SUGAR CANE FOR CATTLE PRODUCTION: PRESENT CONSTRAINTS, PERSPECTIVES AND RESEARCH PRIORITIES

By

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Introduction

From an agricultural point of view, the humid tropics are probably the richest regions in the world in terms of potential for both crop and animal production. Nevertheless, there has not so far been the development of intensive beef and milk production systems as has occured in the temperate regions. More than any other factor, it is probably the scarcity of cereal grains, together with the fact that fast growing tropical grasses are usually of low nutritive value, which have been the reasons for the relative lack of development of intensive systems.

There are now indications of a potential breakthrough in this situation, principally as a result of recent research which indicates that sugarcane, probably the most productive crop in the tropics can be used as a basis of intensive animal production systems. The two possibilities for using this crop are: a) in the form of by-products from normal sugar production, the molasses and bagasse, which together amount to some 3 and 12 tons respectively from one hectare of a good sugarcane crop; and b) by processing the entire sugarcane without extraction of sugar. In this latter case, the potential equivalent iæ a carrying capacity of some 20 animals/ha/year.

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In contrast to this very high animal carrying capacity per unit area, an outstanding feature of the research carried out on the feeding of sugar cane to fattening animals has been the variability and in general the relatively low mean levels of animal performance when considered in relation to its digestibility of 63 to 68% (Montpellier & Preston 1975). The purpose of this review is to attempt to explain this anomaly, by drawing together the results of recent basic and apnlied research with sugar cane and interpreting these in the light of nower knowledge on the requirements for essential nutrients: in particular, the requirements of ruminants for amino acids and glucose precursors Based on these considerations, a working hypothesis is put forward which will be used to allocate priorities for research and development work with this feed.

Until very recently, almost nothing was known about digestion and metabolism in cattle on diets of sugar cane. The work developed in this area, in fact stems from research initiated at the Centro de Investigación y Experimentación Ganadera in México in May 1975 and at the Centro Dominicano de Investigación Pecuaria con Caña de Azucar, CEAGANA, Santo Domingo, R D in August 1975. Quite a lot is known about molasses-based diets as a result of work initiated in Cuba in the late 1960's and which has since been followed up by research in other parts of the world. Molasses-based feeding systems have much in common with those based on sugar cane, in that the principal source of available energy is sugar and the protein content is very low (about 3.5% in molasses compared with 2% in sugar cane). Therefore, much of the work with molasses may be directly applicable to feeding sugar cane. There are, nevertheless, apparently large basic differences between the two feeds. Molasses based diets have a large liquid element, are high in dry matter and contain little fibre, while sugar cane is a solid feed high in fibre and relatively low in dry matter. At this stage it is relevant to summarise what is known concerning sugar cane as a feed for ruminants in terms of results of feeding trials and of experiments on digestion and metabolism.

Applied Research

Processing of sugarcane

We now know that there are no important differences between different methods for processing sugar cane, varying from removal of the rind and grinding as in the Canadian technology developed in Barbados where particle size is less than 3 mm to extreme of chopping as characterised by the use of a machete to give whole cane pieces 3 cm in length (1) None of these processes appears to have a significant effect on voluntary feed intake, live weight gain or feed conversion. A definite finding is that the cane tops must be included with the stalk in order to stimulate voluntary intake. Both with chopped whole cane stalk and also derinded stalk, the inclusion of tops increased voluntary intake by up to 15% (3).

Supplementation

Urea:
The use of an adequate level of urea in the diet is vitally important on sugar cane-based feeds. Giving rice polishings without urea to cattle on sugarcane resulted in zero live weight gain while with 35 g urea/kg DM in the diet, animals grew at almost 700 g daily (5). It appeared that even at this abnormally high level (i.e. for animal feeds given in temperate countries), the maximum response had not been reached or, in other words, there was no indication of any negative effect o animal performance at the levels used.

Rice polishings:
In several centres rice polishings, (CIEG 1974) has been shown to give a consistent response in terms of both voluntary intake and live weight gain. The effect of the supplement is dramatic increasing gain and feed intake from as little as 100 g/d on 13 kg sugar cane (without supplement) to as much as 900 g/d on 17 kg of sugar cane and 1.2 kg of supplement (Preston et al 1975). The effect on gain is largely attributable t° extra intake of sugar cane by the animal.

Other supplements:
In marked contrast, growth rates in cattle using other supplements have been variable; for example, up to 420 g/d of blood meal appears to be quite ineffective as a supplement (12), while other oil

seed meals such as cottonseed meal (40)- coconut meal and ground nut meal (unpublished data, TR Preston) have not increased animal growth to the same extent as rice polishings. In a single experiment, meat meal also failed to stimulate intake and growth (Preston & Bonaspetti 1975). In contrast to the situation in Chetumal and Santo Domingo, a number of supplements appear to have given good results with derinded sugar cane in Barbados (see Pigden 1975). The amounts given however, have been much greater (over 1 kg daily of a supplement such as rape seed meal) and no intake response relationships were obtained. It is therefore difficult to draw firm conclusions as to the application of these findings. In México the response of cattle to different levels of rice polishings was identical whether they were given chopped whole cane or finely ground derinded cane (Preston et al 1975)

Importance of voluntary feed intake

It is important to emphasise that whenever there has been a response to supplementation on sugar cane feeds , whether this was with an organic material such as rice polishings (7) or an inorganic chemical such as urea(5), the improvement in live weight gain has always been associated with, and can be explained by, an increase in voluntary feed intake (see for an example figures 1 and 2)

Figure 1
Voluntary intake of metabolizable energy in response to intake of true protein on diets based on molasses/urea/fish meal and sugar cane/urea/rice polishings (● ○) (Preston 1976)

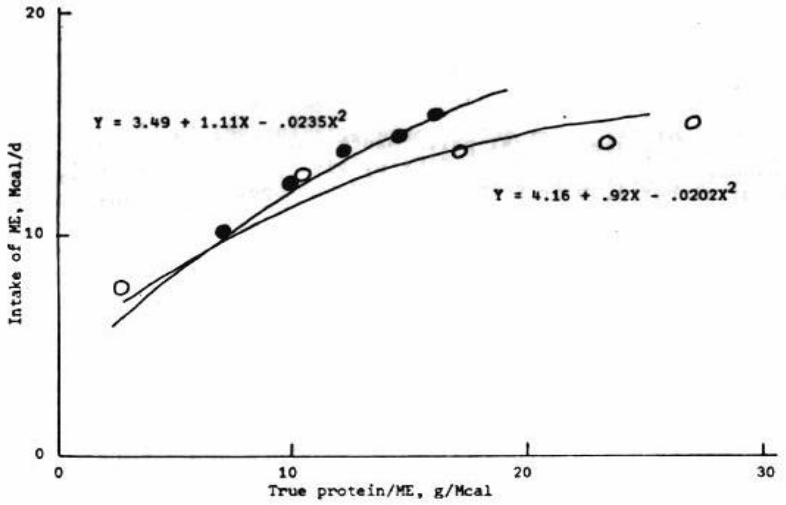
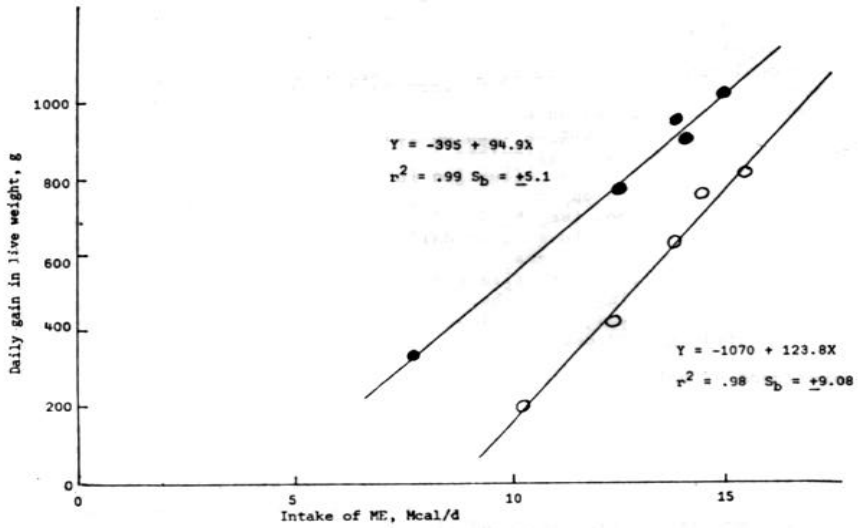


Figure 2
Relation between live weight gain and voluntary intake of ME for diets based on molasses/urea/fish meal (.) And sugarcane/urea/rice polishings (o) (Preston 1976)



Vitamins and minerals

In situations where depressed animal performance was observed on sugar cane, no improvement could be brought about by giving vitamins of the B complex (16) or either A, D or E (Preston and Bonaspetti 1975).

Milk production

The comments above relate specifically to growth and fattening. Less data are available for milk production. In work in Barbados with relatively high producing milking cows sugar cane was used at less than 40% of the total ration dry matter (James 1973). In Mexico (2) and the Dominican Republic (24), only moderate levels of milk production have been aimed at and the policy is to have dual purpose crossbred animals. Results have been highly satisfactory whenever sugar cane feeding has been combined with restricted grazing on relatively good quality pangola or Leucaena leucacephala. In both these situations, true protein intake from the grazing was estimated to be of the order of 400 g/d.

Calf rearing

Another case where results with sugar cane have been above average, is in calves fed sugar cane and molasses/urea (2, 25) allowed 2.5 litres/d by restricted suckling. The amount of milk consumed is not sufficient to account for the fairly high growth rates of 500 to 600 g daily, which again indicates that the supplement (in this case milk only, supplying approximately 100 g glucose and 80 g protein) was having a stimulatory effect on intake of sugar cane and molasses/urea.

Digestion and Metabolism

After some two years of applied feeding trials with sugar cane, it was recognized that further increases in productivity were unlikely to be made without a more complete understanding of the processes of digestion and metabolism on this feed. The major need was to understand how rice polishings in limited amounts could have such a big influence on feed intake and production in cattle. Such a program was initiated six months ago in both the Mexican and Dominican centres and the results to date are summarised below:

Importance of various sites of fermentation in the digestive tract

On the basis of the relative size of the rumen (40 to 50 litres) and the caecum (1 to 2 litres) it is apparent that the latter organ plays only a minor role in digestion; at least 95% of the fermentation take place in the rumen (27). An important observation here was that the amount of dry matter in the rumen was extremely high, relative to body size and in comparison with what is found normally on other more conventional feeds.

Such a situation could perhaps imply that flow rate out of the rumen is relatively low on this feeding system.

pH of rumen fluid

Another consistent finding which is in marked contrast with almost all conventional feeds, has been the high and stable pH in the rumen, in the range 7.3 to 6.8 with only minor variations. It is believed that this is a result of high salivary flow rates since cattle are observed to spend a considerable time eating and ruminating, and is not

necessarily a function of the amount of urea in the diet, since animals given no urea, or limited amounts, have equally high pH values.

VFA levels and proportions in the rumen and other organs

The VFA pattern is also unique. The mean and range of VFA proportions over 24 hr are shown in table 1. In contrast to molasses, sugar cane appears to give considerably higher values for propionic acid and lower ones for butyric acid. Extended sampling experiments have also show that there can be considerable variation in the VFA pattern, both during the day and between days (31). Where variations have occurred, usually acetic and propionic acid vary inversely, while butyric acid has tended to remain the more constant. This was seen quite often following feeding and appeared at times to be associated with large protozoal populations. On occasions butyric acid, however, increased above the values given in table 1.

Table 1
Molar Proportions of VFA and concentrations of NH3 (means and SE for 8 animals at hourly intervals over 24 hr: total VFA were only on a few spot samples)

	Sugarcane[1]	Final molasses[2]
Rumen NH3, mg/litre	292 ± 12	
Total VFA,mM/litre	100 - 150	143
Molar proportions, %		
Acetic	62.5± .4 (50-70)	31
Propionic	23.9± .3 (16-35)	19
Butyric	13.6± .2 (10-25)	41

[1] Abstract (31)
[2] Marty and Preston (1970)

In the slaughter experiments where complete and more uniform sampling could be guaranteed, total values for VFA were relatively high (120 to 150 meq/litre) (27).

Ammonia in rumen fluid

Only a few observations on ammonia levels in rumen fluid have been made, but it has been established that in general these are extremely high, of the order of 200 to 400 mg NH_3/litre (31). In contrast, in animals without urea; ammonia levels have been very low at around 10 to 40 mg/litre NH_3 (23).

Protozoa in the rumen

One quite unique finding that has emerged with respect to digestion on sugar cane diets is the role of protozoa. Initial macroscopic examination revealed apparently very large numbers of protozoa. Subsequent microscopic observations indicated that the population was divided principally between holotrichs and entodinea. The holotrichs were most prevalent in terms of total biomass and could be seen easily by the naked eye. They were largely isotrichs but some dasytrichs were also present. Due to their size and number, it became necessary to examine their role in the rumen particularly in terms of their total biomass. This required new technology appropriate to the conditions. In addition, in the applied studies large numbers of animals were being used. For this reason, a simple and rapid method for detection of protozoal biomass was absolutely necessary. The method is based on determination of packed cell volume occupied by the protozoa. It depends on precipitation of holotrichs from 10 ml rumen fluid, using glucose; concentration to 1 ml and volume determination by centrifugation in a macro haematocrit tube (26).

Holotrich protozoa were found to vary from negligible concentrations up to a packed cell volume of- 5% (26). In slaughter experiments with growing bulls, values were consistently between 2 to 3% of packed cell volume (27). Isolation of quantities of protozoa by similar means indicated the; for a packed cell volume of 1% one litre of rumen fluid contained 3.3 - .20 g dry matter' of protozoa (includes stored starch) (26). Protein content of the protozoa has not yet been analysed but we have assumed that this value would be about 30% (Hungate 1966).Bulls killed at 300 kg live weight were found to have a rumen containing 40 litres of fluid and 3% packed cell volume of protozoa.

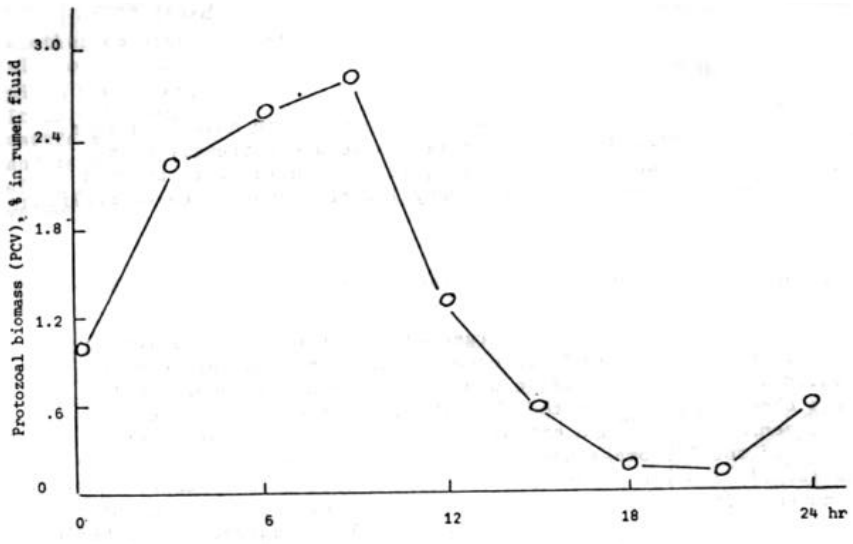
This means that there were about 2 kg or about 400 g dry matter of protozoa. This amount could contain up to 120 g protein.

Variation in protozoal biomass

It was found that there appeared to be consistent patterns in terms of variation in protozoal biomass over 24 hr. Low values were found before feeding but these increased very rapidly after eating by as much as 5 to 10 fold to reach maximum values within two hours. Biomass remained high for a short time then fell gradually to reach low values during the evening and night (figure 3).

Figure 3
Changes in protozoal biomass over 24 hr: the data are from 4 bulls fed sugarcane and rice polishings (31)

Observations of rumen contractions indicated that part of the diurnal variations could be related to changes in frequency and amplitude of rumen movements (37). The apparent speed with which the large



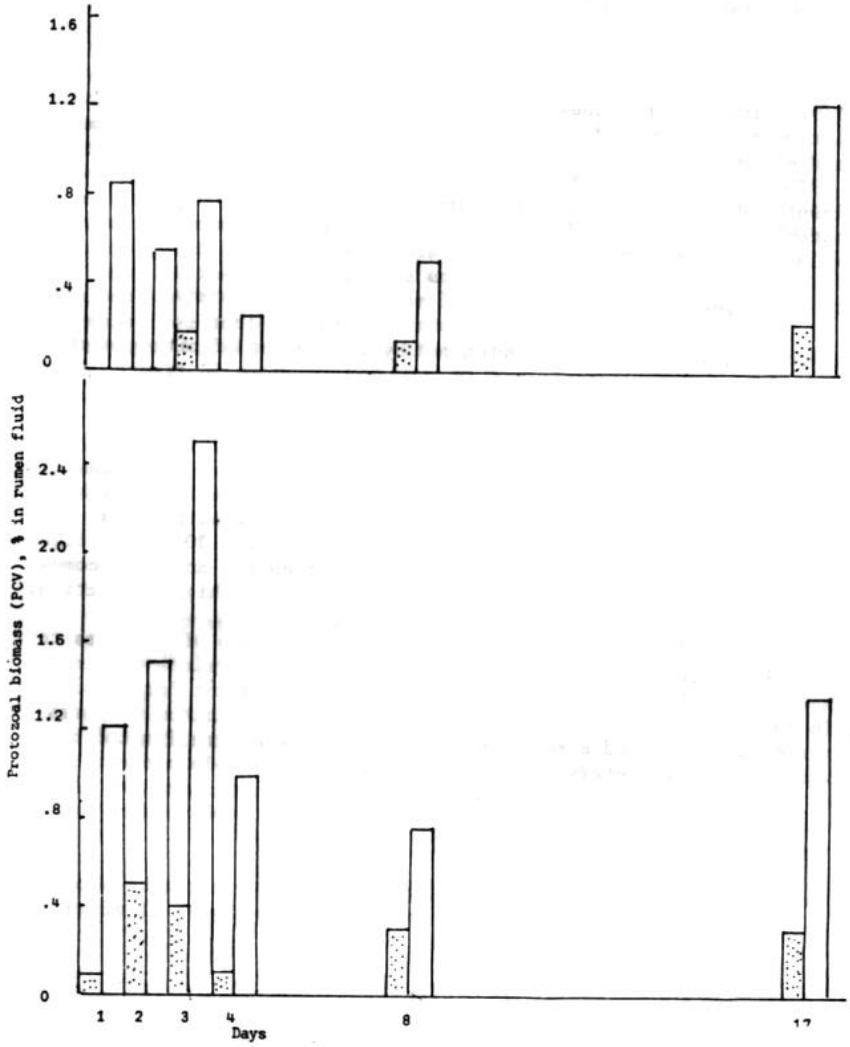
protozoa settled out, as was observed in the course of isolation and determination of biomass, suggested that sedimentation in the rumen was probably an important factor accounting for much of the variation in the amount of biomass. A further observation in vitro studies of protozoal metabolism has been that in the absence of glucose or sugar, the protozoa migrate rapidly to, and attach themselves to, particulate matter or fibres. This suggests that the protozoa tend to become inactive in the absence of substrate. Because of these

factors, we have used maximum biomass as determined in the slaughter experiments, as the basis for calculations referred to later in this paper. Also in relating protozoal biomass to any other parameter, the maximum values encountered, which occur between 2 and 4 hr after feeding, should be used. Plotting maximum values against time in days revealed cyclical pattern in protozoal numbers and mass (31). There appeared to be at least one cycle at 3 day intervals. There were also indications of longer cycles (see figure 4), with the same animal having peak values in packed cell volume varying between 0.5 and 2.5%. The values for entodinea counts (20) were similar to those reported in the literature for other diets (1.0 to 2.0 X 105); however, in terms of contribution to biomass their presence was insignificant in relation to the holotrichs.

Protozoa in the omasum

An outstanding finding in the slaughter experiments was that rarely (in only 2 out of 6 animals) were protozoa found beyond the rumen (27). And even in the two animals with protozoa in the omasum, the concentrations were only 10 to 25% of that in rumen fluid, despite the very marked concentration of dry matter between the rumen and omasum. It should be also noted that in the animals where protozoa were found in the omasum, these actively metabolized glucose, were motile and were readily determined by the packed cell volume method. The pH of the omasum was 6.7 to 7.0

Figure 4:
Maximum and minimum values for protozoal biomass between days in 2 bulls fed sugarcane and rice polishings and having large numbers or small numbers of protozoa (31)



Major contribution of the work to date and an hypothesis explaining low animal productivity on unsupplemented sugarcane diets

The importance of the slaughter experiments in explaining some of the difficulties encountered on sugar cane diets is two fold. It stresses the very large contribution of protozoa to the total microbial biomass in the rumen; and it indicates that probably protozoa do not leave the rumen in significant amounts, compared with their biomass. This suggests that large amounts of the protein synthesised (as protozoa) in the rumen may not become available to the animal thus reducing the net availability of protein on these diets as was described by Leng (1976) for other diets. The significance of this to animal productivity will be discussed later.

In establishing this hypothesis, we have drawn heavily on recent findings in relation to the importance of protected proteins in satisfying amino acid and glucose requirements of potentially high producing ruminants (Leng 1976). It is appropriate at this stage to describe briefly the experimental data on which such requirements are based. The work is attributable to a number of research groups, including work in each of our laboratories.

Protein requirement of ruminants

The requirement for protein as indicated by the amount of nitrogen stored per unit of digestible organic matter consumed is shown in figure 5. The dotted line indicates the estimate of protein stored from and provided by the growth of micro-organisms in the rumen. The point to emphasise here is that, provided that metabolizable energy is not limiting then on average the rumen micro-organisms provide sufficient protein for late growth and early pregnancy but not for early growth and late pregnancy or early lactation. If microbial growth falls below the assumed average reported by many workers (i.e. 30 g N/kg digestible organic matter) (see Preston 1976)then the animal becomes more restricted in its ability to meet requirements for high production.

The work initiated in Cuba on the feeding of high levels of molasses to young growing cattle (see Preston and Willis 1970), and since confirmed by other workers (41, 42), has emphasised the requirement for preformed protein in their diet. Growth rates of cattle on ad libitum molasses (containing 2% urea) and a small quantity of

roughage were limited by the availability of dietary protein. Relatively insoluble protein (such as fish meal see figure 2) stimulated the intake of molasses and growth rate more extensively than soluble protein (such as rape seed protein) (Preston and Willis 1970).

That the beneficial effects of feeding protected protein can be obtained also on grain based diets is shown by the work of Orskov et al given in table 2.

Table 2
Growth rate and feed conversion of lambs on a pelleted diet of barley with 1% urea and minerals supplemented with fish meal(Orskov et at 1970)

Fish Meal Supplement (g/d)	Growth Rate (g/d)	Feed Conversion (kg/kg)
0	230	4.3
0 + 10g urea	224	4.3
17	300	3.5
34	326	3.2
51	332	3.0

In these studies growing lambs were given a diet of pelleted barley plus 1% urea and minerals and the fish meal was given by feeding the animals on a bottle, in this way utilising the reticular groove reflex to get the protein past the rumen into the abomasum. At the lower levels of supplementation, the increased growth when protein was added was a reflection of increased feed intake, but at higher levels of supplementation, the increased growth was due to increased efficiency of utilisation of feed.

The same principles have also been established in Australia by the studies of Williams, Kempton and Leng (unpublished observations) on the utilization of low protein roughages. Marked responses in growing cattle were obtained on low quality pastures (less than 0.5% N in dry matter) when supplements of soya bean and meat meal were given.

On the basis of such studies it is now a well established basic principle that for moderate to high levels of production in ruminants, total true protein is needed than can be obtained from the rumen micro-organisms alone. The amount of supplementary protein required is determined by the net efficiency of microbial protein synthesis which is variable. This principle is applicable for a wide range of feeds, whether the energy source is starch, sugar or cellulose. Average values in the literature for microbial synthesis (see table3) are equivalent to about 30 g of microbial nitrogen per kg of organic matter apparently digested in the rumen. However, reported values vary from 15 to 53 g N/kg fermentable organic matter. Although some of this variation is due to experimental error, it nevertheless appears that depending on net efficiency Of the microorganisms present in the rumen, considerable variation may exist in the availability of true protein reaching the intestine.

Implications of the role of protozoa on protein availability

From these studies, it would seem that the most important contribution to this variability would be the presence of large numbers of protozoa. It may also depend on the species of protozoa, since it is logical to expect that the size of the protozoa may affect their flow from the rumen and that smaller species will be more likely to escape rumen fermentation.

Weller and Pilgrim (1974) recently demonstrated that only 25% of the entodinia leave the rumen, whereas we have found that even fewer holotrichs escape, and these are 10 times larger and probably a much greater proportion of the total microbial biomass in the rumen than on other diets. One of the basic points of the hypothesis is that the low and variable productivity on sugar cane diets represents a form of metabolic dysfunction affecting feed intake, and that this in turn is associated with the presence of large protozoal populations. It is interesting to note that in other cases in the literature where there have been reports of large numbers of the large holotrich protozoa in the rumen of cattle in a production system, this has also been associated with a metabolic disorder namely bloat on grass/clover pastures. Bloat is also associated with low intakes of dry matter and low animal productivity (see Leng 1974: Wolfe and Lazenby 1972).

Table 3
Efficiency of rumen microbial protein synthesis (from Preston 1976)

Feed	Feed N	Microbial crude Protein synthe-sized/100 g OM digested	Truly digestible microbial true protein synthe-sized/Mcal ME
	(%)	(g)	(g)
High protein hay	2.5	10.8-12.9	16.5-20.0
Synthetic (urea sole N source)	0.5-3.3	9.1-17.1	14.6
Rolled barley	1.8	12.0-16.5	18-25
Berseem clover	2.9-4.8	16	24.5
Wheaten straw	1.2	16.8	26.5
Clover hay	3.6	19.7 (∓1.6)	31.4
Wheaten hay	1.6	20.7 (∓2.0)	31.8
Lucerne hay	3.4	20.8 (∓1.4)	31.9
Synthetic (urea + casein, gelatin or zein)	2.2-2.3	19.8-23.3	30.3-35.6
Lucerne hay	3.2	22	33.7
Lucerne hay	2.9	21-23	32-35
Fresh perennial ryegrass	4.7	22.3 (∓0.5)	32.8
Grass and clover hays	1.3-4.6	23	35.2
Fresh white clover	4.0	24.2 (∓0.6)	35.5
Fresh"Tampa" ryegrass	2.0	24.8 (∓1.8)	36.4
Clover hay	4.4	25.4	39.0
Preferred value		20.0	28

The role of glucose in production in ruminants

Recent studies on glucose metabolism have emphasised the interrelationship between amino acid requirements and glucose (figure 5). In this respect it is interesting to note that 0rskov (1970) has suggested that in growing lambs, the N contribution of microbial synthesis is equivalent to only 7g of N retained per kg of organic matter fermented in the rumen. This means that if 30g of N as protein are produced in the rumen per kg of digestible organic matter, then two thirds of this are catabolized in the process of digestion and metabolism. The digestibility of microbial protein has been shown to be of the order of 73% (Bird 1972) therefore the major loss of amino acids must be at the tissue metabolism level. In work carried out recently on the synthesis rates of glucose in growing, pregnant and lactating ruminants, it has been shown that there is a similar pattern of requirements between the amount of nitrogen retained and the amount of glucose synthesised (see figure 5). Thus there is a complex interrelationship between amino acid requirements and glucose. It seems that when amino acid requirements are high, as in rapidly growing animals or lactating females, then there is an associated high requirement for glucose. This could explain the apparent low efficiency of amino acid utilization (23%), in that at times amino acids are necessarily used for glucose synthesis. This would be accentuated by a fall in propionate production in the rumen.

Figure 5a:
Protein stored by sheep at various stages of production (from Orskov 1970)

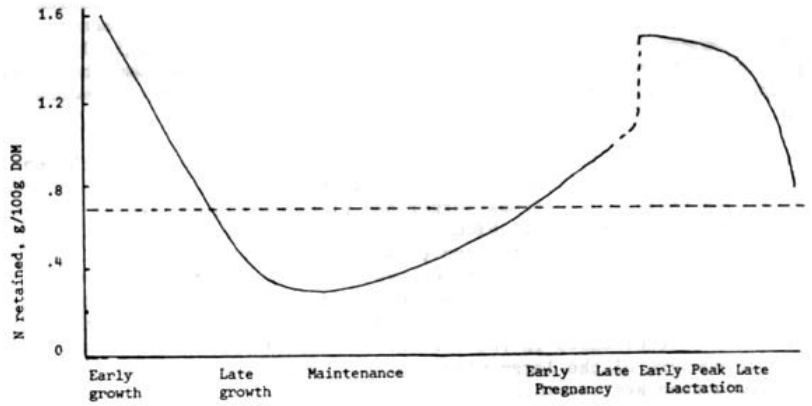
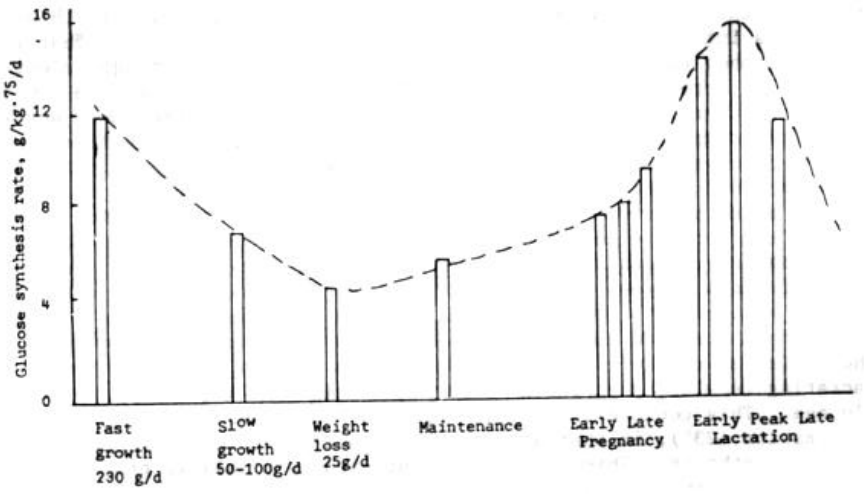


Figure 5b:
Glucose synthesised by sheep at various stages of production (from Leng 1976)



The significance of these findings is that, in contrast to previous thinking that the glucose requirement of ruminants was minimal and easily met (see Leng 1970 b),'t is now apparent that requirements are high (as much as 1.5kg of glucose may be needed by a cow producing 30 litre/d of milk) and not met easily, at least on the kinds of diets we are discussing here. Such a high level of requirement presents no problem on feed high in protein when almost invariably some protein escapes fermentation, but this is not the case on diets discussed here.

The precursors of glucose need some discussion here, since except on maize diets the amount of glucose absorbed from the intestine of cattle is very low and of negligible importance in relation to overall requirements. Therefore, the animal must depend upon two major precursors: propionic acid and amino acids, the latter either from preformed dietary protein or microbial protein synthesised in the rumen, For this reason we have related percentage propionic acid in rumen fluid to growth rate in animals fed sugar cane and in several instances found significant positive relationships with high correlation coefficients (5, 6). This, together with the fact that protozoal protein may not be available to the animal due to them being recycled within the rumen, suggests that amino acid supply, both in relation to direct requirements for growth and for

gluconeogenesis, may have important implications for animals fed on sugar cane. Calculations of the amount of glucose that could arise from propionic acid produced in the rumen also suggest such a critical interaction (table 7).

Some theoretical calculations based on stoichiometric principles of rumen fermentation

To understand the quantitative significance of the interaction between glucose and amino acid supply, we need to know the amount of propionic acid produced in relation to the amount of microbial protein leaving the rumen, and being digested and absorbed in the small intestine. It is the intention, in the next phase of our research program, to obtain quantitative information in this area. This will require the application of more advanced technology, specifically the use of radioisotopes. However, sufficient is now known about the fermentation process in the rumen to be able to make a reasonable estimate of how much propionic acid is produced, provided we know the nature and extent of carbohydrate fermented in the rumen. This estimate from stoichiometric relationships (see Leng 1970a)is probably as close as could be estimated by isotope dilution methodology. We know that on molasses-based diets, the amount of glucose leaving the rumen is negligible (Geerken and Sutherland 1969), and it is to be expected that a similar situation will apply on sugar cane. The rapidity with which soluble sugars are metabolised together with observations on calves reared by restricted suckling and fed sugar cane, where there would be severe diarrhoea if sucrose escaped from the rumen without fermentation, supports this concept. Finally, it has been shown that the digestibility of the fibre in sugar cane does not exceed 25% (35).

The contribution of the VFA to energy metabolism

Taking as a basis the composition of the diet that has supported highest production so far (table 4), and making assumptions about the extent of fermentation of the rice polishings, we can calculate from stoichiometric principles the quantities of end products of fermentation based mean proportions of VFA in the rumen over 24 hr (see table l). mean values for microbial synthesis rate (see table 3) we can a mate microbial protein synthesised in the rumen (see table 5) from the amount of carbohydrate fermented. From the amount of protein produced, and the amount of energy in VFA, it would seem

that the final protein: energy ratio available to the animal is of the order of l Mcal of ME to 33 to 35 g of digestible protein (table 6) , which appears to be in the range of values recommended (Preston & Willis 1970). This ratio is relatively unaffected by the extent that rice polishings escapes fermentation, since the protein lost by fermentation is almost balanced by the amount of microbial protein synthesised when starch and protein of rice polishings are degraded to VFA in the rumen.

Table 4:
Feed intake and estimates of organic matter fermented in the rumen

	Intake kg/ d	Digestibility %	Organic Matter Fermentable kg/d
Sugarcane			
Dry matter	3.45		
Soluble carbohydrate	1.55	100	1.55
Fibre	1.90	25	.68
Protein	.09	100	.09
Final Molasses			
Soluble carbohydrate	.19	100	.19
Rice polishings			
Starch (67%)	.57		
Protein (12.9%)	.155	*	*
Lipids (14. 7%)	.176		
Fibre (5. 7%)	.050		

* Varies according to proportion escaping rumen fermentation

Table 5
Estimate of the availability of fermentation end products and protein synthesis in the rumen

	Degree of fermentation of rice polishings (%)		
	0.	50	100
Fermentation/digestion end products (Kcal/d)			
Rumen			
VFA	7267	8121	8975
CH4	1816	2029	2242
Heat	679	759	839
Microorganisms	2352	2629	2905
Intestine:			
Dietary fat	1267	1267	1267
Rice polishings	2900	1450	-
Digestible protein available (g/d)			
Microorganisms	253	395	436
Dietary	120	60	-
	473	455	436
Propionate production			
(moles/d)	5.82	6.51	7.19
Starch availability (g/d)	570	285	0

1. The fermentation end products were calculated from the carbohydrate assumed to be digested in the rumen, on the basis that VFA proportions were 61: 24: 15 for acetate, propionate and butyrate
2. Microbial growth was assumed to be 30 g N/kg DOM in the rumen; that their N content is 6% and 60% of their weight is protein. The digestibility of the microorganisms is assumed to be 80% and their caloric value is 4.0 Kcal/g.
3. Dietary fat was assumed to have a digestibility of 80% and a caloric value of 9 Kcal/g.
4. Dietary starch was assumed to be either completely fermented or 1002 digestible; protein from rice polishings was assumed to be either completely fermented or 80% digestible

Table 6
Theoretical availability of energy and proteins

	Proportion of energy /protein (Mcal ME / g digestible protein)	
Proportion of rice polishings fermented (%)	E/P	E/P*
100	1:33	1:26
50	1:34	1:26
0	1:35	1:27

*Assuming 300 g dry matter of protozoa in the rumen (2.5 % PCV) which means that about 100 g of protein is fermented in the rumen and not available to the animal as protein.

However, if the protozoa do not leave the rumen and therefore their protein is not available to the animal, then this ratio will vary directly with protozoal biomass in the rumen. It is implicit here that protozoa reproduce and grow and therefore die in the rumen, which is obvious when we examine the large fluctuations in protozoal biomass that occur over a long period (figure 4). It is assumed that dead protozoa for a substrate for microbial growth.

If protozoa contribute 25% of the microbial biomass in the rumen (equivalent to 100 g protein daily), and if this is not available to the animal, then with the various assumptions made in table 5, it can be seen that the protein:energy ratio becomes critically balanced, even with a large amount of rice polishings passing from the rumen intact. Under these conditions, where amino acid supply is precariously balanced, there is a strong interaction with requirement for glucose. We have calculated that propionic acid can supply only 520 g/d (table 7) whereas the minimum required is of the order of 800 g per day and may well be more (the requirement for 800 g per day was based on work with growing lambs and assumes that glucose requirements are proportional to metabolic body size i.e. about 12 g/kg 75/day for a medium level of growth; see Kempton and Leng 1976 as reported by Leng 1976).From table 7, it can be seen that if all of the rice polishings is digested in the intestines, then the animal will have no difficulty in meeting its requirements for glucose. However, if less than 50X of the rice polishings escapes from the rumen, then the animal is critically

Figure 6
Relationships between live weight gain and intake of true protein on diets based on molasses/urea/fish meal (○), molasses/urea/torula yeast (●) and sugarcane/urea/rice polishings (from Preston 1976)

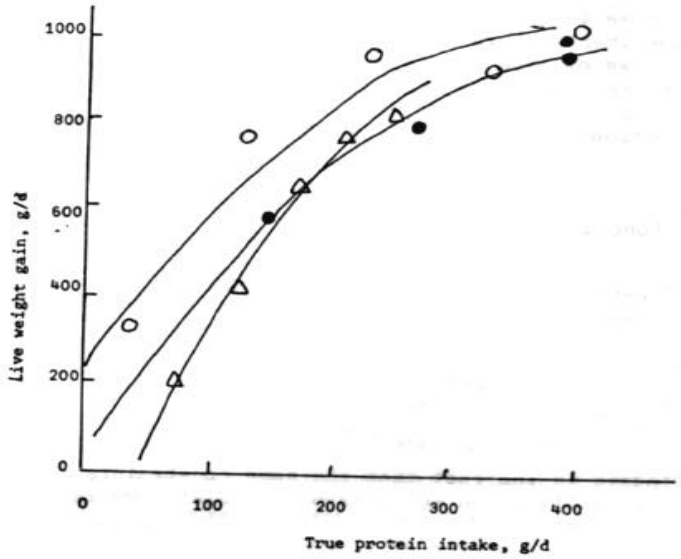
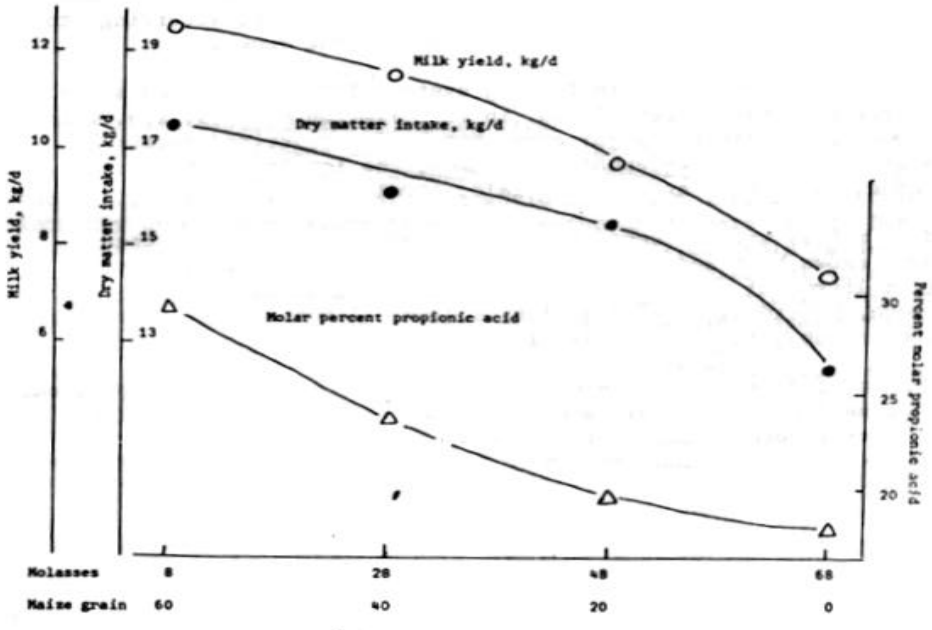


Figure 7
Effect of increasing the maize content of a molasses based ration on rumen propionic acid, dry matter intake and daily milk yield of dairy cows (from Clark 1971)



balanced with respect to supply of both amino acids and glucose. The fact that the fermentability of rice polishings in an in vitro system has been shown to be extremely high (36)(more rapid even than glucose) urges caution in suggesting that rice polishings escape extensive fermentation. However, the small particle size and low density of rice polishings, together with its high lipid content suggests that in vivo , such material could pass through the rumen rapidly. Moreover if it is given along with other more soluble, and therefore particularly more rapidly fermentable materials, i.e. sugar this should help in reducing the rate of its fermentation, giving it time to pass through the rumen relatively intact. In fact, in slaughter experiments where the animal was killed 3 hr after feeding, large quantities of rice particles were found in the digestive tract posterior to the rumen, and specifically in the omasum and abomasum. Some was also found in the caecum. This suggests very strongly that a large proportion of rice polishings does escape rumen fermentation.

Conclusions

The working hypothesis which is proposed as a basis for immediate and future research programmes with sugar cane is as follows:

> *The chief constraint to animal productivity on sugar cane diets is feed intake which in turn is limited by the supply of amino acids for protein synthesis and gluconeogenesis and of propionic acid for glucose synthesis.*

The major support for the hypothesis is the fact that the same constraints are known to determine animal productivity on molasses-based diets, where very definite relationships have been found between protected protein, as a supply of amino acids, and starch as a source of glucose. On molasses based diets, clear relationships have been established between the supply of protected protein, voluntary feed intake and liveweight gain (figure 1,2 & 6): and between substitution of molasses by maize giving rise to increased production of propionic acid, greater voluntary intake and increased milk production (figure 7). The uniqueness of sugar cane diets lies in the fact that these general relationships appear to be confused by the role of protozoa which obviously will vary from day to day, according to their relative contribution to microbial biomass in the rumen.

It is interesting to note that in feeding systems largely based on sugar cane where protozoa have been found in only limited numbers, i.e. with lactating cows fed ad libitum sugar cane, but having restricted access to pangola or Leucaena leucacephala grazing, the levels of production have been consistent and at an acceptable level.

Calves fed mainly with sugar cane and supplemented by restricted suckling have shown high and consistent growth rates. In this situation, the milk (2.6 litres/d) passing directly to the abomasum through the reticular groove, provides a high quality source of both glucose (from lactose) and amino acids (from casein).

Table 7
Potential glucose synthesis (g/d) cattle on sugarcane [1]

	Rice polishings fermented (%)		
	100	50	0
Glucose from:			
Propionate *	647	586	524
Starch **	0	285	570
Protein ***	249	260	271
	896	1131	1365

[1]
Theoretical requirements for glucose are assumed to be 800-900 g/d; animal growing at 750 g/d and weighing 250 Kg.
*Assuming 1 Mol Propionate gives rise to 0.5 Mol glucose
**Assuming that dietary starch that escapes fermentation is 100 % available as glucose
***Assuming that digested protein can be converted to glucose at a rate of 57 g/100 g protein (Krebs 1964)

These responses contrast markedly with the lack of response when supplements such as blood meal and meat meal have been given to growing - fattening animals: however both these protein meals are known to be of variable quality, and before these findings can be explained, it must be established that these meals are capable of supporting growth in monogastric animals. Where these meals have been used, they were given in amounts calculated to supply needs for preformed protein (up to 240 g/day). From the data in table 7, it is

clear that this would have very little effect on availability of glucose, since if all the amino acids were used for glucose synthesis, only 136 g/d could be supplied from this source. Lack of response to blood meal, and the big response to additional rice polishings (12) , suggests that glucose supply is the primary limitation and that amino acids are secondary. From these studies it would appear that much of the apparent requirement by the ruminant for preformed amino acids largely stems from its inability to provide sufficient glucose for tissue synthesis.

References

Bird P R 1972 Austral J Agric Sci 25:195

CIEG 1974 Informe Anual, Centro de Investigación y Experimentación Ganadera, Chetumal Mexico

Clark J 1971 M Cs Thesis Universidad de la Habana

Geerken C M & Sutherland T M 1969 Rev cubana Cienc Agric (Eng ed) 3:217

Hungate R E 1966 The Rumen and its Microbes, Academic Press, New York

James L A 1973 Proc CIDA Seminar on Sugarcane as Livestock Feed, Barbados 30-31 January 1973

Kempton T J & Leng R A 1976 Unpublished observations

Krebs H A 1964 In Mammalian Protein Metabolism. (ed Munro H N & Allison J B) Vol 1 ppl25-176 Academic Press, NY

Leng R A 1970a In Chemistry and Biochemistry of Herbage (ed Butler G W & Bailey R W) Vol 3 p81 Academic Press London & NY

Leng R A 1970b In Advances in Veterinary Science 1.4:209

Leng R A 1974 In Reviews in Rural Science II (ed Leng R A & McWilliam J W)
University of New England

Leng R A 1976 In Reviews in Rural. Science II From Plant to Animal. Protein (ed Sutherland T M & Leng R A) University of New England

Marty R J & Preston T R 1970 Rev cubana Cienc Agric (eng ed) 4:45

Montpellier F A & Preston T R 1975 Rev Mexicaña Prod Anim In press

0rskov E R 1970 In Proc 4th Nutrition Conference for Feed Manufacturers. University of Nottingham (ed Swan 11 & Lewis D) Churchill, London

0rskov E R, Frazer C & Pirie 1973 Brit J Nutrit 30:361

Pigden W J 1973 Proc CIDA Seminar on Sugar Cane as Livestock Feed,
Barbados 30-31 January 1973

Preston T R 1972:Wld Rev Nutrit Diet (ed Bourne G }1) Karger:Basle

Preston T R 1976 In From Plant to Animal Protein (ed Sutherland T M & Leng R A) Reviews in Rural Science II, University New England

Preston T R & Willis M B 1970 Intensive Beef Production 2nd ed Pergamon Press: Oxford

Preston T R, Alvarez F J, Carcano C &.Guttierrez D 1975 Rev Mexican Prod Anim 5:in press

Preston T R & Bonaspetti X 1975 In Informe Anual, Centro de Investigación y Experimentación Ganadera, Chetumal QR, Mexico 1974

Weller R A & Pilgrim A F 1974 Brit J Nutrit 32:341

Wolfe E C & Lazenby A 1972 Austral J Exp Agric Anim Husb 12:119