile fatty acid (**VFA**) production of pasture-only (**PAST**), molasses (**MOL**) plus pasture, corn meal (**CM)** plus pasture, or MOL plus CM (**MOL + CM**) plus pasture diets in continuous culture fermenters.

Item	Diet				standard error of mean	*P*-Value
	PAST	MOL	CM	MOL+CM		
Apparent digestibility						
DM, %	54.3	56.6	55.7	53.7	1.49	NS
OM, %	57.9	59.5	59.7	57.3	1.46	NS
NDF, %	81.2	78.5	75.8	77.2	1.72	NS
True digestibility						
DM, %	68.0	69.9	69.2	66.4	1.13	NS
OM, %	70.7	71.6	72.3	69.6	1.15	NS
Mean pH	6.6	6.7	6.5	6.5	0.05	NS
Minimum pH	6.5	6.6	6.5	6.5	0.05	NS
Maximum pH	6.7^{bc}	6.7^{c}	6.6^{ab}	6.5^{a}	0.04	0.04
VFA, (mmol/L)						
Total	75.8	74.3	75.8	75.2	0.64	NS
Acetate (A)	52.0	51.1	52.0	51.6	0.45	NS
Propionate (P)	14.4	14.2	14.4	14.2	0.11	NS
Butyrate	7.0	6.7	7.0	6.9	0.11	NS
Isobutyrate	0.5	0.5	0.5	0.5	0.03	NS
Valerate	1.4	1.3	1.4	1.4	0.06	NS
Isovalerate	0.5	0.5	0.5	0.5	0.03	NS
A:P	3.6	3.6	3.6	3.6	0.03	NS

^{a,b,c} means within the same row with different superscripts differ at $P < 0.05$.

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 ammonia (Kolver et al., 1998) as well as pre-formed 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 fermenter pH in this study may also have prevented changes in NDF digestibility.

Fermenter pH and Volatile Fatty Acids

Mean fermenter pH tended to be greater ($P = 0.071$) for MOL (Table 3). Minimum fermenter pH was not different across treatments; however, maximum fermenter pH was greatest ($P < 0.05$) for MOL, explaining the tendency towards greater mean fermenter pH. Minimum fermenter 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 fermenter pH were not seen, which would support the lack of differences in nutrient digestibility. Other researchers support these results, reporting 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 volatile fatty acids (VFA), as well as acetate to propionate ratio (**A: P**), were not affected by treatments (Table 3). This lack of response is in contrast to others who found increased concentration 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 to the current trial. In studies where 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 as 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. As there were no significant differences in fermenter 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 non-fiber carbohydrate-microbes out-competing 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, neither RDP nor energy was limiting to the point of depressing microbial protein synthesis; therefore, VFA production was also not altered.

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 due to the substitution of lower-protein supplements for herbage. Fermenter ammonia concentration was lowest ($P < 0.05$) for MOL+CM possibly as a result of reduced N intake (Table 4). However, decrease in ruminal ammonia may be also influenced by microbial uptake of ammonia (Kolver et al., 1998). Soluble carbohydrate supplements have been shown to reduce ruminal ammonia concentration by providing fermentable energy to ruminal microbes to uptake greater amounts of ruminal ammonia (Kolver et al., 1998; Murphy, 1999). While it might be expected that this increased ammonia 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 ammonia 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 to stimulate microbial growth (Satter and Slyter, 1974; Balcells et al., 1993). Fermenter ammonia may have fallen below 5 mg/dL for a period of time in all diets due to diurnal variation, which may have impacted microbial growth (Brito et al., 2006).

Flow of dietary N (g/d) was lowest ($P < 0.05$) for MOL while CP digestibility was greatest for MOL (Table 4) 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 ammonia 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 fermenter microbial digestion of CP, thus reducing CP digestibility (Dixon and Stockdale, 1999). Non-ammonia and bacterial N flows (g/d) were not affected by treatment. When expressed as a proportion of total N flow, ammonia, non-ammonia, and dietary N followed similar trends ($P > 0.05$ but < 0.10) compared to total flows (Table 4).

Efficiency of bacterial N synthesis (Table 4) 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 with data from the current trial; however, at a pH of 5.5, microbial protein yield from sucrose was reduced by 34%.

Table 4. Nitrogen metabolism of pasture-only (**PAST**), molasses (**MOL**) plus pasture, corn meal (**CM**) plus pasture, or MOL plus CM (**MOL + CM**) plus pasture diets in continuous culture fermenters.

	Diet					
Item	PAST	MOL	CM	MOL+ CM	SEM	*P*-Value
Fermenter ammonia, mg/dL	6.5[b]	6.3[b]	6.1[b]	5.3[a]	0.27	0.04
CP digestibility, %	67.2[b]	71.7[c]	67.2[b]	63.2[a]	1.32	0.02
N Flows, g/day						
Total N	1.7	1.5	1.6	1.6	0.04	NS
Ammonia-N	0.2	0.2	0.2	0.2	0.01	NS
Non-ammonia-N	1.5	1.3	1.4	1.5	0.04	NS
Bacterial N	0.7	0.7	0.6	0.6	0.03	NS
Dietary N	0.8[b]	0.7[a]	0.8[b]	0.8[b]	0.03	0.03
N Flows, % of total N flow						
Ammonia-N	12.0	12.8	11.8	10.1	0.59	NS
Non-ammonia-N	88.1	87.2	88.2	89.9	0.59	NS
Bacterial N	45.4	49.4	44.8	44.1	1.43	NS
Dietary N	54.6	50.6	55.2	55.9	1.43	NS
Bacterial efficiency						
OM truly digested, g N/lb	6.5	6.2	5.9	6.3	0.34	NS

[a,b,c] means within the same row with different superscripts differ at $P < 0.05$.

6. Conclusions and Discussion

In general, molasses performed similarly to corn meal at low levels of supplementation. Both supplements performed only marginally better in ruminal fermentation than an all-pasture diet. While greater levels of molasses supplementation may alter the results, cost of feeding as well as possible detrimental effects of too much sugar in the rumen must be considered. The decision to feed low levels of molasses or corn meal as an energy supplement to grazing dairy cows should be based, in part, on the cost of each feed on a DM basis. In the feeding study reported here, income over feed costs were within 1% of each other when comparing supplements, suggesting that molasses was competitive with corn meal in providing supplemental energy to organic grazing dairy cows as long as similar levels of milk production are maintained. However, significant changes in molasses or corn meal prices may dictate the economic feasibility of utilizing molasses as a substitute for organic corn meal and must be considered on an individual basis. For example, in 2011 organic corn prices doubled, topping $15/bushel in some places in the Northeast, while molasses prices remained fairly stable. During such times molasses may be a suitable economic substitute for corn meal.

It must also be noted that grazing management, genetics, environment, and other farm-specific characteristics are as (or more) likely to influence the success or failure of cow performance, therefore close attention must be made to these factors rather than relying on a corn substitute as the "magic bullet."

7. Outreach

Results of this research were presented at:

- Northeast Pasture Consortium annual meeting (February 2011, State College, PA) http://grazingguide.net/2011/06/effects-of-cornmeal-and-molasses-on-milk-production/
- UNH Undergraduate Research Conference (April, 2011, Durham, NH)
- American Dairy Science Association/American Society of Animal Science annual meetings (July 2011, New Orleans, LA)
- WI Grazing Conference (January 2012, Eau Claire, WI).

- Popular press publications about the project
    - http://www.agriview.com/news/dairy/molasses-or-corn-meal-to-grazing-cows-matter-of-cost/article_ba61efec-da31-11e0-8e1f-001cc4c03286.html

A fact sheet (ftp://ftp-fc.sc.egov.usda.gov/NY/news/factsheets/molasses_case_study.pdf) was developed and distributed at grazing field days and events.

Publications authored by PI's

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9. Photos

UNH Burley-Demeritt Organic Dairy Barn

Cows eating in the Calan gates (to assure each cow receives the correct treatment)

Rising plate meter used to determine DM availability in the pasture.

Cows going to pasture.

Cows grazing a new paddock.

Continuous culture fermentation units at the USDA-ARS Facility, University Park, PA

Filtering rumen fluid before inoculating the fermenters