S.Afr. J. Anim. Sci. 11, 119 – 137 (1981)

# BYPRODUCTS OF THE SUGAR INDUSTRY AS ANIMAL FEEDS

B.D.H. van Niekerk
*Tongaat Milling Limited, Maidstone, 4380*

(Keywords: *Byproducts, sugar industry, animal feeds)*
(Sleutelwoorde: *Neweprodukte, suikernywerheid, veevoere)*

South Africa ranks approximately 8th in the world as a producer of sugar from sugar cane (Anonymous, 1979). During seasons of normal rainfall, annual production of sugar presently amounts to some 2 million tons. Sugar production has been increasing at an average rate of about 7,5% per annum over the past 20 years (Anonymous, 1978–79). Needless to say, considerable tonnages of primary by-products such as molasses, bagasse, sugar cane tops and filter press are produced. With the exception of filter press, these products can and are used as sources of animal feed. In addition to this, a large tonnage of molasses distillers solubles, a secondary by-product, results from the molasses fermentation industry. This product also has applications in the animal feed industry.

The feeding value of molasses and the other by-products of the sugar industry have been subjects of earlier reviews by Cleasby (1963) and van der Merwe (1970), while van Niekerk (1979) has described the application of these by-products in the feeding of animals under South African conditions.

The purpose of this paper is to give an updated evaluation of the feeding value of molasses, bagasse and sugar cane tops with special reference to South African findings and applications.

## Molasses

### *Availability and Uses*

Of the abovementioned by-products which can be used in animal feeding, molasses is most widely known and applied. Sugar cane molasses is formed during the sugar crystallization process, being produced at a rate of 36 kg for every ton of cane crushed (Anonymous, 1979, 1980). Molasses is the condensed residue which remains after removal of most of the sugar from the concentrated sugar juice. Molasses has many uses. It is most extensively used in the manufacture of yeast and in the fermentation industry to produce potable alcohol and alcohol for fuel and as a chemical feedstock. It has growing and diverse industrial uses of which the briquetting of chrome ore dust and fines is quantitively most important followed by the use of molasses as a binder in the manufacture of refractory bricks and as a binder for carbon black in tyre manufacture. Molasses is used in feeds basically as an energy source, but it also serves other purposes in mixed feeds as it is highly palatable for horses and ruminants and thus helps increase feed intake, particularly of unpalatable roughages. In this country as well as in the U S A, molasses is used extensively as a carrier for liquid feed ingredients which have many applications in farming practice. Because of its sticky nature, it serves to reduce the dustiness of feeds and feed factories. This characteristic also allows molasses to be used as a binding agent during the pelleting process.

Probably its major disadvantages, as a feed ingredient, are its high moisture and also its high and imbalanced mineral content. Moisture, for obvious reasons, restricts its use in the balanced feed industry while its high mineral, and particulary high potassium level, limits its use in poultry feeds.

There have been significant changes taking place in the use of molasses in South Africa during recent years as can be seen from Table 1.

Although there is a long-term growth trend in molasses production, this increase is not going to be sufficient to meet the future yeast, animal feed and industrial demands for molasses. A further alarming aspect for the feed industry is the fact that the fermentation industry is in the process of expanding its production facilities which would herald an increased demand from this area as well. During the 1980–1981 season, South Africa has, for the first time ever, needed to import molasses, although the shortage was aggravated by the worst dry spell in the sugar cane growing areas in recorded history. It would nevertheless seem that in the long-term, expansion of sugar cane production will not take place rapidly enough for molasses production to keep pace with the growing and increasingly diversified demand for this commodity.

Feed manufacturers and farmers will thus, in future, be faced with intensified competition from other segments

**Table 1**

*The production and uses of sugar cane molasses in South Africa (Hill & Torlage, 1981)*

| Production Season | Fermentation Industry | Yeast Production | Animal Feeds | Industrial Uses | Exports (Imports) | Total S.A. Production |
|---|---|---|---|---|---|---|
| | (ton) | (ton) | (ton) | (ton) | (ton) | (ton) |
| 1969 - 1970 | 267 951 | 26 015 | 65 993 | 2 292 | 116 880 * | 479 131 * |
| 1970 - 1971 | 291 864 | 29 851 | 98 771 | 1 706 | 41 883 * | 464 075 * |
| 1971 - 1972 | 270 210 | 29 599 | 65 515 | 1 777 | 163 583 | 530 684 |
| 1972 - 1973 | 277 789 | 34 139 | 93 803 | 2 039 | 142 414 | 550 184 |
| 1973 - 1974 | 291 939 | 34 411 | 129 879 | 3 025 | 90 504 | 549 758 |
| 1974 - 1975 | 298 372 | 53 585 | 141 688 | 3 382 | 136 213 | 633 240 |
| 1975 - 1976 | 266 705 | 49 990 | 155 049 | 4 345 | 153 621 | 629 710 |
| 1976 - 1977 | 278 773 | 63 221 | 190 121 | 10 352 | 180 996 | 723 463 |
| 1977 - 1978 | 271 305 | 52 840 | 201 050 | 17 334 | 215 470 | 757 999 |
| 1978 - 1979 | 288 709 | 55 563 | 210 694 | 18 730 | 102 830 | 676 526 |
| 1979 - 1980 | 300 656 | 57 457 | 243 636 | 32 940 | 33 221 | 667 910 |
| 1980 - 1981 | 316 978 | 65 795 | 258 189 | 19 892 | ( 55 372)** | 605 482 |

* Total S.A. Production in these two years is made up of true domestic production plus actual exports which included carry over of stocks.

** Imported; made up of Fermentation 18 760, Yeast 5 664, Animal Feeds 29,650, Industrial 1 298.

**Table 2**

*The agricultural price of molasses in South Africa (F.O.R.)*

| YEAR | R | YEAR | R |
|---|---|---|---|
| 1970 | 9,00 | 1976 | 12,00 |
| 1971 | 9,00 | 1977 | 15,00 |
| 1972 | 9,90 | 1978 | 17,00 |
| 1973 | 9,90 | 1979 | 18,50 |
| 1974 | 9,90 | 1980 | 28,50 |
| 1975 | 12,00 | 1981 | 37,05 |

of the industry and by consequent further increases in the price of molasses (see Table 2). The use of molasses extenders will need to be urgently investigated.

The abovementioned statistics do not include the production or export of so-called high-test molasses which, in some years, is used as a means of exporting non-quota sugar. It is also used locally to coat sugar for export purposes while a variable amount is used industrially. High-test molasses cannot be classed as a by-product as it is manufactured directly from sugar or sugar juice.

*Chemical composition of molasses*

Molasses is by no means a homogenous product. Like most feed ingredients its chemical composition shows wide variation, being influenced by factors such as soil on which the sugar cane is grown, by environmental factors such as temperature, rainfall (or irrigation), season of production, crop variety and most important, by the factory processes under which it is produced. Its viscosity at a given temperature and moisture content will also change from year to year and from season to season, being influenced by many of the factors listed above. Sugar mills can control the degree of sucrose extraction and because of this, the sucrose content of molasses produced in different countries can vary considerably according to the production technology employed. Sugar mills also differ in the degree in which they are able or prepared to concentrate molasses and because of this, the moisture level of the molasses produced in this country can vary from as little as 15% to as much as 25%.

**Table 3**

*The average proximate chemical composition of standard molasses (average of 19 South African Sugar Mills)*

| Ingredient | 75% DM basis |
|---|---|
| | (g/kg) |
| Moisture | 250 |
| Crude protein | 50 (1) |
| Ether extract | 1 (2) |
| Crude fibre | 0 (2) |
| Total ash | 115 (2) |
| Nitrogen-free extract | 584 (2) |
| Sucrose | 332 (1) |
| Total Sugars | 467 (1) |
| Gum | 25,5 (1) |
| Wax | 4,7 (1) |
| Starch | 1,7 (1) |
| Calcium | 8,8 (1) |
| Phosphorus | 0,7 (1) |
| Sodium | 1,6 (1) |
| Chlorine | 21,1 (1) |
| Magnesium | 5,4 (1) |
| Potassium | 33,3 (1) |
| Sulphur | 6,8 (1) |
| | (mg/kg) |
| Copper | 2,2 (3) |
| Zinc | 2,7 (3) |
| Iron | 101 (2) |
| Cobalt | 3,8 (2) |
| Manganese | 91 (2) |

(1) MacGillivray & Matic, 1970.
(2) Tongaat Milling Laboratory.
(3) Baker (1979).

In an attempt to reduce the variation in viscosity caused by different moisture levels, molasses is today invariably marketed as "standardised" molasses which has a moisture content of approximately 25%. Standardising molasses to this moisture content is of great help to the end user as it makes the product more easy to handle and pump, particularly during cold weather.

Aside from unrecoverable sucrose, molasses contains other sugars such as glucose, fructose, raffinose and unfermentable sugars. South African molasses has a relatively low total sugar content averaging about 46,7% on a 75% DM basis (MacGillivray & Matic, 1960). The non-sugar organic matter in molasses consists of pentosans, starch, organic acids, waxes, gums, sterols, pigments, crude protein and vitamins. The crude protein consists mainly of non-protein nitrogen compounds such as amides, amino acids and other simple nitrogenous compounds. Molasses is a fair source of vitamin E (5 mg/kg) and of the B-vitamins of which biotin is probably of most importance from a practical point of view. Molasses is also a fairly good source of certain minerals. South African molasses is particularly rich in potassium and this is of practical significance as excessive potassium intake is laxative and is believed to be a major cause of wet droppings in poultry. Further, more detailed, information on the composition of molasses is available from a report recently prepared (Baker, 1979).

**Table 4**

*The approximate B-vitamin content of sugar cane molasses (Baker, 1979)*

| | mg/kg |
|---|---|
| Biotin | 1,2 – 3,2 |
| Folic acid | ca 0,04 |
| Inositol | ca 6 000 |
| Pantothenic acid | 54 – 64 |
| Pyridoxine | 2,6 – 5,0 |
| Riboflavin | ca 2,5 |
| Thiamine | ca 1,8 |
| Nicotinic acid | 30 – 800 |
| Choline | 600 – 800 |

Tables 3 and 4 give the average chemical composition of molasses.

### *Nutritive value of molasses*

In certain countries of the world, molasses is the only inexpensive and freely available energy source that can be used for animal production. Research workers in these countries have demonstrated that high levels of molasses can be used to maintain reasonable standards of animal production under these circumstances (Preston, Elias, Willis & Sutherland, 1967; Elias, Preston & Willis, 1969; Preston, Willis & Martin, 1969; Preston, 1970).

South Africa, however, has a wide assortment of alternative energy sources and very large grain surplusses. The use of molasses in animal feeds can, therefore, only be justified if it can compete, on a least cost basis, with these other energy sources. Molasses nevertheless remains a relatively inexpensive source of energy and it is, therefore, important to know the maximum acceptable bounds at which it can be used in various feeds. In complete cattle feeds it is being used by the industry at rates of 10 to 15%, the upper limit being imposed by moisture in the final feed and by its flow properties which deteriorate rapidly at inclusion rates above a 12% level. In pig feeds we have routinely and over many years used molasses at levels of up to 5% (creep, starter rations), 10% (grower ration) and 15,0% (finisher, sow and boar feeds) without any apparent ill effects. In poultry pullet feeds and poultry layer rations we have similarly fed molasses on a large scale over many years at levels of up to 10% and 7,5%, respectively. The only problem encountered is wetness of the droppings which can be troublesome from a management point of view. In broiler feeds the use of molasses tends to be automatically limited by its low energy concentration and by the wetness of droppings it causes. For these reasons, a maximum of about 3% molasses is normally recommended in broiler rations.

Since molasses contains very little protein and consists mainly of carbohydrates, its nutritive value rests largely on its value as an energy source. Experiments have indicated that there is an optimum level of molasses feeding and that higher levels result in lowered production. Thus, if the replacement value of molasses differs with varying levels, it is important to establish the level of optimum utilization. There is, unfortunately, little unanimity of opinion regarding either the ideal feeding level or the energy value of molasses, particularly for ruminants. This can probably be largely attributed to the so-called associative effect of molasses when mixed with other feeds.

This means that, under certain conditions, molasses could have either no effect or even a beneficial effect on the digestibility and/or energy utilization of the ration as a whole as is evident from the findings of many studies where, in general, molasses has been fed at relatively low levels (Mills, Lardinois, Rupel & Hart, 1944; Burroughs, Long, Gerlaugh & Bethke, 1950; Bently, Johnson, Vanecko & Hunt, 1954; Davis, Trimberger, Turk & Loosli, 1955; King, O'Dell, La Master & Roderick, 1955; Lofgreen & Otagaki, 1960b; Bradley, Overfield & Little, 1966; Martin & Wing, 1966; Brown, Overfield, Bradley & Little, 1967; Owen, Kellogg & Howard, 1967; Beeson & Perry, 1969; Preston, Willis & Martin, 1969; Potter, Little, Bradley & Mitchell, 1971; Hatch & Beeson, 1972; White, Reynolds & Hembry, 1973). It could, on the other hand, under certain conditions, have a depressing effect on ration digestibility and/or energy utilization (Bell, Gallup & Whitehair, 1953; King, O'Dell & Roderick, 1957; Lofgreen & Otagaki, 1960a; Lofgreen & Otagaki, 1960b; Brown, Emery, Blank & Benne, 1964; Lofgreen, 1965; Martin & Wing, 1966).

The apparent beneficial effects of molasses in feed mixtures have been attributed to increased microbial activity (Burroughs *et al.*, 1950; Bentley *et al.*, 1954) or to a unique microbial stimulating activity (Bradley *et al.*, 1966; Brown *et al.*, 1967; Young, Bradley, Little & Bolling, 1969; Hatch & Beeson, 1972). The adverse effects of molasses that have been reported and which are invariably associated with high levels of molasses feeding are probably caused by a combination of factors. Depressed ration digestibility and particularly crude fibre could be one reason (Briggs & Heller, 1945; Bohman, Trimberger, Loosli & Turk, 1954; Brown *et al.*, 1964; Martin & Wing, 1966). The effect of high levels of molasses on crude fibre digestibility in ruminant feeds can be attributed to the fact that molasses will stimulate the growth of fast-growing saccharolytic micro-organisms at the expense of the slower cellulolytic bacteria and lactic acid utilizers. The resultant accumulation of lactic acid lowers rumen pH thus depressing the growth of cellulolytic and lactic acid utilizers even further (Gilchrist & Schwartz, 1972; Henning, van der Linden, Mattheyse, Nauhaus, Schwartz & Gilchrist, 1980). Another possible cause of poor feed utilization is the fact that a high level of molasses feeding changes the proportion of fatty acids formed in the rumen, as suggested by Lofgreen & Otagaki (1960b) and that this could result in a lower net utilization of molasses. That the feeding of high levels of molasses is, in fact, associated with depressed levels of total volatile fatty acids accompanied by marked increases in the concentration of butyric acid has since been demonstrated (Sutton, 1968; 1969; Marty & Preston, 1970; Marty & Henderickx, 1972). Swan (1975) has suggested that this could result in a metabolic glucose deficiency. From Table 5 it is clear that there is reasonable agreement regarding the energy value of molasses for non-ruminants. Values of about 9,8 MJ/kg for pigs and 8,3 MJ/kg for poultry would appear to be fairly representative of the metabolisable energy value of standard molasses for these species. For ruminants there does not appear to be the same consensus. Much of this divergence of opinion appears to be associated with the level of molasses fed.

Morrison (1957) recommended a grain replacement value for molasses of only 40% to 50% when used to substitute 25% to 45% of the grain in fattening rations. But when used in small amounts he considered molasses to be worth 75% to 95% the value of grain. Lofgreen & Otagaki (1960a) found that molasses has a relatively high net energy value when used in steer fattening ra-

## Table 5

*The energy value of standard molasses for pigs, poultry and ruminants (75% DM basis)*

| REFERENCE | | Level of Molasses | TDN | DE | ME | $NE_m$ | $NE_g$ | $NE_\ell$ |
|---|---|---|---|---|---|---|---|---|
| | | (%) | (%) | (MJ/kg) | (MJ/kg) | (MJ/kg) | (MJ/kg) | (MJ/kg) |
| **POULTRY** | | | | | | | | |
| Crampton *et al.* | (1969) | N/A | – | – | 8,2 | – | – | – |
| NRC, Atlas | (1971) | N/A | – | – | 8,2 | – | – | – |
| Latin Amer. etc | (1974) | N/A | – | – | 8,3 | – | – | – |
| Scott *et al.* | (1976) | N/A | – | – | 8,2 | – | – | – |
| Ensminger *et al.* | (1978) | N/A | – | – | 8,3 | – | – | – |
| Feedstuffs | (1980) | N/A | – | – | 8,4 | – | – | – |
| **PIGS** | | | | | | | | |
| Crampton | (1969) | N/A | 56 | 10,3 | 9,8 | – | – | – |
| NRC, Atlas | (1971) | N/A | – | 10,3 | 9,8 | – | – | – |
| Latin Amer. etc | (1974) | N/A | 57 | 10,5 | 10,0 | – | – | – |
| Ensminger *et al.* | (1978) | N/A | 57 | 10,6 | 9,3 | – | – | – |
| N R C | (1979) | N/A | – | 10,5 | 9,9 | – | – | – |
| Feedstuffs | (1980) | N/A | 55 | – | 9,8 | – | – | – |
| **SHEEP** | | | | | | | | |
| Crampton *et al.* | (1969) | N/A | 54 | 10,0 | 8,2 | – | – | – |
| NRC, Atlas | (1971) | N/A | 53 | 9,8 | 8,1 | – | – | – |
| Latin Amer. etc | (1974) | N/A | 53 | 9,8 | 8,1 | – | – | – |
| N R C | (1975) | N/A | 54 | 10,0 | 8,2 | – | – | – |
| **"RUMINANTS"** | | | | | | | | |
| Morrison | (1957) | N/A | 55 | – | – | – | * | – |
| NRC, Atlas | (1971) | N/A | 72 | 13,3 | 10,9 | 7,1 | 4,7 | 8,2 |
| Ensminger *et al.* | (1978) | N/A | 55 | 10,1 | 8,3 | 5,2 | 3,4 | 5,2 |
| Feedstuffs | (1980) | N/A | 55 | – | – | – | – | – |
| **BEEF CATTLE** | | | | | | | | |
| Lofgreen *et al.* | (1960a) | 10 | 63 | 12,0 | – | – | 6,4** | – |
| Lofgreen *et al.* | (1960a) | 25 | 62 | 11,6 | – | – | 3,5** | – |
| Lofgreen *et al.* | (1960a) | 40 | 59 | 10,9 | – | – | 3,2** | – |
| Lofgreen | (1965) | 5, 10, 15 | – | – | – | 5,7 | 3,3** | – |
| Lofgreen | (1965) | 20 | – | – | – | 5,2 | 2,9** | – |
| Crampton *et al.* | (1969) | N/A | 68 | 12,6 | 10,3 | 6,3 | 4,0 | – |
| N R C | (1970) | N/A | 68 | – | 10,3 | 7,1 | 4,7 | – |
| N R C | (1976) | N/A | 54 | – | 8,6 | 6,0 | 3,8 | – |
| **DAIRY COWS** | | | | | | | | |
| Lofgreen *et al.* | (1960b) | 10 | – | 8,9 | – | – | – | 6,3 |
| Lofgreen *et al.* | (1960b) | 30 | – | 9,3 | – | – | – | 2,1 |
| N R C | (1971) | N/A | 68 | 12,6 | 10,8 | 7,1 | 4,7 | 7,6 |
| N R C | (1978) | N/A | 54 | 10,0 | 8,7 | 5,0 | 3,2 | 5,2 |

* Morrison (1957) gives the following *estimated* net energy value for molasses:

| | |
|---|---|
| Fattening sheep and cattle, grain replacement | = 5,27 MJ/kg |
| Fattening sheep and cattle, excellent rations | = 3,98 MJ/kg |
| Dairy cows when not exceeding 10% of concentrate | = 6,57 MJ/kg |

** Net energy *production* values

tions at 10%. They found, however, that as the level of molasses was increased to 25% and 40% , the net energy value was reduced by almost 100%. Similarly, in another investigation by the same workers (Lofgreen & Otagaki, 1960b), the net energy value of molasses for lactation was reduced from 6,27 MJ/kg at a 10% level of inclusion to 2,13 MJ/kg at a 30% inclusion level compared to 4,98 MJ/kg for the basal diet. It will be noted from Table 5 that there was no decrease in the DE value of the molasses when its level of feeding was increased from 10% to 30%. It is, therefore, obvious that indigestibility of the feed cannot account for the large loss in NE recorded in this experiment. Preston *et al.* (1969) are, however, critical of the energy evaluation system employed by Lofgreen & Otagaki and consider this system to be particularly inappropriate when used as in these studies. Preston *et al.* (1969) failed to find support for the claim that increasing levels of molasses lead to a decrease in the efficiency of feed utilization in spite of the fact that the diets they tested supplied as much as 33% and 72% of the ME as molasses. Other studies by Preston *et al.* (1967) and Elias *et al.* (1969) proved that molasses can be used as a major energy source for fattening cattle and that, in terms of livemass gain per unit of ME, it is comparable with high grain diets. In still further studies aimed at evaluating the net energy value of molasses fed to beef steers in typical commercial fattening rations, Lofgreen (1965) concluded that animals receiving 5, 10, 15 and 20% molasses in their rations performed similarly, but that the groups receiving 20% molasses levels required more feed than the other groups when adjusted to equal energy gain. The $NE_p$ of molasses at 5, 10 and 15% of the ration was 3,26 MJ/kg and this declined to 2,93 MJ/kg when the molasses level was increased to 20% of the ration. He concluded that molasses has approximately 74% the value of barley when used up to a 15% level in the feed. Swan (1975) reported results on sheep where molasses was used to replace 10 or 20% barley in the diet. Dry matter and organic matter digestibility were not depressed and the author concludes that molasses has 82% the DE value of barley. Hatch & Beeson (1972) found that when molasses was used to replace maize at 5, 10 and 15% levels, an improvement in various diet parameters under investigation resulted. They suggested, as a result of their findings, that cane molasses need not be assigned an energy value lower than maize when fed at limited levels. From the above it is evident that with the low levels normally fed in South Africa, molasses will have a relatively high energy value and that the lower energy values attributed to molasses in Table 5 are probably unrealistically low at these levels of feeding.

This conclusion is borne out by the results of various South African studies on production rations containing molasses. Stewart (1970), for example, found that molasses could constitute up to 29% of the dry matter in the diet of dairy cows without any adverse effect on milk production or composition of milk. Hugo (1975) in trials with dairy cows, where molasses replaced approximately 8%, 12% and 15% maize meal in the ration, found that neither level of production nor composition of milk are adversely affected although the molasses-fed cows tended to consume more feed than the controls. In beef cattle Lishman (1967) found that where molasses replaced maize meal at levels of 0%, 10%, 20% and 30% there were no significant differences in rate of gain or carcase characteristics. Work done at the Henderson Research Station in Rhodesia (Elliott & O'Donovan, 1972–73) showed that where molasses replaced maize meal at 5 levels varying from 0 to 54%, there was no decrease in the efficiency of livemass gain until the 40% level of molasses was exceeded. There was, however, a steady decline in efficiency of carcase gain as molasses replaced maize. Considering the extremely high levels of molasses fed, the decline in efficiency of carcase gain is surprisingly small. Van Niekerk & Voges (1976) showed that the replacement of maize with molasses at levels of 0%, 7%, 14% and 21%, expressed on a dry matter basis, did not significantly effect rate of live or carcase mass gain although feed conversion rate was markedly poorer at the 21% level of replacement. These results were basically confirmed in a further study of the same design as reported by Kargaard & van Niekerk (1977). In this experiment the replacement of maize meal by molasses at 7% and 14%, on a dry matter basis, had no effect on rate of gain, but animal performance was significantly depressed when molasses replaced 21% of the maize meal in the ration. From these experiments the authors concluded that provided molasses does not exceed 14% in beef fattening rations, it will have a value expressed on a dry matter basis, very similar to maize. This means that on a 75% dry matter basis, molasses should have a TDN value of 68% or $NE_g$ value of 4,65 MJ/kg. This would give molasses a feeding value of about 80% of that of maize, both expressed on an as-fed basis. It is interesting to note that this estimate agrees closely with the much earlier assessment by Scott (1953) who, after an extensive review of the literature, concluded that molasses has about 85% the value of maize grain but that this value could be as low as 75% under unfavourable conditions.

## Bagasse

### *Availability and uses*

Bagasse is the fibrous residue which remains after sugar juice has been crushed from the sugar cane stalk during the sugar milling process. Quantitatively it is the most important by-product of the sugar milling industry. South African sugar cane is relatively high in fibre content. Every 1 ton of harvested cane will yield about 320 kg of bagasse (46% DM). Expressed differently, for every 1 ton of sugar manufactured in this country, about 1,37 ton of bagasse dry matter is produced. The total annual tonnage of bagasse produced in South Africa is thus as follows (Anonymous 1979, 1980):

| | Annual Production (million ton) | |
|---|---|---|
| | As-is basis | DM basis |
| Whole sugar cane bagasse (average 1979–80) | 6,0 | 2,9 |

Bagasse is mostly used as a fuel for sugar mill furnaces, but it has other important industrial applications such as for the manufacture of paper, particle board, furfural and for the manufacture of light weight concrete for structural purposes. There is furthermore, considerable development work in progress on the use of bagasse as a substrate for the production of single cell protein (Sprinivasan & Han, 1969; Han & Callihan, 1974). In the sugar growing areas of the world, bagasse has for many years been used in a variety of ways and in various forms in the feeding of animals. Bagasse can either be used fresh from the sugar mill or it can be dried and processed into various feeds. Because of the seasonal nature of bagasse production, it is often stored in baled form or it is ensiled so as to extend both its agricultural and industrial applications throughout the year and beyond the confines of the sugar milling season.

The extreme bulky nature of raw bagasse (± 100 kg/m$^3$) makes it difficult and expensive to handle and transport. This has, in the past, restricted its animal feeds application to the sugar growing areas, but this problem has in more recent years been overcome in several countries by the drying and pelleting of the product, using limited amounts of molasses (6 to 10%) primarily as a binding agent. In this form it is used almost exclusively as a fibre source in complete dairy, beef, sheep, horse and rabbit feeds. This processing technique greatly increases the bulk density to approximately 600 kg/m$^3$. During the pelleting process bagasse is exposed to steam and high temperatures and pressures which are believed may improve the digestibility of the material. The nutritive value is further enhanced by the addition of 6 to 10% molasses as a binding agent. This pelleting process, with minor modifications, also lends itself to treatment of bagasse with sodium hydroxide.

The unprecedented expansion of the feedlot industry and the great increase in the use of complete dairy feeds in recent years in this country has resulted in the shortage of dependable and readily available roughage sources. The feed industry and some of the larger feedlots have always relied on by-products such as cottonseed hulls, sunflower hulls and peanut hulls as roughage sources for incorporation into complete feeds. More conventional roughage sources such as cereal straw, grass hay and maize cobs, leaves and stalks, although produced in vast quantities, are highly seasonal in availability and are bulky and expensive to collect, transport and store. Bagasse on the otherhand, need not be collected or transported as it comes off the end of a conveyer belt continuously over the normal 8–9 months South African cane cutting season. Surplus production can be ensiled at point of manufacture so that the raw material is available for processing at little cost throughout the year. In the pelleted form, bagasse offers many important advantages such as potentially large available tonnages, dependability of supply and ideal physical properties which do not render any storage, handling or transport problems in modern feed manufacturing plants or with transport to and bulk storage on farms.

Bagasse, because of its porous nature, is also used as a carrier for molasses and molassed- based liquid feed mixtures. Bagasse *pith* will absorb even greater amounts of molasses (up to 80% by weight) and yet remain reasonably free flowing and friable. This characteristic of bagasse has been exploited in various countries of the world, including South Africa, to convert the 2 major sugar industry by-products into a form which is palatable, nutritious and which can easily be used by the farmer.

*Composition of bagasse*

Fresh whole bagasse contains approximately 54% moisture. On a dry basis, whole bagasse has a gross composition of approximately 50% cellulose, 25% pentosans and 25% lignin (Spencer-Meade, 1963). The dry material consists of 2 major physically identifiable constituents, namely the hard strong fibres of the outer cortex and the inner pith or parenchyma which contained the original juice. It can be classified under the ligno-celluloses and is composed of interpenetrating systems of high polymers. It is, therefore, difficult to separate the pith from the fibre. Various techniques exist for separating bagasse. These processes are of importance in practice because in paper or board production, the manufacturer attempts to remove as much pith as possible and to retain the fibre for the subsequent manufacturing process. For use in certain feeds, however, the pith is often preferred as it acts as the ideal carrier for molasses or molasses-based liquid feed mixtures and because of its more attractive appearance in blended feeds. However, because the methods of separation are rather empirical, the resultant products are non-uniform in composition and the results reported in the literature for bagasse fines or "pith" can, therefore, be expected to vary

## Table 6

*Proximate analysis of various forms of bagasse expressed on an as-is basis*

| | Dried (1) whole Bagasse | Bassage (2) Pith | Pelleted (3) Bagasse Pith | Pelleted (4) whole Bagasse silage | Pelleted (5) NaOH Bagasse Pith |
|---|---|---|---|---|---|
| | (g/kg) | (g/kg) | (g/kg) | (g/kg) | (g/kg) |
| Moisture | 66 | 63 | 65 | 67 | 90 |
| Crude protein | 20 | 22 | 26 | 24 | 30 |
| Ether extract | 9 | 10 | 10 | 9 | 9 |
| Crude fibre | 430 | 400 | 346 | 363 | 315 |
| Ash | 39 | 45 | 58 | 55 | 97 |
| N F E | 436 | 460 | 495 | 482 | 459 |
| Ca | 2,3 | 2,3 | 2,4 | 2,4 | 2,2 |
| P | 0,3 | 0,3 | 0,4 | 0,4 | 0,3 |
| Na | 0,6 | 0,8 | 1,0 | 1,0 | 3,0 |
| K | 0,5 | 0,5 | 2,7 | 2,8 | 2,5 |

(1) Unseparated and unprocessed bagasse direct from sugar mill.

(2) Obtained by separating whole bagasse by air flotation into two fractions, namely, the harder rind or sugar cane barrel and the pith or parenchyma plus smaller pieces of the barrel or rind.

(3) As above but pelleted with steam and 6 to 10 % molasses.

(4) Whole ensiled bagasse (no additives) pelleted with steam and 6 to 10 % molasses.

(5) As in (2) above except 5 % NaOH added immediately prior to pelleting.

accordingly. It is, in fact, often not even clear whether the values which appear in the literature refer to whole bagasse or the separated product, because of the failure of research workers to clearly define the product used. Table 6 gives the long-term average composition of bagasse in its various forms as determined in our laboratory.

*Nutritive value of bagasse*

Bagasse contains practically no protein and it is poorly digested. Interest in the use of this product as a feed ingredient, however, stems from its fibre content and thus its value as a readily available and inexpensive source of roughage in complete dairy, beef, horse and rabbit feeds. Because of its extremely bulky nature in the raw unprocessed forms, the commercial use of the product as a fibre source is limited almost entirely to pelleted whole bagasse, pelleted ensiled whole bagasse or pelleted bagasse pith. Being a rather uncommon feedstuff, it is often not listed in feedstuffs tables. Table 7 gives a summary of available information published in various reference sources. Where possible, information relating to the form of bagasse used is given.

*Results of Feeding Trials*

Since "bagasse" is available in a variety of different forms, it can be expected that differences will exist, not only in its composition and energy value (Table 6 & 7), but also in the results of feeding trials. Earlier experiments with whole and often unprocessed bagasse, generally used at relatively high levels to replace conventional roughage sources, revealed poor feed intakes and sometimes sub-standard animal performance (Henke, 1950–52; Wayman, Iwanaga, Henke & Weeth, 1953; Brown, Damon, Singletary & Vernon, 1954).

Table 7

*Energy value of sugar cane bagasse (92% DM basis) for ruminants*

| REFERENCE | | Description of product | TDN | DE | ME | $NE_m$ | $NE_g$ | $NE_\ell$ |
|---|---|---|---|---|---|---|---|---|
| | | | (%) | (MJ/kg) | (MJ/kg) | (MJ/kg) | (MJ/kg) | (MJ/kg) |
| **RUMINANTS** | | | | | | | | |
| Ensminger *et al.* | (1978) | Bagasse | 44 | 8,0 | 6,6 | 3,9 | 0,6 | 4,0 |
| **SHEEP** | | | | | | | | |
| Crampton *et al.* | (1969) | Pulp | 45 | 8,3 | 6,8 | – | – | – |
| Latin Amer. etc | (1974) | Pulp | 45 | 8,4 | 6,9 | – | – | – |
| NRC, Atlas | (1971) | Pulp | 43 | 8,0 | 6,5 | – | – | – |
| NRC, Atlas | (1971) | Pulp, sifted | 46 | 8,5 | 7,0 | – | – | – |
| **CATTLE** | | | | | | | | |
| Crampton *et al.* | (1969) | Pulp | 44 | 8,2 | 6,7 | – | – | – |
| Latin Amer. etc | (1974) | Pulp | 46 | 8,4 | 6,9 | 4,0 | 1,0 | 3,8 |
| NRC, Atlas | (1971) | Pulp | 26 | 4,8 | 3,9 | – | – | – |
| NRC, Atlas | (1971) | Pulp, sifted | 42 | 7,7 | 6,3 | – | – | – |
| **DAIRY** | | | | | | | | |
| NRC | (1978) | Bagasse | 26 | 5,2 | 3,3 | 3,0 | 0 | 2,4 |

Where dried and milled bagasse, and particularly the more recently developed bagasse pellet, has been used primarily as a fibre source in more concentrated feeding regimes and specifically in complete dairy and beef diets, the results have been more encouraging. Even further improvements in animal performance have been observed where sodium hydroxide and other techniques of enhancing digestibility have been applied.

*Fattening Trials*: Perry, Beeson, Kennington & Harper (1959) found that milled maize cobs, sugar cane bagasse and cottonseed hulls were more valuable as sources of roughage in all-pelleted rations for fattening lambs than oat mill feed, soybean mill feed and sun cured lucerne. Kirk, Chapman, Peacock & Davis (1969) reported on a whole series of experiments with beef cattle conducted at both the Florida Range Cattle Experimental Station and at the Everglades Experimental Station. Whole bagasse, bagasse pith, molasses impregnated bagasse and ammoniated bagasse were compared with pongola grass hay, maize cobs and husks and cottonseed hulls. Bagasse products, in general, could be used to replace cottonseed hulls and grass hay without significantly affecting rate of gain. In one of these comparisons, bagasse *pith* as roughage produced the same rate of gain as pongola grass hay. In another comparison between maize cob and husk, whole bagasse and bagasse fines (pith), used as roughage sources, efficiency of gain was found to be slightly superior for maize cob and husk while whole bagasse in turn produced somewhat more efficient gains than bagasse fines. They furthermore found that rations containing bagasse at 20% to 30% levels made rapid and economical gains during the first 70 days but after this, rate of gain decreased because of the low energy content of the rations. There was no difference in rate or efficiency of gain when 15% bagasse was compared with other roughage sources. Chapman & Palmer (1972) used bagasse *pith pellets* in 2 separate experiments to compare bagasse with cottonseed hulls at 7,5% and 15% levels or at 5% and 10% levels of roughage inclusion in beef fattening rations. In 3 out of 4 comparisons, bagasse pith pellets out-performed cottonseed hulls in terms of efficiencies of gain. It was also found that the animals fed the bagasse pith pellets were easier to keep on feed. The best level of feeding for bagasse pith pellets appeared to range between 7,5% and 10,0%.

Sudweeks & Ely (1976) conducted two experiments with steers in which rice husks and bagasse *pellets* were fed at three grain:roughage ratios, namely, 10:90, 40:60 and 70:30. The purpose of the trials was to measure the roughage characteristics of these 2 fibre sources. The low-grain ration, containing ground rice hulls, was refused initially and the low-grain ration containing bagasse, was consumed the first day, then refused, making it necessary to adjust ration composition. Scouring occurred with all animals at the medium grain level when rice hulls were fed and was persistent at the high grain level. Two cases of bloat occurred at the high grain level with the rice hull ration. There was no scouring or bloating when sugar cane bagasse was fed, even at the high grain level where the roughage consisted entirely of bagasse. Ground rice hulls can be included in low energy rations to a maximum of 13% before feed intake is markedly reduced while bagasse pellets could substitute up to 44% of this type of ration..

*Dairy Trials*: Randel (1966) set out to compare a complete dairy feed based on 15% ground bagasse with a conventional feeding system based on concentrate, harvested forage and limited pasture. Cows fed the complete feed based on bagasse, produced more milk (16,2 kg vs 21,5 kg), milk fat, milk protein and milk solids non-fat. The daily mass gains were 0,14 kg for the control and 0,25 kg per day for the complete diet. The differences in mass gain, milk production, milk protein and solids non-fat were highly significant. It was concluded that complete rations based on bagasse were both nutritionally and economically feasible. In further similar trials Randel (1970) used a higher level of bagasse (22,5%) and molasses (20%) in complete feed which was again compared with a conventional feeding system of silage *ad lib* plus concentrates *ad lib.* Since essentially no differences in milk production (22,1 kg vs 21,5 kg) were measured between the complete feed and the conventional feeding system, it was concluded that a complete diet, containing 22,5% ground bagasse, is capable of sustaining milk production at nearly maximum capacity.

Marshall & van Horn (1975) compared whole bagasse pellets with cottonseed hulls in complete diets for lactating cows. When incorporated at 25% in complete diets, milk production on the bagasse pellet ration was about equal that of the diet containing cottonseed hulls. The 25% bagasse level in a ration with 37% citrus pulp contained adequate fibre to maintain milk fat test. In a second experiment by these authors, three levels of bagasse pellets were compared and within each bagasse level, coastal bermuda hay, sodium bentonite and a control were compared. Feed intake was significantly higher on the rations with 25% bagasse. There were no significant treatment effects for the other comparisons. With rations containing 37% citrus pulp, the 25% bagasse inclusion rate appeared to be the optimum level.

Since sugar cane production is seasonal, it is important to know if bagasse stored in the form of silage can be used with equal success in animal feeds. With this in mind, Roman-Ponce, van Horn, Marshall, Wilcox & Randel (1975) compared bagasse pellets made fresh off production, with bagasse pellets made from ensiled material. Both types of pellets were used at 2 levels, namely 30% and 40% in complete diets. Feed intake was higher on the ensiled material than on the fresh bagasse resulting in greater gain in body mass and slightly improved milk production. These results thus prove that the outdoor storage of bagasse during the sugar "off-crop" period is not only feasible, but probably also beneficial.

*Upgrading bagasse*: The treatment of bagasse with NaOH will not be dealt with in detail in this talk as this is the subject of another paper being presented at this conference.

Bagasse lends itself particularly well to treatment with NaOH and other alkali substances. Pelleted bagasse is the only form in which it is practical to market such an extremely bulky product outside the sugar growing areas. It, therefore, requires little extra capital investment to then also treat it with NaOH during the pelleting process. It is for this reason and also because the digestibility of bagasse, with its high degree of lignification, can be greatly enhanced by NaOH treatment (Dekker & Richards, 1973; Martin, Cribeiro, Cabello & Elias, 1974; Martin, Cabello & Elias, 1976; Hofmeyr & Jansen, 1976) that this aspect has enjoyed considerable attention.

A system of making silage from NaOH-treated bagasse has been described by Andreis & De Stefano (1977, 1978). Silages were prepared using combinations of molasses, urea, maize and treated or untreated bagasse. Animals fed silage made from NaOH treated bagasse consistently consumed more feed than those fed untreated bagasse silage. Total feed consumption was 30% to 40% higher for the treated silage while mass gains were about 30% greater.

Randel, Ramirez, Carrero & Valencia (1972) compared NaOH treated raw sugar cane bagasse with untreated bagasse in complete diets for dairy cows. Daily consumption of the treated and untreated bagasse concentrates amounted to 16,5 and 14,2 kg daily. The group receiving treated bagasse produced considerably more milk (17,2 kg vs 12,5 kg) but with lower percentages of milk fat and total milk solids. Daily livemass gain was only 0,04 kg per day on raw bagasse compared with 0,22 kg per day for the NaOH treated bagasse.

A further development in the upgrading of bagasse has been the use of steam pressure with and without added chemicals. Promising results in terms of improved digestibility have been reported by Martin *et al.* (1974) Martin *et al.* (1976) and by Hart, Walker, Graham, Hanni, Brown & Kohler (1981) using high pressure steam and alkali. This technique will, however, require considerable further investigation in view of the poor response in terms of animal performance reported by Garrett, Walker, Kohler, Hart & Graham (1981) on steam treated straw.

**Tongaat Milling Experimental Results**

The form of bagasse being produced and distributed in South Africa at present consists mainly of pelleted bagasse pith derived as described in Table 6. In order to evaluate this product in production rations as applied in South Africa, a series of experiments was conducted. A summary of these investigations, which have not been previously published, follow:

1. *Digestion Trials: In vivo* digestion experiments were sponsored at both the Instituut Voor Veevoedings-onderzoek "Hoorn", Lelystad, Holland and at the Institut für Tierernëhrung in Braunschweig, Germany, using pelleted South African bagasse pith. The digestion experiments conducted in Holland show that untreated bagasse pith pellets had a TDN (DM basis) content of 45,4 % while bagasse pellets treated with 6 % NaOH had a TDN (DM basis) content of 60,9 %. The German trial conducted on untreated bagasse pith pellets only indicated a TDN value of 43,6 % (DM basis). These results are thus in fairly good agreement with majority of values as reported in Table 7.

2. *Lucerne replacement experiment*: The purpose of this experiment was to establish the effect of the partial or total replacement of lucerne meal with sugar cane pith pellets on cattle feedlot gain. Complete cattle feed diets containing the following roughage levels and sources were compared.

| | Treatment 1 | Treatment 2 | Treatment 3 |
|---|---|---|---|
| Cane pith pellets | 14 % | 9 % | 4 % |
| Lucerne meal | 0 | 5 | 10 |

Twelve animals per group were used and the experiment was replicated. The diets were balanced as far as practically possible so that the 3 diets supplied the same levels of protein, minerals, energy and fibre. The following results were obtained:

| | Treatment 1 | Treatment 2 | Treatment 3 |
|---|---|---|---|
| Duration of feeding, days | 133 | 133 | 133 |
| Ave total livemass gain, kg | 176,5 | 170,9 | 166,4 |
| Ave daily feed intake, kg | 8,76 | 8,53 | 8,34 |
| Ave daily live gain, kg | 1,33 | 1,28 | 1,25 |
| Livemass F C R | 6,61 | 6,64 | 6,68 |
| Ave daily carcase gain, kg | 0,86 | 0,85 | 0,84 |
| Carcase mass F C R | 10,32 | 10,09 | 10,05 |

From this work it can be concluded that it is possible to replace lucerne, either partially or totally, with cane pith pellets without significantly adversely affecting livemass gain or feed conversion rates. In fact, in terms of livemass gain and livemass feed conversion rates, the lucerne-free rations appeared to be superior.

Of particular interest is the fact that the cane pith pellets showed a very distinct advantage during the critical adaptation period as is evident from the following results:

| | Voluntary feed intake (kg) | Mass gained (kg) |
|---|---|---|
| | (1st 14 days) | (1st 14 days) |
| 0 % Lucerne, 14 % cane pith | 83,0 | 21,5 |
| 5 % Lucerne, 9 % cane pith | 78,0 | 16,5 |
| 10 % Lucerne, 5 % cane pith | 72,5 | 13,0 |

**Table 8**

*Effect of fibre level and kind of roughage on voluntary feed intake and rate of gain during the first 14 days of fattening*

| TREATMENT | Days 1 – 14 | | Full term | |
|---|---|---|---|---|
| | kg feed/ animal/day | ADG | kg feed/ animal/day | ADG |
| 7,5 % Cane pith pellets | 4,89 | 1,18 | 6,59 | 0,84 |
| 7,5 % Sunflower hulls | 4,55 | 0,40 | 5,83 | 0,71 |
| 7,5 % Rice husks | 3,65 | 0,51 | 5,83 | 0,82 |
| 12,0 % Cane pith pellets | 4,73 | 0,81 | 6,96 | 0,85 |
| 12,0 % Sunflower husks | 4,49 | 0,58 | 6,25 | 0,79 |
| 12,0 % Rice husks | 4,01 | 0,46 | 5,76 | 0,71 |

3. *Comparison of sugar cane pith pellets, sunflower hulls and rice husks as roughage sources*: The purpose of this experiment was to compare three types of roughage whose availability and physical characteristics make their use in commercial feeds possible. Cane pith pellets, sunflowerseed hulls and rice husks were also compared at 2 levels of inclusion (7,5 % and 12 %, respectively) as the sole sources of roughage in complete feedlot diets. The diets were compounded so that the 3 basic treatments supplied the same levels of protein fibre, minerals and energy. The various treatment groups were fed to gain the same total livemass and were thus fed for varying period of time. The results can be summarised as follows:

Voluntary feed intake was found to be influenced quite markedly by the roughage source and this difference was most obvious during the adaptation period as will be seen from Table 8.

The effects of these treatments on animal performance are summarised in Table 9.

This study, in common with all other trials conducted at this research station, shows that animals fed highly concentrated rations adapt far more rapidly when cane pith in pelleted form is used as the roughage source. This observation is borne out by the higher feed intake and more rapid rate of livemass gain during the earlier phases of the feeding period.

The animals fed cane pith pellets also showed the best rate of livemass gain and the best rate of carcase mass gain expressed over the whole experimental period. In terms of feed conversion rates this advantage tended to be negated by the higher feed intakes of the cane pith pellets so that this advantage, in terms of efficiency of feed conversion, was not necessarily maintained over the entire feeding period.

4. *Grain replacement experiment – NaOH treated cane pith*: The results of this investigation are being reported in greater detail (Tarr & van Niekerk) elsewhere at this conference.

*In vitro* and *in vivo* experiments show that the digestibility of cane pith can be considerably increased by treating the product with sodium hydroxide. This process can be easily applied under ideal conditions (i.e. high temperature and pressure) during the cane pith pellet manufacturing process.

The purpose of this experiment was to establish to what extent the upgraded cane pith pellet (treated with 4 % NaOH) could be used as a replacement for more expensive grain in complete feedlot rations. For this purpose upgraded cane pith pellets were used to replace maize meal at levels of 7,5 %, 15,0 %, 22,5 % and 30,0 % in complete cattle fattening diets. Untreated cane pith pellets, used at the same levels, served as control treatments. The 4 rations, containing the 4 different fibre levels, were compounded to contain identical levels of protein and minerals and thus differed from each other only as regards their fibre and energy levels. The main findings are summarised in Table 10.

Feed intake, at all levels of grain replacement, was improved by treating the pellets with caustic soda. As the level of roughage inclusion in the ration increased so the response to caustic soda treatment in terms of voluntary

## Table 9

*Effect of level of roughage and type of roughage on feedlot performance*

| | 7,5 % Roughage level | | | 12% Roughage level | | |
|---|---|---|---|---|---|---|
| | Cane pith | Sunflower hulls | Rice husk | Cane pith | Sunflower hulls | Rice husk |
| Animals per group | 12 | 12 | 12 | 12 | 12 | 12 |
| Days on feed | 112 | 132 | 119 | 112 | 119 | 132 |
| ADG livemass, kg | 0,84 | 0,71 | 0,82 | 0,85 | 0,79 | 0,71 |
| ADG carcase mass, kg | 0,58 | 0,51 | 0,53 | 0,55 | 0,51 | 0,51 |
| FCR* livemass | 6,82 | 7,36 | 6,28 | 7,32 | 7,07 | 7,16 |
| FCR* carcase mass | 9,92 | 10,30 | 9,79 | 11,35 | 10,98 | 10,10 |

* Calculated with feed expressed on a dry matter basis.

## Table 10

*Effect of replacing maize meal with untreated and NaOH treated cane pith pellets on efficiency of feedlot gain*

| PELLETS: | Untreated pith pellets | | | | Treated pith pellets | | | |
|---|---|---|---|---|---|---|---|---|
| INCLUSION RATE: | 7,5 | 15,0 | 22,5 | 30,0 | 7,5 | 15,0 | 22,5 | 30,0 |
| No of cattle | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Days on feed | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 |
| Daily feed intake, kg | 9,61 | 10,01 | 10,14 | 10,04 | 9,96 | 10,72 | 11,04 | 10,63 |
| Daily livemass gain, kg | 1,66 | 1,59 | 1,70 | 1,53 | 1,72 | 1,76 | 1,69 | 1,66 |
| Daily carcase mass gain | 0,97 | 0,91 | 0,91 | 0,77 | 0,98 | 1,01 | 0,97 | 0,90 |
| FCR livemass | 5,78 | 6,29 | 5,97 | 6,56 | 5,78 | 6,09 | 6,56 | 6,41 |
| FCR carcase mass | 9,95 | 10,96 | 11,17 | 13,04 | 10,21 | 10,58 | 11,43 | 11,80 |

**Table 11**

*Effect of NaOH treatment of cane pith on voluntary feed intake during the first 14 days of feedlot feeding*

| | Voluntary feed intake (1st 14 days) | Mass gained (1st 14 days) |
|---|---|---|
| **Untreated cane pith pellets** | | |
| 7,5 % inclusion | 105,5 | 13,0 |
| 15,0 % inclusion | 117,0 | 15,0 |
| 22,5 % inclusion | 113,0 | 15,0 |
| 30,0 % inclusion | 104,0 | 10,5 |
| Average | 110,0 | 13,5 |
| **4 % NaOH treated cane pith pellets** | | |
| 7,5 % inclusion | 126,5 | 22,5 |
| 15,0 % inclusion | 122,0 | 24,0 |
| 22,5 % inclusion | 132,0 | 20,0 |
| 30,0 % inclusion | 128,0 | 16,5 |
| Average | 127,0 | 21,0 |

feed intake increased, except at the highest level of roughage inclusion.

From the above results it is evident that rate of livemass gain, rate of carcase mass gain and efficiency of feed conversion for livemass gain were consistently improved by caustic soda treatment. In terms of efficiency of carcase mass gain, there appeared to be no consistent advantage to be gained from caustic soda treatment, although there was a small positive advantage. However, the more rapid rate of gain could be of considerable economic interest to feedlot operations as days in feedlot would be significantly reduced.

Of possibly greater practical significance is the rapid adaptation achieved through caustic soda treatment of cane pith as is evident from the greatly improved feed intake (and probably water intake) as well as more rapid rate of gain achieved during the early phases of feeding. This is evident from Table 11.

5. *Maintenance trial to compare sugar cane pith pellets and 4% NaOH treated cane pith pellets:* It is generally believed that the primary objective in treating roughage with sodium hydroxide is to improve the quality of the roughage and consequently the performance of animals under maintenance conditions shows improvement.

An experiment was conducted to compare untreated cane pith pellets with 4% NaOH treated cane pith pellets as sources of roughage for animals under maintenance conditions. In addition, various protein supplements were given.

The trial was terminated after 56 days and the main features in respect of the cane pith pellets are presented below.

| Treatment | Voluntary feed intake (kg/animal/day) | Mass lost over 56 days |
|---|---|---|
| Untreated cane pith pellets | 2,8 | − 30,0 |
| 4 % NaOH treated cane pith pellets | 5,3 | − 5,0 |

From these results the 2 main features are in the first instance the improved palatability as evident by the markedly higher voluntary intake of the treated pellets. In the second instance, the mass lost over the 56 day period was significantly lower on the treated pellets compared to the loss in the groups on the untreated.

From the foregoing experiments the following general conclusions can be drawn.

Cane pith pellets, when used in highly concentrated fattening diets, will give results equivalent to those obtained with hay and the other crop residues tested. In common with work conducted mainly in Cuba, Puerto Rico and Florida, U.S.A., we have found that cane pith pellets give more rapid feedlot adaptation with a lower incidence of digestive upsets, even when used at low levels of total fibre. These findings lend credence to the claim that bagasse is a highly "effective" fibre source for use in complete ruminant diets (Bull, 1977). It may also be concluded from this series of experiments that voluntary intake of cane pith pellets can be greatly improved by caustic soda treatment and that under certain conditions this can result in improved animal performance.

## Sugar cane tops

*Availability and Uses*

During the harvesting process only about 70% of the whole sugar cane plant is removed from the field. The remainder of the material consisting of striped leaves (trash) and the upper leafy section of the cane stalk (cane tops) are discarded. The amount of in-field waste material available from the annual South African sugar crop is thus estimated to be as follows:

| | Million tons/annum | |
|---|---|---|
| | As-is basis | Dry basis |
| Sugar cane tops and trash | 5,6 | 2,0 |

The quantity of material which could actually be made available for animal production would, however, be somewhat less because a variable proportion of this material is lost due to burning, a practice which is sometimes applied prior to harvesting. This nevertheless results in a large volume of material which is of little or no value to the sugar cane farmer, but which has potential as an animal feed.

Unlike molasses and bagasse which arise from the sugar milling process, the cane tops and trash remain behind in the field. If the cane top is to be used as feed, then it must be specifically collected and processed. This is costly and labour intensive process. Because of this, cane tops are seldom sold on a commercial basis. To the author's knowledge, the commercial distribution of cane tops is being applied only in Thailand and the Phillipines. Cane tops were also formerly distributed commercially in Taiwan, but this company has gone into liquidation. According to this process the cane tops are collected, chopped, dried artificially and marketed in baled form as a roughage.

In South Africa cane tops are widely used, either fresh or in the ensiled form as a roughage source for dairy cattle, beef cattle, mules and horses on sugar cane farms. Because of the limited stock numbers in the cane growing areas, the percentage of available material actually being used is infinitesmally small and this, therefore, remains a potentially large source of unexploited raw material.

*Composition of Cane Tops*

The moisture content of sugar cane tops varies, as can be expected, from approximately 25% to approximately 35%, but expressed on a dry matter basis, the chemical composition of cane tops does not show great variation. The following composition, as given by Ensminger & Olentine (1978), seems to be fairly representative of other published data.

**Table 12**

*The chemical composition of fresh sugar cane tops and sugar cane top silage*

| | Dry Matter | Composition on absolute dry basis | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Protein | Crude Fibre | Ether Extract | Ash | N.F.E. | Ca | P |
| | (g/kg) | (g/kg) | (g/kg) | (g/kg) | (g/kg) | (g/kg) | (g/kg) | (g/kg) |
| Sugar cane tops, fresh | 260 | 52 | 331 | 17 | 118 | 481 | 3,5 | 2,7 |
| Sugar cane tops, silage | 300 | 51 | 358 | 20 | 95 | 476 | – | – |

## Table 13

*The energy value of sugar cane tops and sugar cane silage in the feeding of ruminants expressed on an absolute dry basis*

| REFERENCE | TDN | D E | M E | N $E_m$ | N $E_g$ | N $E_\ell$ |
|---|---|---|---|---|---|---|
| | (%) | (MJ/kg) | (MJ/kg) | (MJ/kg) | (MJ/kg) | (MJ/kg) |
| **Fresh Cane Tops** | | | | | | |
| Ensminger & Olentine (1978) | 49 | 9,0 | 7,4 | 4,4 | 0,92 | 4,5 |
| **Cane Tops Silage** | | | | | | |
| Ensminger & Olentine (1978) | 52 | 9,7 | 7,9 | 4,7 | 1,5 | 4,9 |

This composition is also in fairly close agreement with figures for South African cane tops as reported by Greeff & Brown (1967) and van der Merwe (1975).

*Nutritive value of cane tops*

The above energy values are attributed to cane tops and cane top silage by Ensminger & Olentine (1978) and these values appear to be representative of other published data.

From the foregoing it is obvious that the cane top is comparable, in nutritive value, with average quality grass hay. Its main deficiency is its fairly low protein value.

Supplemented with protein, cane tops make out a good maintenance diet. For milk production in conventional rations it serves as a source of long fibre and is considered to be superior to bagasse in this respect. In conventional feeding systems it must, of course, be supplemented with a grain-rich dairy concentrate. It can also be used in beef fattening rations (Greeff & Brown, 1967) where it serves merely as a source of fibre and most of the nutrients need to be supplied in the form of grain-rich concentrate.

*Feeding experiments with sugar cane tops*

In order to establish the practical and economic feasibility of the large scale use of sugar cane tops and other sugar industry by-products, an extensive feeding scheme was initiated by the Triangle Estates in the Rhodesian Lowveld (Cattle World, 1975, de la Hunt, Bennett & Bowyer, 1975). The system evolved consisted of breeding cattle in confinement using fresh cane tops as the basal ration and supplementing the cane tops with a molasses-bagasse based protein-energy concentrate during the lactation phase and for finishing off slaughter stock. The concentrate used contained 23% dried bagasse pith and 69% molasses. This mixture was supplemented with protein and energy (from cottonseed or cottonseed oilcake and urea), with minerals and vitamin A. During a 3 year period the breeding herd was increased from 400 cows to 4 000 breeding cows and heifers during 1975. Cane tops were collected and chopped into a feeder wagon in the sugar cane fields and transported directly to the feedlot, thus eliminating double handling and reducing labour requirements.

The main advantages of this "breedlot" concept are:

(a) A large saving in land. It was possible to greatly reduce the area of land normally required to ranch cattle in that area.

(b) Reduced labour and supervision requirements.

(c) Need for dipping was reduced and disease control was greatly facilitated.

(d) The introduction of A.I. was possible, thus making it practical to upgrade the animals bred through the use of superior bull semen. Under normal extensive ranching conditions A.I. would not be practically feasible.

This innovative project at Triangle Estates has demonstrated the feasibility of using sugar cane tops and other sugar industry by-products for the large-scale intensive breeding of cattle and for the intensive feeding of their progeny for slaughter. This does not imply, however, that such a scheme is necessarily economically viable under all conditions.

## References


ANDREIS, H.J. & DE STEFANO, R.P., 1977. Silage made from sugar cane bagasse treated with sodium hydroxide. *Sugar J.*, January, p. 11.

ANDREIS, H.J. & DE STEFANO, R.P., 1978. Silage made from sugar cane bagasse treated with sodium hydroxide. *Sugar J.*, October, p. 13.

ANONYMOUS, 1978 79. *S. Afr. Sugar Yearbook No.* 49, 97.

ANONYMOUS, 1979. "World Sugar Production 1978–1979". *Int. Sugar J.* 81, 62.

ANONYMOUS, 1979, 1980. Sugar Milling Res. Inst. Monthly Summary of Lab. Rep. Final Report.

BAKER, B.P., 1979. The availability, composition and properties of cane molasses. Pure Cane Molasses Company, Durban.

BEESON, W.M. & PERRY, T.W., 1969. Effective utilization of urea by beef cattle. *Purdue Agr. Exp. Sta.* 1969 Cattle Feeders Day Rep.

BELL, M.C., GALLUP, W.D., WHITEHAIR, C.K., 1953. Value of urea nitrogen in rations containing different carbohydrate foods. *J. Anim. Sci.* 12, 787.

BENTLEY, O.G., JOHNSON, R.R., VANECKO, S. & HUNT, C.H., 1954. Studies on factors needed by rumen microorganisms for cellulose digestion *in vitro*. *J. Anim. Sci.* 13, 581.

BOHMAN, V.R., TRIMBERGER, G.W., LOOSLI, J.K. & TURK, K.L., 1954. The utilization of molasses and urea in the rations of growing dairy cattle. *J. Dairy Sci.* 37, 284.

BRADLEY, N.W., OVERFIELD, J.R. & LITTLE, C.O., 1966. Source of nitrogen for supplementing ground ear corn rations. *Ky. Agr. Exp. Sta. Prog. Rep.* 164.

BRIGGS, H.M. & HELLER, V.G., 1945. Tolerance of lambs for blackstrap molasses. *J. Agr. Res.* 71, 81.

BROWN, P.B., DAMON, A.A., SINGLETARY, C.B. & VERNON, E.H., 1954. Comparison of roughages for winter feeding and maintenance of beef cattle. *J. Anim. Sci.* 13, 1006.

BROWN, L.D., EMERY, R.S., BLANK, G.N. & BENNE, E.J., 1964. Adding dried molasses to grain for lactating dairy cows. *Michigan Agric. Exp. Sta. Quart. Bull.* 46, 570.

BROWN, G.H., OVERFIELD, J.R., BRADLEY, N.W. & LITTLE, C.O., 1967. Source of nitrogen for supplementing ground ear corn rations for feedlot cattle. *Ky. Agr. Exp. Sta. Prog. Rep.* 170.

BULL, L.S., 1977. What does "crude fiber" really mean. *Hoard's Dairyman*, December, p. 1451.

BURROUGHS, W., LONG, J., GERLAUGH, P. & BETHKE, R.M., 1950. Cellulose digestion by rumen micro-organisms as influenced by cereal grains and protein rich feeds commonly fed to cattle using an artificial rumen. *J. Anim. Sci.* 9, 523.

CATTLE WORLD, 1975. Breeding beef in barracks. June, p. 3.

CHAPMAN, H.L. & PALMER, A.Z., 1972. Bagasse pellets in beef cattle fattening rations. *Univ. Florida Agric. Exp. Sta. Circular* S–216.

CLEASBY, T.G., 1963. The feeding value of molasses. *S.A. Sugar J.* 47, 260.

CRAMPTON, E.W. & HARRIS, L.E., 1969. Applied Animal Nutrition. 2nd Ed. San Francisco, W.H. Freeman & Co.

DAVIS, R.F., TRIMBERGER, G.W., TURK, K.L. & LOOSLI, J.K., 1955. Feeding value and digestibility of cane molasses nutrients for dairy heifers. *N.Y. Agr. Exp. Sta. Bull.*, 914.

DEKKER, R.F.H. & RICHARDS, G.N., 1973. Effect of delignification on the *in vitro* rumen digestion of polysaccharides of bagasse. *J. Sci. Fd. Agric.* 24, 375.

DE LA HUNT, T.E., BENNETT, M.J. & BOWYER, W., 1975. The development of high molasses diets for beef production in Rhodesia. Molasses Technical Seminar. Pure Cane Molasses Company, Durban.

ELIAS, A., PRESTON, T.R. & WILLIS, M.B., 1969. Sub-productos de la caña y producción intensiva de carne. 8. El efecto de la inoculación ruminal y de distintas cantidades de forrajes sobre el comportamiento de toros Cebú cebados con altos niveles de miel/urea. *Rev. cubana Cienc. Agric.* 3, 19.

ELLIOTT, R.C. & O'DONOVAN, W.M., 1972–73. Comparative feeding trial T32 and high energy maize diets for feed conversion and laminitis observations. *Henderson Res. Sta. Annual Report* 1972/73.

ENSMINGER, M.E. & OLENTINE, C.G., 1978. Feeds and Nutrition – Complete. Clovis, California, Ensminger Pub. Co.

FEEDSTUFFS, 1980. Reference Issue. 52, 28.

GARRETT, W.N., WALKER, H.G., KOHLER, G.O., HART, M.R. & GRAHAM, R.P., 1981. Steam treatment of crop residues for increased ruminant digestibility. II. Lamb feeding studies. *J. Anim. Sci.* 51, 409.

GILCHRIST, F.C.M. & SCHWARTZ, H.M., 1972. Microbiology of the rumen in relation to the nutrition and physiology of the animal. *S. Afr. J. Anim. Sci.* 2, 161.

GREEFF, W.L. & BROWN, D.W., 1967. The use of sugar cane tops, methyl-thiouracil and the sodium salts of volatile fatty acids in the fattenening of old oxen. *Proc. S. Afr. Soc. Anim. Prod.* 6, 84.

HAN, Y.W. & CALLIHAN, C.D., 1974. Cellulose fermentation: Effect of substrate pre-treatment on microbial growth. *Appl. Micro.* 27, 159.

HART, M.R., WALKER, H.G., GRAHAM, R.P., HANNI, P.J., BROWN, A.H. & KOHLER, G.O., 1981. Steam treatment of crop residues for increased ruminant digestibility. I. Effects of process parameters. *J. Anim. Sci.* 51, 402.

HATCH, C.F. & BEESON, W.M., 1972. Effect of different levels of cane molasses on nitrogen and energy utilization in urea rations for steers. *J. Anim. Sci.* 35, 854.

HENNING, P.A., VAN DER LINDEN, Y., MATTHEYSE, M.E., NAUHAUS, W.K., SCHWARTZ, H.M. & GILCHRIST, F.M.C., 1980. Factors affecting the intake and digestion of roughage by sheep fed maize straw supplemented with maize grain. *J. Agric. Sci. Camb.* 94, 565.

HENKE, L.A., 1950–52. *Hawaii Agr. Exp. Sta. Bi. Rep.* p. 30.

HILL, T. & TORLAGE, R., 1981. Pure Cane Molasses Company, Durban. Personal communication.

HOFMEYR, H.S. & JANSEN, T.H., 1976. Die moontlikheid van bytsoda-behandelde ruvoere vir veeproduksie. *S. Afr. J. Anim. Sci.* 6, 147.

HUGO, W.C., 1975. Die benutting van melasse deur produserende melkkoeie. M. Sc. Tesis, Univ. Oranje-Vrystaat.

KARGAARD, J. & VAN NIEKERK, B.D.H., 1977. Incorporation of D.P.W., Urea and fish meal with varying molasses levels in cattle feedlot rations. *S. Afr. J. Anim. Sci.* 7, 117.

KING, W.A., O'DELL, G.D., LAMASTER, J.P. & RODERICK, D.B., 1955. Comparison of cottonseed meal, molasses containing urea, and ammoniated molasses as protein supplements for dairy heifers. *J. Dairy Sci.* 38, 624.

KING, W.A., O'DELL, G.D. & RODERICK, D.B., 1957. Utilization of blackstrap molasses, urea in molasses, and ammoniated molasses by dairy heifers. *J. Dairy Sci.* 40, 810.

KIRK, W.G., CHAPMAN, H.L., PEACOCK, F.M. & DAVIS, G.K., 1969. Utilizing Bagasse in cattle fattening rations. *Univ. Florida Exp. Sta. Bull.* 641 A.

LATIN AMERICAN TABLES OF FEED COMPOSITION, 1974. University of Florida, Gainesville, U.S.A.

LISHMAN, A.W., 1965. Cane molasses as a substitute for maize in beef finishing rations. *S. Afr. J. Agric. Sci.* 10, 51.

LOFGREEN, G.P., 1965. Net energy of fat and molasses for beef heifers with observations on the method for net energy determination. *J. Anim. Sci.* 24, 480.

LOFGREEN, G.P. & OTAGAKI, K.K., 1960a. The net energy of blackstrap molasses for fattening steers as determined by a comparative slaughter technique. *J. Anim. Sci.* 19, 392.

LOFGREEN, G.P. & OTAGAKI, K.K., 1960b. The net energy of blackstrap molasses for lactating dairy cows. *J. Dairy Sci.* 43, 220.

MACGILLIVRAY, A.W. & MATIC, M., 1970. Composition of South African Final Molasses. *Proc. S. Afr. Sugar Technol. Ass.* June, 1970.

MARSHALL, S.P. & VAN HORN, H.H., 1975. Complete rations for dairy cattle: II. Sugar cane bagasse pellets as roughage in blended rations for lactating cows. *J. Dairy Sci.* 58, 896.

MARTIN, P.C., CABELLO, A. & ELIAS, A., 1976. The use of fibrous sugar cane by-products by ruminants. 2. Effect of the NaOH pressure combination on the digestibility and chemical composition of bagasse and bagasse pith. *Cuban J. Agric. Sci.* 10, 19.

MARTIN, P.C., CRIBEIRO, T.C., CABELLO, A. & ELIAS, A., 1974. The effect of sodium hydroxide and pressure on the dry matter digestibility of bagasse and bagasse pith. *Cuban J. Agric. Sci.* 8, 21.

MARTIN, R.J., Jr. & WING, J.M., 1966. Effect of molasses level on digestibility of high concentrate ration and on molar proportions of volatile fatty acids produced in the rumen of dairy steers. *J. Dairy Sci.* 49, 846.

MARTY, R.J. & HENDERICKX, H.K., 1972. Study of the buffering properties of the rumen fluid of sheep fed a high sugar cane molasses diet. *Proc. 2nd World Congress on Animal Feeding,* 5, 327.

MARTY, R.J. & PRESTON, T.R., 1970. Molar proportions of the short chain volatile fatty acids produced in the rumen of cattle given high-molasses diets. *Rev. cubana Cienc. Agric.* 4, 183. (Abstr.).

MILLS, R.C., LARDINOIS, C.C., RUPEL, I.W. & HART, E.B., 1944. Utilization of urea and growth of heifer calves with corn molasses or cane molasses as the only readily available carbohydrate in the ration. *J. Dairy Sci.* 27, 571.

MORRISON, F.B., 1957. Feeds & Feeding, 22nd Ed. Ithaca, N.Y., The Morrison Pub. Co.

N.R.C. ATLAS OF NUTRITIONAL DATA ON UNITED STATES AND CANADIAN FEEDS, 1971. National Academy of Sciences, Washington, D.C.

NATIONAL RESEARCH COUNCIL, 1970. Nutrient Requirements of Beef Cattle. National Academy of Sciences, Washington, D.C.

NATIONAL RESEARCH COUNCIL, 1971. Nutrient Requirements of Dairy Cattle. National Academy of Sciences, Washington, D.C.

NATIONAL RESEARCH COUNCIL, 1975. Nutrient Requirements of Sheep. National Academy of Sciences, Washington, D.C.
NATIONAL RESEARCH COUNCIL, 1976. Nutrient Requirements of Beef Cattle. National Academy of Sciences, Washington, D.C.
NATIONAL RESEARCH COUNCIL, 1978. Nutrient Requirements of Dairy Cattle. National Academy of Sciences, Washington, D.C.
NATIONAL RESEARCH COUNCIL, 1979. Nutrient Requirements of Swine. National Academy of Sciences, Washington, D.C.
OWEN, F.G., KELLOGG, D.W. & HOWARD, W.T., 1967. Effect of molasses in normal and high grain rations on utilization of nutrients for lactation. *J. Dairy Sci.* 50, 1120.
PERRY, T.W., BEESON, W.M., KENNINGTON, M.H. & HARPER, C., 1959. Pelleted complete mixed rations for feeder lambs. *J. Anim. Sci.* 18, 1264.
POTTER, G.D., LITTLE, C.O., BRADLEY, N.W. & MITCHELL, G.E., 1971. Abomasal nitrogen in steers fed soybean meal, urea or urea plus two levels of molasses. *J. Anim. Sci.* 32, 531.
PRESTON, T.R., 1970. Sub-Productos de la caña de azucar en el engorde de ganado bovino y porcino. *Rev. Mex. Prod. Anim.* 2, 21.
PRESTON, T.R., ELIAS, A., WILLIS, M.B. & SUTHERLAND, T.M., 1967. Intensive beef production from molasses and urea. *Nature* 216, 721.
PRESTON, T.R., WILLIS, M.B. & MARTIN, J.L., 1969. Efficiency of utilization for fattening of the metabolizable energy of molasses-based diets. *J. Anim. Sci.* 28, 796.
RANDEL, P.F., 1966. Feeding lactating dairy cows concentrates and sugar cane bagasse as compared with a conventional ration. *J. Agric. Univ. Puerto Rico* 50, 255.
RANDEL, P.F., 1970. *Ad libitum* feeding of either a complete ration based on sugar cane bagasse or a conventional concentrate mixture to dairy cows. *J. Agric. Univ. Puerto Rico* 54, 429.
RANDEL, P.F., RAMIREZ, A., CARRERO, R. & VALENCIA, I., 1972. Alkali-treated and raw sugar cane bagasse as roughages in complete rations for lactating cows. *J. Dairy Sci.* 55, 1492.
ROMAN-PONCE, H., VAN HORN, H.H., MARSHALL, S.P., WILLCOX, C.J. & RANDEL, P.F., 1975. Complete rations for dairy cattle. V. Interaction of sugar cane bagasse quantity and form with soybean meal, urea and starea. *J. Dairy Sci.* 58, 1320.
SCOTT, M.L., 1953. Use of molasses in the feeding of farm animals. Review and annotated bibliography. *Sugar Res. Found. Inc. N.Y. Tech. Rep.* Series No. 9.
SCOTT, M.L., NESHEIM, M.C. & YOUNG, R.J., 1976. Nutrition of the Chicken. Ithaca, N.Y., M.L. Scott & Associates.
SPENCER-MEADE, 1963. Cane Sugar Handbook. 9th Ed. Inc. N.Y., John Wiley & Sons.
SPRINIVASAN, V.R. & HAN, Y.W., 1969. Utilization of bagasse. *Advance Chem. Ser.* 95, 447.
STEWART, M.J., 1970. Molasses meal as an alternative energy source in rations of dairy cows. M.Sc. Thesis. Univ. Stellenbosch.
SUDWEEKS, E.M. & ELY, L.O., 1976. Using sugar cane bagasse and ground rice hulls in ruminant rations. *Proc. Georgia Nutr. Conf. for Feed Industry* p. 98.
SUTTON, J.D., 1968. The fermentation of soluble carbohydrates in rumen contents of cows fed diets containing a large proportion of hay. *Br. J. Nutr.* 22, 689.
SUTTON, J.D., 1969. The fermentation of soluble carbohydrates in rumen contents of cows given diets containing a large proportion of flaked maize. *Br. J. Nutr.* 23, 567.
SWAN, H., 1975. Molasses Technical Seminar. Pure Cane Molasses Company, Durban.
VAN DER MERWE, F.J., 1970. Die benutting van suikerrietprodukte deur herkouers. *S. Afr. J. Anim. Sci.* 9, 43.
VAN DER MERWE, P.K., 1975. The nutrinomics of molasses. Molasses Technical Seminar. Pure Cane Molasses Company, Durban.
VAN NIEKERK, B.D.H. 1979. World Aberdeen Angus Forum, Johannesburg.
VAN NIEKERK, B.D.H. & VOGES, D.J., 1976. Cane molasses as a replacement for maize meal in beef fattening rations. *S. Afr. J. Anim. Sci.* 6, 67.
WAYMAN, O., IWANAGA, I.I., HENKE, L.H. & WEETH, H.J., 1953. Fattening steers on sugar cane byproducts. *Hawaii Agr. Exp. Sta. Circ.* 43.
WHITE, T.W., REYNOLDS, W.L. & HEMBRY, F.G., 1973. Influence of urea and molasses on nutrient digestibility of high roughage rations by steers. *J. Anim. Sci.* 37, 1428.
YOUNG, A.W., BRADLEY, N.W., LITTLE, C.O. & BOLING, J.A., 1969. Level of feed intake and molasses additions to urea rations for feedlot steers. *Ky. Agr. Exp. Sta. Prog. Rep.* 181, 32.