MOLASSES IN BEEF NUTRITION

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INTRODUCTION

The most recent comprehensive literature review on the feeding of molasses to beef cattle was an annotated bibliography by Scott in 1953. During the last 30 years a large quantity of information has been published on the use of molasses in cattle diets. It includes fundamental data obtained with new research techniques which give a better understanding of the metabolism of molasses in the rumen, and feeding trial data which have better identified the response of cattle fed diets containing molasses.

Also, recent developments have completely revolutionized beef cattle feeding. The use of formulated liquid feeds, non-protein nitrogen and high-concentrate finishing diets are major feeding practices fully developed over the last three decades and often involve the use of molasses. During this same period, previously untried methods using molasses as the major energy ingredient in diets for growing and fattening beef cattle have been developed and evaluated.

EFFECT OF MOLASSES ON RUMEN METABOLISM

Rumen Microorganisms

In 1945, Bortree et al., reported that the addition of 1.3 kg daily of glucose to the diet of cattle fed hay increased the number of bacteria in rumen contents about 100%. The addition of a similar quantity of starch did not change the number of bacteria from that obtained with hay alone. Later, Foreman and Herman (1953) found that gradient feedings of 0 to 3.6 kg of cane molasses daily (up to 35% of the diet) to cows fed a hay diet linearly increased the number of bacteria from 60 to 115 billion per ml of rumen contents. The two predominant bacteria types were single cocci and short rods, both of, which increased with increasing levels of molasses. The short rod shaped bacteria were acknowledged as being capable of digesting cellulose, but it was noted that cellulose digestion was reduced in diets containing the higher levels of molasses. Possibly this general classification of bacteria by shape was too broad since it has been- shown that the supplementation of corn stalk diets with increasing levels of corn grain reduced the number of cellulytic bacteria in the rumen to an extent which was correlated with the decrease in mass of cellulose digested (Henning et al., 1980) Foreman and Herman (1953), reported that protozoa (ciliates) numbers decreased from approximately 320 to 158 thousand per ml of rumen contents when the level of molasses was increased from 0 to 20% of the diet, but then increased to 323,000 per ml when the level of molasses was further increased to 35% of the diet.

Cuban workers (Preston et al., 1967b; Elias et al., 1968; Martin et al., 1968; Preston et al., 1968; Elias et al., 1967; 1969; Elias and Preston 1969) studied the microbial population in the rumen contents of cattle fed high-molasses diets and found bacterial numbers in the range of 80 to 160 billion per ml of rumen contents. The predominant protozoa were flagellates (200 to 500 thousand per ml) and the ciliate *Endodinium* (60 to 460 thousand per ml). Smaller numbers of other ciliates, *Epidinium*, *Eudiplodinium*, *Isotricha*, and *Ostracodinium*, were also identified.

Studying only rumen protozoa, Silvestre et al. (1977) did not observe a consistent trend in the total protozoal population (measured by packed cell volume) or the numbers of *Holotrichs*

(175,000 per ml) or *Endodinia* (34,000 per ml) in the rumen fluid of cattle fed sugar cane based diets containing from 10 to 50% molasses. Likewise, Bond et al., (1962) did not find a consistent difference in the numbers or types of ciliates in the rumen contents of steers fed high energy diets containing either sucrose or starch.

Elias (1978) isolated 169 strains of anaerobic gram positive bacteria classified into four different groups from the rumen of cattle fed a high-molasses diet. The bacteria were different from those originating from traditional diets, but the data presented did not suggest any specific relationships between these bacteria groups and the unique metabolism known to occur with molasses based diets.

Preston (1982) referred to several studies which identified what appeared to be a sizeable population of Methanosarcina bakerii in the rumen of cattle and sheep fed molasses diets. This bacteria, by way of secondary fermentation, is capable of transforming acetate to methane and carbon dioxide. In sheep fed a molasses based diet, up to 14% of the ruminal acetate was apparently oxidized when this organism was present in large numbers.

A somewhat different microbial population would be expected in the rumen of cattle fed diets containing molasses in view of the ruminal VFA pattern observed (to be discussed later) and the substrate specific requirements of different rumen microorganisms (Hungate, 1966). The data available are too limited to really determine if this is, in fact, the case. Additional investigations are needed which compare different types of diets to those containing molasses, with a thorough identification of the microbial population.

Rumen Volatile Fatty Acids (VFA) and pH

Belasco (1956) reported that quantities of dextrose added to an artificial rumen medium of cellulose and urea resulted in a substantial increase in the molar percentage of butyric acid, a reduction in the percentage of acetic acid, and a slight decrease in the percentage of propionic acid. These changes in VFA composition were very different from that obtained when starch was added to the medium, which resulted in an increase in the molar percentage of propionic acid at the expense of a reduction in the percentage of acetic acid, with very little change in the percentage of butyric acid (Table 1). In subsequent studies on intraruminal administration of glycogenic materials, Waldo and Schultz (1960) noted that dosages of sucrose resulted in a much lower level of acetic acid and higher level of butyric acid than would normally be observed in the rumen if cattle had been feed the forage used without sucrose (Table 1).

Sutton (1968) reported a similar response when glucose and fructose were infused into the rumen of cows given a meadow hay diet, but not with xylose and arabinose as the infused sugars. When cows were fed a flaked corn diet (Sutton, 1969), glucose and fructose infusions increased the molar percentage of butyric acid, but glucose reduced the percentage of acetic acid while fructose reduced propionic acid. Additions of the five carbon sugars reduced the percentage of butyric acid and increased propionic acid (Table 1). The results of the above studies with pure sugars suggest that the feeding of molasses to cattle could affect the VFA pattern in the rumen.

Table 1. The Effect of Feeding Sugars or Molasses on Rumen Volatile Fatty Acids and pH

Reference and Treatment	Acetic Acid	Propionic Acid	Butyric Acid	Total VFA mM/ℓ	pH
	------------molar percent-----------				
Belasco (1956)					
(in vitro studies)					
Cellulose-starch (1:1)	50.6	44.3	4.2	204.8	---
Cellulose-glucose (1:1)	38.9	37.0	16.6	140.3	---
Waldo and Schultz (1960)					
intraruminal dosage of sucrose	49.3	26.4	24.3	---	---
Sutton (1968)					
(Ruminal infusion, 200 g/h, hay diet)					
Control	70.7	17.5	9.5	66.9	6.4
Glucose	57.1	21.9	18.8	81.4	6.1
Fructose	58.8	21.6	17.5	78.4	6.0
Xylose or Arabinose	66.7	22.8	9.1	79.2	6.0
Sutton (1969)					
(Ruminal infusion, 200 g/h, flaked corn diet)					
Control	52.6	29.2	12.7	62.5	6.6
Glucose	45.8	31.3	17.2	86.4	6.2
Fructose	49.9	22.7	20.3	68.8	6.0
Xylose or Arabinose	49.5	40.7	5.9	85.2	6.0
Martin and Wing (1966)					
(Molasses subst. for corn)					
Control	62.2	20.7	12.9	---	6.5
4.2% molasses	63.5	19.6	12.8	---	6.6
8.4% molasses	63.1	19.9	13.1	---	6.6
12.6% molasses	63.3	19.4	13.1	---	6.7
Owen et al., (1967)					
(Sucrose subst. for corn)					
Control	56.5	24.8	18.7	113.0	6.7
6% sucrose	53.6	26.7	19.7	106.0	7.0

Table 1. (Continued)

Reference and Treatment	Acetic Acid	Propionic Acid	Butyric Acid	Total VFA mM/ℓ	pH
	------------molar percent-----------				
Kellogg and Owen (1969) (Sucrose subst. for corn)					
Control	52.0	24.0	16.0	NE[a]	NE
3% sucrose	53.5	19.5	19.0	NE	NE
6% sucrose	52.0	22.0	19.0	NE	NE
9% sucrose	53.5	19.0	22.5	NE	NE
Batch and Beeson (1972) (High grain fattening diet)					
Control	58.8	22.0	11.3	85.7	6.6
5% molasses	56.3	22.5	8.1	88.4	6.6
10% molasses	63.0	20.1	13.6	99.2	6.5
15% molasses	56.6	17.9	14.5	90.4	6.6
Marty and Preston (1970)b (Fattening bulls)					
Alfalfa	74.0	18.0	8.0	107.0	---
High grain	39.0	40.0	21.0	115.0	---
77% molasses	31.0	19.0	41.0	143.0	---
Reyes (1974)					
Napiergrass	61.4	25.9	4.9	NE[a]	NE
+1.5 kg molasses daily	60.4	24.8	10.6	NE	NE
+3.0 kg molasses daily	62.1	20.1	15.8	NE	NE
+4.5 kg molasses daily	60.1	22.2	12.7	NE	NE
Olbrich and Wayman (1972)					
60% corn - 0% sugar	48.9	33.3	14.2	---	6.7
40% corn - 16% sugar	46.2	30.9	15.5	---	6.8
20% corn - 32% sugar	46.7	28.4	15.9	---	7.0
0% corn - 48% sugar	42.9	21.4	24.9	---	6.7
55% molasses- 0% sugar	49.2	19.9	26.0	---	6.8
37% molasses-16% sugar	44.4	19.2	29.6	---	6.8
18% molasses-32% sugar	49.6	19.0	24.1	---	6.8
Pierson and Otterby (1971)					
Alfalfa Hay	57.1	35.3	7.6	---	---
+2.3 kg sucrose daily	50.1	26.9	13.0	---	---
+4.1 kg sucrose daily	53.0	28.7	18.2	---	---
+5.1 kg sucrose daily	45.6	35.7	18.8	---	---

Table 1. (Continued)

Reference and Treatment	Acetic Acid	Propionic Acid	Butyric Acid	Total VFA mM/ℓ	pH
	------------- molar percent	------------			
Silvestre et al., (1977)					
(Sugarcane based diets)					
11% molasses	48.2	35.8	16.0	---	---
50% molasses	51.9	23.3	24.9	---	---
Seibert (1978)					
(Bagasse based diets)					
36% corn meal	67.0	17.2	14.4	76.7	6.9
37% soybean hulls	69.6	18.5	10.4	78.9	7.0
38% raw sugar	52.8	20.5	24.1	75.1	6.9
Chappell and Fontenot (1968)					
(cellulose based diets fed to sheep)					
0% glucose-starch	57.1	35.3	7. 6	83.7	---
8% glucose-starch	50.1	36.9	13.0	103.9	---
16% glucose-starch	53.0	28.7	18.2	91.0	---
32% glucose-starch	45.6	35.7	18.8	116.1	---
Bowman and Huber (1967)					
Corn supplement	64.0	17.4	18.6	---	6.7
Lactose supplement	56.8	16.6	23.3	---	7.0
Rumsey et al., (1971)					
Pasture (orchard grass)	69.4	15.4	9.4	82.4	6.6
Pasture + 2kg molasses	64.6	20.0	12.4	84.3	6.4
Pasture + 2kg corn	55.3	28.8	10.4	75.8	6.4

[a] Tabular values not presented, but text indicated there was no effect (NE) of dietary treatment.

[b] Values for the molasses diets were determined during this study, but values for the alfalfa and high grain diet were taken from other sources for use as a comparison.

Martin and Wing (1966) reported similar rumen VFA patterns in the rumen of fistulated steers offered diets containing either 0, 4.2, 8.4, or 12.6% molasses (Table 1), with only a slightly lower molar percentage of isovaleric acid in the rumen fluid of steers fed all diets containing molasses. In a series of studies conducted to determine why a low level of molasses (10%) in dairy diets depressed the efficiency of milk production, Nebraska workers (Owen et al., 1967; Kellogg and Owen, 1969) reported that the addition of up to 9% sucrose in the diets of lactating cows resulted in a significant increase in the molar percentage of butyric acid in the rumen, but there were no consistent trends in the percentages of acetic or propionic acids (Table 1). Hatch and Beeson (1972) reported the same response when 15% molasses was substituted for corn in a high concentrate steer finishing diet (Table 1).

Several studies have shown that the feeding of diets containing high levels of molasses drastically altered the rumen VFA pattern (Table 1). Marty and Preston (1970) reported that the molar percentages of acetic, propionic and butyric acids were 31, 19 and 41%, respectively, in the rumen fluid of growing bulls fed a diet containing 77% molasses, which were quite different from molar proportions normally found in the rumen of cattle fed hay or grain based diets. Reyes (1974) and Silvestre et al., (1977) noted a very substantial increase in the molar percentage of butyric acid, at the expense of propionic acid, in the rumen fluid of cattle fed increasing quantities of molasses in a forage based diet. Olbrich and Wayman (1972) reported a much higher molar percentage of butyric acid in the rumen fluid of steers fed diets containing high levels of molasses in comparison to that of steers fed diets containing corn.

Similar changes in the VFA pattern occurred when increasing quantities of sucrose, glucose or lactose were added to ruminant diets (Table 1, Page 7). Pierson and Otterby (1971) reported a substantial increase in the molar percentage of butyric acid, at the expense of acetic acid, in the rumen fluid of cattle fed alfalfa hay diets containing increasing quantities of sucrose. Likewise, Seibert (1978) found that steers fed a sugar cane bagasse based diet containing 38% raw cane sugar had a higher percentage of butyric acid and a lower percentage of acetic acid than similar diets containing either corn meal or flake soybean hulls. Olbrich and Wayman (1972) also found increasing percentages of butyric and valeric acids, but at the expense of propionic, when sucrose was substituted for corn in the diet of fattening steers. A higher molar percentage of butyric acid, at the expense of acetic acid, resulted from the addition of a glucose-starch mixture (1:1) to a cellulose based diet fed to sheep (Chappel and Fontenot, 1968) or when lactose was substituted for corn meal in a supplement fed to lactating dairy cows (Bowman and Huber, 1967).

In a study with grazing steers (Rumsey et al., 1971), supplementation with molasses resulted in higher molar percentages of butyric and propionic acid and a lower percentage of acetic acid in rumen fluid, but the differences were not significant. However, the supplementation with a similar quantity of a corn-fat mixture (9:1) resulted in a significant increase in the molar percentage of propionic acid and a decrease in the percentage of acetic acid in comparison to acid concentrations in the rumen of unsupplemented steers.

Total rumen VFA concentration or pH (Table 1) did not appear to be affected by the feeding of low levels of molasses in most studies (Martin and Wing, 1966; Owen et al., 1967; Kellogg and Owen, 1969). However, the addition of up to 15% molasses to a high concentrate finishing diet did increase total VFA content of rumen fluid, but did not affect rumen pH (Hatch and Beeson, 1972). Data presented by Marty and Preston (1970) suggested that the total VFA concentration in the rumen would be higher for cattle fed high-molasses diets than for cattle fed forage or grain based diets. However, this was not confirmed by Reyes (1974) in an experiment in which increasing quantities of molasses were fed to cattle consuming a forage based diet. Sutton (1968; 1969) reported that the infusion of simple sugars into the rumen of cows fed either a hay or flaked corn diet increased the total VFA concentration and reduced pH.

In summary, the above data strongly indicates that feeding molasses to cattle increases the molar percentage of butyric acid in the rumen beyond that normally found for cattle fed forage or grain based diets. The effect this may have on nutrient utilization and animal production will be discussed in later sections on energy metabolism and metabolic problems with molasses feeding. Less apparent is the effect of feeding molasses on the other VFAs. However, it appears that the increased percentage of butyric acid is at the expense of propionic acid when molasses is substituted for grain, of at the expense of acetic acid when molasses is fed as a supplement in forage based diets. In general, the feeding of molasses does not appear to have a consistent effect on the total VFA concentration or pH of rumen contents.

Dry Matter and Fiber Digestibility

Generally, the additional of readily available carbohydrates to forage based diets increases the digestibility of the total diet dry matter because of the higher digestibility of the readily available carbohydrates ingredient, but decreases the digestibility of the forage dry matter (Burroughs et al., 1949) or the forage fiber fraction (Swift et al., 1947; Head 1953). It has been reported that the addition of sugars to forage based diets depressed fiber digestion more than does starches (Mitchell et al., 1940; Hamilton, 1942). Thus the value of supplementing ruminants fed a forage based diet with molasses could be partially negated by a reduced digestibility of the forage.

Using *in vitro* studies, Arias et al. (1951) reported that molasses stimulated cellulose digestion, and even when relatively large quantities (33 and 50% of medium) were added to the fermentation medium it did not depress cellulose digestion as happened when similar quantities of dextrose, sucrose or starch were added. In similar studies, Burroughs et al., (1950; 1951) demonstrated that molasses ash was the factor responsible for stimulating the digestibility of cellulose *in vitro* . Subsequent animal trials (Brannon et al., 1954) demonstrated that the digestibility of forage dry matter by grazing steers was noticeably reduced by molasses supplementation, and the degree of depression was related to the quantity of molasses consumed. Supporting data have been presented by Herrera et al., (1981) and Hugh-Jones and Peralta (1981). They reported that the disappearance of dry matter of low quality roughages such as sisal pulp, bagasse and sugar cane tops from nylon bags *in situ* was very negatively correlated to the level of molasses in diets fed to fistulated cattle. Likewise several studies (Johnson et al., 1942) Martin et al., 1981) have shown that the additional of molasses to forage based diets increased dry matter digestibility, but significantly depressed the digestibility of crude fiber or cellulose which indicated that the digestibility of the forage component was reduced. Studying the effect of different readily available carbohydrates ingredients on the digestibility of diets formulated with sugar cane bagasse a very poor quality roughage, Seibert (1978) found that a diet containing raw sugar (38% of the dry matter) had a slightly higher digestibility of dry matter but a significantly lower digestibility of neutral detergent fiber than a diet containing a similar quantity of corn meal. In contrast, White et al. (1973) reported that the addition of molasses (0 to 20%) to a rice straw based diet significantly increased both dry matter and crude fiber digestibility.

In a study which compared different supplements offered to heifers fed a timothy hay diet, Bohman et al. (1954) reported that a molasses supplemented diet had a slightly lower digestibility of dry matter and a much lower digestibility of crude fiber than a corn supplemented diet. However, a similar comparison made in a study with steers fed a prairie hay diet demonstrated that the digestibility of dry matter and crude fiber was only slightly lower when the diet contained 40% molasses than when the diet contained a similar quantity of corn (Bell et al., 1953).

Studying the effects of various quantities of cane molasses offered to cows fed basal diets composed of different types of roughages, Foreman and Herman (1953) found that the feeding of up to 1 kg of molasses daily tended to increase or had little effects on the digestibility of crude fiber or cellulose. The feeding of higher quantities of molasses, 2 to 3.5 kg daily, drastically reduced fiber digestibility. Although it was not very obvious from the data presented, the authors suggested that molasses tended to affect the digestibility of fiber of high quality roughages to a greater degree than it did that of low quality roughages. In contrast, other studies have indicated the opposite relationship between roughage type and molasses feeding. Herrera et al., (1981) found that while increasing poor quality roughages placed in nylon bags, it only slightly reduced the disappearance of a legume forage (*Leucaena leucocephala*). Ahmed and Kay (1975) reported that only after molasses was increased from 25% to 50% of the dry matter in a ryegrass diet was there a real effect on the digestibility of crude fiber. King et al. (1957) reported that the addition of molasses to corn silage diets did not influence the digestibility of crude fiber.

The negative effect that sugars and molasses appear to have on forage digestibility has been shown to be related to the crude protein content of the diet. Mitchell et al., (1940) showed that the negative effect of glucose supplementation on the digestibility of crude fiber in hay diets of yearling cattle was completely eliminated by increasing the protein content of the diet. Pathak and Ranjhan (1976b) found that the digestibility of crude fiber and acid detergent fiber was drastically lower in a chaffed oat/corn forage diet supplemented with molasses in comparison to a similar diet supplemented with a dry concentrate (corn, peanut meal, fish meal, wheat bran mixture). However, the addition of peanut meal or fish meal to the molasses supplemented diet significantly improved the digestibility of the fiber components. A similar response has been reported by Martin et al. (1981) when urea was added to low quality forage diet containing molasses, and by Fontenot et al. (1955) when cottonseed meal was added to prairie hay diets supplemented with cerelose. As will be discussed later, the feeding of molasses, significantly reduces the apparent digestibility of protein. In view of the above interrelationships between levels of molasses, dietary crude protein and the digestibility of fiber, the inhibition of molasses on protein metabolism apparently is occurring in the rumen.

In high concentrate steer finishing diets the addition of 5% (Owen et al., 1971) or 10% (Crawford et al., 1978) cane molasses did not significantly affect the digestibility of dry matter or fiber. However, Hatch and Beeson (1972) reported that the addition of 5, 10, and 15% cane molasses to a steer finishing diet tended to increase the digestibility of dry matter and energy. Comparing 24 and 48% molasses levels in a barley based finishing diet, Campbell et al. (1970) found a slightly lower digestibility of dry matter and a drastically lower digestibility of crude fiber in the higher molasses diet, but this diet also contained more sugar cane bagasse (7 vs 2%) which could have contributed to the lower digestibility of fiber.

From the literature available it is without question that molasses, per se, does depress the digestibility of dry matter and fiber components of forages fed to ruminants, and particularly low quality roughages. However, the degree of depression is very dependent upon the level of molasses in the diet and the crude protein balance. With a properly balanced forage based diet, molasses supplementation will increase the total dry matter digestibility and does not appear to severely depress the digestibility of fiber.

Nitrogen Metabolism

The effect of molasses feeding on dietary nitrogen (N) metabolism in ruminants is of great concern in beef production because of the extensive use of liquid supplements formulated with molasses and urea.

It has been well established that the level at which urea can be utilized in ruminant diets and the efficiently of urea utilization is very dependant on the quantity of readily fermentable carbohydrates present (Reid, 1953; Conrad and Hibbs, 1968; Helmer and Bartly, 1971; Goodrich et al., 1972). Relating to the use of molasses in diets containing urea, basic *in vitro* studies by Pearson and Smith (1943), Smith and Baker (1944), Belasco (1956) and Bloomfield et al. (1958) indicated that sugars, and particularly sucrose, were less effective than starch in promoting protein synthesis from urea.

In an animal experiment, Oltjen and Putman (1966) reported that steers fed purified diets containing 56% glucose and starch (1:1) had a slightly lower retention of urea-N than steers fed 56% starch diet, but steers fed the glucose and starch diet had a significantly higher fecal-N loss and lower urinary-N loss. Mills et al. (1944) reported that the addition of 0.9 kg per day of starch to a timothy hay diet containing 0.9 kg of corn molasses and 200 gm of urea hay increased the total quantity of protein in the rumen of the fistulated heifer and increased weight gains by growing heifers, indicating that the addition of starch stimulated protein synthesis from urea. Similarly, Rowe et al. (1980) reported that the addition of 1kg of cassava root to a molasses-urea and cassava forage diet substantially increased the quantity of microbial protein synthesized in the rumen.

Others have conducted feeding experiments to study urea-N utilization in forage based diets supplemented with either molasses or corn. Steers fed a prairie hay diet containing 40% molasses-urea had a significantly lower N retention than steers fed a diet containing corn-urea (Bell et al., 1953). A similar response was obtained with sheep fed low quality pangola digitgrass hay supplemented with 10% molasses containing corn with urea or biuret in comparison to sheep fed a dry supplement containing corn with urea or buiret (Martin et al., 1981).

The above *in vitro* and *in vivo* studies all indicated that urea-N is less efficiently utilized in forage based diets supplemented with molasses than those supplemented with starch or corn. In the data reported by Bell et al. (1953) the estimated biological value of urea-N was lower in diets containing molasses than in diets containing corn (65 vs 70%), however, the higher biological value for the corn diet could be related to by-pass corn protein. Other studies showed that the estimated biological value of urea-N was equal to soybean meal-N and superior to casein-N when fed in molasses supplemented forage diets (Johnson et al., 1942; Gallup et al., 1954). Considering that the amino acid composition of rumen microbes varies little under widely differing dietary regimes (Conrad and Hibbs, 1968), it is doubtful that the value of microbial protein derived from urea in corn supplemented diets.

Possibly the most revealing N balance data relative to molasses-urea diets is urinary-N losses. This loss was significantly higher for animals fed a molasses-urea supplement than those fed a corn-urea supplement (Bell et al., 1953; Martin et al., 1981) or animals fed a molasses-plant protein supplement (Bohman et al., 1954; King et al., 1957). If in fact, the biological value of all microbial protein is similar, these higher urinary-N loss values indicate that urea-N is less efficiently synthesized into microbial protein by cattle fed molasses-urea supplemented diets and the excess ammonia is being absorbed and excreted in the urine.

The unanswered questions is why molasses or sugars would be less affective than a starch source in promoting protein synthesis from urea-N. It has been suggested that the sugars of molasses are absorbed or degraded too rapidly (Reid, 1953), and this would appear to be compatible with the rapid hydrolysis of urea to ammonia upon entering the rumen. As previously discussed, the VFA pattern indicates that sugars were metabolized differently than starch which could have a bearing on ammonia utilization. In reporting studies on purified diets containing glucose or starch, reference was made to the lack of branched-chain fatty acids at the ruminal level and the occurrence of related amino acids in blood plasma (Oltjen and Putman, 1966). This again relates to the biological value of microbial protein which has been discounted as a factor in practical type diets (Conrad and Hibbs, 1968). Data on microbial populations in the rumen of cattle fed diets containing molasses are limited, and those presented have not indicated a possible explanation (Elias and Preston, 1969; Silvestre et al., 1977).

A number of studies have shown that molasses also significantly depressed the apparent digestibility of dietary protein (Briggs and Heller, 1943; 1945; Colovos et al., 1949; Bell et al., 1953; Foreman and Herman, 1953; Bohman et al., 1954; King et al., 1957). Even with diets in which urea supplied most of the N consumed, increasing levels of molasses in the diet reduced the apparent digestibility of dietary-N by sheep (Martin et al., 1981). It is also interesting that the apparent digestibility of urea-N (only N source) by steers fed a purified diet containing glucose and starch (1:1) was significantly lower than that by steers fed a diet containing only starch (Oltjen and Putman, 1966). The letter two studies give evidence, though limited, that the feeding of molasses or glucose reduces the digestibility of microbial protein. An explanation for this apparent reduction in the digestibility of crude protein was not ventured. One interpretation is that molasses partially inhibits the digestion of performed or microbial protein leaving the rumen. However, data presented by Hamilton (1942) indicated that the feeding of corn sugar to sheep resulted in increased metabolic-N excretion which would also explain a decrease in the apparent digestibility of dietary-N with the feeding of diets containing molasses or sugars.

The above data suggest that the feeding of moderate to high levels of molasses reduces the apparent digestibility of crude protein in the range of 5 to 15%. This presents a very interesting question relative to a practical feeding situation. Do beef cattle fed diets containing moderate to high levels of molasses require more dietary crude protein than has been recommended by the National Research Council (NRC) (1976) for cattle fed more conventional type diets? Ruiz (1977) reported that the protein required to produce 1.0 to 1.1 kg per day of gain by 300 to 400 kg young bulls fed a high-molasses diet was 0.4 to 0.5 kg daily of crude protein (fish-meal supplement) per 100 kg of liveweight, a level which is 30 to 60% above the NRC recommendation for similar size bulls making similar gains. In an optimum economic feeding system for this type animal gaining 1.04 kg daily and fed a high-molasses diet in which 45% of the dietary N is derived from urea, Ruiz recommended feeding 1.34 kg per animal per day of N x 6.25 which is approximately 20% above the NRC recommendation. In support of this recommendation the crude protein (N x 6.25) level for high-molasses diets used in a commercial feedlot system developed in Cuba is approximately 20% higher than that recommended by NRC (Munoz et al., 1970).

In high concentrate grain diets, the addition of 5% cane molasses did not significantly influence crude protein digestibility or nitrogen retention by steers (Owen et al. 1971). The addition of 10% cane molasses to a corn-peanut meal diet fed to steers tended to increase both crude protein digestibility and N retention (Crawford et al., 1978). The addition of 10 or 15%, but not 5%, cane molasses to a corn-urea (urea N 33% of total N) based steer finishing diet significantly improved N retention (Hatch and Beeson, 1972). Potter et al. (1971) found that the quantity of N reaching the abomasum of steers fed a corn meal diet containing urea was only 79% of that obtained with a diet containing soybean meal. However, the addition of 2.5% cane molasses to the urea diet increased abomasal-N flow to 92.5% of that obtained with soybean meal, but the addition of 10% molasses to this diet was of no benefit over 2.5% molasses. In steer fattening diets, Campbell et al. (1970) observed that the digestibility of crude protein and N retention was noticeably lower with a diet containing 48% molasses than that of a diet containing 24% molasses.

Wood molasses (hemicellulose extract) was reported to depress the digestibility of crude protein more than cane molasses (Colovos et al., 1949; Williams et al., 1969). Recently, Hartnell and Satter (1978) demonstrated with continuous fermentators charged with rumen ingesta that 15% more soy protein escaped degradation when treated with wood molasses than when treated with cane molasses. They reasoned that the phenolic constituents of wood molasses protected the protein from microbial degradation in the rumen which would be advantageous in terms of by-pass protein. However, when diets containing soybean meal extruded with either 10% wood molasses or cane molasses were fed to lambs there was no difference in digestibility of diet components or animal performance. Crawford et al. (1978) reported that steers fed finishing diets containing 10% wood molasses had a slightly higher digestibility of crude protein and a slightly lower N retention than steers fed a diet containing 10% cane molasses. Performance of steers fed fattening diets containing 10% (Crawford et al., 1978) or 3% (Cooper et al., 1978) of wood or cane molasses were similar.

Energy Metabolism

The National Research Council (1976) lists the metabolizable energy (ME), net energy (NE) for maintenance and NE for gain values for cane molasses s 2.75, 1.91 and 1.20 Mcal per kg of dry matter, respectively. These values are approximately 83% of respective values listed for No. 2 yellow corn. The lower energy value for molasses is partially explained by a 7 to 8% higher mineral content than that of corn. Morrison (1956) states that the value of molasses is highest when fed at less than 10% of the diet, and the energy value is reduced by as much as 30% with higher levels.

Using the comparative slaughter technique, Lofgreen and Otagaki (1960a) determined the NE value for fattening of blackstrap molasses at various levels in beef finishing diets. They reported that the NE value of molasses in a diet containing 10% molasses was similar to an estimated NE value listed by Morrison (1956), but in diets containing 25 to 40% molasses the NE value was reduced 100%. In a similar study with lactating cows (Lofgreen and Otagaki, 1960b), the NE value of blackstrap molasses for milk production was 3 times lower in a diet containing 30% molasses than its NE value in a diet containing 10% molasses.

To better define the relationship between the level of molasses in the diet and its energy value, Lofgreen (1965) conducted a second study in which beef heifers were fed diets containing 5, 10, and 20% cane molasses. In the 5, 10, and 15% diets the NE value for maintenance and NE value for gain of molasses were similar, averaging 1.93 and 1.10 Mcal per kg of molasses dry matter, respectively. These values are in close agreement with calculated values reported by NRC (1976). In the 20% diet, NE value for maintenance and NE value for gain were 10% lower, being 1.73 and 0.99 Mcal per kg of molasses dry matter respectively. It was concluded that the decline in the NE value of molasses begins with the diet of contains about 20% molasses. However, it was recognized that the decrease in the NE value of molasses observed in the 20% diet was less drastic than the decrease observed between the 10% and 25% molasses diets in the previous experiment (Lofgreen and Otagaki, 1960a).

In contrast to the above data, Preston et al. (1969) reported that the efficiently of utilization of ME for gain (energy content of empty body gain divided ME available for gain x100) was 17.5 and 29.1%, respectively, by growing bulls fed diets containing 30 or 70% molasses dry matter in addition to greenchopped corn forage or napiergrass. The lower value for the 30% diet was attributed to the overestimation of the ME values assigned to the forages used. However, it was acknowledged that the efficiently value determined for the 70% molasses diet was 60% of that expected, a discrepancy explained by the age of the animals (24 months) used in the study. It was estimated that the NE value for fattening of the 70% molasses-30% corn forage diet was 1.24 Mcal per kg of dry matter which would be close to the value calculated for this diet using figures.

Further evidence as to the energy value of molasses is offered by the studies reported by Nehring et al. (1964) on the NE value of pure sucrose, cellulose and starch. When sucrose was fed to steers as a 23% supplement to a hay, barley straw, beet pulp, barley meal and peanut meal basal diet its NE value was 16% lower than the NE value for cellulose or starch. The authors also cited a NE value for sucrose determined by Kellner in 1900 which was 26% lower than a NE determined for starch. If, in fact, the energy value of sucrose is lower than that of starch it would help explain, in conjunction with the high ash content of molasses, the 17% lower NE value assigned to molasses dry matter relative to that of corn grain (NRC, 1976).

Nehring et al. (1964) also presented data which indicated that sucrose was utilized as efficiently as starch when fed to monogastrics. Thus, any difference in the utilization of sucrose and starch by cattle must be explained by differences in their fermentation in the rumen or the efficiency of utilization of the end of products of rumen fermentation. As previously discussed, the ruminal VFA composition of animals fed molasses or sucrose diets is quite different from that of animals fed cereal grains or starch. Blaxter (1962) presented data which indicated that the relative proportions of acetic, propionic and butyric acids did not greatly affect their utilization as energy for maintenance, but their proportional relationship could be very critical in terms of their utilization as energy for fattening.

Unfortunately, most of the data available on the effect of different proportions of VFAs on energy utilization has concerned various acetic to propionic acid ratios, with higher ratios being negatively correlated to energy utilization. Specifically, energy utilization data are needed relative to low molar proportions of propionic acid and high proportions of butyric acid which has been associated with the feeding of diets containing high levels of molasses. Since butyric acid, like acetic, is not a glucose precursor a similar relationship could exist and would support the contention that the productive energy value of molasses is reduced when high levels are fed. Essig et al. (1959) found little difference in the gains of sheep fed purified diets containing various proportions of the salts of acetic, propionic and butyric acids, but none of the ratios used were similar to hat which has been identified with the feeding of high-molasses of sucrose diets.

In contrast to the data presented by Blaxter (1962), Ørskov (1978) presented data which indicated that the relative proportions of acetic to propionic acids produced in the rumen are not very critical in terms of their efficiency of utilization as energy for fattening. Ørskov's data did indicate that the production of different proportions of VFAs affect the efficiency of utilization of the carbohydrate source fed, but it was related to the conversion of carbohydrate energy to VFA energy in the rumen. Ørskov states that the most efficient capture of carbohydrate energy in the fermentation process occurs with the production of propionic acid, followed by butyric and acetic acid, respectively. Again, in relation to the VFA pattern observed the feeding of molasses or sucrose diets, Ørskov's hypothesis would explain the lower energy values of molasses (in addition to its high ash content) or sucrose in comparison to the energy values of cereal grains or starch. However, this hypothesis would not support the contention that the energy value of molasses itself is influenced by the level at which it is included in the diet.

From the above discussion it can be seen that the relative energy value of molasses is a controversial subject, particularly as related to the feeding of diets containing moderate to high levels of molasses to beef cattle. The feeding value of molasses in animal production trials will be covered in a subsequent section which should shed more light on the energy metabolism of molasses.

Metabolic Problems with Molasses Feeding

A problem often observed with the feeding of diets containing moderate to high levels of cane molasses is a loose feces which is often associated with diarrhea. Scott (1953) stated that because of this condition it is important not to set the level of molasses in the diet "too high". However, one of the studies (Barnett and Goodell, 1923) cited by Scott showed that fattening steers exhibiting this laxative effect when fed a diet high in molasses (2.4 kg per steer daily) also had the highest rate of gain.

The mineral fraction of cane molasses, and particularly the relatively high potassium (K) content (2 to 6%), has been implicated as the cause of certain digestive problems. To study this factor Briggs and Heller (1943) fed lambs a control alfalfa hay-corn grain diet and a diet in which 25% of the corn was replaced by cane molasses. In two other dietary treatments pure sucrose or K, quantities equivalent to that contained in the molasses, were individually added to the control diet. All three diets containing additives resulted in a soft feces, but scouring did not occur. This result suggested that both sugar and K contributed to the laxative property of molasses. Other results showed that molasses and sucrose additions, but not K, reduced the apparent digestibility of crude protein. In contrast, only the addition of K to the diet reduced the digestibility of crude fiber.

A review on K metabolism of ruminants did not reveal any problems caused by the feeding of diets containing high levels of K with the exception of grass tetany (Ward, 1966). Newton et al. (1972) reported that the feeding of diets containing 4.9% K, a level obtainable with a high-molasses diet, significantly reduced magnesium (Mg) absorption, but not Mg balance, and temporarily lowered blood serum concentrations of Mg. Jackson et al. (1971) reported that the feeding of cereal grain diets to lambs which contained from 0 to 3% K resulted in a significant linear decrease in energy utilization and a reduced rate of gain from 102 to 75 gm per day. The feeding of diets containing 4% as KCl to ewes did not affect ewe weights, lamb birth weights, number to lambs dropped or raised, or blood plasma levels of K, Na, Ca, Mg or P (Daniel et al., 1952).

Preston and co-workers (1967a; 1970b) observed a condition in growing cattle fed high-molasses (70-80% of DM) diets which was termed “molasses toxicity”. Affected animals exhibited accelerated breathing, lowered body temperature, pronounced weakness, a drunken appearance, a characteristic stance of crossed forelegs and a forward leaning position with their shoulders resting against corral fencing. Other clinical symptoms associated with the condition include dancing in circles, lowered head, digging into the earth and excessive salivation (Creek et al., 1974; Pathak and Ranjhan, 1976a). Originally, the problem was though to be related to a mineral imbalance, but was identified as cerebrocortical necrosis, also known as polioencephalomalacia, by Verdura and Zamora (1970). The condition did not respond to intraruminal or intramuscular administration of thiamine and common treatment for polioencephalomalacia (Losada et al., 1971), but it was prevented by oral dosages of 400 gm per day of glycerol (Gaytan et al., 1977). Although molasses toxicity does not appear to be caused by a true thiamine deficiency, Lora et al. (1978) presented data which indicated that it was not caused by a lack of glucose precursors.

Molasses toxicity appears to be precipitated by a low intake of forage in the high-molasses feeding system developed by Preston et al. (1967a). The most practical preventative measure is to assure that all animals consume enough forage, which can be a problem in this restricted forage feeding system. The most practical cure is to place the animal on *ad lib* forage feeding when the initial stages of the condition is observed, because in the advanced stages the condition is irreversible.

Molasses toxicity was also related to high levels of ketone bodies in the blood (Losada and Preston, 1974). The authors also recognized a relative high production of ketone bodies in the blood of normal animals and suggested the possibility of subclinical ketosis in all cattle fed a high-molasses diet which would be related to the animal’s incapacity to metabolize the ketone bodies derived from the higher production of butyric acid obtained with feeding of molasses-based diets.

Ruiz (1976) has shown that the feeding of high-molasses diets will cause ruminal parakeratosis, but the severity of the lesions was low in spite fo the low level of fiber in the diet, and its effect on the liveweight gain of animals was of no importance.

THE PERFORMANCE OF BEEF CATTLE FED MOLASSES

Interpretation of Data Presented

In the following presentation on the feeding of diets containing molasses two adjustments were made for certain data extracted from the literature in order to more accurately interpret the results obtained within a study, and to some extent allow a more accurate comparison of results obtained in separate studies. One adjustment was to show all diet intake data on a dry matter basis. In many studies reviewed these data were presented as such, or could be accurately calculated from dry matter values presented for the diets fed. However, in some studies dry matter intake data were calculated from as-fed diet intake values presented and logical estimates of the dry matter content of the as-fed diet. The latter values, when presented, have been properly identified along with the assumed dry matter values used.

In most of the feedlot performance data presented in this review the rate of gain data and resulting dry matter:gain ratio values were recalculated from a final liveweight based on the actual carcass weight data and a standard carcass dressing percent (final liveweight = carcass weigh ÷ standard dressing percentage x 100). In all cases the standard carcass dressing percentage used has been identified and was approximately the average dressing percentage actually obtained within a specific study. The reason for using this procedure was to standardize final liveweight to a common fill which ensures that rate of gain and feed efficiency data, assays most often used to compare the performance of cattle on different dietary treatments, were proportional to carcass gain which is the best measure of true production. The advantages and justification for using this procedure in interpreting cattle performance have been throughly discussed by Goodrich and Meiske (1971).

Close attention should be given to the carcass dressing percentages obtained in the specific experiments presented in this review because of their wide range (52 to 62%). A lower carcass dress greatly inflates real gains which is the reason for making data adjustments within an experiment. Although it is recognized that the initial condition, management, genetics, etc. of cattle used in separate studies can be very different, it is felt that rate of gain and feed efficiency data in experiments in which low carcass dressing percentages were obtained also tend to be inflated relative to rate of gain and feed efficiency data in experiments in which high dressing percentages were obtained.

Diet Intake

One of the most important characteristics of a feedstuff is its influence on diet intake because of the close positive relationship on intake to animal performance and production efficiency. The first and most recognized benefit of feeding molasses to cattle has been its ability to improve diet palatability. Data presented in the following tables (Note: tables referred to in this section are present in subsequent sections where they are discussed relative to other data.) which summarize the results of numerous feeding studies show, in most cases, that the addition of up to 10% molasses to both roughage and concentrate diets improved daily dry matter intake. Although this response has usually been attributed to improved taste or reduced diet dustiness, the previously discussed ability of low levels of molasses to increase fiber digestibility and microbial activity may be responsible.

Less known is the relationship between diets containing moderate to high levels of molasses and feed intake, and how this relationship relates to the established mechanisms known to control diet intake (Balch and Campling, 1962; Conrad et al., 1964; Conrad, 1966). Silvestre et al. (1978) conducted a study in which growing bulls were fed sugar cane based diets containing up to 41% cane molasses and found that dry matter intake increased linearly with increasing levels of molasses (Table14). A similar response was reported by James (1973) and Toranzos et al. (1975) when 43% or 30% cane molasses was added to chopped sugar cane or sorghum silage based diets, respectively (Table 12). Bond and Rumsey (1973) and Delgado et al. (1978) also reported that the *ad lib* supplementation of hay or fresh forage based diets with cane molasses (39 and 23% of diet dry matter, respectively) substantially increased daily dry matter intake (Table 12). Drannon et al. (1954) reported that the daily dry matter intake by grazing steers was increased from 6.0 kg to 6.7 kg with the *ad lib* supplementation of 1.0 to 1.5 kg per day of cane molasses. Comparing different supplements Bohman et al. (1954) and Merrill et al. (1959) observed that heifers supplemented with molasses consumed more forage dry matter and total dry matter than heifers supplemented with a similar quantity of corn. In contrast, King et al. (1960) noted no difference in the intake of oat hay by heifers fed either molasses or corn supplements. The above data on molasses feeding support the general concept that dry matter intake by cattle increases with increasing concentrations of digestible nutrients in a forage based diet.

At the opposite extreme, that is, diets with high levels of molasses and low levels of forage, the data available are very limited. Elias et al. (1969) fed growing cattle restricted quantities, of forage and cane molasses *ad lib* such that the diets contained 75 to 90% molasses-protein supplement. Data showed that with increasing levels of molasses, or decreasing levels of forage, there was a linear decrease in daily dry matter intake (Table 14). It is also interesting that daily liveweight gains of cattle fed diets containing the different levels of molasses were similar, suggesting that available energy intake was similar by steers fed each diet. In a study with *ad lib* molasses feeding, Martin et al. (1968) found daily dry matter intake by growing bulls fed a restricted forage diet which contained 85% molasses was substantially less than the intake by bulls fed the *ad lib* forage diet which contained 29% molasses. Again, these intake data of diets containing high levels of molasses support the general concepts relating to the control of diet intake that is, physiological factors limit intake of highly digestible diet even when molasses is the concentrate energy source.

Studies in which molasses is added to or substituted for concentrate ingredients in high energy fattening diets also give evidence as to the effect of molasses on feed intake. Lofgreen and Otagaki (1960a) reported that the addition of 10% cane molasses to a relatively fibrous fattening diet fed to steers increased dry matter intake, but further additions of 25 or 40% molasses drastically reduced intake (Table 3). This curvilinear relationship between the level of molasses in the diet and dry matter intake tended to be confirmed by Heinemann and Hanks (1977) when 0, 10 and 20% molasses was fed *ad lib* with a barley based fattening diet (Table 3). O'Mary et al. (1959) also reported a much lower intake of dry matter by steers fed a diet containing 47% cane molasses than that of steers fed a diet containing 54% corn, but this result may have been influenced by the use of different roughage ingredients, cottonseed hulls (CSH) and alfalfa hay, respectively, in the two dietary treatments (Table 5).

A number of studies (Bray et al., 1945; Riggs and Blankenship, 1955; Brown, 1962; 1967; Campbell et al., 1970) have shown that increasing levels of molasses of up to 48% of feedlot diets has little effect on dry matter intake by growing or fattening cattle (Tables 3, 5 and 14 respectively). Bray et al. (1945) did observe that when cane molasses was substituted for 10 to 15% of corn grain or other dry ingredients in the concentrate ration, steers consumed more hay or silage which were offered *ad lib* as a roughage component, but higher substitutions of molasses did not appear to encourage a further increase in the intake of roughage.

In a second study, Lofgreen (1965) found that the substitution of cane molasses for 5, 10, 15 and 20% of the barley in a fattening diet resulted in a slight linear increase in dry matter intake by heifers, but intake of all diets containing molasses was below that of heifers fed a control diet (Table 3). Feeding studies by Lishman (1967), Van Niekerk and Voges (1976) and Kargaard and Van Niekerk (1977) showed that the substitution of cane molasses for up to 22 to 30% of corn meal in steer finishing diets resulted in increases in dry matter intake (Table 4). In a feeding study involving 15 separate feedlot trials, Baker (1954) found that the substitution of citrus molasses for up to 50% of ground ear corn in finishing diets resulted in an increase in dry matter intake over the controls, but in a subsequent study (Baker, 1955a) there appeared to be a negative relationship between the level of citrus molasses in the diet and dry matter intake by fattening steers (Table 6). Gaili and Ahmed (1980) reported a much higher intake of dry matter by growing cattle fed diets containing 25 and 50% cane molasses than that of cattle fed a 45% sorghum grain diet (Table 13).

In two studies involving the substitution of raw sugar for up to 40 and 48% of com meal in steer fattening diets, Beardsley et al. (1971) and Olbrich and Wayman (1972) noted little effect of dietary treatment on dry matter intake indicating that the effects of sucrose and starch were similar (Table 8). However, when diets contained different combinations of cane molasses and raw sugar, increasing levels of molasses consistently increased dry matter intake by fattening steers (Olbrich and Wayman, 1972) (Table 8).

Although the types of molasses are somewhat different in composition, studies (Baker, 1955a; 1955b; Riggs and Blankenship, 1955; Kirk et al., 1966; Crawford et al., 1978; Cooper et al., 1978) that have made direct comparisons between diets containing either cane, corn, citrus or wood molasses have not demonstrated consistent differences in terms of dry matter intake (Table 2, 3, and 7). However, the type of feed ingredients with which molasses is combined does influence intake. Both Brown (1962; 1967) and Salais et al. (1977) found that sugar cane roughage feeds fed in combination with cane molasses could be quite detrimental to dry matter intake relative to other roughage sources (Table 15). Baker (1966) reported that the addition of 15% molasses to a ground ear corn diet increased dry matter intake, but a similar quantity of molasses added to a shelled corn diet did not affect intake (Table 6).

Molasses in Fattening Diets

A number of studies (Bray et al., 1945; Lofgreen and Otagakit, 1960a; Bradley et al., 1966; Lishman, 1967; Brown et al., 1967; Copper et al., 1978) have shown a very obvious advantage in rate of gain and/or dry matter utilization from the addition of 2 to 10% cane molasses to concentrate diets fed to finishing cattle (Tables 2, 3, 4 and 5). Only in three studies reviewed did the feeding of up to 10% cane molasses not result in an improvement in animal performance in comparison to a control treatment (Van Niekerk and Voges, 1976; Kargaard and Van Niekerk,, 1977; Hinemann and Hanks, 1977) (Tables 3 and 4). In either of the above studies carcass quality was not measurably affected by the feeding of low level's of molasses. The above data strongly support the conclusions of basic studies that the addition of up to 10% molasses to finishing diets stimulate microbial activity, the digestibilities of energy and fiber, and nitrogen utilization (Potter et al., 1971; Batch and Beeson, 1972; Crawford et al., 1978).

Table 2. Response of Yearling Steers to Low Levels of Molasses in Corn-Based Finishing Diets

Reference and treatment	Initial wt/kg	Dry matter	Gain [a] kg/day	Dry matter: gain kg	Carcass grade
Bradley et al. (1966)					
(Gr. ear corn; 124 days)					
Control	362	10.5[b]	0.98	10.7	Choice
2.3% cane molasses	362	11.0[b]	1.02	10.8	Choice
Brown et al. (1967)					
(Gr. ear corn; 119 days)					
Control	310	8.3	0.91	9.1	Choice
2.3% cane molasses	310	9.2	1.00	9.2	Choice
Cooper et al. (1978) (Dry shelled corn)					
Control	353	8.8	1.37	6.5	Good+
3.6% cane molasses	343	9.0	1.49	6.0	Good+
2.8% wood molasses	345	9.4	1.54	6.1	Choice-
Crawford et al. (1978)					
(Gr. shelled com diet; 134 days)					
10% cane molasses	255	8.1	1.16	7.0	Good+
10% wood molasses	261	7.8	1.18	6.6	Good+

[a] Calculated from a final weight based on a 62% carcass dress.
[b] Estimated from as fed intake values, assuming a 90% dry matter content of diet.

Basic studies have suggested that the addition of low levels of wood molasses might protect dietary protein from bacterial attack thereby increasing by-pass protein and dietary protein utilization. However, practical feedlot studies (Riggs and Blankenship, 1955; Cooper et al., 1978; Crawford et al., 1978) have not shown a consistent difference in the performance of fattening cattle fed low levels of either wood or cane molasses (Table 2 and 9).

Table 3. Effect of Low to Moderate Levels of Cane Molasses in Finishing Diets

Reference and treatment	Initial weight kg	Dry matter intake kg/day	Gain [a] kg/day	Dry matter: gain, kg	Carcass grade
Lofgreen and Otagaki (1960a) (Barley-alfalfa-bagasse diet; steers; 133 days)					
Basal	292	8.8	1.01	8.7	---
10% molasses	304	9.5	1.12	8.5	---
25% molasses	298	6.8	0.70	9.7	---
40% molasses	292	6.8	0.68	10.0	---
Lofgreen (1965) (Barley diet; heifers; 169 days)					
Control	281	8.1	0.97	8.4	Choice-
5% molasses	281	7.3	0.92	7.9	Choice-
10% molasses	277	7.3	0.96	7.6	Choice-
15% molasses	281	7.4	0.98	7.5	Choice-
20% molasses	262	7.7	1.01	7.6	Good+
Riggs and Blankenship (1955) (Sorghum silage-sorghum grain diet; 140 days)					
Control	266	2.6 [c]	1.05	12.6	Choice
13% molasses [b]	266	2.6 [c]	0.95	12.5	Choice
26% molasses [b]	266	2.6 [c]	0.89	13.1	Good+
Heinemann and Hanks (1977)[d] (Barley-beet pulp diet; steers; 146 days)					
Control	340	10.1	1.23	8.2	Choice
10% molasses	340	10.4	1.26	8.3	Choice
20% molasses	338	10.0	1.07	9.3	Choice

[a] Calculated from a final weight based on a 60% carcass dress, except for Lofgreen (1965) where values are empty body weight gains.

[b] Five kinds of molasses used at each level.

[c] Actual values reported as dry matter intake per 100 kg of liveweight.

[d] Molasses fed separately from dry concentrate.

The response of fattening steers to the feeding of molasses may be related to the type of diet in which it is substituted. Baker (1966) found that the addition of 15% citrus molasses to a ground shell corn diet reduced rate of gain and dry matter utilization by fattening steers 13 and 10%, respectively, but a similar quantity of citrus molasses added to a ground ear corn diet increased rate of gain to a level which was equal to that obtained with the ground shelled corn diet, but did not influence dry matter utilization which was 15% lower than that obtained with the ground shelled corn diet (Table 6). Lishman (1967) reported that the substitution of cane molasses for 20 and 30% of corn meal in a corn silage diet increased rate of gain by fattening steers 15%, but it did not influence the efficiency of dry matter utilization (Table 4). In a series of 15 feeding trials, Baker

Table 4. South African Data on the Performance of Steers Fed Finishing Diets Containing Low to Moderate Levels of Cane Molasses as a Substitute for Corn Meal

Reference and treatments	Initial weight kg	Dry Matter intake kg/day	Gain kg/day	Dry Matter: gain kg
Lishman (1967) [a]				
(Corn silage-cornmeal diets; 56 days)				
Control	342	8.2	0.84	9.8
10% cane molasses	345	9.0	1.06	8.4
20% cane molasses	344	9.4	0.98	9.6
30% cane molasses	343	9.5	0.96	9.9
Van Niekerk and Voges (1976) [b]				
(Corn meal diet; 168 days)				
Control	201	7.5	1.03	7.3
7% cane molasses	202	7.6	1.02	7.5
15% cane molasses	203	7.6	1.02	7.5
22% cane molasses	203	8.1	1.02	7.9
Kargaard and Van Niekerk (1977) [c]				
(Corn meal diets; 134-162 days)				
Control	215	6.9	1.07	6.4
7% cane molasses	215	7.1	1.09	6.5
14% cane molasses	217	7.3	1.10	6.6
21% cane molasses	215	7.0	0.87	8.0

[a] Results of two trials using steers which were 3 to 3.5 years of age in trial 1, and 2 years of age in trial 2. Gain data were calculated from a final weight based on a 55% carcass dress.

[b] Results of two trials, in one hay was fed in complete mixed diet and in a second hay was fed separately. Gain data for yearling steers calculated from a final weight based on a 57% carcass dress.

[c] Gain data for weaned calves were calculated from a final weight based on a 55% carcass dress.

Table 5. Performance of Fattening Steers Fed Diets Containing Moderate to High Levels of Cane Molasses

Reference and treatment	Initial wt	Dry matter intake day	Gain[a] day	Dry matter: gain	Carcass grade
	---------- kg	----------	----------	----------	
Campbell et al. (1970)					
(Barley diets; 144-165 days)					
24% molasses	290	8.0	0.85	9.4	Good+
48% molasses	282	8.0	0.70	11.4	Good+
O'Mary et al., (1959) (139 days)					
54% corn-40% alfalfa hay	340	11.2	0.99	11.3	Good+
47% molasses-32% CSH	341	9.9	0.74	13.4	Good-
Bray et al. (1945)					
(3 trials; 112 days)					
Corn grain-rice straw, rice	224	8.8	1.35	6.5	-
bran, polishings, (control)	224	8.9	0.91	9.8	-
10% molasses	224	8.9	1.01	8.8	-
20% molasses	225	9.0	1.06	8.4	-
30% molasses	225	8.8	1.04	8.5	-
40% molasses	225	8.8	1.06	8.3	-
Webb and Bull (1945)					
(Corn silage-alfalfa hay based diets 150 days)					
Control (50% corn)	342	8.8	1.18	7.5	Choice
21% Molasses-12% corn 12% oats	340	8.1	1.02	7.9	Good+
47% molasses	342	8.4	0.87	7.7	Good+

[a] Based on final weight and 60% dress, except Bray et al. (1945), based on a 55% dress.

(1954) found that the substitution of citrus molasses for 22 and 37% of ground ear corn in steer finishing diets improved rate of gain 28% and the efficiency of dry matter utilization 11 to 15%. The performance of steers fed diets containing 50% citrus molasses was similar to that of steers fed the control diet, but in a subsequent study (Baker, 1955a), steers fed a diet containing 51% molasses as a substitute for ground ear corn had a similar gain and were 6% more efficient than steers fed the control diet (Table 6).

Table 6. Response of Yearling Steers to Various Levels of Citrus Molasses in Ground Ear Corn Finishing Diets

Reference and treatment	Initial wt	Dry matter intake [a] day	Gain [b] day	Dry matter: gain	Carcass grade
	----------	---------- kg	----------	----------	
Baker (1954)					
(15 trials; 92-107 days)					
Control	307	9.2	0.74	12.4	Good+
22% Citrus molasses	314	10.6	0.96	11.0	Good+
37% Citrus molasses	307	10.0	0.94	10.6	Good+
50% Citrus molasses	323	9.7	0.77	12.6	Good+
Baker (1955a)					
(1 trial; 113-126 days)					
Control	329	11.3	1.14	9.9	Choice
26% Citrus molasses	328	11.3	1.15	9.8	Choice
40% Citrus molasses	328	10.7	1.09	10.1	Choice
51% Citrus molasses	328	10.3	1.11	9.3	Choice.
Baker (1966)					
(1 trial; 102 days)					
Gr. ear corn control	321	9.6	1.11	8.6	Good+
+ 15% citrus molasses	321	10.8	1.22	8.8	Choice-
Gr. shelled corn control	321	9.5	1.24	7.6	Good+
+ 15% citrus molasses	321	9.5	1.13	8.4	Good+

[a] Estimated from as fed intake values, assuming 90 and 75% dry matter values for dry ingredients and citrus molasses, respectively.

[b] Calculated from a final weight based on a 60% carcass dress.

Several studies have compared the feeding value of different types of molasses in steer finishing diets (Table 7). Baker (1955a) reported that citrus molasses had a higher feeding value than blackstrap molasses when both were fed as 40% of a ground ear corn based diet. Steers fed a ground ear corn diet containing 20% blackstrap molasses performed better than steers fed a diet containing 20% standard cane molasses (Baker, 1955b). Kirk et al. (1966) observed little difference in the performance of fattening cattle fed diets containing 29% of either blackstrap or citrus molasses. Riggs and Blankenship (1955) fed diets containing 13 and 26% molasses of four different types and reported that fattening cattle performed best on diets containing blackstrap molasses, followed in order by corn, citrus and wood molasses.

Table 7. Comparison of Different Types Of Molasses in Finishing Diets to Yearling Steers

Reference and treatment	Initial wt	Dry matter intake day	Gain[a] day	Dry matter: gain	Carcass grade
	---- kg ----				
Baker (1955a)					
(Gr. ear corn diets; 122 days)					
40% citrus molasses	328	10.7[b]	1.09	9.8	Choice
40% molasses	329	11.7[b]	1.04	11.3	Choice
Baker (1955b)					
(Gr. ear corn diets; 120 days)					
20% std. cane molasses	322	9.7[b]	1.12	8.7	Choice
20% mill run blackstrap	323	9.3[b]	1.17	7.9	Choice
Riggs and Blankenship (1955)					
(Sorghum grain diet; molasses fed at 13 and 26%; 140 days)					
Blackstrap molasses	266	2.5[c]	0.95	12.5	Choice
Corn molasses	266	2.7[c]	0.92	12.9	Choice
Citrus molasses	266	2.5[c]	0.88	13.0	Choice
Wood molasses	266	2.5[c]	0.83	13.9	Choice
Kirk et al. (1966)					
(Hay-citrus pulp diet; 120 days)					
29% molasses	279	6.9	1.03	6.7	Good-
29% citrus molasses	283	7.2	1.04	6.9	Good-

[a] Calculated from a final weight based on a 60% carcass dress.

[b] Estimated from as fed intake values, assuming 90, 75, 80, and 70% dry matter values for dry ingredients, citrus molasses, blackstrap and standard cane molasses, respectively.

[c] Presented as kg of dry matter per 100 kg of liveweight.

Two studies have shown that raw sugar was superior to corn meal as an energy ingredient in steer finishing diets (Beardsley et al., 1971; Olbrich and Wayman, 1972). The substitution of raw sugar for up to 48% of corn meal did not affect the rate of gain by fattening steers, but increasing levels of raw sugar tended to improve the efficiency of dry matter utilization by about 10% (Table 8). These data indicate that the sugars, the principle component of cane molasses, do not adversely affect the performance of finishing cattle when included into their diets at moderate to high levels.

Table 8. Performance of Yearling Steers Fed Finishing Diets Containing Various Levels of Raw Sugar or Cane Molasses as a Substitute for Cornmeal in Finishing Diets

Reference and treatment	Initial wt	Dry matter intake day	Gain[a] day	Dry matter: gain	Carcass grade
	----------	---------- kg	----------	----------	
Beardsley et al. (1971)					
(Corn meal diets; 120 days)					
Control	369	10.7	0.96	11.1	Good+
5% raw sugar	369	10.8	0.92	11.7	Good+
10% raw sugar	370	11.0	1.04	10.6	Choice-
20% raw sugar	369	10.7	0.99	10.8	Choice-
40% raw sugar	367	10.1	0.98	10.3	Choice-
Olbrich and Wayman (1972)[b]					
(19% bagasse diets; 135 days)					
60% corn meal	308	7.7	1.03	7.5	Good+
40% corn meal-16% raw sugar	308	7.6	1.03	7.4	Good+
20% corn meal-32% raw sugar	309	7.0	0.95	7.4	Good+
0% corn meal-48% raw sugar	327	7.4	1.12	6.6	Good+
55% molasses	313	9.0	0.86	10.5	Good
37% molasses-16% raw sugar	309	8.4	0.88	9.5	Good
18% molasses -32% raw sugar	309	7.9	0.95	8.3	Good

[a] Calculated from a final weight based on a 60% carcass dress, except for Olbrich and Wayman (1972) where values were on 24 hr. shrunk weights taken at the beginning and end of trial.

[b] Dry matter intake was calculated from as fed feed intake assuming dry matter values of 50% for fresh bagasse, 80% for cane molasses and 90% for dry ingredients.

In the early 1950's Wayman and co-workers, in Hawaii, initiated a series of studies to develop steer fattening diets using cane molasses as the major energy source. In the initial studies (Wayman et al., 1952; 1953; 1954), three problems were associated with the feeding of high-molasses diets: 1) the adaptation of cattle to utilize molasses based diets was very critical and should be done over a period of several weeks, 2) the feeding of fresh-chopped forage was essential, especially during the adaptation period, and 3) the level of sugarcane bagasse, the dry roughage source, should be limited to less than 10% of the diet and the fresh-chopped forage should be limited by restricted feeding to about 5 to 7% of diet (dry matter basis) after the cattle have adapted (Table 9). Further investigations found that dehydrated legume forage could be completely substituted for fresh forage after an initial two week period during which fresh forage was fed. The good performance of steers fed diets containing 60% cane molasses is presented in Table 9 (Wayman and lwanaga, 1956)

Table 9. Hawaiian Data on the Feeding of Diets Containing High Levels of Cane Molasses to Finishing Beef Steers

Reference and treatment	Initial wt	Dry matter intake [a] day	Gain day	Dry matter: gain	Dressing percent
	------	------	kg	------	
Wayman et al. (1952)(182 days)					
42% grain-35% forage -13% molasses	330	6.7	0.48	14.0	-
40% mol.-25% bagasse -20% forage	332	7.7	0.25	30.8	-
Wayman et al. (1953) (4 kg napiergrass; 2nd 70 days)					
50% molasses-30% bagasse	255	6.4	0.32	20.0	-
60% molasses-20% bagasse	277	8.3	0.45	18.4	-
70% molasses-10% bagasse	245	6.9	0.64	11.0	-
Wayman et al. (1954)(140 days)					
65% molasses (*ad lib*); 20% restricted napiergrass	255	9.9	0.89	11.1	55
60% molasses; 8% bagasse; 7% restricted napiergrass	256	9.1	0.96	9.5	55
Wayman and lwanaga (1956)(163 days)					
60% molasses; 8% bagasse; 7% restricted napiergrass	326	10.3	0.83	12.4	60
60% molasses; 10% bagasse; 5% dehydrated legume forage	325	9.9	0.92	10.7	60
Olbrich and Wayman (1972) (4% pineapple bran; 19% bagasse; 135 days)					
60% corn meal	308	7.7	1.03	7.5	60
55% molasses	313	9.0	0.86	10.4	60

[a] Estimated from as fed intake values, assuming 90, 80 and 20% dry matter values for dry ingredients, molasses and napiergrass forage, respectively.

In a subsequent study (Olbrich and Wayman, 1972) it was shown that the rate of gain and efficiency of dry matter utilization of steers fed a 55% cane molasses diet was 83 and 72%, respectively, of that by steers fed a 60% corn meal diet (Table 8). The utilization of total digestible nutrients in the molasses diet was 78% of that in the corn meal diet.

More recent investigations to develop high-cane molasses diets for the commercial fattening of beef cattle were conducted by Preston and co-workers in Cuba (1967a; 1969; 1970a). They confirmed the conclusions reached by the Hawaiian workers, that cattle had to be slowly adapted to molasses based diets through the initial feeding of fresh-chopped forage, after which fresh forage should be limited to 1.5 kg per 100 kg of body weight or approximately 10 to 15% of the diet dry matter. It was also found that high intakes of molasses and relatively good animal performance could also be obtained by restricted grazing (Morciego et al., 1970) (Table 10). The importance of restricted forage feeding on the performance of growing bulls was demonstrated in commercial feeding operations (Munoz et al., 1970), results of which are presented in Table 10.

Table 10. Cuban Data on the Feeding of Diets Containing High Levels of Cane Molasses to Fattening Yearling Bulls

Reference and treatment	Initial wt	Dry matter intake day	Gain [a] day	Dry matter: gain	Carcass grade
	------- kg	-------	-------	-------	
Preston et al. (1967b)[b]					
(Molasses *ad lib*; 140 days)					
Forage *ad lib* + 2 kg mol.	216	7.1	0.59	23.7	48
Forage *ad lib* + 1.5 kg mol. +1.5 kg sorghum grain	218	8.1	0.83	14.5	51
Sorghum grain *ad lib* + 2 kg molasses	199	6.1	0.94	7.0	53
Preston et al. (1970b)					
(70-80% mol. diets; 140 days)					
Molasses + .35 kg fish meal	279	7.4	1.00	7.4	52
Molasses + .67 kg fish meal	283	7.2	1.09	6.6	52
Molasses + .98 kg fish meal	282	7.8	1.12	6.9	52
Munoz et al. (1970)					
(Commercial feedlot; 20,000 bulls; 180 days)					
Forage *ad lib* + 3.1 kg mol.	275	6.7	0.43	15.3	---
Molasses *ad lib* (8.8 kg); restricted forage	275	9.5	0.88	10.8	---
Morciego et al. (1970) (Commercial grazing; 3,500 bulls; 80 days)					
Molasses *ad lib* (9.1 kg); grazing (3.5 hr/day)	313	7.6[c]	0.83	---	---

[a] Gain calculated from a final weight based on carcass dressing percent shown.
[b] Initial weight on test taken after a 10 day adaptation period.
[c] Dry matter intake of molasses, urea and fish meal only. the prescribed molasses-urea-fish

An additional factor introduced into this high-molasses feeding system was the utilization of large quantities of non-protein nitrogen avoiding the use of natural protein concentrates if possible. However, in comparison to a sorghum grain diet, bulls fed the molasses-urea diet performed poorly, particularly in terms of dry matter utilization (Preston et al., 1967b) (Table 10). Further investigation showed that some natural protein in the molasses-urea diet was essential and it was recommended that fattening bulls receive 140 gm of fish meal daily per 100 kg of liveweight because of its ability to provide by-pass protein (Preston, 1969; 1972). The performance of bulls fed meal-fresh forage diet on an experimental (Preston et al., 1970b) and commercial feedlot basis (Munoz et al., 1970) is presented in Table 10. The only abnormal problem encountered with this feeding system was a high incidence of molasses toxicity in the feedlot program. The incidence of this problem was much lower in the restricted grazing program (Morciego et al., 1970).

Other investigators have also tested a high-molasses feeding system and made comparisons to the performance of cattle fed more conventional diets (Table 11). In Kenya, Creek et al. (1974)

Table 11. Performance of Growing Fattening Beef Cattle Fed Diets Containing High Levels of Cane Molasses in Comparison to Diets Containing Other Concentrate Ingredients

Reference and treatments	Initial wt	Dry matter intake day	Gain[a] day	Dry matter: gain
	----------	---------- kg	----------	----------
Creek et al. (1974)				
(Fed 102 and 138 days, respectively)				
58% corn silage, 29% hominy	265	7.0	0.84	8.6
58% molasses, 22% straw, 14% hominy	265	7.0	0.63	11.1
Molina (1977)[b]				
(Fed 267, 346, and 520 days, respectively)				
Sorghum grain diet *ad lib*	121	---	1.28	---
Mol. *ad lib*, restric. forage[c]	121	---	0.90	---
Napier green forage *ad lib*	121	---	0.58	---
Gaili and Ahmed (1980)				
45% sorghum grain, 33% wheat bran	141	6.4	0.89	7.2
25% molasses, 29% wheat bran, 19% rice bran	141	7.0	0.86	8.1
50% molasses, 23% wheat bran	141	8.3	0.87	9.5

[a] Calculated from a final weight based on a 53% carcass dress.

[b] Feed intake data were not presented.

[c] Fed in accordance with system recommended by Preston et al. (1967a) for feeding high molasses diets (molasses-urea *ad lib*, and 1.5 kg and 150 gm of fresh napiergrass and fish meal, respectively, per 100 kg of liveweight).

reported that gains and dry matter conversions by steers fed a diet containing 53% cane molasses were 25 to 30% lower than that by steers fed a 58% corn silage diet. They, too, encountered a high incidence of molasses toxicity (18%) which was completely corrected by replacing corn silage with straw, feeding some cereal grain, using a moderate level of urea, and using molasses minimally diluted with water. Molina (1977) fed growing calves to a constant weight and found that those fed cane molasses-urea-fish meal and restricted forage gained 30% slower than calves fed sorghum grain, but 36% faster than calves fed fresh napiergrass forage (feed intake data were not presented). In Sudan, Gaili and Ahmed (1980) found that crossbred bulls fed diets containing 25 and 50% cane molasses gained similarly to bulls fed a 45% sorghum grain, 33% wheat bran diet, but were respectively 12 and 32% less efficient in converting dry matter to gain. Again, a high incidence of molasses toxicity (23%) was encountered with cattle fed diets containing molasses.

As a summary the following conclusions were drawn from the literature studied on the feeding of molasses in beef cattle fattening diets.

1) The addition of less than 10% molasses to concentrate fattening diets has a stimulating effect on animal performance; improving feed intake, rate of gain and/or feed utilization.

2) The feeding of fattening diets containing 20 to 40% molasses reduces rate of gain and/or feed efficiency but to a degree that is explained by the energy content of molasses relative to the energy content of ingredients for which it is substituted. The majority of the feeding data do not suggest that the energetic efficiency of molasses itself declines when its level in the diet exceeds the 10 to 20% level.

3) At moderate levels, molasses appears to be better utilized when it is fed with certain concentrate feeds such as ground ear corn. This, and other information, suggest that molasses combines best with certain levels and kinds of fiber in a complete diet.

4) Several studies have demonstrated that high levels of molasses can be formulated into diets for fattening cattle. The success of this feeding system is very sensitive to feed management practices, particularly during the initial animal adaptation period, and to diet composition in general, the production data suggest that the metabolizable nutrients of diets containing high levels of molasses are utilized less efficiently than those of diets formulated from more conventional concentrates. The economics of production is the most important factor and may indicate that feeding high-molasses diets is justified in many parts of the world.

Molasses in Forage Diets For Growing Cattle

An often stated beneficial use of molasses is its addition to diets based on low quality forages or roughages to improve palatability and provide a readily available source of energy. But, it must be remembered that molasses contains little crude protein and for it, or the diet to which molasses is added, to be efficiently utilized a source of supplemental crude protein is theoretically required. This concept was clearly demonstrated by Delgado et al. (1978) with yearling bulls fed fresh pangola grass which contained 4.7% crude protein (Table 12). Supplementation with 1.4 kg of cane molasses actually reduced rate of gain although total dry matter intake was substantially increased. Adding

Table 12. Performance of Growing Cattle Fed Forage Without and With Various Combinations of Corn, Cane Molasses, Urea and Plant Protein

Reference and treatments	Initial weight kg	Forage intake	Suppl. intake	Total intake	Gain kg/day
		------kg dry matter/day ------			
Delgado et al. (1978)					
(Yearling bulls fed 145 days)					
Pangolagrass (4.7% CP)	164	4.6	---	4.6	-0.04
Forage + molasses	141	4.6	1.4	6.0	-0.15
Forage + molasses-urea	154	6.3	1.6	7.9	0.33
Forage + sunflowerseed meal	161	6.9	1.2	8.1	0.57
Toranzos et al. (1975)					
(Steers fed 56 days)					
Sorghum silage unsupplemented	340	5.9	---	5.9	0.49
Silage + 3 kg molasses-urea	354	5.6	2.4	8.0	1.11
Silage + kg corn + 2 kg alfalfa	357	5.0	4.6	9.6	1.29
Bond and Rumsey (1973)					
(Calves fed 112 days)					
Hay alone (9.4% CP)	99	3.2	---	3.2	0.26
Hay + molasses *ad lib*,	104	2.5	0.6	3.1	0.29
Hay + molasses-urea *ad lib*	108	3.1	0.4	3.5	0.28
Bond and Rumsey (1973)					
(Yearling steers fed 84 days)					
Hay alone (4.3% CP)	213	6.0	---	6.0	0.52
Hay + molasses *ad lib*	194	5.2	2.6	7.8	0.56
Hay + molasses-urea *ad lib*	220	4.5	2.4	6.9	0.52
James (1973)[a]					
(Steers fed 160 days)					
Derinded cane + tops	299	7.2	1.9	9.1	0.99
Molasses Supplement	312	5.9	5.8	11.7	1.08
Corn Supplement	312	5.3	5.4	10.7	1.27
Pangolagrass	290	6.7	1.8	8.5	0.82
Molasses Supplement	291	5.8	5.5	11.3	0.98
Corn Supplement	289	6.1	5.0	11.1	1.17

[a] Urea containing (60% of N) supplement fed at 1.8 to 1.9 kg/steer/day.

Table 13. Performance of Growing Heifers Fed Forages With Various Combinations of Cane molasses and Corn Supplements Containing, Urea or Plant Protein

Reference and treatments	Initial weight kg	Forage intake	Suppl. intake	Total intake	Gain kg/day
		------ kg dry matter/day -----			
Bohman et al. (1954) [a] (Heifers fed timothy hay (6% CP) for 9 to 12 weeks)					
Hay + molasses-urea	370	7.0	2.6	9.6	0.33
Hay + corn-soy	371	6.1	2.0	8.1	0.41
Hay + molasses-soy	371	6.7	2.6	9.3	0.37
Hay + molasses-corn-urea	368	6.9	2.8	9.7	0.33
Davis et al. (1955) [a] (Heifers fed hay and corn silage (10% CP) 148 days)					
Corn supplement	332	6.3	1.9	8.2	0.64
Molasses supplement	332	6.4	2.4	8.8	0.70
Merrill et al. (1959) [a] (Hay-corn silage (10% CP) fed to heifers for 169 days)					
Forage + corn-soy	311	6.5	1.5	8.0	0.66
Forage + molasses-soy	314	7.0	1.6	8.6	0.66
Forage + molasses-urea	312	7.2	1.6	8.8	0.56
King et al. (1960) [a] (Heifers fed oat silage (9% CP) or oat hay (6% CP) for 84 days)					
Oat silage + 1.4 kg mol.	258	4.4	1.0	5.4	0.60
Oat silage + 2.7 kg mol. (*ad lib*)	261	3.6	2.0	5.6	0.65
Oat hay + shelled corn	252	4.3	1.9	6.2	0.63
Oat hay + molasses (*ad lib*)	252	4.2	1.9	6.1	0.60
Oat hay + molasses-urea (*ad lib*)	262	4.5	1.8	6.3	0.40

[a] All diets were isonitrogenous.

Table 14. Effect of Different Levels of Cane Molasses in Forage or Roughage Diets on Dry Matter Intake and Gains by Growing Cattle

Reference and treatments	Initial weight kg	Forage intake	Molasses intake	Total intake [a]	Gain kg/day
		------- kg	dry matter/day	-----	
Silvestre et al. (1978) (sugar cane-molasses mixed diets, 141 days)					
0% molasses	204	3.2	---	3.6	0.06
19% molasses	215	3.2	0.9	4.5	0.17
32% molasses	214	3.3	1.8	5.6	0.19
41% molasses	224	3.3	2.6	6.4	0.23
Brown (1962; 1967) (140 and 112 days, respectively)					
25% molasses-45% bagasse	299	---	---	11.0	0.75
30% molasses-40% bagasse	299	---	---	10.8	0.75
35% molasses-35% bagasse	299	---	---	11.7	0.85
40% molasses-30% bagasse	299	---	---	11.6	0.79
35% molasses-35% bagasse	234	---	---	7.3	0.32
40% molasses-30% bagasse	234	---	---	9.0	0.69
45% molasses-25% bagasse	234	---	---	9.5	0.66
50% molasses-20% bagasse	234	---	---	9.8	0.85
Elias et al. (1969) (Fresh napiergrass, molasses *ad lib*, 230-249 days)					
1.5 kg fresh grass/100 kg liveweight	191	0.7	4.9	6.8[a]	0.78[b]
2.5 kg fresh grass/100 kg liveweight	195	1.1	5.1	7.4[a]	0.78[b]
3.5 kg fresh grass/100 kg liveweight	196	1.5	4.9	7.7[a]	0.86[b]
4.5 kg fresh grass/100 kg liveweight	196	1.9	4.8	7.9[a]	0.83[b]

[a] Total dry matter intake values also include protein and mineral supplement.
[b] Calculated from a final weight based on a 52% carcass dress.

urea to the molasses markedly increased rate of gain and the addition of sunflower seed meal resulted in an even better rate of gain. Toranzos et al. (1975) also reported a very positive response in rate of gain by steers fed a sorghum silage diet when supplemented with 3 kg of a molasses-urea mixture. Bond and Rumsey (1973) found that weaned calves or yearling steers fed hay diets which contained 9.4 and 4.3% crude protein, respectively, did not respond to molasses supplementation, but neither was there a response to a molasses-urea supplement.

James (1973) conducted a study with derinded sugar cane, cane tops and pangolagrass diets in which a urea containing (60% of the N) protein-mineral-vitamin supplement was fed in all experimental treatments (Table 12). Supplementation with 3.8 kg of molasses dry matter (33% of diet) increased rate of gain 10 to 15%. However, supplementation with 3.3 kg of corn grain increased rate of gain 30%.

Several studies reviewed did not use a negative control (forage alone) or the molasses supplement was fortified with urea or natural protein (Table 13). These studies demonstrated that molasses was equal to corn grain as an energy supplement in forage based diets fed to growing heifers, if plant protein provided the supplemental nitrogen (Bohman et al., 1954; Davis et al., 1955; Merrill et al., 1959; King et al., 1960). In studies where urea provided the nitrogen source in the molasses supplement a lower rate of gain was obtained.

Silvestre et al., (1978) fed growing bulls sugar cane based diets containing 0, 19, 32 and 41% cane molasses and found that the addition of 19% molasses improved rate of gain, but the animals did not significantly respond to further increases in the percentage of molasses in the diet even though there was a linear increase in dry matter intake (Table 14). Brown (1962; 1967) also noted little difference in rate of gain or dry matter intake by steers fed bagasse diets containing from 25 to 40% cane molasses. But, in a second study there was an increase in both dry matter intake and rate of gain by
steers fed bagasse diets as the level of molasses increased from 35 to 50% (Table 14). At the opposite extreme, Elias et al., (1969) reported that increasing levels of forage in diets containing 61 to 70% molasses increased total dry matter intake by fattening bulls, and slightly increased rate of gain (Table 14).

The response to molasses supplementation appears to be related o the roughage with which it is fed. Brown (1962; 1967) reported a much lower rate of gain by steers fed a bagasse diet containing 20% cane molasses than that of steers fed grass hay, rice straw or cottonseed hull diets containing 20% molasses (Table 15). The best rate of gain was obtained with the rice straw diet. However, When steers were fed these same roughages with 40% molasses there was little difference in the performance of animals fed the different roughage sources (Table 15). With growing bulls fed diets containing 80% molasses, Salais et al., (1977) noted a much lower rate of gain when either sugar cane or cane tops were used as a roughage source than when either bermudagrass or a mixture of bermudagrass and a legume forage was provided (Table 15).

Table 15. Effect of Various Roughage Sources on the Performance of Cattle Fed Diets Containing Moderate to High Levels of Cane Molasses

Reference and treatments	Initial wt	Dry matter intake day	Gain[a] day	Dry matter: gain
	----------	----------	kg ----------	----------
Brown (1962; 1967) (154 days)				
20% molasses-63% bagasse	298	6.9	0.40	17.3
20% molasses-63% grass hay	298	10.6	0.69	15.4
20% molasses-63% rice straw	298	11.3	0.85	13.3
20% molasses-63% cotton hulls	298	12.2	0.67	18.2
Brown (1962; 1967) (112 days)				
40% molasses-30% bagasse	252	8.4	0.79	10.6
40% molasses-30% grass hay	252	9.3	0.83	11.2
40% molasses-30% rice straw	252	8.5	0.73	11.6
40% molasses-30% cotton hulls	252	9.8	0.70	14.0
Salais et al. (1977)[b] (63 days)				
80% molasses + sugar cane	203	4.1	0.38	10.8
80% molasses + sugar cane tops	206	4.0	0.35	11.4
80% molasses + bermudagrass	202	5.0	0.58	8.6
80% molasses + bermudagrass + Leucaena leucocephala	202	5.0	0.62	8.1

[a] Gain data based on actual initial and final weights, carcass data were not obtained.
[b] Forages were fed as fresh chopped material.

From the above data the following conclusions can be drawn relative to the addition of molasses to forage or roughage diets.

1) A nitrogen supplement should be provided with molasses when added to low quality forage diets, and natural protein is superior to non-protein nitrogen sources.

2) Molasses supplementation will usually result in a lower intake of forage dry matter but an increased intake of total dry matter.

3) The benefits in rate of gain obtained with molasses supplementation are disproportionately lower relative to increases obtained in total dry matter intake. This may result from poorer utilization of forage dry matter.

4) The response to molasses feeding appears to be related to the forage or roughage with which it is fed.

Molasses Supplementation of Growing Cattle on Pasture

Molasses is most often fed to growing cattle as a supplement to pasture. The organic soil region of Florida has provided the opportunity to study molasses strictly as an energy supplement because green St. Augustinegrass pasture which contains 14% or more crude protein is available year-round (Pate et al., 1980). Also, cane molasses produced in this area contains 7% or more crude protein. Grazing studies (Kidder and Beardsley, 1952; Chapman et al., 1953; 1961; Pate et al.,1972; Pate, 1978) have shown a meager response of around 0.1 kg per day of additional gain by steers consuming approximately 2 kg per day (*ad lib*) of blackstrap molasses (Table 16). Results of the above studies indicated that the response to molasses supplementation was low whether fed during the winter when the quantity and quality of St. Augustine grass were limited or during the summer when forage was abundant. Even in studies conducted on mineral soil where forage availability or quality were not extremely limited (Morris and Gulbransen, 1970; Carlo et al., 1972; Holder, 1972; Veitia et al., 1974; Villaca et al., 1976), growing cattle have shown an inconsistent response to molasses supplementation but average response which tends to agree with the Florida data (Table 17).

Delgado et al., (1975) and Vilela et al., (1976) presented evidence that grazing cattle might respond best to molasses-urea feeding when forage availability was extremely low, as would occur with dry season pastures in Cuba (Table 18). This response was not confirmed by Copeman et al., (1977) with steers grazed under similar conditions and fed a molasses-natural protein-urea supplement in northern Australia (Table 18). Also in Cuba, Porres (1971) and Martin and Alfonso (1978) observed a poorer response by grazing cattle to molasses or molasses-urea supplementation during the dry season than during the wet season (Table 19).

The response of growing cattle to molasses supplementation and its relationship to forage availability has been best demonstrated in studies involving varying stocking rates. Chapman (1965) showed that the response of grazing cattle to molasses feeding was much higher (.16 vs .09 kg per day) on heavily stocked pastures than when the molasses fed group was compared to an unsupplemented group of steers grazed at a lower stocking rate (Table 16). Hart et al., (1971) graphically demonstrated this relationship between stocking rate and response to molasses supplementation. By progressively increasing the stocking rate of steers grazing orchard grass pasture the response to the feeding of 4 kg per steer per day of cane molasses was increased to approximately 0.2 kg daily of additional gain, which appeared to be the maximum response obtainable. This maximum response by grazing steers to molasses feeding would be supported by the literature in general.

Table 16. Effect of Blackstrap Molasses Supplementation to Yearling Steers Grazing St. Augustinegrass Pasture Which Contained 14-16% Crude Protein

Reference and treatments	Initial wt kg	Gain kg/day
Kidder and Beardsley (1952)		
(Winter, 3 trials; 120 days)		
Pasture alone	292	0.53
+ 2.4 kg molasses *ad lib*	287	0.62
+ 2.2 kg ear corn	290	0.68
Chapman et al. (1953),		
(Winter, 3 trials; 122 days)		
Pasture + 3.1 kg cane molasses	298	0.52
Pasture + 3.5 kg citrus molasses	299	0.51
Pasture + 2.3 kg gr. ear corn	302	0.53
Pasture + 2.3 kg citrus pulp	301	0.49
Chapman et al., (1961)		
(Winter, 140 days)		
Pasture alone	314	0.48
+ 2.6 kg molasses	306	0.65
+ 2.6 kg ear corn	314	0.72
Pate (1978)		
(3 trials; 240 days)		
Pasture alone	246	0.29
+ 1.4 kg molasses	246	0.37
+ 2.2 kg molasses, *ad lib*	246	0.39
Pate et al., (1972)		
(Fed 351 and 309 days, respectively)		
Pasture alone	238	0.43
+ 1.4 kg molasses, *ad lib*	240	0.49
Chapman (1965)		
(Summer-Fall, 206 days)		
Pasture, 5.0 steers/hectare (ha)	307	0.43
Pasture, 7.5 steers/ha	309	0.36
+ 1.8 kg molasses, 7.5 steers/ha	307	0.52

Table 17. Effect of Supplementing Growing Cattle Grazing Fertilized and/or Wet Season Pasture with Molasses or Molasses-Urea

Reference and treatments	Initial wt. kg	Gain kg/day
Morris and Gulbransen (1970)		
(Rhodesgrass, 104 days)		
Pasture only (6% CP)	154	0.38
+ 2 kg molasses, *ad lib*	148	0.43
+ 2 kg molasses-urea, *ad lib*	148	0.51
Carlo et al., (1972)		
(Fertilized pasture, 361 to 400 days)		
Pasture alone	165	0.42
+ 1.4 kg molasses	163	0.48
+ 1.4 kg corn	174	0.55
Holder (1972)		
(Fertilized Pangolagrass, 280 days)		
Pasture alone (4 to 6% CP)	152	0.47
+ 2.2 kg molasses-urea	157	0.42
+ 2.0 kg copra meal	164	0.62
+ 2.2 kg rice bran	151	0.56
Veitia et al., (1974)		
(Fertilized pangolagrass, 157 days)		
Pasture alone	181	0.54
+ 3.7 kg molasses-urea	178	0.51
Villaca et al., (1976)		
(Molasses grass, 140 days)		
Pasture alone (5-6% CP)	268	0.56
+2.5 kg molasses	263	0.64
+2.8 kg molasses-urea	267	0.74

Table 18. Effect of Supplementing Growing Cattle Grazing Poor Quality Dry Season Pasture with Molasses or molasses-Urea

Reference and treatments	Initial wt. kg	Gain kg/day
Delgado et al., (1975)		
(Pangolagrass, 148-165 days)		
Pasture alone (3 to 5% CP)	299	0.37
+ 1.9 kg molasses-urea-natural protein	301	0.77
Vilela et al., (1976)		
(Guinea grass, 84 days)		
Pasture alone (65 CP)	403	-0.04
+ 2.3 kg molasses-urea	422	0.23
Copeman et al., (1977)		
(Grass-legume, 134 days)		
Pasture alone	---	0.40
+ 1.7 kg molasses-urea-natural protein	---	0.43

Table 19. Effect of Supplementing Growing Cattle Grazing Wet and Dry Season Pasture With Molasses or Molasses-Urea

Reference and treatments	Initial wt. kg	Dry season	Wet season	Total
		---------Gain, kg/day--------		
Porres (1971) [a]				
(Fertilized Pangolagrass)				
Pasture alone (8-15% CP)	188	0.52	0.91	0.64
+ 3.1 kg molasses	185	0.53	0.96	0.69
+ 3.6 kg molasses-urea	193	0.57	1.01	0.73
Martin and Alfonso (1978) [b]				
(Pangolagrass, fertilized wet season)				
Pasture alone	160	0.17	0.27	0.20
+1.5 kg molasses-urea	155	0.20	0.48	0.30
+2.5 kg molasses-urea	149	0.22	0.52	0.33

[a] Stocking rates were 4.8 and 7.3 animals per hectare for dry and wet seasons, respectively.
[b] In this study the dry season grazing period followed the wet season grazing period.

The above data bring out two points relative to supplementing grazing steers with molasses. First, there is a slight additive response in rate of gain obtained with molasses feeding, probably through an increase in total daily dry matter intake as was demonstrated with grazing steers by Brannon et al. (1954). Second, molasses feeding to grazing cattle substitutes in part for intake of forage as was shown in the previous section which discussed the feeding of molasses in forage or roughage diets. Thus, the feeding of molasses to grazing cattle also extends the availability of pasture forage or increases stocking rate. In fact, this latter point was accurately demonstrated by Mott et al. (1967). Their data (Table 20) showed that the, feeding of 2 kg per day of cane molasses to steers grazing quineagrass pasture increased daily gain up to .07 kg per day (10 to 15%) and increased stocking rate up to 0.5 animals per hectare (15 to 20%). If molasses is fed to growing cattle grazing pasture only during the dry or winter seasons perhaps its benefits should be viewed solely from the standpoint of an increased stocking rate. In a study similar to that conducted by Mott et al. (1967), but involving a dry concentrate supplement fed only during the dry season, Bisschoff et al. (1967) found that the increased gains of growing steers obtained from supplementation during the dry season were lost during the subsequent wet season when forage was abundantly available.

Table 20. Effect of Blackstrap Molasses and Urea Supplementation on the Performance of Two-Year-Old Steers Grazing Guinea grass Pastures (Mott et al., 1967)

Trials and Treatments	Dry season [a] 112 days	Wet season [a] 196 days	Total 308 days
One trial, 367 kg steers	---------------------	Gain, kg/day	-------------------
Pasture alone	-.07	.68	.41
+ 1.3 kg molasses	.17	.72	.52
+ 1.4 kg molasses-urea [b]	.21	.71	.52
+ 1.0 kg ear corn-urea [b]	.24	.64	.50
Three trials, 310 kg steers	---------------------	Gain, kg/day	------------------
Pasture alone	.32	.63	.49
+ 2 kg molasses [c]	.39	.67	.56
	-------------	Stocking rate, steers/hectare	--------
Pasture alone	1.21	2.19	1.80
+ 2 kg molasses [c]	1.37	2.67	2.16

[a] CP content of guinea grass was 4 to 5% for dry season and 8 to 9% for wet season.

[b] Urea intake was 81 and 69 gm per steer daily for molasses and ear corn diets, respectively.

[c] Molasses containing 5% urea was fed in one trial with no noticeable response in animal performance relative to the other two trials.

Several studies have made direct comparisons between molasses and Other energy feeds as supplements to growing cattle on pasture (Kidder and Beardsley, 1952; Chapman et al., 1953; Chapman et al., 1961; Mott et al., 1967; Hart et al., 1971; Carlo et al., 1972; Holder, 1972). In general, the results show that corn and other concentrate feeds were superior to molasses in terms of increasing rate of gain (Tables 16, 17, and 20).

Molasses is often mixed with additives for use as a supplement to cattle grazing pasture. The most important of these is non-protein nitrogen compounds, usually urea. Several studies have shown an advantage of adding urea to molasses (Morris and Gulbransen, 1970; Porres, 1971; Villica et al., 1976), but others did not indicate an advantage in rate of gain with the addition of urea to a molasses supplement (Mott et al., 1967) or showed that cattle were less responsive to molasses-urea than to other energy-protein supplements (Holder, 1972) (Tables 17, 18, and 20).

In addition to being mixed with non-protein nitrogen compounds, molasses has been used as a carrier for many minerals, vitamins, growth stimulants and medicinals (Chapman and Pace, 1974). In some cases, the feeding of these additives with molasses appeared to be superior to other methods of administration. For example, Copeman et al. (1977) reported a response by growing cattle to copper and cobalt supplementation when added to molasses as compared to no response when these elements were administered through injections to the animal. These data also suggest that certain additives may be beneficial to the utilization of molasses.

To summarize the above discussion the following conclusions are offered.

1) The intake of molasses by growing cattle on pasture is relatively low (2 to 4 kg per day), thus molasses itself is not a very palatable feed.

2) Growing cattle fed a molasses supplement will gain an additional 0.1 to 0.2 kg per day with a relative poor efficiency in terms of additional gain per unit of molasses consumed.

3) Grazing cattle fed molasses tend to eat less forage, thus it should be fed only during period's when pasture forage is limited. This would maintain higher stocking rates during these periods, which would allow more efficient utilization of forage available during the summer or wet season growth periods. Any benefits obtained in increased gains from molasses supplementation during the dry or winter season maybe lost during subsequent periods when forage is more available.

4) Molasses supplementation to grazing animals is the area of production that would most benefit from additional research. Many questions remain unanswered relative to the use of non- protein nitrogen and other additives that could improve the utilization of molasses and the total supplemented diet.

Molasses for Brood Cows

In recent years, molasses has been increasingly used as a supplement for brood cows. In Florida, Chapman et al. (1965) conducted a four-year study which evaluated blackstrap molasses solely as an energy supplement to producing cows grazing St. Augustine grass pasture on organic soils. As discussed in the previous section crude protein requirements were more than adequate under the conditions of this study. Treatments included an unsupplemented control, the feeding of 2.3 kg daily of molasses during a 130-day winter period which included the breeding season, and the feeding of 2.3 kg daily of molasses year-round. Six breed groups were used which included straight-bred Angus, Brahman and Hereford cattle and the three possible two-way cross-breds (cows and calves) of these three breeds. Various production measures are presented in Table 21. There was a definite breed difference with respect to straight-bred vs. cross-bred cattle. The winter feeding of about 300 kg of molasses to straight-bred cows increased both cow reproduction and calf survival and weaning rate which resulted in a 26 kg increase in annual calf production per cow. Winter supplementation of cross-bred cows primarily increased calf weaning weight, and annual calf

Table 21. Effect of Seasonal and Year-Round Molasses Supplementation on Performance of Brood Cows Grazing St. Augustinegrass on Organic Soils (Chapman et al., 1965)

Production trait	Molasses Supplementation [a] None	Winter season	Year-round
Pregnancy rate, % [b]			
Straight bred [c]	83.8	91.0	92.5
Cross bred [d]	93.3	94.5	95.4
Calf survival, %			
Straight bred	88.6	93.7	98.2
Cross bred	96.8	94.2	95.9
Weaning rate, % [b]			
Straight bred	74.2	84.4	90.8
Cross bred	90.3	89.0	91.5
Calf weaning weight, kg			
Straight bred	141	154	163
Cross bred	163	177	176
Annual Production/cow, kg [e]			
Straight bred	104	130	148
Cross bred	147	158	161

[a] Molasses fed at 2.3 kg per cow daily. Winter feeding was 130 days beginning December l.
[b] Based on number of cows exposed to bulls.

[c] Angus, Brahman and Hereford cows.
[d] Cows and calves were all the possible two-way crosses of the above breeds.

[e] Average weaning weight of calf x weaning rate ÷ 100.

production per cow by 11 kg. Year-round feeding of straight-bred cows with about 600 kg of molasses further increased annual calf production per cow by 18 kg over winter supplementation, but cross-bred cows did not exhibit the additional response to year-round molasses feeding. Seasonal and year-round molasses feeding also increased cow weights 15 and 20 kg, respectively, which would have economic implications in terms of cull cow sales.

Additional information is currently being collected on molasses supplementation of Angus x Brahman cross-bred cows in the organic soil region of Florida (Pate, unpublished data). Three years of data have shown that the feeding of 2.3 kg daily of molasses during a 70-day winter breeding season or a 135-day fall and winter calving and breeding season increased annual calf production per cow by 16 and 24 kg and cow weights 18 and 15 kg, respectively, over that of cows not fed molasses.

In Oklahoma (Totusek et al., 1971) and Louisiana (Pearson, 1974), range cows fed a high-crude protein liquid feed during the winter months produced lighter calves at weaning or had a lower calf crop than cows supplemented with cottonseed meal. In contrast, Grelen and Pearson (1977) reported that the year-round *ad lib* feeding from a lick tank of a 32% crude protein liquid mixture to range cows in Louisiana produced a 10% higher calf crop and 7 kg heavier calves at weaning than cows fed an average of 1 kg daily of cottonseed meal during the winter months. These results suggest that range cows respond best to year-round feeding of a molasses-urea mixture which includes the spring breeding season. It was interesting that with year-round feeding cows consumed about 2 kg daily of liquid supplement during the summer as compared to only 0.9 kg during the winter months. The question presented is to what extent the benefits derived from year-round supplementation were due to the additional energy provided by molasses in comparison to the additional nitrogen.

In a series of one-year feeding experiments, Rush and Totusek (1976) found that grazing brood cows fed dry supplements containing natural protein or urea during a 140-day winter period tended to lose less weight than cows fed a liquid supplement containing urea. Also, cows fed 1.6 kg daily of a liquid supplement containing urea lost less weight than those fed 3.1 kg of cane molasses. However, cows that lost the most weight during the winter gained more weight during the subsequent summer period, and the birth and weaning weights of calves were similar regardless of the winter supplementation regime. In a 118-day wintering trial Bond and Rumsey (1973) found that non-lactating beef cows fed timothy hay containing 4.3% crude protein lost less weight than cows fed hay and 2.1 kg daily of cane molasses or cane molasses-urea.

Brown (1962; 1967) evaluated different roughage sources in 40%, cane molasses supplements fed to brood cows on open range. During a 41-day winter feeding period, cows fed supplements containing either bagasse or cottonseed hulls lost considerably more weight than cows fed supplements containing grass hay or rice straw (roughage was 27.5% of supplement). These data support those results previously discussed relative to the influence of the roughage source on the response of growing cattle to diets containing molasses.

The following general conclusions are presented relative to the feeding of molasses to brood cows.

1) Molasses supplementation of grazing brood cows will improve cow reproduction and calf weaning weights. Straight-bred cows appear to respond better to molasses feeding than cross-bred cattle.

2) Molasses should be fed to brood cows only during periods of poor forage production, although straight-bred cattle or cattle grazing range appear to respond to year-round molasses supplementation.

3) Additional information is needed relative to the use of formulated liquid supplements to better define the benefits of non-protein nitrogen and other additives. There is a particular need for long-term studies (3 to 5 years) which evaluate the benefits of molasses as an energy source and non-protein nitrogen as a crude protein source, both separately and in combination.

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