Effect of Molasses and Sugar Supplements on Rumen Fermentation and Animal Performance

Dr. Stephen M. Emanuele
Cargill Molasses Liquid Products Div.
Clifton Park, NY 12065

Introduction

The value of molasses and sugar in cattle feeding has been recognized for more than 40 years. In 1956, Frank Morrison wrote "Molasses consisting chiefly of sugars may be very desirable in stock feeding as it increases the palatability of feeds that might not otherwise be well liked." (1). Concerning sugar, Morrison wrote "Though the nutritive value of sugar is no greater than that of starch, the great fondness for it shown by stock makes it helpful in some cases for stimulating the appetite." (2). Clearly Morrison saw the value of molasses and sugar as palatability and appetite stimulants. Since 1956, our knowledge of ruminal fermentation and rumen bacteria has greatly increased. We know that rapidly fermented carbohydrates such as sugar may play a specific role in rumen fermentation and have value in addition to improving the palatability of poor forage.

The value of molasses and sugar for cattle feeding is based on our recent understanding of ruminal fermentation and microbial protein production. All carbohydrates are not equal when it comes to supporting microbial growth in the rumen.. The quantity and efficiency of microbial protein production is not constant. The yield of microbial protein is influenced by carbohydrate source, nitrogen source, rate of carbohydrate fermentation, bacterial growth rate, dilution rate and pH (3). The NRC predicts microbial growth from total TDN but this assumes that all TDN has equal value to rumen bacteria. This is not true for all rumen bacteria. Not all TDN is digested in the rumen and not all TDN can be used as an energy source by the rumen bacteria (4). Fat measured as ether extract is part of the TDN equation but is not an energy source for rumen bacteria. Likewise protein is not used with the same efficiency as carbohydrates by rumen bacteria when used as an energy source. The amount of organic matter and carbohydrate digested in the rumen has a direct impact on the quantity of microbial protein produced when rumen degradable protein is not limiting (5). Since not all carbohydrates support the same level of microbial growth, a system has been proposed which distinguishes carbohydrates based upon their rate of fermentation.

The Cornell Net Carbohydrate and Protein System

The Cornell Net Carbohydrate and Protein System (CNCPS) divides carbohydrates into 4 fractions (6). *See Figure 1 for a diagram of these subdivisions.* The model places sugars in a different fraction than starch and pectin based upon different rates of fermentation in the rumen. The current value in the CNCPS for the digestion rate of sugars is 300% per hour (7). Ruminal digestion rates for starch are variable. The rates can vary from 6 to 60% per hour (8), significantly slower than sugar. The large difference in digestion rates for sugars versus starch has stimulated

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interest in using sugar and other soluble carbohydrates like molasses to increase microbial fermentation and protein production in the rumen.

FIGURE 1 Carbohydrate Fraction and Digestion Rates in the CNCPS

Rumen Digestion Rate	Fraction	Carbohydrate Type
Fast	*A*	*Sugars and Organic Acids*
Medium	*B1*	*Starch and Pectin*
Slow	*B2*	*Digestible Fiber*
None	*C*	*Indigestible Fiber*

By placing sugars and organic acids in a different category from starches and pectins, the CNCPS implies that sugars and organic acids may impact ruminal fermentation and microbial growth differently than starches and pectins. The basis for classifying sugars separately from starches and pectins is found in understanding the factors which affect the growth of bacteria in the rumen.

The CNCPS classifies feed protein into three fractions (6). These fractions are nonprotein nitrogen (NPN), true protein and unavailable protein. The true protein fraction is subdivided into three subfractions B1, B2 and B3 based upon degradation rates in the rumen. The NPN and B1 protein fractions are degraded rapidly to ammonia in the rumen. The B2 protein fraction may be degraded in the rumen to ammonia or it may escape the rumen without being degraded. This will depend upon the rate of passage and digestion rate of the protein. The B3 protein fraction is slowly degraded in the rumen or it may escape degradation in the rumen. The C protein fraction is not degraded in the rumen and is considered unavailable to the animal. This protein is measured as either ADIP or ADIN. *See figure 2 for a diagram of these fractions.*

Figure 2. Protein Fractions As Classified in the CNCPS

Rumen Digestion Rate	Fraction	Protein Source or Type
Fast	*A*	*Nonprotein Nitrogen, (ammonia, peptides)*
Fast	*B1*	*Soluble True Protein, (RDP)*
Medium	*B2*	*Insoluble True Protein not associated with the NDF carbohydrate fraction, (glutelin proteins, animal proteins)*
Slow	*B3*	*Digestible Cell Wall Protein*
None	*C*	*Unavailable or bound protein, (Maillard products, tannin-protein complexes, lignin-protein complexes)*

The protein sources used in liquid feeds manufactured today would be classified into fractions A, B1 and B2. The theory behind classifying carbohydrates and protein into these fractions is based upon factors which affect the growth of rumen bacteria. If a diet is formulated so that the majority of the protein falls into the A or B1 protein fractions, for the rumen bacteria to efficiently capture that protein they need carbohydrates which fall into the A and B1 carbohydrate fractions. The majority of the protein in ensiled forages is NPN. If beef or dairy cattle are to utilize this NPN efficiently, their diets need to contain carbohydrates which are degraded rapidly in the rumen. Molasses based liquid supplements can be beneficial when they are used to add rapidly degraded sugars and organic acids to the diet.. The majority of the carbohydrate in molasses is sugar and organic acids. Of the sugars in molasses, 68% is sucrose and 19% is glucose. Both of these sugars are used efficiently by rumen bacteria for energy. By understanding the requirements for efficient rumen microbial growth and fermentation, one can begin to appreciate the special role sugars and molasses may have in animal diets.

Ruminal Bacteria: Growth

Bacteria inhabiting the rumen can be categorized according to the type of carbohydrate they ferment. In the CNCPS bacteria are divided into those that ferment non-structural carbohydrates (sugars and starches) and those that ferment structural carbohydrates (cellulose and hemicellulose). In the rumen and in the CNCPS , the growth rate of both groups of bacteria is directly proportional to the rate of carbohydrate fermentation when the supply of nitrogen and amino acids are not limiting (9). The yield of bacteria (g cells/ g carbohydrate) is increased as carbohydrate fermentation rate is increased. As yield of bacteria is increased so is the quantity of bacterial protein produced per day. Ruminal bacteria are able to use urea and NPN to synthesize protein only if adequate amounts of energy, branched-chain volatile fatty acids, peptides, amino acids and sulfur are available (9). Molasses and other liquid byproducts used in the manufacture of liquid feeds would supply energy, sulfur, branched-chain volatile fatty acids, peptides and amino acids. It has been suggested that in order to maximize ruminal microbial protein production the ruminal digestion of carbohydrate and protein must be synchronized (10). Clark and co-workers reported that the amount of microbial protein (lbs/day) produced in the rumen was a function of the amount of organic matter digested (lbs/day) in the rumen (11). The greatest microbial growth as measured by microbial protein yield occurred when 25 pounds of organic matter was digested in the rumen. Hoover and Miller (12) have suggested guidelines for dairy rations which maximize total carbohydrates fermented in the rumen without depressing feed intake and fiber (NDF) digestion. *These guidelines are summarized in Figure 3.*

FIGURE 3. Guidelines to Maximize Microbial Growth and Protein Production

1. *Ruminal protein and carbohydrate digestion should provide a continuous supply of nitrogen and energy to the microbes.*
2. *Rate of carbohydrate digestion should not depress rumen pH.*
3. *Digestion of carbohydrates must continue at moderately low rumen pH (6.0-6.2).*
4. *Maximum level of sugars and starches should not exceed 30% of ration DM.*
5. *Ration NDF should not exceed 32% and ration NSC should fall between 35% and 40%.*
6. *Rumen degradable protein should be 11-12% of diet dry matter.*

Feeding trials, where molasses or molasses based liquid supplements have been used at high inclusion rates have violated guidelines 1,2 and/or or 3 listed above (16, 34, 35). Many of those trials fed molasses or molasses based liquid supplements at 12% of the diet dry matter or greater. They concluded that molasses depressed rumen pH, forage fiber digestion and forage dry matter intake. The remainder of this paper will address how sugar and molasses impact ruminal fermentation and how to use molasses and sugar in feeding programs which fit into the guidelines proposed by Hoover and Miller.

Impact of Sugar and Molasses on Rumen Fermentation

Morrison recognized that the value of molasses and sugar for livestock feeding varied with the amount fed and the type of ration. He listed three estimated energy values for molasses depending upon ration quality and amount fed (13). His assumptions were accurate based on recent feeding trials. When compared with barley as a supplement to grass silage - fed steers, molasses was used more efficiently than barley when fed at 20% of diet dry matter but its relative energy value declined as the feeding level was increased to 33% of diet dry matter (14). Petit and co-workers (15) observed that with grass silage - fed steers, molasses was used more efficiently for growth when fed at 6.6 % of diet dry matter versus 13.3% of diet dry matter. In their feeding trial, molasses was used more efficiently when fed with canola meal which supplied rumen degradable peptides and amino acids. These results support the predictions of the CNCPS. The CNCPS would predict greater ruminal microbial protein production when grass silage is fed with molasses and canola meal compared to molasses alone. The relatively insufficient use of molasses when fed at high inclusion rates in the diet may reflect differences in rumen pH, fiber digestion and end products of rumen fermentation .

The impact of sugar and molasses on rumen pH, total volatile fatty acid production and the proportion of acetate, propionate and butyrate depends upon the amount of sugar or molasses fed in the diet and the amount and type of forage. When molasses or sucrose was fed at greater than 15% of the diet dry matter, rumen pH was depressed rapidly (within 1hr.) after feeding and remained depressed for up to 4 hours after feeding (16,17). This depression of rumen pH by feeding molasses or sucrose was not seen in trials where molasses or sucrose was fed at levels below 12% of the diet dry matter (18,19,20). The effect of sugar or molasses on VFA production follows the same trend observed with rumen pH. In trials where sugar or molasses made up more than 15% of the diet dry matter, the molar proportions of butyrate and propionate were increased while acetate was decreased (16,17). Other trials report no effect of sugar or molasses on the proportion of VFA in the rumen (18,19,20). In one study the effect of molasses on ruminal VFA patterns was dose dependent. When molasses was fed at 6% of the diet there was no effect on VFA production but when fed at 18% of the diet, butyrate concentration was increased significantly (21). Total VFA production in the rumen is usually not increased significantly when molasses or sugar is substituted for barley or corn (16, 17, 18, 20). There have been exceptions to this trend. When dextrose replaced part of the barley in a TMR containing 75% forage, total VFA concentration was increased from 82.4 mM on the control diet to 91.2 mM on the dextrose diet (23). Both the control diet and the dextrose diet contained 75% forage. The control diet contained 10% barley and the dextrose diet contained 4% barley and 6% dextrose. In the same trial the concentration of VFA was not different between the dextrose diet (91.2 mM) and a high starch TMR diet (90.5 mM). The high starch diet contained 48% forage and 40% barley. These observations suggest that in certain situations where rumen fermentable carbohydrate may be limiting, supplementation of diets with feeds containing sugar can increase ruminal fermentation.

The effect of molasses or sugar on ruminal VFA concentration is directly related to the effect of those carbohydrates on ruminal organic matter and fiber (NDF) digestion. In trials where ruminal organic matter digestion was increased and fiber digestion not depressed molasses or sugar supplementation increased total VFA concentration in the rumen (23). Some trials have reported increases in ruminal dry matter or organic matter digestion and decreased ruminal fiber digestion with sucrose or molasses supplementation. The net result in these trials was that total VFA concentration was unchanged when molasses or sucrose replaced corn or barley (17, 18, 20). When liquid supplements containing molasses and fat have been used to replace corn there was a slight reduction in total VFA but this reduction was not significant (19). This can be explained by the addition of fat to the liquid supplement. Fat does not contribute to the supply of energy available to the rumen bacteria and would not increase VFA production. Maiga and coworkers (19) replaced 3.6 pounds of corn with 4.5 pounds of molasses containing fat. Based on total ruminal VFA concentration (table 1.), the amount of rumen fermentable carbohydrate was similar between the two carbohydrate sources. In contrast when 3 pounds of corn was replaced by 2.9 pounds of dry whey and fat in the same trial there was a significant decrease in total VFA concentration (table 1.). This suggests that dried whey and fat supplied less rumen fermentable carbohydrate than molasses with fat or corn. *Results from selected trials are presented in Table 1.*

Impact of Sugar or Molasses on Microbial Protein Production

Supplementation of grass silage-based diets with a source of readily available carbohydrate (sugar) has been found to increase the flow of microbial protein to the small intestine (22, 25, 26). These three trials were published between 1985 and 1987 and generated a great deal of interest in the role of sugar in stimulating rumen fermentation. Feed intake was restricted in these 3 trials and sugar was infused directly into the rumen. The increase in the flow of microbial protein when sugar was fed is not surprising. The grass silage fed in these trials contained significant amounts of rumen degradable protein. The fermentation of this type of silage in the rumen would lead to elevated concentrations of rumen ammonia. In order for the rumen bacteria to capture this ammonia, they need a supply of rapidly fermentable carbohydrate. The sugars infused into the rumen stimulated microbial growth which resulted in an increase in microbial protein. Direct evidence for increased capture of rumen ammonia by the rumen bacteria is that in all 3 trials rumen ammonia concentration was decreased when sugar supplements were included in the diet (22, 25, 26).

Since 1987 there have been 4 digestion trials which have examined the effect of sugar or molasses on nitrogen flow from the rumen to the intestine. *These trials are summarized in Table 2.* In all the trials, feeding sugar or molasses along with barley or beet pulp increased the supply of bacterial protein (17, 20, 23, 24). The increase in microbial protein was greatest when the soluble carbohydrate was fed in combination with casein, or soybean meal or sodium bicarbonate (17, 24). This would be expected because the casein and soybean meal would provide amino acids and peptides to the rumen bacteria and sodium bicarbonate would increase liquid turnover rate in the rumen. The impact of molasses or sugar on microbial growth may depend on the level of feed intake. Petit and co-workers observed that under ad libitum feeding, molasses supplementation did not change nitrogen retention in steers fed timothy silage (18). They concluded based on nitrogen balance that the utilization of nitrogen was not improved by molasses supplementation. Nitrogen balance may not be the most sensitive method to determine if dietary treatments are affecting nitrogen utilization in the rumen. They observed that supplementing grass silage based diets with molasses significantly decreased rumen ammonia concentration (10 .2 mg% versus 6.4 mg%) and decreased the rumen concentration of the branched-chain VFA, isobutyrate and isovalerate. When Petit and coworkers supplemented grass silage with molasses and canola meal, rumen ammonia concentrations were decreased (10.2 mg% versus 7.64 mg%) and isobutyrate and isovalerate concentrations were decreased compared to grass silage alone (18). Branched- chain VFA are required by the fiber digesting cellulolytic bacteria for growth (27). One explanation for the decreased ruminal concentrations of ammonia and branched-chain VFA is that microbial growth rates were increased due to molasses supplementation. Faster growing microbes would utilize more rumen ammonia and branched-chain VFA thereby decreasing their concentration in the rumen.

Impact of Sugar or Molasses on Animal Performance

Dairy Diets

Animal performance when diets are supplemented with sugar or molasses will depend upon the amount and type of forage in the diet. Under ad libitum feeding conditions when a liquid supplement containing molasses and fat replaced corn in a TMR containing corn silage and alfalfa hay, dry matter intake and milk production was increased (19). The efficiency of milk production expressed as pounds of milk produced per pound of dry matter intake was not different among the treatments. In this trial, molasses and fat could replace corn and corn plus fat without decreasing milk yield, milk fat or the efficiency of milk production. This suggests that the energy in a liquid supplement containing molasses and fat was used as efficiently as energy supplied by a combination of ground corn and fat. In a recently completed trial, a liquid supplement containing molasses and fat when fed with roasted soybeans was able to replace a combination of corn, roasted soybeans and tallow (28). The efficiency of milk production was 3.7% greater when part of the corn in the ration was replaced by molasses, fat and roasted soybeans. This increase in efficiency was due to the feeding of fat as all diets were isonitrogenous. In this trial, the energy from molasses and fat was used as efficiently as the energy from corn plus tallow.

Cows in early lactation appear to respond to sugar supplementation. When sucrose was added to a TMR containing alfalfa haylage and corn silage, dry matter intake was not changed but milk production was increased 2 pounds/cow/day (29). This resulted in a 3.25% increase in the efficiency of milk production. Morales and coworkers (30) reported that the response to molasses supplementation was influenced by the type and amount of forage in the diet. When the forage source was alfalfa haylage (65% of diet DM), molasses was used as efficiently as corn for milk production when fed at 4% of the diet dry matter (table 3.). When the forage source was a combination of alfalfa haylage and cottonseed hulls, molasses was not used as efficiently as corn for milk production when fed at 4% of diet dry matter. *Results from selected trials are presented in Table 3.*

Feedlot Diets

On low forage, high energy, finishing diets for beef steers, molasses or molasses and fat can replace a portion of the corn in the diet without decreasing performance (31, 32). Dry matter intake, average daily gain and feed efficiency were increased when molasses or molasses and fat replaced a portion of the corn in feedlot finishing diets. A liquid supplement containing molasses and fat was used as efficiently for growth compared to a combination of corn and fat (31). Feed efficiency expressed as feed intake divided by ADG was not different for molasses with fat or corn with fat (table 4.). Response of feedlot steers to molasses supplementation is influenced by the protein source fed in combination with the molasses. Feed efficiency and ADG were greater when molasses was fed with soybean meal and urea compared to urea alone (33).

Summary

Animal performance and rumen fermentation data collected with dairy and beef cattle suggest that at low levels of inclusion in the diet, molasses and sugar can be used to replace corn or barley without detrimental effects. Rumen pH and VFA measurements indicate that when fed at less than 10% of ration dry matter or 2.5 lbs dry matter , molasses will not alter rumen pH or VFA proportions. At higher feeding rates (15% of diet DM) molasses may depress rumen pH and increase the concentration butyrate in the rumen. This may be related to the sugar content of molasses. Feeding 2.2 lbs of supplemental sugar dry matter per day has depressed forage fiber digestion but feeding less than 1 pound of supplemental sugar increased NDF digestion rate. In certain situations molasses or sugar were superior to barley in stimulating microbial protein production. When diets contain significant amounts of NPN or soluble true protein from ensiled forages, molasses or sugar may reduce ruminal ammonia concentration and increase the supply of microbial protein.

The value of molasses or sugar for meat or milk production will depend on the amount and quality of protein and forage in the diet . When molasses or sugar are fed with protein sources which supply amino acids or peptides to rumen bacteria, they will support higher levels of performance compared to molasses alone or molasses and urea combinations. When molasses or sugar are fed in diets with adequate effective fiber or buffers, they can replace corn or barley and will not depress feed intake. The CNCPS predicts that molasses will increase the amount of microbial protein produced in the rumen as long as rumen pH is maintained above 6.2 (Table 5). The CNCPS and in vivo data indicate that molasses may be superior to barley in increasing the supply of microbial protein reaching the duodenum when ruminal ammonia concentration is not limiting (Table 5).

It appears that molasses and fat combinations can be used as efficiently as corn and fat combinations for meat and milk production. Additional work is needed to evaluate molasses or molasses and fat on diets containing corn silage as the major forage. When alfalfa haylage or grass silage is the major forage in the diet, it appears that molasses can replace corn or barley. The key to successful substitution will be to make sure that molasses maintains or increases dry matter intake. If molasses is fed at a level in the diet that depresses feed intake, animal performance may be depressed. Molasses and sugar may play a role in the synchronization of protein and carbohydrate digestion in the rumen. Computer models like the CNCPS can help predict animal response to molasses and sugar supplementation.

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TABLE 1 EFFECT OF SUGAR AND MOLASSES ON RUMEN PH AND VFA PRODUCTION

REFERENCE	ANIMAL TYPE	FORAGE SOURCE	LEVEL OF INTAKE	TYPE AND AMOUNT OF CARBOHYDRATE FED/DAY, DM BASIS	RUMEN PH	ACETATE %	PROPIONATE %	BUTYRATE %	VALERATE %	TOTAL VFA MMOL/L/D
Moloney Etal 1995	Steers	Grass Silage	Ad libitum	Barley 10.6 lbs.	6.94	66.50	15.80	14.00	3.29	71.20
				Molasses 10 lbs.	6.86	58.40	16.60	23.00	2.02	71.70
Petit Etal 1994	Steers	Grass Silage	Ad libitum	No Supplement	6.59	70.80	17.00	8.70	1.14	100.00
				Molasses, 1.15 lbs.	6.52	71.20	17.10	8.90	0.96	103.00
				Molasses, 2.5 lbs.	6.50	70.80	17.50	9.10	0.97	101.00
				Molasses + Canola Meal (1.15 lbs. + .83 lb.)	6.50	71.50	16.80	8.90	0.98	106.50
				Molasses + Canola Meal (2.5 lbs. + .60 lb.)	6.47	70.70	17.50	9.20	0.95	103.00
Khalih & Huhtanen 1991	Dairy Steers	Grass Silage	Restricted	Barley, 2.75 lbs.	6.28	63.60	17.80	14.90	1.48	105.00
				Barley + Sucrose (2.75 lbs. + 2.2 lbs.)	6.03	58.90	16.50	19.70	2.35	104.00
				Barley + Surcose + Buffer (2.75 lbs. + 2.2 lbs.)	6.24	62.10	18.90	15.70	1.54	114.00
Huhtanen 1988	Dairy Steers	Grass Silage	Restricted	Barley, 6.1 lbs.	6.33	65.20	15.50	16.10	1.39	98.00
				Barley + Molasses (4.1 lbs. + 2.1 lbs.)	6.21	62.00	17.10	17.90	1.46	100.00
				Beet Pulp, 6.1 lbs.	6.40	67.60	17.50	12.80	1.17	100.50
				Beet Pulp + Molasses (4.1 lbs. + 2.1 lbs.)	6.45	65.50	18.50	13.70	1.19	93.00
Maiga Etal 1995	Dairy Cows	Corn Silage & Alfalfa Hay	Ad libitum	Corn, 15 lbs.	6.71	60.10	23.40	12.80	1.20	99.50
				Corn + Molasses + Fat (11.4 lbs. + 4.5 lbs.)	6.68	60.80	22.90	13.20	1.00	96.80
				Corn + Dried Whey + Fat (12 + 2.9 lbs.)	6.85	61.40	22.40	12.90	1.10	88.90
Wing Etal 1988	Dairy Cows	Cottonseed Hulls	Ad libitum	Corn, 19.4 lbs.	5.95	57.50	25.80	16.70	NA	NA
				Corn + Citrus Molasses Solubles (6%) (17.4 lbs. + 1.9 lbs.)	5.83	58.00	25.90	16.10	NA	NA
				Corn + Citrus Molasses Solubles (12%) (15.4 lbs. + 3.7 lbs.)	6.05	60.20	22.70	17.00	NA	NA
				Corn + Citrus Molasses Solubles (18%) (13.4 lbs.+ 5.6 lbs.)	6.19	61.50	19.10	19.30	NA	NA

NA = Data not reported in published paper

TABLE 2 EFFECT OF CARBOHYDRATE SOURCE ON MICROBIAL PROTEIN PRODUCTION

REFERENCE	ANIMAL TYPE	FORAGE SOURCE	LEVEL OF INTAKE	TYPE AND AMOUNT OF CARBOHYDRATE FED/DAY, DM BASIS	TOTAL NITROGEN FLOW TO DUODENUM G/DAY	BACTERIAL NITROGEN G/DAY	NON-NH3 NITROGEN G/DAY	BACTERIAL GROWTH EFFICIENCY G/KG OMD
Khalih and Huhtanen 1991	Dairy Steers	Grass Silage	Restricted	Barley, 2.75 lbs.	140.60	71.80	135.30	25.50
				Barley + Sucrose (2.75 lbs. + 2.2 lbs.)	165.70	89.80	162.20	27.60
				Barley + Surcose + Buffer (2.75 lbs. + 2.2 lbs.)	158.60	93.80	155.50	26.40
Piwonka & Firkins 1993	Dairy Heifers	Corn Silage Orchard Grass Hay	Restricted (1.8% BWT)	Barley, 10% of DM	125.10	64.00	NA	22.80
				Barley + Dextrose (4.4% + 6% of DM)	137.90	74.20	NA	23.80
Rooke and Armstrong 1989	Dairy Cows (non-lactating)	Grass Silage	Restricted	Sucrose, 2.1 lbs.	135.00	105.00	120.00	NA
				Sucrose + Urea (2.2 lbs.)	148.00	108.00	128.00	34.00
				Sucrose + Casein (2.15 lbs.)	158.00	126.00	142.00	29.00
				Sucrose + Soybean (2.15 lbs.) Meal	142.00	112.00	127.00	30.00
Huhtanen 1988	Dairy Steers	Grass Silage	Restricted	Barley, 6.1 lbs.	107.00	71.00	104.00	26.60
				Barley + Molasses (4.1 lbs. + 2.1 lbs.)	118.00	74.00	113.00	27.40
				Beet Pulp, 6.1 lbs.	114.00	60.40	111.00	24.50
				Beet Pulp + Molasses (4.1 lbs. + 2.1 lbs.)	125.00	75.50	121.00	30.20

NA = Data not reported in published

TABLE 3 IMPACT OF SUGAR OR MOLASSES ON ANIMAL PERFORMANCE: LACTATING DAIRY COWS

REFERENCE	ANIMAL TYPE	FORAGE SOURCE	LEVEL OF INTAKE	TYPE AND AMOUNT OF CARBOHYDRATE FED/DAY, DM BASIS	DRY MATTER INTAKE LBS./DAY	MILK YIELD LBS./DAY	EFFICIENCY MILK/DMI	MILK FAT %	MILK PROTEIN %
Maiga Etal 1995	Dairy Cows	Corn Silage Alfalfa Hay	Ad libitum	Corn, 15 lbs.	51.00	70.30	1.38	3.48	3.00
				Corn + Molasses + Fat (11.4 lbs. + 4.5 lbs.)	54.00	74.20	1.37	3.52	2.91
				Corn + Dried Whey + Fat (12 lbs. + 2.9 lbs.)	54.00	74.90	1.39	3.40	2.86
				Corn + Fat (14.5 lbs. + 1 lb.)	53.50	74.20	1.39	3.65	2.98
Morales Etal 1989	Dairy Cows	Alfalfa Haylage (35%) Cottonseed (14%) Hulls	Ad libitum	Corn, 16.6 lbs.	54.00	58.60	1.09	3.58	3.23
				Corn + Molasses (4%) (13.7 lbs. + 2.1 lbs.)	52.80	54.00	1.02	3.42	3.17
				Corn + Molasses (8%) (10.4 lbs. + 4 lbs.)	50.00	56.60	1.13	3.50	3.08
		Alfalfa Haylage (65%)	Ad libitum	Corn, 9.1 lbs.	45.40	52.70	1.16	3.46	3.17
				Corn + Molasses (4%) (6.6 lbs. + 1.8 lbs.)	44.50	51.60	1.16	3.36	3.29
				Corn + Molasses (8%) (4.6 lbs. + 3.9 lbs.)	48.50	52.70	1.09	3.36	3.07
Nombekela Etal 1995	Dairy Cows (Holsteins & Jerseys)	Alfalfa (30%) Haylage Corn Silage (10%)	Ad libitum	Corn, 16.7 lbs.	42.00	62.60	1.49	3.40	3.51
				Corn + Sucrose (16.1 lbs. + .63 lb.)	42.00	64.60	1.54	3.30	3.28
Firkins 1996 (unpublished data)	Dairy Cows	Corn Silage (25%) Alfalfa (25%) Haylage	Ad libitum	Corn, 13.7 lbs.	49.80	78.70	1.58	3.62	3.16
				Corn + Molasses + Fat (10.2 lbs. + 2.6 lbs.)	50.20	82.10	1.64	3.59	2.98
				Corn + Roasted Beans (12.7 lbs. + 4.2 lbs.)	50.00	80.70	1.61	3.41	3.10
				Corn + Fat + Roasted Beans (11.9 lbs. + .76 lb. + 4.2 lbs.)	50.70	83.40	1.64	3.77	3.04

NA = Data not reported in published paper

TABLE 4 IMPACT OF SUGAR OR MOLASSES ON ANIMAL PERFORMANCE: BEEF CATTLE

REFERENCE	ANIMAL TYPE	FORAGE SOURCE	INTAKE LEVEL DIET	TYPE AND AMOUNT OF CARBOHYDRATE FED/DAY, DM BASIS	DRY MATTER INTAKE LBS./DAY	ADG LBS./DAY	EFFICIENCY FEED/ADG
Rush Etal. 1995	Steers (Finishing Phase)	Corn Silage (10% of diet)	Ad Libitum	Corn, 20.5 lbs.	24.40	3.89	6.27
				Corn + Molasses + Fat (20.3 lbs. + 1.24 lbs.)	25.30	4.14	6.11
				Corn + Fat (20.9 + 2.8 lbs.)	25.20	4.10	6.15
Petit Etal. 1994	Steers (Growth Phase)	Timothy Silage (83-100% of diet)	Ad libitum	Silage Only	14.40	1.26	11.40
				Silage + Molasses (7.5%) (1.1 lbs. Molasses)	16.50	1.45	11.40
				Silage + Molasses (7.5%) + Canola Meal (1.2 lbs. Molasses)	18.70	2.40	7.80
				Silage + Molasses (15%) (2.3 lbs. Molasses)	17.20	1.45	11.90
				Silage + Molasses (15%) + Canola Meal (2.5 lbs. molasses)	19.00	2.09	9.10
				Silage + Canola Meal (1.28 lbs.)	19.50	2.40	8.10
Pritchard Etal 1995	Steers	Hay (8% of diet)	Ad libitum	Molasses + Urea (Diets 1 & 3)	22.10	4.21	5.25
				Molasses, Urea + Animal Protein (Diets 6 & 7)	21.90	4.29	5.11
				Molasses, Urea + Soybean Meal (Diets 2, 4, 5, 8)	22.50	4.38	5.12
Pritchard 1993	Steers	Oat Silage (10% of diet)	Ad libitum	Corn	22.42	3.89	5.78
				Corn + Molasses	23.41	4.11	5.71
				Corn + Molasses + Fat	23.41	4.23	5.57

Table 5. Effect of Molasses on Rumen Fermentation as Predicted by the Cornell Net Carbohydrate and Protein Model

Ration Ingredients	Ration 1 lbs/day, As Fed	Ration 2 lbs/day, As Fed	Ration 3 lbs/day, As Fed	Ration 4 lbs/day, As Fed	Ration 5 lbs/day As Fed	Ration 6 lbs/day As fed
Hay	0	0	2.5	2.5	4	5.5
Corn Silage	42	40	37	37	35	31
Alfalfa Haylage	14	16	38	38	14	14
Ground Corn	14	13	13.6	13.6	0	0
HMS Corn	0	0	0	0	12	12
Barley	1.2	1.2	0	0	6	5
Whole Cottonseed	3	0	3.6	3.6	0	0
Soybean Meal	5	5	5	3	5	5
Distillers Grains	2	2	3.2	5	3.75	3.75
Protein Premix	1.5	1.5	3.6	2.5	0.5	0.25
Cane Molasses	**0**	**2**	**0**	**2.5**	**0**	**1.75**
Tallow	0.5	0.5	0.2	0.2	0	0
Min./Vit. Supplement	1	0.75	1	0.75	1	1
Microbial Protein, g/d	1,495	1,577	1,413	1,441	1,477	1,488
Protein from UIP, g/d	1,207	1,221	1,221	1,255	1,093	1,077
Total Protein, g/d	2,702	2,798	2,634	2,696	2,570	2,565
ME Milk, lbs/day	87.8	91	88	91.7	80	85
MP Milk, lbs/day	85	89.7	81.3	85	80	80
Rumen pH	6.3	6.3	6.35	6.34	6.42	6.4
Predicted MUN, %	15	15	17	15	15	14

All rations exceeded the CNCPS recommendations for effective fiber, measured as pounds of effective NDF. All rations met or exceeded NRC recommendations for crude protein, ADF, NDF and NEL. Total NSC concentrations in all rations were between 38 and 40% of total carbohydrate. The DIP concentrations in all rations were between 62 and 65% of total crude protein. Actual results may differ from model predictions because model was not set up to consider increases in dry matter intake due to improved ration palatability.