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Nutritive Value of Fresh Sugarcane Pith

ABSTRACT

NUTRITIVE VALUE OF FRESH SUGARCANE PITH AND ALKALI-TREATED DIFFUSED SUGARCANE PITH FOR RUMINANTS

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In a feeding trial conducted in St. Kitts, W.I., Senepol and Holstein steers individually fed a fresh sugarcane pith supplemented ration had average daily gains of 0.63 and 0.32 kg, respectively, over 77 days, while over an additional 21-day group feeding period, average daily gains were 0.82 and 0.39 kg for Senepol and Holstein, respectively. High Relative Intake (99.2) and energy digestibility (76.8%) values for the ration were obtained with sheep resulting in an average Nutritive Value Index of 76.

Alkali treatment of diffused sugarcane pith (sugar removed) showed that NaOH was a more active delignification agent than ammonia as manifested by significantly ($P < 0.05$) higher *in vitro* cellulose digestibility. With sheep fed a NaOH-treated pith ration, satisfactory nutrient digestibility but low voluntary intake due to poor palatability characteristics of the pith were observed. Cellulose digestibility of treated pith was similar *in vivo* and *in vitro*.

NUTRITIVE VALUE OF FRESH SUGARCANE PITH AND ALKALI-TREATED DIFFUSED SUGARCANE PITH FOR RUMINANTS

by

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INTRODUCTION

To feed the burgeoning world population it is of importance that the efficiency of food production systems be improved through more efficient use of existing facilities, introduction of new genotypes of crop plants and animals, and development of new feed processing techniques.

Present trends of feeding animals for human food production are of concern because of the direct competition imposed on nutriture for man, as envisaged for example in the large amounts of grain being incorporated in poultry broiler and swine rations. Despite this competition, there is an almost indispensable place for animal agriculture in the overall pattern of food production. Whereas in some instances animals do seriously compete with man, in many others they do not. This latter situation is exemplified by herbivorous animals, particularly ruminants, which possess digestive abilities that man does not.

Of importance to these species is the presence of a reticulo-rumen, fore compartments of the complex stomach of ruminants, in which, through the presence of a vast microbial flora and fauna, the β-1:4 linkages of cellulose are hydrolysed eventually producing energy and releasing plant

cellular components which are also utilised by the animal.

Cellulose is the structural component of all plant cells and is the most widely distributed single organic compound in the plant kingdom. Despite this abundance, only herbivorous animals, particularly ruminants, can utilise cellulose as a source of energy, since other species do not possess facilities for enzymic degradation of the cellulose. Cellulase, the enzyme responsible for this degradation, is produced by the micro-organisms in the reticulo-rumen of ruminants and the caeca of other non-ruminant herbivorous animals. The volatile fatty acids produced by these cellulolytic micro-organisms serve as the actual energy source for the host animal.

Feedstuffs of low quality such as cereal straws, mature herbage, seed coatings, etc. not utilised by man because of their high cellulose and low available energy content, could potentially be utilised by ruminants as an energy source. The extent of utilisation of the cellulose of these low quality feedstuffs is affected by the degree of encrustation of the cellulose by lignin, a complex undigestible compound that gives support to the plant structures and serves as a barrier against microbial attack of plant cellulose in the reticulo-rumen.

Animal husbandry in any tropical country is generally adversely affected by the climate, directly on the animals and indirectly on the animals' environment. Direct stress on the animals is imposed by high temperatures, humidity and solar radiation, and the effects of these conditions are manifested in depressed feed intake, growth, production, reproduction and health. Indirectly, the climate influences animal husbandry through its effects on the quantity and quality of available feed. Seasonality of precipitation causes wide fluctuation in plant yields and the quality of tropical forage deteriorates quite rapidly with age.

One of the problems in cattle feeding in the tropics is the provision of adequate dietary energy. In one instance, in the dry season, this insufficiency may be due to the highly lignified fiber content of the mature forage with lowered available energy. Secondly, stemming from the highly succulent nature of the feed in the wet season, the animal is unable to ingest sufficient quantities of feed containing adequate dry matter to satisfy its nutrient requirements.

In the West Indies, part of the expanse of humid tropical areas, climatic stress is not so severe on domestic livestock and here it is possible that animal production can be expanded, provided suitable breeds of cattle and favorable

feedstuffs can be made available.

Competition between man and animals for food, in the tropics, is not marked as is in temperate countries, for cereals grown are essentially for human consumption, cattle being left to procure their requirements either from developed or underdeveloped pastures.

Sugarcane, Saccharum officinarum, a giant member of the grass family, is widely grown in tropical countries for production of sucrose, mainly for export. This crop provides one of the cheapest forms of energy food, with the lowest unit of land area required per unit of energy produced. Although sucrose does not provide a complete diet for man, it represents about one seventh of his total energy intake. As an efficient energy producer, it has been estimated that energy produced by one acre under sugarcane is equivalent to that produced by seven acres under wheat, twenty acres under milk production and over one hundred acres under beef production.

Despite the energy potential of sugarcane, its use in cattle feed has not been widely advocated. This lack of incentive in exploiting the potential of sugar for cattle production could be attributed to an unfavorable price relationship between sugar and the value of animal products. There

are times when the price of raw sugar on the world market occasionally falls to a point where it might be considered as a source of energy in livestock feeding.

By-products of the extraction of sucrose from sugar-cane, particularly molasses with its high proportion of sugars mainly as invert sugars, have been incorporated into cattle rations over a considerable period of time. As such, molasses has been supplied mainly as an energy supplier and as an agent for improving the palatability and increasing the intake of less acceptable feedstuffs. This dark very viscous material, apart from its energy potential has reasonable amounts of macro and micro inorganic elements and some of the essential vitamins required for satisfactory animal performance. Because of the presence of these ingredients, early investigators into the use of molasses in cattle rations concluded that molasses had a "growth factor" which improved the efficiency of animals utilising the stuff.

Bagasse, the coarse fibrous waste from the cane crushing operation in sugar extraction, is widely used at the sugar factory as fuel material for plant operations, though considerable quantities of it have been used in other industries for making various forms of soft boards and ceiling materials. To animals, bagasse is an unpalatable stuff when

fed alone, but intake has been considerably increased with addition of molasses. Bagasse utilisation by animals is primarily limited by its high content of lignified material.

Whole mature sugarcanes have been used in limited amounts for feeding to cattle. Sugarcane tops, however, have been frequently fed and readily consumed by draught animals in the sugarcane fields, but the efficiency of its utilisation is questionable owing to the coarse nature of the material.

Vast quantities of lignified fibrous materials are thus present in various forms in tropical countries and since for economical animal production, these materials should be utilised, it is of importance that investigations be made towards improving their nutritive value. Successful attempts in this direction have been reported by several European workers investigating improvement of low quality materials in their countries, for animal use. Both chemical and physical methods have been devised particularly to remove the obstruction posed by the lignin barrier. A pioneer in the development of a delignification method for fibrous materials was Beckmann, and through more recent modifications in his procedure, more efficient methods have been developed, resulting in an increased potential use of low quality fibrous

materials as feedstuffs for ruminants.

The purpose of the study reported herein was to ascertain the nutritive value for ruminants, of two products derived from sugarcane, both made possible by the development of a "separation apparatus" which removes the highly lignified outer rind (peeling) layer of the sugarcane. The first of the by-products consists of the sugar-rich pith fraction after removal of the rind layer. The second by-product is the fibrous pith remaining after the extraction of sugar from the sugar-rich pith fraction.

II. REVIEW OF THE LITERATURE

A. NUTRITIVE VALUE OF SUGARCANE AND BY-PRODUCTS AS FEED FOR RUMINANTS

1. General

Tropical countries find much less difficulty in producing energy than protein, as exemplified particularly in production statistics of food energy from sugarcane versus protein production from beef. The idea of using sugarcane for animal production may play a commendable role in supplying part of the protein requirement of the human population of some tropical areas where sugarcane is produced and by-products of the sugar extraction process abound.

All sugarcane products are essentially energy suppliers and need to be supplemented with proteinaceous material. Non-protein nitrogen sources such as urea, which can be utilized by ruminants, might well serve as an economic nitrogen supplement for sugarcane derived feedstuffs.

Preston and Hagelberg (1967) attributed a lack of incentive in exploiting the potential of sugar as an energy source for animals to an unfavorable price relation between sugar and animal products.

2. Feeding Whole Sugarcanes

Sugarcane is grown mainly as a crop for sugar production. Some varieties of sugarcane, e.g. 38G774, 38G677 and Japanese sugarcanes are grown as fodder canes in India, Southern United States and other parts of the tropical world. The crop is harvested when mature and can be fed to cattle as stalks in the paddock, but is better utilized when chopped. Mead and Noonan (1959) concluded that at an average yield of 40 tons per acre, a 30 cow production herd can be fed on an acre of fodder cane for approximately 32 days provided a protein rich supplement is available, since fodder canes only have an approximate digestible protein content of 0.6% on fresh basis.

Because of the large yields of green forage obtained from the harvest of sugarcanes, methods of preservation and storage are essential for continued animal feeding programs.

In early experiments with sugarcane, Quesenberry (1925) in the sugarcane belt of the United States, reported that silage made from whole sugarcane can be utilized advantageously as a feed for cattle. Average daily gains of 1.58 pounds were obtained with steers on sugarcane silage, while over the same period daily gains of 2.13 pounds were realised with steers on corn silage, making the sugarcane silage 74.1%

as valuable as the corn silage, a feedstuff with a high feeding value (Morrison, 1956).

In Florida, because of a limitation on grain production it is important to make maximum use of available forages. Shealy et al. (1941) compared the feeding value of silages made from Napier grass, sorghum and sugarcane, and reported that the latter had a feeding value of 70% that of sorghum silage, producing average daily gains of 1.79 pounds per steer.

Kidder and Kirk (1941) conducted trials over three years with steers comparing whole fresh sugarcane with ensiled sugarcane, supplemented with snapped corn and cottonseed meal with and without molasses. The results indicated that there was little difference inaverage daily gain and feed efficiency though steers fed freshly cut sugarcane gained slightly more than those on the ensiled sugarcane (1.95 vs. 1.87 lbs./day).

Kirk and Crown (1942) investigated several possible ways for keeping sugarcane during the winter months in Florida. These workers concluded that the most satisfactory method of storing fresh sugarcane was in shocks (approximately one ton of sugarcane in a round upright pile with butts on the ground). It was also observed that mature cows

fed shocked sugarcane as the only source of roughage in three wintering trials remained in a thriftier condition than those on sugarcane silage or grazing Carpet grass. These workers reported that shocked sugarcane contained more dry matter, less fiber and more nitrogen free extract than did sugarcane silage.

In Brazil, Roverso et al. (1969) used 21 month old Nellore bulls to compare the efficiency of rations based on corn cobs, rice straw and sugarcane, each supplemented with cottonseed meal. Bulls on a ration of 40% corncobs, 40% sugarcane and 20% cottonseed meal gained an average of 0.62 kg daily, while those on 75% rice straw and 25% cottonseed meal gained 0.74 kg and the controls on 35% cornmeal, 30% alfalfa hay, 20% cottonseed meal and 15% rice straw, gained 1.3 kg daily. Feed efficiency (feed required per unit gain) on the sugarcane containing ration was 19.25:1, while on the control ration it was 9.36:1.

From these observations of feeding trials with cattle, it appears that feeding whole sugarcane either fresh or in preserved forms, is capable of supporting cattle production provided an adequate protein supplement is available.

3. Sugarcane By-products

a. Bagasse

This is the coarse fibrous residue of the sugarcane

juice extraction process. Dependent on the efficiency of the crushing operation, this bagasse will vary in its content of sugars, although such sugars will represent a relatively small fraction of the bagasse. Primarily, this material is used as fuel in the sugar factories, but is widely used in soft board manufacture and other industries.

Considerable effort has been expended in many tropical countries to investigate the possible use of bagasse as a cattle feed. Most of the investigations have shown that it takes more energy to digest the bagasse than is obtained from it by the animals. Satisfactory results have however been obtained from animal trials when bagasse is incorporated with other feedstuffs. Davis and Kirk (1958) observed that increased consumption of bagasse and bagasse pith resulted from the addition of up to 55% molasses in a bagasse molasses ration, and that bagasse pith mixed with other ingredients especially in a concentrate feed was readily consumed. These workers also reported considerable variability in digestibility of bagasse by individual animals, the older ones being more efficient than younger ones.

Sugarcane bagasse because of its highly absorptive nature serves as an excellent roughage carrier for feeding molasses to cattle. Eremeef and Lennox (1928) as reported by

Brown et al. (1959) fed a ration of 29% bagasse, 59% molasses and 12% soybean oil meal to beef steers which made average daily gains of 3.06 pounds over a 89 day feeding period.

Brown et al. (1959) in their trials with beef cattle feeding varying levels of molasses and bagasse to 70% of the ration reported satsifactory gains when the bagasse/molasses ratio ranged from 45:25 to 20:50. In Queensland, Beames (1961) compounded a bagomolasses feed incorporating 70% molasses with 30% bagasse. Average daily gains of 2.3 pounds were obtained from steers when bagomolasses formed 50% of the ration, the rest being composed of sorghum meal, lucerne chaff, urea and minerals.

Kirk, Peacock and Davis (1962) at the University of Florida Agricultural Experimental Station conducted a series of trials from 1952 - 1960, based on the utilisation of bagasse in cattle fattening rations. They concluded that balanced rations with 20 - 30% bagasse fed to cattle were capable of producing rapid and economical gains.

Pakistani workers Khan, Qazi and Schneider (1962) in a trial with old bullocks to demonstrate the usefullness of bagasse and molasses to animals, reported average daily gains of 2.91 and 1.11 pounds when the ration contained 10% bagasse pulp and 20 - 25% molasses. Though the differences in body

weight gain between the bullocks on rations with and without bagasse pulp were not significant, the gains realised were reportedly quite economical.

Ghauri et al. (1964) in an experiment with sheep significantly depressed the average daily gain by substituting 9.5% of cottonseed hulls which composed 29.5% of the total ration, with bagasse pulp.

It can be concluded that although bagasse is a poor feed when constituting the predominant part of a ration, it can be successfully used as a component of a mixed ration, particularly when the other ingredients of the mixture are of high palatability and high available energy content.

b. Filter press cakes and cane juice coagulates

Filter press cakes are the dark product of the sugar juice clarification process with quicklime. Normally this is returned to the cane field as a soil conditioner, but it is reportedly eaten by poorer people in some sugar producing countries.

The nutritive value of filter cakes is affected by its content of available protein, sugar and other digestible polysaccharides, lipids and crude fibre. Chemical analysis of filter cakes reported by Parish (1962) shows that this

material could be beneficial to ruminants as an energy and protein source. Results published in 1963 as reported by Parish (1967) assesses the value of filter cakes in rations for milch cattle, pigs and rabbits. With the milch cows there was no difference in milk production between the controls and cows fed the filter cakes to 20% of the ration. From a series of digestibility trials with wethers it was concluded, as reported by Parish (1967) that filter cakes despite their 18% crude protein content, are equivalent only to poor quality hay because of low digestibility of the crude protein.

The cane juice coagulate is a product with a lower sugar content but higher crude protein level than filter cakes, and is produced from a new process developed in Mauritius. The nutritive value of this material was investigated by De Sainte Antoine and Vignes (1962) in Mauritius, using milking cows. The animals received the same feed except that lucerne meal in the control ration was replaced by cane juice coagulate for the test ration. From the results, there was no difference in milk production by incorporating 20% of coagulate into the ration for milking cows.

Indications are that filter press cakes and cane juice coagulates could be beneficially incorporated into cattle

rations despite the low digestible nature of the crude protein content.

c. Molasses

Molasses is the dark, very viscous fluid that remains after crystalisation of sucrose in the sugar extraction process. This material has quite a large content of sugars (approximately 56% comprising sucrose and invert sugars), and has found widespread use in the animal industry over a considerable period of time. An indication of its acceptability is the large amount of molasses exported from the tropics to the temperate areas of North America.

The nutritive value of molasses as a stock feed is centered around its ability to supply energy and improve the palatability and physical nature of feeds. Hermstadt in 1811 was the first to suggest the inclusion of molasses in stock feed.

Observations on feeding molasses to cattle have been somewhat conflicting. Georgeson et al. (1893) concluded that molasses is neither a good feed nor in the line of economy following feeding trials with steers.

Craig and Marshall (1906) on the other hand consistently increased live weight gain of steers by addition of molasses, without any ill effects.

Bohstedt (1933) in feeding trials with dairy cows, fattening steers, fattening lambs and growing fattening pigs, replaced 10% of corn in the grain mixture by molasses and reported that rations with molasses required more feed to produce 100 pounds gain than with rations without molasses.

Mather and Bender (1951) replaced four pounds grain in the ration of growing heifers by ad libitum molasses without significantly increasing rate of gain, though the molasses consumption ranged from 6.1 - 20.6 pounds per heifer per day. With milking cows these workers replaced half of the Total Digestible Nutrients (TDN) supplied by grain, with molasses and observed significant reductions in daily milk production, but no weight changes. In this case the reduction in production was associated with borderline protein intake with regard to requirements.

Davis et al. (1954) replaced the TDN supplied by four pounds, two pounds and one pound of corn by TDN from molasses in a ration consisting of corn, corn silage, early cut grass hay and sorghum oil meal, fed to dairy heifers. From their results (Av. daily gains of 1.41 lbs.), these workers concluded that molasses is an excellent feed ingredient for growing dairy cattle.

Mather et al. (1953) increased hay and total nutrient

intake by dairy cattle by spraying 2 pounds of molasses over feed. Mott et al. (1967) supplemented Zebu (Nellore) steers on Guinea grass pasture with 2 kg molasses daily and reported average daily gains of 0.08 kg per steer.

The effect of molasses on the digestibility of nutrients in the ration has been investigated. Patterson and Outwater (1907) reported that molasses increased the digestibility of hay and grain in steer rations. Lindsay and Smith (1910) showed that when molasses represented less than 13% of the dry matter of the ration to sheep, little effect was realised on hay digestibility, while if the molasses level was increased to 20% of the dry matter there was a 6% loss in hay digestibility.

Williams (1925) and Snell (1935) working with dairy cows and steers, respectively, concluded that molasses did not uniformly affect digestion of other nutrients in the ration.

Briggs and Heller (1940) substituted 230 gms molasses for the same amount of corn in a corn-alfalfa ration to lambs, and reported significant reduction in the digestibility coefficient of fat, but non-significant lowering in the digestibility coefficients of crude protein, crude fibre and nitrogen-free-extract. These same workers in 1945 substituted 5%,

10% and 15% of corn in a corn, cottonseed meal and alfalfa ration for lambs, by molasses, and observed reduction in digestibility of crude protein, fat and nitrogen-free-extract with increasing levels of molasses. Crude fibre digestibility did not seem to be affected at the levels of molasses fed.

In balance studies with dairy steers, Davis et al. (1954) consistently observed decreased utilisation of crude protein from both natural sources and urea, when high levels of molasses were incorporated into the ration.

Foreman and Hernan (1953) also reported decreased digestibility of crude protein, crude fibre and cellulose when a ration of good quality hay to dairy cows was supplemented with four pounds of molasses. They concluded that four pounds of molasses could be included in practical rations except when the ration was good quality hay, when the limit was two pounds.

Bohman et al. (1954) and Randel (1967) reported inefficient use of molasses by growing dairy heifers on poor quality forages.

The ability of the rumen microflora and fauna to convert urea, ammonium salts and other non-protein nitrogenous compounds into bacterial protein, subsequently digested by

the ruminant and serving to furnish the needs of the host animal for both essential and non-essential amino acids, has been discussed by Stangel et al. (1963), Virtanen (1966) and others. Limitation in use of these products is imposed by lack of palatability, a factor which has been improved by molasses supplementation.

In ruminants a marked association between dietary protein and supply of soluble carbohydrates has been observed, the combination of casein and soluble carbohydrate stimulating the rate of fermentation in the rumen.

Reid (1953) reviewing use of non-protein nitrogen sources for ruminants stated that urea nitrogen in rations with adequate energy and a certain level of preformed protein has a biological value approaching that of protein of many feeds.

Gallup et al. (1954) working with Hereford steers, maintained positive nitrogen balance by supplementing a basal diet containing 44.8% cane molasses with urea or soybean oil meal. The supplement increased the digestibility of organic matter and crude fibre of the ration.

Preston et al. (1967) reported average daily gains of 0.78 kg with Zebu bulls on a ration with 73% of the dry matter supplied by molasses, 59% of the total dietary protein

provided by urea and a protein/mineral/vitamin supplement.

In the ammoniation of molasses, Scott (1953) reports that ammonia has been caused to react with the sugar to form a nitrogenous material having a protein equivalency of 15 to 30 percent.

McCall and Graham (1952) investigating the value of several ammoniated products as cattle feed observed no difference in gains of experimental animals over the controls, when 32% of the protein supplement of the control ration was replaced by ammoniated molasses.

Tillman et al. (1957a,b) reported that the nitrogen of ammoniated cane molasses was not well utilised as urea by beef steers and sheep, the latter developing an endocardial hemorrhagic condition.

Stallcup (1954) using both in vivo and in vitro systems observed that while ammonia was readily released from urea, there was no apparent effect of urease on ammonia release from ammoniated molasses. The failure of ammonia release from ammoniated molasses could probably account for the poor performances as reported by Tillman et al. (1957).

From the series of experimental observations, it appears that molasses is a valuable ingredient in compounding feedstuffs for animals, particularly ruminants.

4. Sucrose

In the manufacture of sugar, the product of the sugar mill is termed raw sugar, as it still contains some impurities, particularly traces of molasses. Raw sugar destined for human consumption, usually is re-crystalised, with the resultant purified product essentially pure sucrose.

The more practical direct method of incorporating high levels of sugars in livestock rations has been through the addition of molasses. While considerable evidence exists in the literature with regard to the nutritive value of molasses to cattle, there is a paucity of information concerning the use of sucrose (raw or purified) in cattle rations.

Nofziger (1968) in California fed raw sugar at 6% and 13% of the ration to good quality Okie steers in feedlot. The rations used were calculated to be isocaloric and isonitrogenous. Steers on the control ration gained a daily average of 2.9 pounds, while those on the 6% and 13% sugar rations gained 2.9 and 3.1 pounds daily, respectively. Animals receiving the 13% sugar in the feed required a significantly lesser amount of total feed for each pound of gain than those on the control ration. These workers observed no adverse digestive disturbances as a result of incorporating sugar in the ration.

Sucrose has been incorporated in animal diets for reasons other than energy supply. Preston (1967) reports that granulated sugar has been utilised in relatively small quantities mainly to enhance palatability rather than as a prime source of energy. Deliberate incorporation of sucrose into ruminant diets may not be always economical on a large scale, but has been done to investigate the advantages or disadvantages of sucrose in the diets for ruminants.

Phillipson et al. (1942) reported a rapid decrease in rumen pH and increased volatile fatty acid (VFA) production after administering 100 gms of cane sugar to sheep. Kurilov et al. (1965) observed that large amounts (above 5 gms/kg body weight) of sugar in ruminant ration increased ketone bodies in blood, lactic acid in the rumen, reduced rumen pH and number of protozoa in the rumen. They also stated that while there was no ill effect on animal health and condition, there was a sharp fall in cellulolytic activity of rumen fluid.

Faichney (1965) reported that sucrose at 45 and 90 gms/day to sheep did not significantly affect digestibility of dry matter and crude fibre and the rate of cellulose digestion in the rumen, but that the digestibility of crude fibre decreased with sucrose supplements.

The effect of sucrose on the voluntary intake has also been investigated. Faichney (1965) reported that intake of straw by sheep decreased as the level of sucrose increased. Campling et al. (1962) and Hemsley and Moir (1963) working with cows and sheep, respectively, observed that addition of sucrose to a diet supplemented with urea did not increase intake but increased utilisation of organic matter.

The utilisation of the energy of sucrose varies with the species of animal using the material. Nehring et al. (1964) in their work with ruminants reported that while the digestible energy of sucrose is similar for bullocks and wethers, the metabolic and net energy values is higher to wethers than to bullocks because of greater methane production in the latter species. They also confirmed that sucrose supplements reduce digestibility of crude fibre in the ration.

B. UREA SUPPLEMENTATION OF RATIONS FOR LIVESTOCK

According to the previous literature cited, it can be realised that rations incorporating sugarcane or sugarcane by-products need to be supplemented with other nutrients, particularly nitrogenous ingredients. A supply of nitrogen inadequate to satisfy the growth requirements of the microbial population of the rumen is a major limiting factor in

the utilisation of low-quality roughages by ruminants.

Convincing evidence abounds, Pearson and Smith (1943), Hudman et al. (1953), Chalupa et al. (1963), Virtanen (1966), in support of the importance of nonprotein nitrogenous compounds as protein substitutes in ruminant nutrition through mediation of the flora and fauna of the rumen. A very comprehensive review of urea and nonprotein nitrogen in ruminant nutrition has been made by Stangel et al. (1963).

Urea is the commonest nonprotein nitrogen source used in ruminant nutrition. The efficiency of urea utilisation is dependent on certain conditions. Resulting from work conducted by Wegner et al. (1940), Mills et al. (1944) and others, it has been concluded that a low level of true protein and a high level of starch or less readily available carbohydrate form in the ration favors urea utilisation.

The age of the animal affects urea utilisation and Loosli and McCay (1943) suggest that calves as young as two months old are able to convert urea nitrogen to protein nitrogen.

Cases of urea toxicity have resulted particularly where too high levels are incorporated, or when poorly mixed into the ration. Reid (1953) mentions that cattle will rarely ingest a toxic quantity of urea because of its lack of palatability; he suggests though that urea should not constitute

more than 2% of the dry weight of the total ration. Virtanen (1966) in his experiments on the production of milk on protein free rations, gradually increased the daily intake of urea by approximately 450 kg dairy cows to 550 - 600 gms without any adverse effects on animal health.

A safe level for practical urea feeding to ruminants is generally stated at that where it supplied 33% of the total crude protein of the ration, the remainder being provided by grains and protein supplements such as soybean meal.

C. EVALUATION OF NUTRITIVE VALUE OF FEEDSTUFFS

1. General

Feeds are generally assessed by their ability to promote energy retention in the body, promote secretion of energy in milk and eggs or to prevent loss of energy from the body. Blaxter (1956) summarised that the nutritive value of a feed as a source of any nutrient is a measure of its ability to promote or sustain some group of metabolic activities in the animal body and this value differs dependent on the criteria used for measuring it. The nutritive value of a feed is not a constant since it varies significantly with the species considered, the criteria under investigation, the physical state of the animal and the other constituents in

the ration to which it is added.

2. Chemical Composition of Feed

The most generally used chemical method for describing feedstuffs is the proximate analysis which partitions the feed into six fractions, viz., moisture, ether extract, ash, crude protein, crude fiber and nitrogen-free-extract, the last two fractions constituting the carbohydrate content of the feed. The crude fiber was initially presumed indigestible whereas the nitrogen-free-extract contained the soluble and readily digestible carbohydrates.

Errors associated with the prediction of nutritive value of a feed from its chemical composition arise because of factors influencing metabolism of the nutrients in the animal. Kleiber (1959) reported that no single value is adequate for evaluation for milk production and growth mainly because of different metabolic demands for energy and protein.

Common (1952) stated that an obvious major defect of this analysis is the complete failure to provide any reasonable precise direct fractionation of the carbohydrates of roughages into more or less digestible fractions so far as ruminant digestion is concerned.

Newlander and Jones (1932) working with dairy cows

observed that the crude fibre of forages was digested to almost the same extent as the crude protein fraction. Crampton (1956) reported that the crude fibre fraction of the proximate analysis may be a misleading index of the overall digestibility of a feed since it is as highly digestible as the nitrogen-free-extract by ruminants.

The original concept of crude fibre indigestibility did not of course take into consideration the cellulolytic activity of the rumen microorganisms, cellulose constituting the largest component of the crude fiber fraction.

Sell et al. (1959) observed that many forage workers were prone to consider high protein levels with high forage quality. Crampton and Jackson (1944) working with sheep and steers observed that changes in digestibility reflect changes in nutritive value, and protein, because of high negative correlation between crude protein and forage digestibility, is not suitable as an index of nutritive value.

The proximate analysis, while it provides information on the chemical composition of a feed, cannot satisfactorily be used for prediction of the nutritive value of the feed because of inconsistent correlation with criteria of animal performance. Crampton (1956) states that the proximate analysis has been the cornerstone for determining the useful digestible or metabolisable energy of a feed.

3. Digestibility Data

The digestibility of a nutrient is calculated from the difference between the nutrient intake and nutrient excretion in the feces, which is expressed as a percent of the nutrient intake.

Efficient utilisation of a feed is dependent on the extent to which its component nutrients are digested. Crampton and Jackson (1944) reported that changes in toughness of forage stems when fed to steers are promptly reflected in increased feces output on constant levels of feed intake, inversely affecting the digestibility of the ration. Phillips et al. (1954) observed that the feeding value, attested by feeding and digestibility, of grasses decrease with maturity while the crude fibre content particularly lignin increased.

Changes in digestibility of the feed affect the available energy potential of the feed, a criterion that has been reported by Crampton and Jackson (1944) to be correlated with feeding value. One of the main functions of a feed is as an energy source and Armstrong et al. (1950) have stated that irrespective of the requirements for specific nutrients, the energy requirement is primary and under ordinary conditions will be satisfied even at the expense of any other. Crampton

(1957) supported this statement in his conclusion that the feeding value of a forage depends primarily on the magnitude of its contribution towards the daily energy need of an animal.

Reid et al. (1959) summarised the criteria for digestible energy value most widely used for feedstuffs in North America as Total Digestible Nutrient (TDN), Digestible Energy (DE) and Digestible Dry Matter (DDM). The TDN system being in general use in North America since the beginning of this century supplies most of the available information on feed evaluation. This system is limited in its accuracy of evaluation of food energy since it implies that digestion losses only are accounted for, and does not take into consideration losses of energy of combustible gases in ruminants and heat loss which are larger for roughages than for concentrates.

Smith et al. (1945) in their work with dairy cows concluded that the TDN system considerably overrates the production value of good alfalfa hay when fed in large quantities. Moore et al. (1953) showed that the net energy (energy available for production and/or work) value of a unit TDN in concentrate was greater than that of a unit in roughage, and disagrees with Kleiber (1959) who states that the system of TDN provides replacement equivalents based on the postulate

that two feeds are equivalent when they contain the same amount of total digestible nutrient. Because of the method of calculating TDN values, Crampton (1955) emphasised that errors in this TDN system are the sum of all errors existing in the chemical determinations of the fractions, and those due to variation in digestion coefficients between animals.

Digestible Energy (DE) values are obtained from the digestion coefficients for gross energy, and the gross energy content of a feed, and thus takes into account only energy lost in digestion. Swift (1957) from his studies of digestion experiments concluded that one pound of TDN is equivalent to 2,000 K cals. of digestible energy to sheep and cattle. Because of its ease of determination, digestible energy is becoming more widely used despite its shortcomings in failing to consider other losses of energy, e.g. gas (methane) and heat (specific dynamic action or heat increment).

Digestible Dry Matter (DDM), like TDN is subject to limitations in interpretation of forage nutritive value, due to its lack of high correlation with animal performance data. McCullough (1959) attributes the significance of this simple determination to its ability to measure energy changes in forages. McCullough (1963) further used values of DDM to

obtain a calculated net energy for forages which he found to follow closely the average daily gains of dairy heifers.

Crampton et al. (1960) summarised that the usefulness of quantitative digestion data, expressed as TDN values or digestibility of calories (energy) are limited as indices of forage evaluation, as they consistently fail to describe the effective feeding value of the forage as measured by animal performance subsisting thereon.

4. Voluntary Intake and Nutritive Value Index

Despite the considerable efforts expended in trying to arrive at an estimate of forage nutritive value, Crampton (1957) states that the most practical estimate of this value is obtained from the voluntary intake of the forage by the animal. The subject of voluntary intake and feed intake regulation in ruminants has been reviewed by Balch and Campling (1962), Freer and Campling (1963), Van Soest (1965), Conrad (1966) and others. The general conclusion is that voluntary intake of roughages by ruminants is related to the amount of digesta in the reticulo-rumen at certain times, but while on high concentrate feeds, thermostatic and chemostatic mechanisms are presumably also involved.

On all forage diets, Crampton et al. (1960) state that

50% of the potential energy is derived from the cellulose and hemicellulose fractions. To ruminants this potential energy becomes available through microbial fermentation of the forage material. Crampton et al. (1960) proposed a hypothesis that the effective nutritive value of a forage is determined jointly by the level of maximum voluntary intake when it constitutes the entire ration, and by the extent of its ultimate yield of digestible energy. These workers used these two criteria to derive a numerical index of forage nutritive value.

This index, the Nutritive Value Index, is obtained by multiplying the Relative Intake of a forage by its energy digestibility, to sheep. Relative Intake is obtained as follows -

(1) Compute for the sheep in question its metabolic body size ($W_{kg}^{.75}$).

(2) Calculate the expected daily dry matter intake of standard forage by this sheep ($W_{kg}^{.75}$ X 80 gms).

(3) Divide the observed intake of test forage by expected intake of standard forage and multiply by 100.

Values for Nutritive Value Index (NVI) of forages have been highly correlated (r = 0.88 - 0.94) by Crampton et al. (1960) and Mohammed (1966) with corresponding body weight

changes in sheep and in cattle, respectively.

5. In Vitro Rumen Fermentation Systems

It has long been recognised that utilisation of cellulose is a primary factor in nutrition of ruminants on roughages, and that microorganisms are the agents responsible for its digestion and eventual utilisation. The rate and extent of cellulose digestion in vitro may thus be possibly used to predict in vivo digestibility coefficients for ruminants.

Marston (1948), Louw et al. (1949), Burroughs et al. (1950), Bentley et al. (1954) have all contributed to the development of an in vitro system, consisting of an anaerobic environment in which a known volume of inoculum containing microorganisms and a buffered nutrient medium are mixed with a forage or feed sample, the system being kept at constant temperature for a specified period. This technique has yielded valuable information on the nutritive value of forages (Barnes, 1965).

As a procedure for evaluating forage quality, Pigden and Bell (1955) used the artificial rumen to evaluate eleven forages. They reported a significant correlation between anthrone carbohydrate digestion in vitro and the digestion of organic matter of forages in vivo using sheep.

In the rumen the main products of cellulose and carbohydrate fermentation are volatile fatty acids. Marston (1948) stated that the fatty acids arising from carbohydrate digestion in the rumen provide the ruminant with its main source of energy. Gray et al. (1951) reported evidence that the amount and nature of volatile fatty acid (VFA) production in vitro may be related to forage quality, while Asplund et al. (1958) found significant correlation between VFA production and dry matter digestibility in vitro and in vivo.

The specific VFA produced may be more important than the total VFA production and it has been suggested by Barnes (1965) that the definition of optimum proportions of VFA for efficient animal performance and the subsequent study of VFA production in vitro may aid in forage evaluations.

Forage cellulose content can constitute a large fraction of the dietary energy supplied to ruminants. Attempts have been made to correlate in vivo energy concentration criteria with in vitro cellulose digestibility. Hershberger et al. (1959), Karn et al. (1967) reported high correlations between in vitro cellulose digestibility and in vivo digestibility of dry matter and digestible energy.

In vitro results have also been used to predict Relative Intake and digestible energy intake, criteria for prediction of the Nutritive Value Index of forages. Donefer et

al. (1960) used an in vitro system for predicting the Nutritive Value Index (NVI) as described by Crampton et al. (1960), from in vitro cellulose digestion results. They observed that the twelve hour in vitro cellulose digestion of forages was highly correlated with Relative Intake and NVI. In further studies Donefer et al. (1962) working with twenty-six forages fed chopped and sixteen forages fed ground to sheep, found highly significant correlation coefficient (r) of 0.91 for chopped and 0.87 for ground forages, between twelve hour cellulose digestion and NVI.

D. DELIGNIFICATION AND FEEDING VALUE OF DELIGNIFIED FORAGES

1. General

Lignin, a complex compound whose structure is not yet completely unravelled, has been ascribed the function of encrusting the cellulose of plant material, thus giving rigidity and strength to plant structures. Lignin content of plant material increases as the plant matures. Considerable evidence indicates that the feeding value of many low-quality forages is limited not only by the shortage of potential nutrients but also by the encrustation of nutrients present within the lignin structure which is impenetrable by the

rumen microorganisms responsible for forage degradation.

The importance of cellulose in ruminant nutrition has already been indicated, with early workers like Kellner concluding that one pound of digestible cellulose had the same fat producing value to ruminants as one pound of digestible starch. This led to the development of processes to render cellulose in plants more available. Delignification involves processes destined to dissolve or remove the lignin making the cell walls and contents more accessible to the enzymes of the digestive juices and microflora and fauna of the gastro-intestinal tract of the animal.

Both chemical and physical methods have been employed to effect the delignification of different materials.

2. Chemical Methods

Most of the chemicals and procedures used in chemical delignification processes stem from those used by paper manufacturing enterprises.

a. Sodium Hydroxide

i. Straw

In 1900, German workers Kellner and Kohler, as reported by Woodman and Evans (1947) digested rye straw with a solution of sodium hydroxide (NaOH), sodium carbonate and a mixture of

sodium sulphite and sodium thiosulfite under pressure. The resultant material when used in a digestion trial with bullocks showed that the total organic matter was 88.3% digestible, the nitrogen-free extractives (NFE) 79.2% and the total crude fibre 95.8% digestible. Other workers have since used various concentrations of sodium hydroxide in their attempts to delignify and improve feeding value of fibrous materials.

Beckmann (1921) treated chopped straw for four hours with eight times its weight of 1.5% aqueous sodium hydroxide at normal temperatures and pressure and after washing obtained a material with 86.24% crude fibre utilised by animals and a nutritive value of approximately 70% the value of starch.

Hvidsten and Homb (1948) reported that using the Beckmann method for treating straw, the product had an organic matter digestibility coefficient for sheep of 66%, compared with 87% for fodder cellulose (delignified cellulose probably of wood origin), while the protein required for cellulose digestion was 9 gm/kg dry matter for treated straw and 37 gm per kg dry matter for fodder cellulose.

Magidov (1952) reported satisfactory results with alkali treated straw and better nitrogen utilisation by animals on treated straw.

Hvidsten (1958) reported that alkali treated straw has the reputation of improving the health of cows on farms where acetonemia and tetany were common. In an experiment with dairy cows, no statistical difference was observed in performance of cows on treated and untreated straw.

Lampila (1964) using a more concentrated sodium hydroxide solution for straw digestion, observed a 62% better organic matter digestion than obtained with material from the Beckmann process, though crude fiber digestibility was of the same order.

A dry process to eliminate loss of soluble nutrients with washing of alkali treated straw has been described by Wilson and Pigden (1964) using 30 mls of alkali solution per 100 gms of straw. In vitro digestibility of dry matter increased with increased alkali concentration up to 9% treatment level (9 gms NaOH/100 gms straw).

Donefer (1968) at Macdonald College, treated ground oat straw with a 13.3% NaOH solution for 24 hours, then neutralised the excess NaOH with a 50% acetic acid solution to pH 6.0. The resultant mixture when supplemented with 2.5% urea and fed to sheep, had a Relative Intake of 99.9% and a Nutritive Value Index of 58.1, which were significantly greater than intake and NVI of treated straw without urea or

untreated straw with or without urea. Digestibility of dry matter and gross energy of the treated straw was significantly greater than that of the untreated material.

ii. Bagasse

Sodium hydroxide treatment of bagasse has also been carried out in areas where this material is readily available. Nordfelt (1951) in Hawaii, predigested sugarcane bagasse with an aqueous solution of 1.5 - 1.8% sodium hydroxide for 24 hours then washed with water and used this resultant material as a ration ingredient. In palatability and digestibility trials with sheep, the treated material was very acceptable while organic matter digestibility was doubled in the treated material. In production experiments, 11.2 pounds treated bagasse satisfactorily replaced 40.7 pounds fresh Napier grass for live weight gain in dairy heifers, while growing steers on the treated bagasse gained an average 0.25 pounds more daily than those on untreated bagasse.

Wayman et al. (1952) in a steer feeding trial with predigested bagasse concluded that there was no benefit to be derived from caustic predigestion of bagasse. These workers however stated that part of the poor results obtained could be attributable to the failure of animals to adapt to the environment.

Stone et al. (1965) used a 2.0% sodium hydroxide

solution to treat bagasse at a ratio of ten parts caustic to one part of dry bagasse for a minimum of six hours at room temperature, then washed the product with water. In vitro determinations indicated a three fold increase in the digestibility of cellulose in bagasse (17.5% for untreated, 57.5% for treated) as a result of caustic treatment.

Jones (1967) treated bagasse with the same sodium hydroxide levels as used by Donefer (1968) for treatment of straw, then neutralised the excess alkali with acetic acid, and obtained a 2.5 times increase in in vitro cellulose digestibility (68.9 vs 24.4%) compared with the untreated material.

b. Calcium Hydroxide

Beckmann (1921) in his observations with alkali digestion of straw observed that calcium hydroxide may be used but has generally not rated as satisfactory when compared with sodium hydroxide. Using a process analagous to that of Beckmann, Czadeck (1941) treated 100 kg of chopped straw with 12 kg quicklime (calcium oxide) and 800 litres of water for twelve hours then washed the straw. He reported that the starch equivalent of the straw doubled with treatment.

Kormščikov (1945) stated that milk cows and wethers willingly consumed and performed better on lime (250 - 300

parts of lime solution to 100 parts of straw for 24 hours) treated straw than on the untreated material.

Arrazola et al. (1950) in their analysis of alkali treated straw reported that prolonged heating (15 hours) of straw in a 1.0% calcium hydroxide solution results in loss of approximately 20% more crude cellulose and 7% more lignin than when digestion occurred in a cold 1.5% NaOH solution for 12 - 16 hours.

In replacing hay by limed straw in the ration of dairy cows, Filatov (1958) observed no reduction in milk yields or alteration of milk composition, and that the treated material had no adverse effect on the health or growth of the animals.

Elpat'evskij (1962) treated straw with quicklime and sodium hydroxide (50:50) using 3 - 4 kg alkali per 100 kg straw. The treated mass was then ensiled. Loskutova (1969) using the method of Elpat'evskij treated straw for feeding to Simmental bullocks. The treated straw comprised 40% of the ration along with 20% hay, 15% silage and 30% concentrate. Over a 100 day feeding period, gains of 59.6, 65.7 and 76.6 kg were obtained for three groups of bullocks on the treated straw regime.

c. Ammonium Hydroxide

Ammoniation of forages could be of dual benefit in ruminant nutrition, firstly by allowing a certain amount of delignification and secondly by providing a source of non-protein nitrogen supplement which can adequately be handled by the ruminant. In describing the reactions during alkalisation of forages, Zafren (1960) states that when straw is treated with alkali, the latter combines with acetyl groups from the straw and forms acetates. With ammonia or ammonium hydroxide this results in the formation of ammonium acetate, a source of available nitrogen for microbes in the rumen.

In a feeding trial with young bulls, Zafren (1960) reported that ammonium hydroxide treated rye straw had a value of 56 feed units/100 kg, while the untreated straws had a value of 22 feed units/100 kg. Zafren (1962) describes a procedure for treating straw in pits, trenches or stacks with ammonia at 3% level or 120 litres of 25% ammonium hydroxide solution per ton of straw. In a feeding trial with this material using cattle, he reported that ammonia treatment of straw improved the total feed value by 0.5 feed units/kg and protein value by 20 - 25 gms/kg.

Jones (1967) observed increased <u>in vitro</u> cellulose digestibility of oat straw following treatment with 1.5 or

3.0 gms of ammonia, using a solution volume of 12 mls of solution per 100 gms straw.

Bourne (1955) described a satisfactory method of ammoniating sugarcane pith and increasing its crude protein content to 11.58% by treatment with 28% ammonia at the rate of one part ammonia to two and one half parts air dry pith in a closed vessel at room temperature for twenty hours then drying at 70°C. These workers however, did not make any observations on the effect of treatment on digestibility.

Davis and Kirk (1958) and Zafren (1962) all observed more efficient utilisation of ammoniated products for protein synthesis by cattle. In a digestion trial with ammoniated bagasse, Davis and Kirk (1958) indicated that the treated material had an apparent crude protein digestibility of approximately 63%, though bagasse digestibility measured in terms of crude fiber was not greatly improved by the ammoniation. These workers concluded that with older animals the bagasse product served equally as well as a grass hay for fattening animals.

3. Physical Methods

If lignification of plant tissue involves the encrustation of cellulose by a lignin sheath, then disintegration of

the tissue could increase the amount of cellulose available for digestion through physical rupture of the barrier.

Dehority and Johnson (1961) used the ball mill to effect physical delignification of forages. They reported that the total amount of cellulose digested *in vitro* increased with the time of ball milling up to 72 hours, and that comparing material at different stages of maturity the amount of increase in cellulose digested *in vitro* after 72 hours ball milling of forages became larger with advancing maturity of the forage materials.

Rony (1964) also observed that the quantity of cellulose digested *in vitro*, from ball milled (for 72 hours) alfalfa and bromegrass substrates was higher at all stages of growth, than that digested from ground substrates.

4. Radiation

Ionising radiation of suitable intensity produces chemical changes in materials subjected to radiation.

Lawton *et al*. (1951) irradiated basswood with high velocity electrons, and used this treated material in fermentation studies with rumen bacteria, using the volatile fatty acid production as a measure of digestibility. They observed increased digestibility with irradiation of between

6.5×10^6 and 1.0×10^8r, and decreased volatile fatty acid production when samples irradiated above 10^8r. They concluded that irradiation above 10^8r causes conversion of the carbohydrate fraction into compounds not utilised by the rumen microorganisms.

Pritchard *et al.* (1962) observed similar decreased digestibility *in vitro*, using wheat straw irradiated above 2.5×10^8 rads.. The practicable nature of delignification by irradiation is questionable because of the high levels of radiation required.

III. OBJECT OF RESEARCH

The research conducted, as reported in this thesis was to -

1. Observe the performance as measured by liveweight changes of steers fed *ad libitum* on fresh sugarcane (*Saccharum officinarum*) pith (i.e. whole mature sugarcane without the rind), supplemented with urea, soybean meal, minerals and vitamin A.
2. Determine digestibility, voluntary intake and Nutritive Value Index of fresh sugarcane pith plus supplement (as above) as fed to sheep.
3. Observe cellulose digestibility of alkali-treated diffused sugarcane pith (sugar removed) as determined by *in vitro* rumen fermentation.
4. Determine digestibility, voluntary intake and Nutritive Value Index of alkali-treated diffused sugarcane pith as fed to sheep, and comparison of *in vivo* and *in vitro* cellulose digestibility of alkali-treated diffused sugarcane pith.

IV. PERFORMANCE OF RUMINANTS ON A FRESH SUGARCANE PITH SUPPLEMENTED RATION

A. EXPERIMENT 1 - GROWTH TRIAL WITH CATTLE

1. Introduction

Use of whole mature sugarcanes as form of fodder for cattle feeding has not been an accepted practise in sugarcane growing countries. The literature presents information on the use of mature sugarcane as fodder and the sugarcane tops as fed to cattle in the fields. Whole sugarcane has also been ensiled in various ways, the finished product when adequately supplemented, reported to provide a favourable ration for cattle. By-products of sugar extraction, particularly molasses and raw sugar have been used in compounding rations for various classes of livestock.

The following report describes the use by cattle and sheep of a new sugarcane product, fresh sugarcane pith, obtained by the machine separation of the outer rind of mature sugarcanes from the inner pith containing the sugars.

2. Experimental Procedure

a. Location and climate

This trial was conducted during June to September

1968 at the Bayfords livestock farm in St. Kitts, West Indies, at an altitude of approximately 1,200 feet (360 metres) above sea level. The highest temperature recorded during the experimental period was 94°F (34°C), in August; the average maximum over the period was 88°F (31°C), and the greatest diurnal temperature variation was 20°F (6.5°C). The lowest recorded temperature was 68°F (20°C), with an average minimum of 72°F (22°C). The average monthly rainfall during the experimental period was 5.28 inches (13.4 cms), with the highest 6.56 inches (16.6 cms) falling in July.

b. Housing

A shaded shelter 42 ft. X 6 ft. (12.8 m X 1.83 m) (Figure 1), was constructed to enable individual housing, feeding and watering of 12 steers. Each steer was kept in a 6 ft. X 3 ft. (1.83 m X 0.91 m) pen, with bedding consisting of a layer of dried sugarcane trash or bagasse (Figure 2). Provision was also made at one end of the shelter to accommodate eight sheep on a digestibility trial.

c. Animals

Six of the animals used in this trial were obtained from the government herd in Nevis, and brought into St. Kitts by boat. These animals were Senepol steers (breed

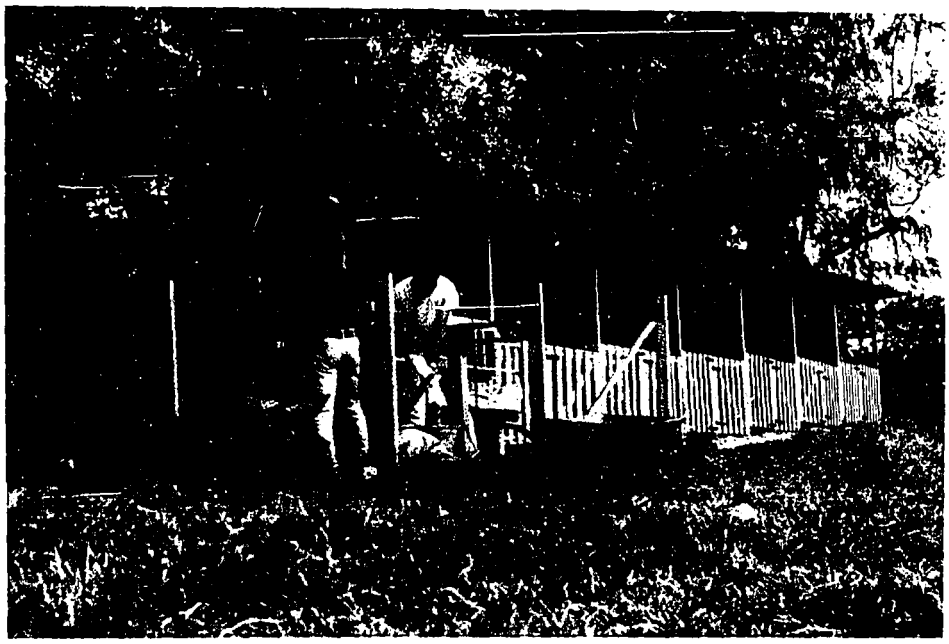

Figure 1. Animal shelter

Figure 2. Individual calf pen

Figure 1. Animal shelter

Figure 2. Individual calf pen

derived originally from 3/4 Senegal X 1/4 Red Poll), representing animals with beef producing potential, crossbred for tropical conditions (Figures 2,3). These animals ranging in weight from 200 - 402 pounds (90.8 - 182.5 kg) were in good condition at the beginning of the trial.

The other six steers procured from the government stock farm at Bayfords, St. Kitts, were Holstein (with some Zebu blood), and represent animals essentially bred for milk production under tropical conditions (Figure 4). These animals ranged in age from 4 - 8 months old, and 160 - 206 pounds (72.6 - 93.5 kg) in weight, while their general condition was apparently poorer than that of the Senepols.

d. Animal conditioning

Trichostrongyle spp. ova counts were made by Dr. A. Vaughan, the St. Kitts government veterinary officer, from fecal samples obtained from each steer, in order to assess parasitic burden. Following this, each animal was treated with Promintic,[1] (and Liquamycin[2] in some cases), dosage being dependent on severity of infestation and body weight

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[1]Promintic (ICI); 2-(P-methoxyethyl) pyridine administered subcutaneously.

[2]Liquamycin (Pfizer); Oxytetracycline hydrochloride administered intramuscularly.

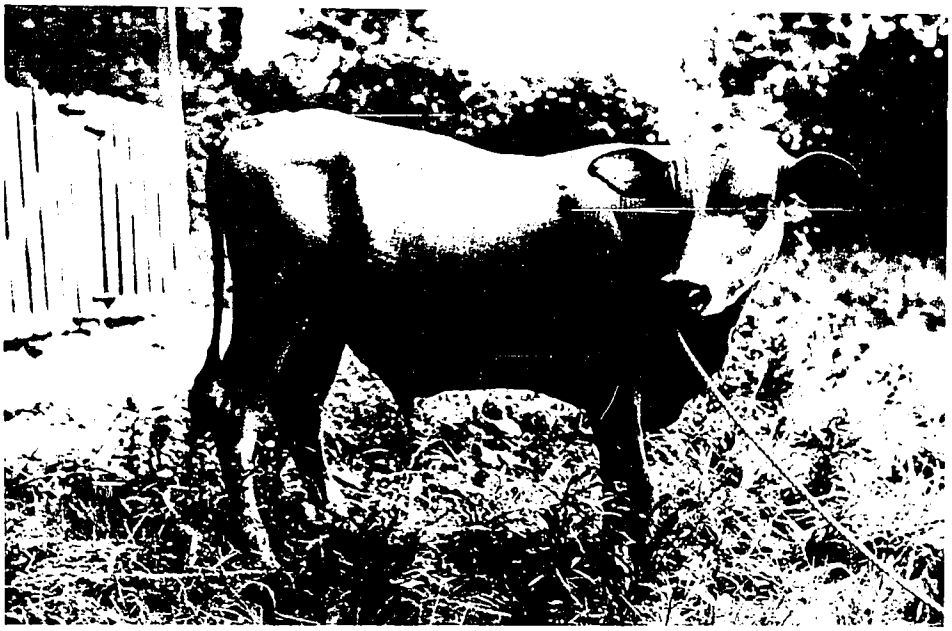

Figure 3. Senepol steer

Figure 4. Holstein steer

of the animal. Blood samples were also taken to determine the haemoglobin content. The animals were placed on trial one week after treatment, and sprayed with Sevin[1] for protection against ticks.

e. Design of experiment

i. Intensive feeding period

Two different rations were tested. Eight steers, four of each breed, were placed on a fresh sugarcane pith[2] supplemented ration, and the other four, two from each breed, placed on a control (dairy ration - citrus pulp) ration. The animals were all randomly allocated to their feed, penned separately and individually fed and watered during the first 77 days of the trial. The animals were individually fed in galvanised wash basins, approximately 22 inches (55.8 cms.) in diameter and 12 inches (30.5 cms.) deep, water being provided in smaller plastic buckets. Initially the animals were fed once daily, but during the last month of this period, animals consuming the most feed were fed twice daily. The

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[1]Sevin; 1-naphthyl-N-methyl carbamate. Sprayed on as suspension.

[2]Whole mature sugarcane stalks from which the rind has been removed, and consisting of mechanically shortened internal fibrovascular bundles and pith, attached to or intermixed with the bundles. This material is designated as Comfith Gr. by Cane Commodities Ltd., Montreal, developers of this particular process.

weight of each animal was determined weekly during this entire period. Daily feed intake was determined for each calf during the entire 77-day period. Sugarcane pith left over from the previous day's feeding was always discarded.

ii. Extended feeding period

At the completion of the intensive feeding (77-day) period, the pen partitions in the shelter were removed, and ten steers, i.e. the eight formerly on the sugarcane pith supplemented ration, plus the two Senepol steers formerly on the control ration, were group fed the sugarcane pith supplemented ration for an additional 21 days. This extended feeding period was used to determine what effect, if any, individual versus group feeding might have on animal performance. The steers were weighed at the beginning and end of this period. The animals were full fed the sugarcane pith supplemented ration but no data was collected on actual feed consumption during this period.

f. Preparation of sugarcane pith ration

The sugarcane pith was prepared daily, during the morning from mature sugarcane stems (10 - 12 months old, topped and leaves removed), which normally would be used for sugar production. The canes were first split down the middle into two halves, and each fed through a separator developed

by Canadian Cane Equipment Ltd. (Montreal, Que.). In this separation process, the pith with sugar was obtained as a fluffy mass, with fibres ranging from 0.25 inches (1 cm) to 4.5 inches (11 cms) with an approximate average of 2.5 inches (6.5 cms) in length, free from the outer rind and covering waxes. The fresh sugarcane pith was then loaded into jute bags for transport to Bayfords farm.

A supplement with the following composition was fed at a rate of 2 lbs. (900 gms) and 1 lb. (450 gms) per animal per day to Senepols and Holsteins, respectively.

	%
Soybean meal (44% protein)	67
Urea (42% Nitrogen X 6.25 = 262% crude protein)	13
Mineral mix (Purina)[1]	20

Vitamin A premix (10.000 I.U./gm) was added at a rate of 1 gm per 900 gms of supplement.

This supplement was prepared daily with the proper amount of supplement mix for each steer placed in a separate

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[1]The approximate composition of the mineral mix was as follows as listed on the label supplied by the manufacturers.

	%
Calcium not more than	15.0
Calcium not less than	13.0
Phosphorous not less than	6.5
Iodine not less than	0.006
Salt (NaCl) not more than	45.0
Salt (NaCl) not less than	40.0

plastic bag for transport to Bayfords. At feeding, the supplement was mixed into the top third of the sugarcane pith.

g. Control ration

Commercial feeds used to constitute the control ration were commercial dairy ration,[1] fed at 4 pounds (1.8 kg) per steer per day, and citrus pulp (dried),[2] fed ad libitum.

3. Results and Discussion

a. Observations

Table 1 shows mean Trichostrongyle spp. ova counts before and after treatment of steers, which was accomplished on June 10th, that obtained on June 15th, 5 days after treatment, indicating a substantial decrease in infestation compared with pre-treatment counts, this reduction being sustained for most of the animals during the trial as indicated by the ova counts made on July 23rd.

During the 14 day adaptation period, the Senepol steers fed on the sugarcane pith supplemented ration, readily

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[1]Robin Hood Flour Mills, Montreal. Guaranteed analysis as listed on feed label, minimum crude protein 16.0% (included not more than 5.0% equivalent crude protein from urea), minimum crude fat 2.3%, maximum crude fibre 14.0%.

[2]Trinidad origin.

Table 1. Mean Trichostrongyle spp. ova counts before and after treatment and pre-trial Haemoglobin count

Calf No.[1,2]	Ration	Pre-treatment[3] June 6th	Post-treatment[3] June 15th	Post-treatment[3] July 23rd	Haemoglobin count[4] June 6th
S1	Sugarcane	530	30	0	8.3
S2	"	630	27	30	9.0
S3	"	200	32	0	9.4
S4	"	66	17	0	8.7
S5	Control	170	0	0	10.2
S6	"	230	100	97	8.4
H1	Sugarcane	270	28	64	9.3
H2	"	130	0	0	8.6
H3	"	200	0	0	8.5
H4	"	67	0	0	9.8
H5	Control	300	0	293	7.2
H6	"	166	30	0	7.1

[1]S: Senepol steers. [2]H: Holstein steers

[3]Figures indicate eggs/gm feces (Modified McMaster Method).

[4]Figures represent gms Haemoglobin/100 mls blood (Sahli Method).

consumed it and showed no signs of ill effects. Two of the Holstein steers developed diarrhoea when the supplement was fed above 500 gms each, daily. The supplement level was subsequently maintained at 1 lb. (450 gms) each daily for the Holsteins, and gradually brought to 2 lbs. (900 gms) each daily for the Senepols, and maintained at these levels for the duration of the 77-day intensive study phase.

b. Body-weight changes

i. Intensive feeding period (77 days)

For the greater part of the trial, the weights of the two largest Senepol steers were estimated with a calibrated tape measure[1] due to their large size and thus awkward fitting in the weighing scale.

Body weight changes of steers during the first 77-day period on trial are summarised in Tables 2 (pounds) and 3 (kilograms), and individual results as per Appendix Table 1. Statistical analysis (Appendix Table 2) according to Goulden (1939) showed no significant differences in average daily gain between the two breeds and between the two rations (main effects). This result is attributable to the completely reversed performance of the two breeds on the two rations, as

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[1]Weighband; distributed by Cooper McDougall and Robertson Ltd., Berkhamstead, Herts, England.

Table 2. Summary of results of 77-day feeding period (pounds)

	RATION			
	Sugarcane Supplemented		Control	
	Holstein	Senepol	Holstein	Senepol
Number of calves	4	4	2	2
Av. Initial Wt.	181	277	179	301
Av. Final Wt.	236	383	291	340
Av. Total Gain	55	106	112	39
Av. Daily Gain	0.71	1.38	1.45	0.51
Daily Feed Consumed				
Sugarcane pith (as fed)	16.4	25.2	-	-
" "	4.7	7.2	-	-
(D.M. basis)[1]				
Supplement (as fed)	1.0	1.9	-	-
" (D.M. basis)[2]	0.9	1.7		
Citrus Pulp (as fed)	-	-	3.0	3.0
Dairy Ration (as fed)	-	-	3.9	3.4
Total (as fed)	17.4	27.1	6.9	6.4
Total (D.M. basis)[3]	5.6	8.9	6.2	5.8
Feed Efficiency				
(As Fed)	26.7	19.9	4.7	12.4
(D.M. Basis)	7.9	6.4	4.3	11.4

[1]Sugarcane pith with 28.6% D.M., as fed.

[2]Supplement mix with 78.3% D.M.

[3]Assuming 90% D.M. content of as fed control ration.

Table 3. Summary of results of 77-day feeding period (kilograms)

	RATION			
	Sugarcane Supplemented		Control	
	Holstein	Senepol	Holstein	Senepol
Number of calves	4	4	2	2
Av. Initial Wt.	82.17	125.76	81.26	136.65
Av. Final Wt.	107.14	173.88	132.11	154.36
Av. Total Gain	24.97	48.12	50.85	17.70
Av. Daily Gain	0.32	0.63	0.66	0.23
Daily Feed Consumed				
Sugarcane pith (as fed)	7.44	11.44	-	-
Sugarcane pith (D.M. basis)[1]	2.13	3.27	-	-
Supplement (as fed)	0.45	0.90		
Supplement (D.M. basis)[2]	0.39	0.78		
Citrus Pulp (as fed)	-	-	1.36	1.36
Dairy Ration (as fed)	-	-	1.77	1.54
Total (as fed)	7.89	12.30	3.13	2.90
Total (D.M. basis)[3]	2.54	3.94	2.81	2.63
Feed Efficiency				
(As Fed)	26.7	19.9	4.7	12.4
(D.M. Basis)	7.9	6.4	4.3	11.4

[1]Sugarcane pith with 28.6% D.M. as fed.

[2]Supplement mix with 78.3% D.M.

[3]Assuming 90% D.M. content of as fed control ration.

indicated in the highly significant Breed X Ration interaction ($P < 0.01$). The Holsteins performed better on the control ration, while the Senepols had a greater growth rate on the sugarcane pith supplemented ration. The major limitations in statistical interpretation is the small number of observations available for each group.

The statistically significant interaction necessitates that results for each ration be separately presented.

With regard to calves fed the sugarcane pith supplemented ration, the Senepol steers bodyweight gain was at twice the rate of the Holstein steers (1.38 lbs. vs. 0.71 lb./day), this difference being found to be statistically highly significant ($P < 0.01$), as per Appendix Table 3a. A possible explanation of the difference in rates of gain between the two breeds might be attributed to the heavier initial weight of the Senepol steers as well as the reduced intake of ration by the Holstein steers and their generally poorer pre-trial condition.

On the control ration, the Holstein calves gained at almost three times the rate of the Senepol calves (1.45 lbs. vs. 0.51 lb./day), this difference although large, was not statistically significant (Appendix Table 3b). On this regime, the better performance observed by the Holstein calves

could be attributed to better adaptability, since these animals were previously exposed to the citrus pulp and dairy ration ingredients which constituted part of the normal Bayfords farm feeding programme. The average performance of the Senepol steers (two calves) on this regime was considerably reduced as a result of almost negative gain by one of the calves (S5), which was almost off-feed for several days during the trial and only gained eight pounds during the entire 77-day period. It would be assumed that this condition was unrelated to the feeding programme. The limited number of animals per treatment group thus handicaps comparison of these results.

ii. Extended feeding period (21 days)

Results of body weight changes during the additional 21-day extended period are summarised in Table 4 and individual animal changes presented in Appendix Table 4. The values

Table 4. Weight changes during additional 21-day period

No. of Animals	Senepols 6		Holsteins 4	
	lb	kg	lb	kg
Av. Initial Wt. (Aug. 31st)	369	(167.5)	236	(107.1)
Av. Final Wt. (Sept. 20th)	407	(184.8)	254	(115.3)
Av. Total Gain	38	(17.3)	18	(8.2)
Av. Daily Gain	1.81	(0.82)	0.86	(0.39)

show that steers fed the sugarcane pith supplemented ration under feed-lot conditions achieved even higher rates of gain than when individually pen fed.

The average weight gain of all Senepols increased from 1.08 to 1.81 pounds per day when the initial 77-day data are compared with the results of the extended period. Disregarding the data from steers S5 and S6, whose rations were switched from that fed during the intensive feeding period, the average daily gain of the four Senepols which were continued on the sugarcane pith ration increased from 1.38 to 1.81 pounds per day. The increased gain was thus observed for all Senepols (Appendix Tables 1 and 4) but is most apparent in the case of the two calves (S5 and S6) which were switched from the control to the sugarcane pith ration. Particularly in the case of calf No. S5, where essentially no growth (0.10 lb./day) took place during the 77-day period, a growth rate of 1.89 lbs./day was achieved over the extended 21-day period.

The growth rate of the Holsteins in all but one case, also markedly increased during the extended feeding period from an average 0.71 to 0.86 pounds per day for the same four animals continued on the sugarcane pith ration. In the case of calf No. H4, an unexplained drop in growth rate occurred,

with a loss of two pounds in liveweight over the extended feeding period. The two Holstein calves on the control diet were removed from the trial at the end of the 77-day period, so that no comparative data are available for them.

Reasons for the better performance by the same animals during the extended trial might be attributed to the exercise which Morrison (1956) claims aids in keeping animals in better condition, and also to the change over to the sugarcane pith ration in the case of the two Senepol calves previously on the control ration.

The data from the intensive 77-day feeding trial and 21-day extended period thus show that the fresh sugarcane pith was very satisfactorily used in a ration as the main source of energy.

In tropical areas cattle receive their nutriture essentially by grazing forage material either from developed or undeveloped pastures. Performance of some tropical cattle under grazing conditions have been summarised by Williamson and Payne (1965). On good feed at the best time of the year, daily gains of 0.75 pounds (0.34 kg) could be considered satisfactory. In Jamaica, Motta in 1961 as reported by Creek (1967) quotes daily liveweight gains of 0.97 pounds (0.44 kg) with cattle on pasture. Creek (1967) in his trial with high

protein concentrate supplementation of well managed pastures using 21 month old animals in Jamaica, reported daily gains of 1.53 pounds (0.69 kg).

Production under a feedlot system, as simulated in the 21-day extended period, gives a better indication of the performance which would be expected on the sugarcane pith ration under more practical conditions. Average daily gains from other trials with steers on ensiled whole sugarcane rations reported by Quesenberry (1925) and Shealy et al. (1941) of 1.58 pounds (0.72 kg) and 1.79 pounds (0.81 kg), respectively, compare favorably with the results from the extended period of this trial, and indicate the ability of sugarcane with protein and mineral supplements for producing satisfactory gains with cattle.

In summary, comparing the daily average of 1.38 pounds (0.63 kg) and 1.81 pounds (0.82 kg) made by the Senepol steers in the 77-day and 21-day periods, respectively, with that obtained under existing systems of cattle rearing in the tropics, it can be seen that production on a sugarcane based ration is superior than that normally obtained. Weight gains of the Holsteins in this trial, though limited, still gave values comparable with the average under some tropical conditions.

c. Feed consumption

Feed consumption data are summarised in Tables 2 (pounds) and 3 (kilograms) with individual animal daily intakes tabulated in Appendix Table 5. It can be seen that average daily feed intake by the Senepol steers on the sugarcane ration was approximately 1.5 times that of the Holstein calves on the same diet. Lack of ability of the Holstein steers to consume higher levels of the sugarcane pith and supplement mix could probably be attributed to their poorer pre-trial condition and to their lower body weights.

The average total digestible energy (DE) content of the ration consumed daily by each breed on the sugarcane pith supplemented feed was calculated based on (a) sugarcane pith with gross energy value of 3.90 k.cal./gm, (b) supplement mix with gross energy value of 3.01 k.cal./gm, (c) energy digestibility coefficient of 76% for sugarcane pith supplemented ration (as determined in Experiment 2 with sheep, to be described). The calculation can be outlined as follows:

Energy from sugarcane pith (k.cals.) = sugarcane pith intake (gm) X 3.90 = A

Energy from supplement mix (k.cals.) = supplement intake (gm) X 3.01 = A_1

Total energy intake (k.cals.) = $A + A_1$

Total DE intake (k.cals.) = $(A + A_1) \times 0.76$

It was thus calculated that the Holstein steers received an average of 7.35 meg. cals. DE daily while the Senepols received 11.75 meg. cals. DE daily.

The average total protein supplied daily to each breed can be calculated assuming a negligible contribution by the sugarcane pith, and the supplement mix with an average of 70.9% crude protein. For the Holstein consuming 450 gm supplement daily, total protein intake would thus be 319 gm daily, while for the Senepols, it would be 638 gm.

The following table indicates the requirements for DE and crude protein according to the 1966 standards set by the National Research Council (U.S.) for 200 - 400 pound dairy breed calves to realise average daily gains of 1.5 pounds, as compared to the actual amounts of DE and crude protein supplied to the two breeds as calculated.

	Daily required	Daily supplied (sugarcane pith supplemented feed)
Digestible energy (meg. cals.)	8.0 - 12.8	7.35 (Holstein) 11.75 (Senepols)
Crude protein (gm)	430 - 520	319 (Holstein) 638 (Senepols)

From these values it can be seen that the Holstein steers did not meet their daily requirements for either DE or total protein, because of their low intakes. The lower

gains made by these animals were apparently in accordance with their reduced nutrient intake, smaller size and poorer pre-trial condition. The Senepols, however, adequately met their protein requirement, but were marginal in DE intake as reflected in the gains realised which were lower than that anticipated from the standards (1.38 vs. 1.54 lbs./day).

It must, however, be realised that requirements as stipulated by the National Research Council may not be directly applicable to tropical animals, which in their environment are subjected to stresses not normally encountered by temperate type cattle in their environment, for which the standards were designed.

The Holsteins on the control ration consumed more dry matter (0.5 lb./day) than the Holsteins on the sugarcane pith ration, partially explaining the former's better growth performance. The control fed Holsteins consumed markedly less dry matter than the Senepols fed the sugarcane ration, this difference possibly attributable to the larger size of the Senepol calves.

d. Feed efficiency

Average feed efficiency (units feed/unit gain, dry matter basis) values are summarised in Tables 2 and 3. It can be seen that of the four groups, the Holstein on the

control ration were the most efficient converters, the efficiency of the Senepols on this regime being low due to the one calf (S5) which essentially made no gain throughout the trial. On the sugarcane ration the feed efficiency of the Senepols, although lower than that of control fed Holsteins, is comparable with that obtained with normal feedlot rations fed to beef cattle.

e. Cost analysis

A feed cost analysis of the results obtained from this trial based on St. Kitts prices for the various feedstuffs is outlined in Table 5. The value of sugarcane pith

Table 5. Feed cost analysis

Av. Daily Feed Costs per Animal Ingredient	RATION			
	Sugarcane Pith		Control	
	Holstein	Senepol	Holstein	Senepol
Sugarcane pith (0.015¢/lb)	0.25	0.38	-	-
Soybean Meal (0.16¢/lb)	0.11	0.20	-	-
Urea (0.14¢/lb)	0.02	0.04	-	-
Mineral Mix (0.13¢/lb)	0.03	0.05	-	-
Dairy Ration (0.15¢/lb)	-	-	0.59	0.51
Citrus Pulp (0.06¢/lb)	-	-	0.18	0.18
Total	0.41	0.67	0.77	0.69
Av. Daily Gain (lbs)	0.71	1.38	1.45	0.51
Av. Feed Cost/lb/ wt. gain	0.58	0.49	0.53	1.35

was set at 1.5¢[1] per pound on the assumption that sugarcane selling at $15.00 per 2,000 pounds would yield 80% fresh sugarcane pith with a processing cost of 0.5¢ per pound. Adding the 0.5¢ per pound to the 0.94¢ per pound for sugarcane pith results in 1.44¢ or 1.5¢ per pound for fresh sugarcane pith. The soybean meal, urea and mineral mix were specially imported for the trial, so that their prices are not established locally (St. Kitts) but based on retail prices in other Caribbean areas (Barbados and Puerto Rico). The prices for the commercial dairy ration (Robin Hood, Canada) and citrus pulp (Trinidad), represent the retail prices in St. Kitts.

On the basis of this feed costing, it can be calculated that the cost per pound of gain on the sugarcane supplemented ration was $0.58 and $0.49 for the Holsteins and Senepols, respectively, while on the control ration, it was $0.53 and $1.35, respectively for the Holsteins and Senepols. The high figure for the Senepols fed the control ration is of course a result of the one calf (S5) whose feed intake and growth rate appeared abnormally retarded.

Whereas it is of interest to calculate feed costs on

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[1]All costs are quoted in Eastern Caribbean (E.C.) Currency. $2.00 E.C. = $1.00 U.S. = $1.08 Can.

the bases of information obtained at the time of the trial, it must also be recognised that certain arbitrary and changeable cost relationships do exist. The cost of sugarcane pith was based on the price paid for sugarcane destined for raw sugar production for potential human consumption. It is highly feasible that marginal land could be used to produce sugarcane pith exclusively for cattle, so that the cost of the crop so used would be related to actual field and harvesting costs as considered in relation to alternative crop uses. The processing cost factor for producing the fresh sugarcane pith from whole sugarcane was estimated on the basis of a large sugar mill integrated separator unit, without taking into consideration the possibility of using a simpler portable unit designed specially for production of animal feed. Another factor to be considered is the cost of non-energy supplement ingredients, which in this trial accounted for approximately 40% of the total cost of the sugarcane pith supplemented ration. It would appear to be quite possible to further reduce costs of ingredients used to supplement the sugarcane ration by replacing part or all of the soybean meal by locally available cottonseed meal, coconut-oil meal, brewery by-products and separate purchases of salt and calcium phosphates to replace the commercial (Purina) mineral mix.

B. EXPERIMENT 2 - DIGESTIBILITY AND INTAKE TRIAL WITH SHEEP

1. Introduction

This experiment was conducted to obtain digestibility and voluntary intake data of the sugarcane pith supplemented ration using smaller and thus more easily managed animals. Since the digestive system of the sheep is functionally the same as that of cattle, the data obtained with the sheep would provide information on the nutritive value of the ration which should be generally applicable to ruminants.

2. Experimental Procedure

a. Animals

Eight mature indigenous adult male sheep weighing between 40 - 60 pounds (18.2 - 27.2 kg) were obtained from the Belmont Sugar Estates, St. Kitts, for this trial which was conducted at Bayfords livestock farm. The animals were kept in individual cages designed to enable total fecal collection and voluntary intake determinations. The sheep cages were located at the North end of the shelter housing the steers from Experiment 1.

b. Animal conditioning

Following fecal ova counts to estimate parasitic infestation, the sheep were all treated[1] to reduce parasitic burden by the local veterinary officer.

c. Design of experiment

Two different feeding regimes were adopted differing only in the amount of protein-mineral supplement fed, as follows:

1st Period - ad libitum sugarcane pith and 200 gm supplement (same composition as fed to steers in Experiment 1).

2nd Period - ad libitum sugarcane pith and 100 gm supplement

Following a 5-week adaptation period, when the sheep were all fed ad libitum sugarcane pith with increasing supplement mix to 200 gm, a 7-day test period was employed to determine the digestibility and voluntary intake of this sugarcane pith supplement combination. In order to determine if nutrients other than those supplying energy were limiting the utilisation of the sugarcane pith, the supplement level was reduced in the 2nd period. This change in supplement level was accomplished over a 7-day adaptation period following the completion of the 1st period, and voluntary intake and digestibility were determined in another

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[1] Promintic (ICI); 2-(P-methoxyethyl) pyridine administered subcutaneously.

7-day test period following the adaptation period.

The sugarcane pith and supplement were prepared as described for Experiment 1, with the supplement mix for each sheep pre-weighed and individually packaged in plastic bags for transport to the Bayfords farm. The sheep were fed twice daily in plastic containers, measuring approximately 12" long X 8" wide X 4" deep (30.5 cm X 20.3 cm X 10.2 cm) with water and feed constantly before them. Feed consumption was determined daily, with ad libitum intake of sugarcane pith provided by feeding a minimum 10% excess of the previous day's consumption. Feed samples were taken daily during the two 7-day test periods, with each sample oven dried and packaged in polyethylene bags for transport to Macdonald College for subsequent analyses.

Total feces excreted per sheep daily was determined during the two 7-day test periods, with aliquot amounts oven dried and stored in polyethylene bags for transport to Macdonald College. Fecal collection was facilitated by the use of a chute made from jute bags attached to the rear and sides of each cage, and in the bottom of which was placed a 12" long X 8" wide X 4" deep (30.5 cm X 20.3 cm X 10.15 cm) plastic container to collect the fecal droppings. The rear section of the platform of each cage contained a perforated

screen mesh to allow for urine drainage under the cage, and thus prevent contamination of feces with urine.

d. Live weight changes

Each animal was weighed on the day prior to the first day of the fecal collection period, and again on the last day of fecal collection. This data was used for calculating the Relative Intake of the ration.

e. Chemical analyses

Determinations were made for dry matter and crude protein content of both feed and fecal samples, according to A.O.A.C. methods (1965). The samples were dried in a vacuum oven at 94°C (200°F) with a vacuum of approximately -25 mm mercury for at least four hours for the dry matter determination. Crude protein content was calculated after determination of nitrogen (N) by the macro Kjeldahl method, and multiplying this value by 6.25. Cellulose content of feed and feces was determined by a modification of the method of Crampton and Maynard (1938) as described by Donefer et al. (1960). Gross energy content of feed and feces samples was determined using a Parr Oxygen Bomb Calorimeter,[1] fitted with an automatic temperature recorder.

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[1]Parr Instrument Co., Inc., Moline, Illinois.

f. Calculations

i. Digestibility coefficients

The apparent digestibility coefficients of dry matter, gross energy, crude protein and cellulose were calculated using the following formula:

$$\text{Coefficient of digestibility (\%)} = \frac{(F_o \times A_o) - (F_i \times A_i)}{(F_o \times A_o)} \times 100$$

where F_o = grams of feed consumed

F_i = grams of feces excreted

A_o = percentage nutrient in feed

A_i = percentage nutrient in feces

(nutrient relates to dry matter, crude protein, cellulose or k.cals. gross energy/gm, with all data converted to dry matter basis)

ii. Relative intake

The Relative Intake of each feed was calculated from the following formula (Crampton et al., 1960):

$$\text{Relative Intake} = \frac{\text{Observed intake}}{80(W_{kg}^{0.75})} \times 100$$

where $(W_{kg}^{0.75})$ is the metabolic body size of the animal.

iii. Nutritive Value Index

This index (NVI) described by Crampton et al. (1960) for feeds is calculated by multiplying the Relative Intake

of the feed by its percent gross energy digestibility.

N.V.I. = Relative Intake X % gross energy digestibility.

iv. Statistical analysis

The statistical significance of the difference between criteria due to level of supplementation was analysed using the "t" test as described by Steel and Torrie (1960).

3. Results and Discussion

a. Observations

The sheep quickly became adapted to their new environment and feed, and did not exhibit any ill effects during the trial.

b. Chemical analysis

The chemical composition of the sugarcane pith and supplement used in the ration are presented in Table 6.

Table 6. Chemical analysis of components of ration (values on D.M. basis)

Ingredient	Dry matter	Gross energy k.cal/gm	Crude Protein	Cellulose
	%		%	%
Sugarcane pith	91.9	4.25	1.5	17.5
Supplement mix	87.3	3.44	70.9	8.0

Quite obvious from this table is the low protein content of the sugarcane pith, necessitating the supplementation of this nutrient. Although the cellulose content is higher than that normally found in grain seeds (corn, barley, oats, etc.) it is lower than that found in forages such as hay and silage. In fact, the cellulose content being lower than 18%, this material would be defined as an energy feed, i.e. a concentrated source of available energy (Crampton and Harris, 1969).

The low gross energy value of the supplement mix is a result of the non-energy containing mineral components of the mixture. The high crude protein content of the supplement is a reflection of its urea content, this non-protein nitrogen source containing the equivalent of 262% crude protein. The relatively high cellulose content for the supplement mixture reflects the contribution to this component by the soybean meal which analysed 10.2% cellulose.

c. Apparent digestibility coefficients

Values for the apparent digestibility of dry matter, gross energy, crude protein and cellulose are summarised in Table 7, with individual sheep determinations presented in Appendix Tables 6 and 7.

Increasing the level of supplement in the ration did

Table 7. Summary of apparent digestibility values and Relative Intake, Nutritive Value Index of sugarcane pith supplemented ration to sheep

Apparent Digestibility (%)	Level of Supplementation 100 gm	200 gm
Dry matter	77.2	77.6
Gross energy	76.1	76.8
Crude protein	71.8	80.8**
Cellulose	57.1	59.6
Relative Intake	84.9	99.2*
Nutritive Value Index	64.7	76.2*

*Indicates statistically significant difference ($P < 0.05$).

**Indicates statistically significant difference ($P < 0.01$).

not have any effect on the apparent digestibility of the different nutrients except crude protein, which increased by approximately nine percentage units, this difference being highly significant ($P < 0.01$). Although cellulose digestibility increased by 2.5 percentage units, this difference was statistically non-significant ($P < 0.05$).

The values indicate that all the components under investigation are adequately digested, and that the utilisation of the energy of the sugarcane pith was not limited by nutrient deficiency. Of particular interest is the high cellulose digestibility (average of 58.4%) compared with that of good quality alfalfa hay of 60.6% (reported by

Donefer, 1966) suggesting that cellulose utilisation was not appreciatively limited by a lignin complex. Also of interest is the high cellulose digestion achieved in the presence of the high soluble carbohydrate content of the sugarcane pith. High levels of readily available carbohydrate in ruminant rations have been associated with reduced crude fibre (cellulose) digestibility, since it is presumed that the microflora in the rumen preferentially derive their energy from the readily available source and are not required to attack the fibrous fractions of the ration, an alternate source of energy.

The slight increase in cellulose digestibility at the higher level of supplementation might be attributed to greater microbial activity in the rumen since the increased nutrient contribution at the higher supplement level could have acted as a stimulant to microbial activity.

The large increase in protein digestibility at the higher supplement level might be attributed largely to the extra amount of urea supplied. This material is completely soluble in the gastro-intestinal fluids, so that in actuality it would have an apparent digestibility of 100%.

The availability of the gross energy of the sugarcane supplemented ration (average 75.5%) is in the order of

that observed for a grain such as barley. Although the digestibility values presented represent the contribution of both the sugarcane pith and the supplement components of the ration, the energy values can be largely attributed to the sugarcane pith as it approximated 85% of the ration. In fact, the energy availability of the sugarcane pith alone would be higher than that reported for the mixture since the supplement would not be considered as a good source of available energy.

d. Relative Intake and Nutritive Value Index

Relative Intake (RI) is a measure of voluntary intake as compared to that of a standard high quality forage, a scheme initiated by Crampton et al. (1960). The Nutritive Value Index (NVI) is an index of feed nutritive value, also initiated by the above workers. Since the NVI is calculated as the product of RI and the gross energy digestibility of a feed, it is used as a measure of its digestible energy intake potential.

Values for RI and NVI of the sugarcane pith supplemented at two different levels, are summarised in Table 7, with individual sheep values presented in Appendix Table 8. The difference in these two criteria due to levels of supplementation was found to be statistically significant

($P < 0.05$).

Increased voluntary intake by ruminants has been associated (Conrad, 1966 and others) with increased rate of disappearance of digesta from the rumen due to increased microbial activity in the rumen, this having already been attributed to the increased level of protein on the higher supplement level. No doubt this could be responsible for the increase in Relative Intake observed, and reflected in the increased Nutritive Value Index between the two rations. Donefer (1968) has shown that the voluntary intake of alkali-treated oat straw, a material of low protein content, can be increased 2-3 fold when urea was added to the diet. Although the increase observed in this trial was not of that magnitude it does indicate that nutrients particularly nitrogen were limiting voluntary intake at the lower level of supplementation.

Of interest was the Relative Intake value of 99.2 observed for the sugarcane pith ration at the 200 gm supplement level. This value is essentially the same as the RI of 100 which is used to define a high quality legume forage such as alfalfa or clover hay (Crampton et al., 1960). It has been observed (Donefer et al., 1963) that when a concentrated source of available energy such as barley was added

to an alfalfa ration for sheep, RI and NVI decreased with increased barley level. The RI of 99 is thus far higher than those of 70-87 as reported by these workers for alfalfa rations with added barley. This observation indicates that the high cellulose content of the sugarcane pith may prevent depressions in voluntary intake observed when soluble carbohydrate are added to the diet.

e. Live weight changes

Table 8 summarises changes in liveweight of the sheep on the two feeding regimes over the seven-day collection periods, with individual gains tabulated in Appendix Table 9. The values indicate that animals gained more on

Table 8. Live weight changes[1] of sheep on rations over 7-day test periods

	Level of Supplementation	
	100 gm	200 gm
Av. Total Gain (gm)	269	766
Av. Daily Gain (gm)	38.4	109.4

[1]Values represent average of eight sheep.

the higher level supplementation, the difference in average gain on the two regimes being statistically significant ($P < 0.05$). Liveweight changes of sheep were not major

criteria under investigation in this trial, since adult sheep supposedly of mature weight were used. Increases in weight represent the effect of a superior nutrient contribution as compared with the prior feeding program as also manifested by the high values for NVI of the experimental ration at both levels of supplementation. Despite the fact that adult sheep of mature weight were used, the weight gains realised indicate that better results could be anticipated if the ration had been fed to fattening lambs or younger stock.

V. THE NUTRITIVE VALUE OF ALKALI TREATED DIFFUSED SUGARCANE PITH

A. EXPERIMENT 3 - EFFECT OF TYPE AND CONCENTRATION OF ALKALI ON THE IN VITRO CELLULOSE DIGESTIBILITY OF DIFFUSED SUGARCANE PITH AND OAT STRAW

1. Introduction

Water extraction of sugars from fresh sugarcane pith leaves a residue comparable with bagasse from conventional sugar extraction processes from sugarcane, except that without the rind, the pith tends to be less coarse and less lignified a material than bagasse. This material, of low nutritive value due to its high content of lignified fibres, could possibly be improved through chemical delignification processes and thus become a more valuable ingredient in ruminant rations.

In vitro rumen fermentation methods have been shown to be economical, convenient and relatively dependable techniques for predicting the nutritive value of a forage for feeding to ruminants. It is thus possible to obtain in vitro digestion values for a number of feed samples and treatment combinations over a short period of time, thus screening possible treatments for more elaborate in vivo

feeding trials.

The following experiment was thus designed to chemically delignify small samples of water diffused (extracted) sugarcane pith[1] and oat straw, with different types and levels of alkali, and subject the treated samples to *in vitro* fermentation procedures for estimation of their feeding potential.

2. Experimental Procedure

a. Preparation of diffused sugarcane pith

Fresh sugarcane pith was obtained, as previously described, by removal of the coarse outer rind from the sugarcane, by mechanical separation. The pith was then repeatedly washed with water to remove as much of the sugars as possible. A light whitish-grey fibrous material was obtained on air drying. Approximately 300 pounds (136 kg) of diffused sugarcane pith was thus prepared in St. Kitts, West Indies and air shipped to Macdonald College for *in vitro* and *in vivo* trials.

b. Sampling and grinding

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[1]Fresh sugarcane pith as used in previous trials reported but from which the sugars particularly have been removed by repeated washings with water. In this and the following trials the term pith is used to designate diffused sugarcane pith.

Each bag of pith was sampled and a sub-sample taken from the pooled samples, for alkali treatment. Oat (Avena sativa) straw samples as a control, was similarly sampled from five bags of ground straw left from a previous feeding trial.

Both samples were ground in a Raymond laboratory Hammer Mill, fitted with a No. 30 mesh screen (0.024 inches or 0.6 mm diameter), and stored in large glass bottles.

c. Preparation of alkali solutions

The alkalis tested in this trial were sodium hydroxide (NaOH), and ammonia, as the hydroxide (NH_4OH). The expression treatment level which will be used, refers to the weight of alkali, i.e. NaOH or NH_3 in grams per 100 gm of untreated material. Thus a 4% treatment level of NaOH or NH_3 refers to 4 gm of NaOH or NH_3/100 gm of material (straw or pith).

The solutions were prepared from reagent grade chemicals,[1] the NaOH solution prepared on a weight to volume basis, and the ammonium hydroxide on a volume to volume basis. The NaOH solutions were prepared from NaOH pellets (97% minimum NaOH), while for ammonia treatment, ammonium hydroxide

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[1]Fisher Scientific Co., Montreal.

solutions were prepared from concentrated NH_4OH (NH_3 assay 28%). Distilled water was used to make up all solutions.

Each material was treated at three different alkali levels as indicated below:

Treatment level %	Alkali	Amount used for 120 ml soln.
4	NaOH	4.12 gm
8	"	8.24 gm
16	"	16.48 gm
1.5	NH_4OH	6.00 ml
3.0	"	12.00 ml
6.0	"	24.00 ml

The NaOH solutions were prepared on the evening prior to treatment, while the NH_4OH solutions were prepared just before treatment.

d. Treatment of materials

The solution volume used in each case was 120 ml per 100 grams of material to be tested, or in actuality 30 ml of solution per 25 gm of material. A 25 gm sample of ground pith was placed in each of ten 600 ml pyrex beakers. One of the ten samples served as a treatment control with 30 ml of distilled water added, while the remaining nine were treated as follows.

i. Three samples, each treated with one of the three levels of NaOH.

ii. Three samples each treated with one of the three levels of ammonia.

iii. Three samples treated as ii above.

A similar pattern of alkali solutions, concentration and treatment was used with ground oat straw samples. Thorough mixing of the materials with the solutions was done by hand, using a spatula. The beakers were then covered over with a thin plastic wrap and taped to avoid loss of treatment material, either as water or ammonia. Finally the beakers were stored at room temperature for approximately 24 hours.

e. Termination of treatment

i. Acid neutralisation

The reaction of samples treated with NaOH solution along with a sample of each of the materials treated with the three different ammonia levels, was terminated by neutralisation with acetic acid. It was decided to use a 10% acetic acid solution for neutralising the ammonia treated samples, and a 20% acetic acid solution for the NaOH treated samples, since pilot investigations had shown the volume of 10% acetic acid required to neutralise the 16% treatment level of NaOH solution to be too high in comparison with that required to neutralise the ammonium hydroxide solutions, and

would result in a wetter material after neutralisation.

Acetic acid solutions were prepared from glacial acetic acid[1] (99.7%) and pipetted onto the treated materials, constantly mixing with a spatula, until a pH meter (Beckmann Zeromatic) reading of slightly less than seven, was obtained.

The neutralised samples were then thinly spread out on aluminium pans and allowed to air dry for 24 hours at room temperature.

ii. Neutralisation by air drying

The treatment of the remaining samples, i.e. one sample of each material treated at the different levels of ammonia, was terminated by air drying, thus taking advantage of the volatile nature of ammonium hydroxide. The treated samples were transferred directly into aluminium pans, spread thinly and allowed to air dry for 24 hours at room temperature.

On drying, all samples were placed in individual jars labelled and kept for subsequent determinations.

f. Procedure for *in vitro* rumen fermentation

The procedure adopted was similar to that used by Donefer (1961).

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[1]Anachemia, Montreal, Que.

i. Source of rumen ingesta

A rumen fistulated steer fed ad libitum a diet consisting exclusively of good quality alfalfa hay, cobalt-iodized salt and water available at all times, served as source of rumen ingesta.

ii. Phosphate buffer extract

About 6 litres of rumen ingesta was collected and the rumen liquid pressed out through two layers of cheesecloth and discarded. A sample of 1,800 gm (4 lbs.) of the resultant solid ingesta was mixed with 1,500 ml phosphate buffer (pH 7). After moderately mixing the ingesta and buffer, the mixture was repressed, and the resultant liquid, designated as phosphate buffer extract (P.B.E.), filtered through 4 layers of cheesecloth into a preheated thermos container for transport to the laboratory.

Prior to making the extract, the phosphate buffer solution was preheated to 45 - 48°C (to compensate for drop in temperature with transport), 25 ml 20% Na_2CO_3 (sodium carbonate) added and CO_2 (Carbon dioxide) bubbled through the solution until the pH returns to 7, as measured by pH meter.

iii. Nutrient medium

The composition of the nutrient medium was as per Table 9.

Table 9. Composition of *in vitro* basal medium

Solution	Volume used per tube	Amount used per tube
	ml	mg
Mineral mixture[a]	10	
Iron and Calcium ($FeCl_16H_2O$, 4.4 mg/ml	0.5	2.200
$CaCl_22H_2O$, 5.29 mg/ml)	-	2.645
Glucose (100 mg/ml)*	0.5	50
Urea (126 mg/ml)*	0.5	63
Biotin (10 µg/ml)	1.0	10 µg
P.A.B.A. (100 µg/ml)	0.25	25 µg
n-Valeric acid (5 mg/ml)	3.00	15
Casein hydrolysate-enzymatic[b] (20 mg/ml)*	2.50	50
Na_2CO_3 (200 mg/ml)	1.50	300
Phosphate buffer Extract[c]* (Inoculum)	20.00	

[a] Na_2HPO_4, 5.65 gm; $NaH_2PO_4H_2O$, 6.27 gm; KCl, 2.15 gm; NaCl, 2.15 gm; $MgSO_47H_2O$, 0.582 gm; and Na_2SO_4, 0.75 gm per litre.

[b] Nutritional Biochemicals Corp.

[c] Na_2HPO_4, 1.059 gm; KH_2PO_4, 0.436 gm per litre.

*Prepared on evening prior to each fermentation run.

iv. Substrates

Dried forage substrates were prepared for *in vitro* studies by grinding in a Raymond hammer mill, fitted with a screen having 0.24 inch (0.6 mm) diameter holes. Each tube in the *in vitro* system contained approximately 200 mg of cellulose, provided by 430 - 570 mg of pith or 460 - 600 mg oat straw, the actual amount of substrate dependent on the cellulose content of the control and treated materials as determined by analysis prior to the fermentation runs.

v. *In vitro* system

This system consisted of 32 fermentation tubes (90 ml Pyrex No. 8260) each fitted with a 1-hole rubber stopper (No. 6) through which was inserted a glass delivery tube (Fisher No. 13-711) attached by means of rubber tubing to a gas manifold with 32 outlets each fitted with a needle valve, adjusted to deliver 160 bubbles per minute. The gas manifold was connected to a tank of carbon dioxide fitted with a gas pressure regulator. The glass delivery tube was fitted so that its tip was approximately 40 mm from the bottom of the fermentation tube. Gas was exhausted by way of the clearance between the pouring lip of the tube and the rubber stopper.

vi. Preparation of nutrient medium, dispensation of medium and inoculum, and initiation of fermentation run

All the components of the nutrient medium, Table 9, except iron and calcium, were premixed in a 2-litre Erlenmeyer flask, in quantities necessary for the inoculation of 40 fermentation tubes and conditioned (heated to 40°C, saturated with CO_2, and adjusted to pH 7). Following this, 800 ml of the inoculum and 20 ml of iron and calcium mixture were added to the flask containing the nutrient medium, and the total volume made up to 2 litres with distilled water. The flask was then placed on a magnetic stirrer and attached to a Brewer Automatic Pipette which dispenses 50 ml of the mixed medium and inoculum to each fermentation tube (into which preweighed amounts of substrate had been previously placed).

Addition of the inoculum and nutrient medium mixture to the substrate initiated the fermentation run. Two drops of mineral oil were added to each tube to prevent foaming, after which the tubes were connected to the CO_2 gas supply, and placed in a water bath (Fisher No. 15-470) kept at 40°C, for 24 hours.

vii. Termination of fermentation

At the conclusion of the fermentation period, the

tubes were removed from the water bath with any adhering material washed from the CO_2 delivery tube and sides of the fermentation tube. The fermentation tubes were then centrifuged at 2,200 r.p.m. for 6 minutes, the supernatant discarded and the residue retained for analysis.

viii. Cellulose determination

The method adopted was a slight modification of that described by Crampton and Maynard (1938).

Acid digestion - Acid digestion mixture consisted of 650 ml acetic acid (99.7%), 150 ml distilled water and 80 ml concentrated nitric acid. Twenty-five ml of this mixture was dispensed into each fermentation tube using an automatic pipette (Machlett). A glass stirring rod was placed in each tube to facilitate mixing during the digestion. Eight tubes were placed in a stainless steel wire basket, then immersed in a boiling water bath for 30 minutes, with the contents of the tubes stirred every ten minutes. After removing from the water bath the tubes were allowed to cool for 5 minutes.

Filtration - Twenty-five ml of 95% ethanol was added to each tube and mixed with the contents. The tubes were then allowed to stand for several minutes, following which the contents were transferred quantitatively to a filtering crucible (coarse porosity, sintered glass), with repeated

washings with 95% ethanol. The residue in the crucible was then washed with approximately 10 ml each of acetone and ether in succession.

Drying and Ashing - The crucibles were next dried in a vacuum oven at 95°C for approximately 4 hours, after which they were allowed to cool in a dessicator, then weighed. They were then ashed overnight in a muffle furnace at 600°C, cooled in a dessicator, then reweighed.

Calculations - Cellulose content.

Cellulose (gm) = wt. (gm) dry crucible and contents
- wt. (gm) ashed crucible and contents

$$\text{Cellulose (\%)} = \frac{\text{wt. (gm) of cellulose}}{\text{wt. (gm) of substrate}} \times 100$$

Cellulose digestibility.

Cellulose digestibility (%) =

$$\frac{\text{wt. (gm) initial cellulose - wt. (gm) cellulose residue}}{\text{wt. (gm) initial cellulose}} \times 100$$

g. In vitro fermentation runs

Four fermentation runs were made over a period of six weeks to determine the in vitro cellulose digestibility of the alkali treated materials and control samples (samples treated with distilled water only). At the end of the 24-hour fermentation period the undigested (residual) cellulose was determined and the digestibility of cellulose was

calculated for each of the materials based on original cellulose content of samples. Cellulose content was determined by the modified method of Crampton and Maynard (1938), already described. Analysis of variance was conducted, and the Duncan's multiple range test used to determine the statistical significance of observed differences in the cellulose digestibility data.

h. Crude protein content

Crude protein (Nitrogen content X 6.25) content was determined for untreated samples and ammonia treated samples of pith and oat straw. In all cases the macro Kjeldahl method was used for nitrogen determinations.

3. Results and Discussion

a. Observations

Both pith and oat straw samples changed to a golden color on treatment with either NaOH or ammonia, while samples treated with NaOH tended to generate reaction heat. On neutralisation, all samples turned to a paler shade of gold.

Results from one of the *in vitro* runs had to be discarded as it was discovered that the fistulated steer had been fed immediately prior to sampling, this tending to reduce the microbial population of the extract and decreasing

the initial activity of the system.

b. Cellulose content

The cellulose content of the treated materials are presented in Table 10. Decreases in percentage cellulose

Table 10. Cellulose content of alkali-treated pith and oat straw

Treatment level %	Neutralisation	Cellulose Content %	
		Pith	Oat straw
0.00[1]		43.3	43.3
	Ammonia Treatment		
1.50	air drying	46.3	42.7
3.00	" "	46.5	43.7
6.00	" "	47.0	42.9
1.50	acetic acid	45.3	40.6
3.00	" "	44.0	41.0
6.00	" "	41.6	40.5
	Sodium Hydroxide Treatment		
4.00	acetic acid	42.3	42.7
8.00	" "	40.6	39.5
16.00	" "	35.3	33.3

[1]Zero treatment level indicates material treated only with distilled water.

content compared with the untreated control were observed with ammonia treatment and acid neutralisation of oat straw and also with pith treated at the highest ammonia level and

acid neutralised. There was also the unexplainable observation that other ammonia treated pith samples exhibited a slightly greater cellulose content than the untreated control.

The cellulose content of both sodium hydroxide treated pith and oat straw tended to decrease as the level of alkali treatment increased. Similar results were reported by Jones (1967) and was attributed to increased ash content per unit weight due to the addition of alkali and acid, thus tending to reduce the cellulose content of the material, per unit weight.

c. In vitro cellulose digestibility

Data on in vitro cellulose digestibility of samples are summarised in Table 11, illustrated in Figures 5 and 6 with detailed results and statistical analysis appended (Appendix Tables 10 to 13).

i. Cellulose digestibility of ammonia treated pith

The data indicates that percentage cellulose digestibility increased slightly with increases in the level of ammonia treatment compared with the untreated control. These increases were statistically significant ($P < 0.05$) at the highest treatment level (6%) of the samples neutralised

Table 11. *In vitro* cellulose digestibility of alkali-treated pith and oat straw

Treatment level %	Neutralisation	*In vitro* cellulose digestibility[1]	
		Pith	Oat straw
0.00[2]		22.6^{a}	29.0^{a}
	Ammonia Treatment		
1.50	air drying	24.8^{ab}	34.9^{bc}
3.00	" "	25.5^{abc}	36.6^{bc}
6.00	" "	32.1^{d}	41.8^{e}
1.50	acetic acid	24.4^{ab}	34.3^{b}
3.00	" "	27.5^{bc}	38.2^{cd}
6.00	" "	28.8^{cd}	39.5^{de}
	Sodium Hydroxide Treatment		
4.00	acetic acid	37.3^{e}	53.8^{f}
8.00	" "	70.9^{f}	65.9^{g}
16.00	" "	76.7^{g}	68.0^{g}

[1]Each value, on air dried basis, indicates mean of three runs. Cellulose digestibility means in the same column with the same superscript are not significantly ($P < 0.05$) different.

[2]Zero treatment level represents material treated only with distilled water.

either by air drying or by acid neutralisation.

Despite the trend observed, the overall cellulose digestibility in this trial was of a low order (greatest observed value being 32.1%) and it may be possible that for more effective delignification, a more concentrated ammonia solution be required. Limitations in using a concentrated

Figure 5. *In vitro* cellulose digestibility of alkali-treated pith

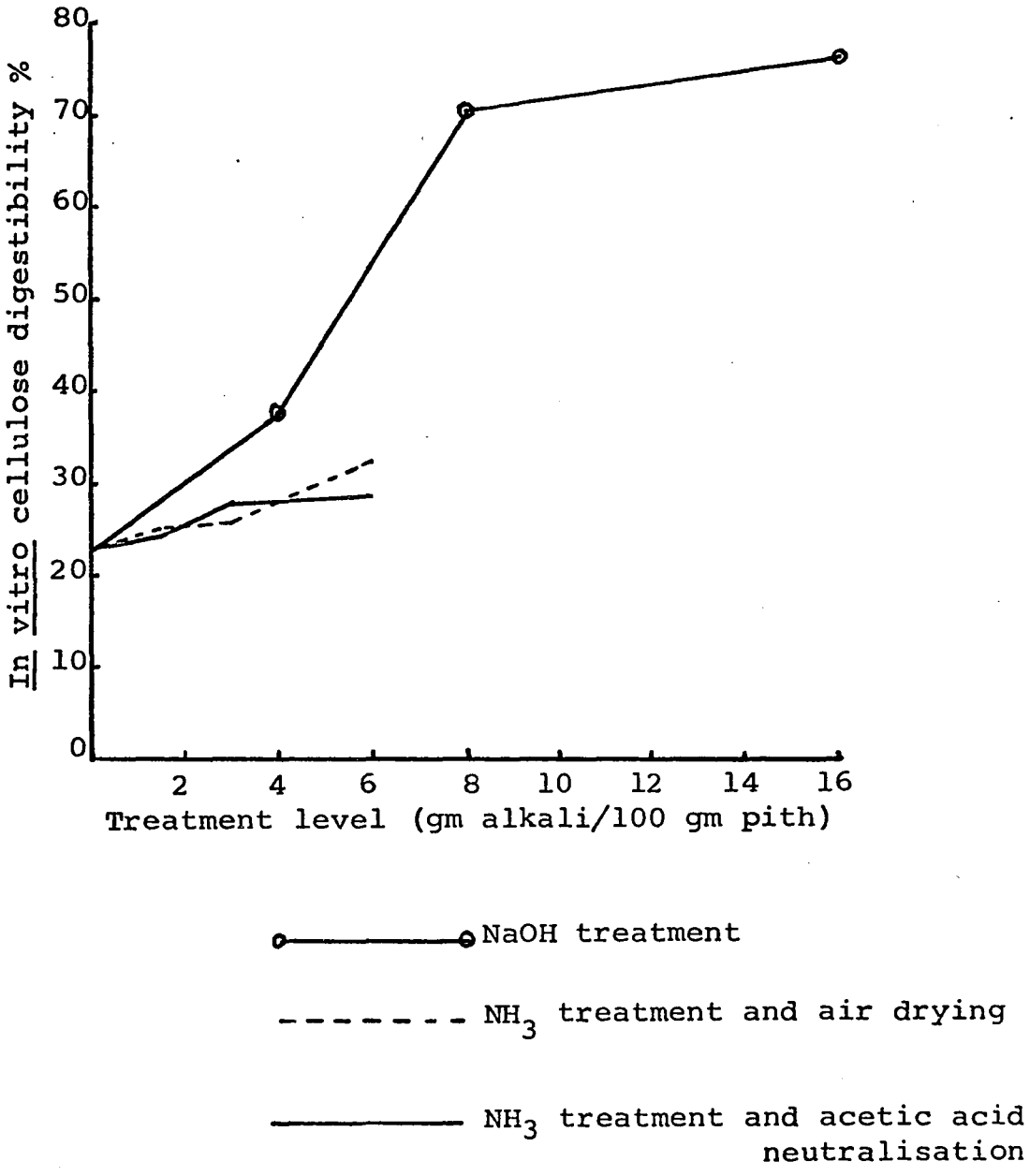
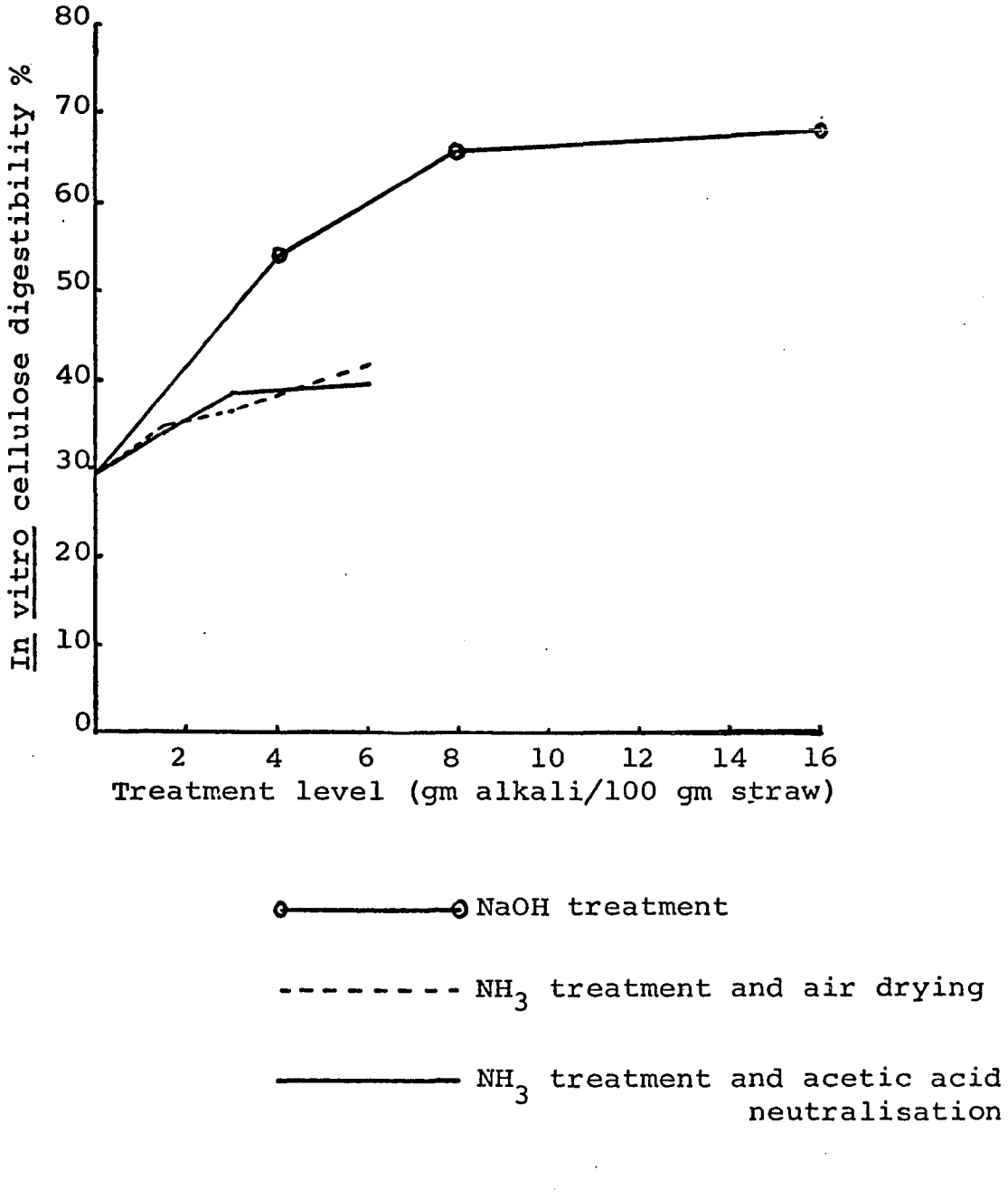


Figure 6. *In vitro* cellulose digestibility of alkali-treated oat straw



ammonia solution would arise because of the difficulty in handling such concentrated solution, and also the maximum amount of NH_3 (28%) which is present in concentrated ammonium hydroxide solutions.

ii. Cellulose digestibility of NaOH treated pith

Contrary to the results observed with ammonia treatment cellulose digestibility of pith was greatly increased due to NaOH treatment. Cellulose digestibility was highly significantly different ($P < 0.05$) at all levels of NaOH treatment, the highest percentage cellulose digestibility observed being 76.7% (at the 16% treatment level), this value approximately 3.5 times that of the untreated control, and twice that of the sample treated at the lowest level of NaOH. Treatment of pith at the 8% treatment level resulted in a product with cellulose digestibility three times greater than that of the untreated control (70.9 vs. 22.5%). For practical purposes it may be more economical to use this level of treatment rather than the higher 16% level, considering a doubling of treatment material was necessary to achieve an increase of approximately six percentage units in cellulose digestibility.

Jones (1967) obtained similar trends of cellulose digestibility using sugarcane bagasse, though the values

obtained (24.4% for control, 52.1% and 68.8% for 8 and 16% treatment levels) were not as high as those observed in this experiment with pith. The lower values for bagasse in comparison with sugarcane pith could be attributed to the presence of more highly lignified material (rind fibres) in the bagasse tending to reduce the effect of delignification and subsequent cellulose digestion.

iii. Cellulose digestibility of alkali treated pith and oat straw compared

From the summaries of *in vitro* cellulose digestibility of pith and oat straw, in Table 11, it can be seen first that cellulose digestibility of untreated oat straw is approximately seven percentage units higher than that of pith (29.0 vs. 22.5%). As in observations with alkali-treated pith, cellulose digestibility of alkali-treated oat straw increased with increases in treatment level irrespective of the alkali used. At any level of ammonia treatment, cellulose digestibility of oat straw was ten percentage units higher than that of pith. This difference, however, might be largely attributable to the initial greater cellulose digestibility of untreated oat straw compared with untreated pith.

With NaOH treatment, the cellulose digestibility was higher for pith, at the two higher treatment levels than observed for similarly treated oat straw.

The data thus indicates a slightly greater degree of delignification of the pith than oat straw by treatment with NaOH, which is also indicated to be a more active delignification agent than ammonia, at the levels used in this trial.

d. Crude protein content of ammonia treated pith and oat straw

The crude protein content of ammonia treated samples are summarised in Table 12. The protein values obtained for

Table 12. Crude protein content of ammonia treated pith and oat straw

Treatment level	Neutralisation	Crude protein content %[1]	
		Pith	Oat straw
0.00	-	1.8	3.9
1.50	air drying	9.5	5.5
3.00	" "	5.5	5.4
6.00	" "	7.4	7.0
1.50	acetic acid	4.5	7.9
3.00	" "	8.1	9.3
6.00	" "	12.3	12.1

[1]Values obtained from mean of two determinations, on air dry basis.

treated acid neutralised samples of both pith and oat straw, appear to follow a trend of increasing with increasing levels of ammonia treatment. Although the crude protein values for the samples neutralised by air drying were increased

substantially over the untreated controls, no consistent pattern was observed in this group. Acid neutralised samples showed a consistent increase in protein content. This variability in crude protein content of treated samples neutralised by air drying could be accounted for by loss of ammonia in the drying process, whereas with acid neutralisation non-volatile ammonium acetate would be formed and remain to contribute to the nitrogen and thus crude protein content of the samples.

B. EXPERIMENT 4 - *IN VIVO* DIGESTIBILITY AND INTAKE OF ALKALI TREATED DIFFUSED SUGARCANE PITH

1. Introduction

While *in vitro* digestibility values have been highly correlated with *in vivo* observations, it is of great importance that *in vivo* trials be conducted when possible, for it is only then that a direct measure of animal performance on the feeding regime under investigation can be obtained.

The following trial was thus conducted to observe the performance of sheep fed chemically delignified diffused sugarcane pith, and to compare cellulose digestibility of delignified sugarcane pith as obtained both *in vitro* and *in vivo*.

2. Experimental Procedure

a. Animals

Six female Cheviot sheep weighing between 74 and 79 pounds (34 and 36.2 kg) were procured from the Macdonald College farm and placed individually in digestibility cages designed to enable total collection of feces and measurement of voluntary intake.

b. Design of experiment

Three of the sheep were randomly allocated to the untreated pith ration, while the other three received the treated pith ration. Feed was constantly before the animals in excess of consumption as determined daily, and each sheep was provided with a cobalt-iodized salt lick and water at all times.

The feeding practise adopted consisted of a preliminary period of two weeks followed by a seven-day experimental period during which feed consumption and fecal excretion measurements were made. The animals were all fed once daily. During the initial stages of adaptation to the experimental rations, chopped alfalfa hay was added in small quantities to the rations, the amount of hay being gradually reduced daily.

c. Feed preparation

i. Treatment of pith

Approximately 300 pounds (136 kg) of pith were prepared in St. Kitts and air shipped to Macdonald College, in October 1968. Because of its bulkiness, treatment of this material, in early February 1969, was done in small batches of 15 kg which was an adequate load for the small horizontal

mixer employed (Davis S-3, 17 cu. ft. or 481.44 cm^3 capacity).[1]

The treatment procedure adopted was similar to that reported by Donefer (1968). Nine litres of 13.3% NaOH solution was prepared by making 1.575 litres 50% NaOH to 9 litres with tap water, with the solution kept in a polyethylene container fitted with a delivery tap. The amount of alkali prepared for treating 15 kg of pith was based on a treatment level of 60 litres of 13.3% NaOH solution per 100 kg of material, according to the method of Donefer (1968).

The NaOH solution was allowed to drip slowly over the pith contained in the mixer, while the mixing blades were revolving. The alkali addition took approximately 25 minutes with mixing continued for approximately an hour. Samples were then taken for pH determinations, with the treated pith then allowed to remain in the mixer for 24 hours.

The treated pith was neutralised with 2.5 litres of 50% acetic acid, by allowing this solution to drip onto it, with mixing continued for one hour. This acid level for 15 kg pith was based on an amount of 16.7 litres of 50% acetic acid per 100 kg of material according to the method described by Donefer (1968). The neutralised material was

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[1]H.C. Davis Sons Manufacturing Co. Inc., Bonner Springs, Kansas.

removed from the mixer, samples again taken for pH and dry matter determinations and the treated-neutralised pith spread thinly on the floor of the barn for air drying over a 2-day period.

ii. Initial rations

Untreated or treated-neutralised pith was mixed with feed grade urea (42% Nitrogen equivalent to 262% crude protein) to constitute a ration with 97.5% pith and 2.5% urea.

iii. Modified rations

Due to observed poor palatability during the preliminary (adaptation) period, the rations were modified with molasses addition so that the composition of the modified rations was 90% pith, 7.5% molasses and 2.5% urea. All rations were stored in covered plastic containers prior to and during the feeding period.

d. Feed and fecal collection

Total daily feed intake and fecal output were measured for each sheep during the experimental period, with feed and fecal samples collected during this period. Samples were weighed, dried in a forced air oven at 40^{o}C, ground to pass through a mesh screen with holes of 0.024 inches (0.6 mm) diameter, and stored for subsequent analyses.

e. Chemical analyses

Chemical analyses were carried out on both feed and fecal samples for the determination of dry matter, gross energy, crude protein and cellulose content. Procedures for these determinations were similar to those already described for Experiment 2.

f. Live weight measurements

The animals were weighed on the day prior to the first fecal collection and again on the last day of the fecal collection period. Live weights were determined primarily for calculation of voluntary intake on the basis of metabolic size ($W_{kg}^{0.75}$), as used in the Relative Intake system.

g. Calculations

Calculations of apparent nutrient digestibility, Relative Intake and Nutritive Value Index of the rations as fed <u>in vivo</u> were similar to that described for Experiment 2.

3. <u>Results and Discussion</u>

a. Observations

Pith which was whitish grey before treatment, turned to a bright gold color on NaOH treatment, and a dull yellow on neutralisation. During the treatment, enough heat of

reaction was generated to raise the temperature of the side of the mixer a few degrees.

The pH (as determined with a Corning pH meter) of the NaOH treated samples was 12.2, while that of the neutralised sample was 5.4, the latter with a dry matter content of 59.5% prior to air drying.

During the first seven days of the adaptation period feed intake was poor on all diets particularly the untreated pith diet where the animals were virtually off-feed. The chopped alfalfa added during this period was selectively consumed by the sheep. Complete removal of alfalfa from the meals resulted in extremely low intakes (approximately 280 gm vs. 15 gm for treated and untreated pith, respectively).

In order to increase palatability, molasses was added to each ration. The level of molasses incorporated was minimal (7.5%) so that its effects would not mask the nutritive value measurements intended primarily for the pith.

Since intake of the untreated pith ration did not increase to a satisfactory level following addition of 7.5% molasses, voluntary intake and digestibility determinations were thus carried out only with the three sheep on the treated pith ration, and as such, no comparison could be made of *in vivo* performance on treated and untreated pith.

b. Chemical analyses

The chemical composition of the ration containing treated pith, urea and molasses was as follows, on a dry matter basis:

Dry matter %	Gross energy k.cal/gm	Crude protein %	Cellulose %	Ash %
89.4	4.26	6.0	41.3	11.3

c. Apparent digestibility

The apparent digestibility of nutrients in the feed by the three sheep are summarised in Table 13. The values

Table 13. Apparent digestibility coefficients of nutrients, and Relative Intake and Nutritive Value Index of feed to sheep

Sheep #	Dry matter %	Gross energy %	Crude protein %	Cellulose %	R.I.	N.V.I.
16	55.2	51.3	26.9	62.0	29.4	15.1
85	61.3	55.9	30.2	71.1	35.6	19.9
87	60.6	57.6	33.5	69.7	46.8	26.9
Mean	59.0	54.9	30.2	67.6	37.3	20.6

obtained for percentage dry matter and cellulose digestibility of treated pith of 59.0 and 67.6 compare favorably with respective values of 59.8 and 60.6 quoted for alfalfa hay (Donefer, 1966), while the dry matter and gross energy

digestibility values of 59.0 and 54.9% for treated pith also compare favorably with values of similar criteria for treated oat straw of 62.5 and 58.5%, respectively, as observed by Donefer (1968).

d. Relative Intake and Nutritive Value Index

Summary of the values obtained for Relative Intake (RI) and Nutritive Value Index (NVI) are presented in Table 13. Values for these two criteria of 37.3 and 20.6, respectively, are much lower than that of 99.9 and 58.1 obtained with treated oat straw, reported by Donefer (1968), the lower values being due mainly to considerably reduced intake on the pith ration.

In this trial, low intakes were assocaited with low palatability characteristics. Palatability ranking of a feed could be evaluated by the readiness in which a feed is selected and eaten as measured by the relative amounts of offered feeds voluntarily consumed over a period of time. Thus, if an animal has a choice between two or more feeds, the quantitative selection of each feed by this animal indicates the palatability ranking of the feed. That palatability was the character influencing Relative Intake and subsequently Nutritive Value Index, was evidenced by the selective

behaviour of the sheep during the adaptation period, when alfalfa mixed with the pith ration was selectively consumed from the mixture.

This preliminary trial would thus indicate that while the delignification process results in a material of digestibility similar to that observed for high quality forages, the limiting factor in the use of this material is its low voluntary intake characteristics, thus restricting the digestible energy intake potentially available to the animal.

C. EXPERIMENT 5 - IN VITRO TRIAL

1. Experimental Procedure

a. Substrates

The substrates used in this trial were untreated pith and treated pith samples obtained during the feeding trial (Experiment 4) and samples treated at the 8% NaOH treatment level from the small scale laboratory treatment preliminary test (Experiment 3). Alfalfa and Bromegrass samples were also included to serve as controls.

b. Fermentation runs

The in vitro rumen fermentation procedure adopted was similar to that as described for Experiment 3, except for differences in length of fermentation period. Three fermentation runs were carried out, within each run, cellulose digestion observations were made after three time periods, viz. 12 hours, 24 hours and 48 hours.

c. Calculations

In vitro cellulose digestibility calculations were similar to that of Experiment 3.

2. Results and discussion

The results of in vitro cellulose digestibility of

untreated, laboratory treated and bulk treated pith are presented in Table 14, Appendix Table 14, and illustrated graphically along with cellulose digestibility of alfalfa and bromegrass, in Figure 7. Statistical analysis of the data using Duncan's multiple range test, is presented in Appendix Table 15.

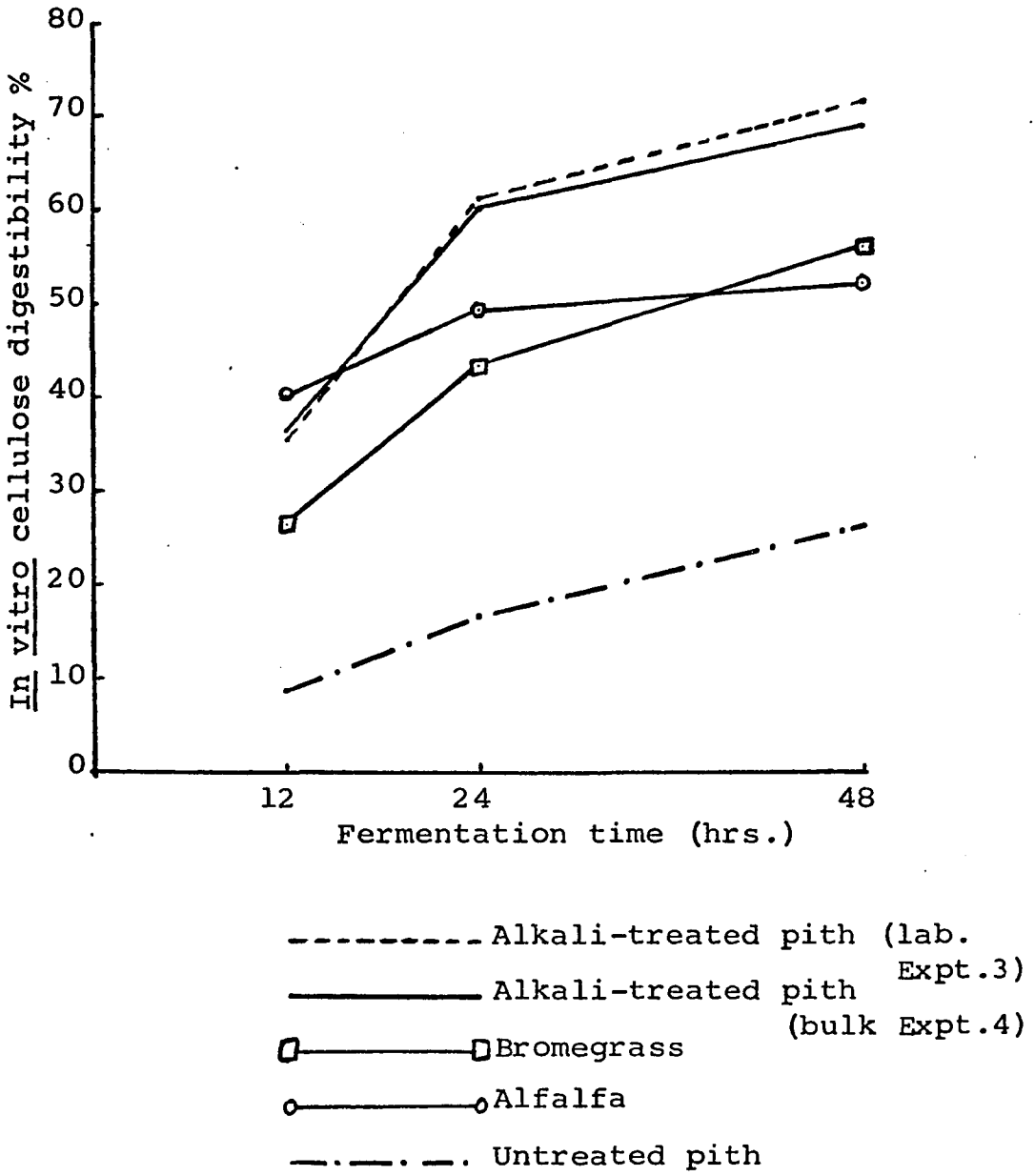
Table 14. *In vitro* cellulose digestibility of untreated and alkali treated pith

Substrate	Cellulose Digestibility (%)[1]		
	12 hrs.	24 hrs.	48 hrs.
Untreated pith	8.9[a]	16.9[b]	26.8[c]
Treated pith (lab.)	35.3[d]	61.2[e]	71.9[f]
Treated pith (bulk)	35.6[d]	60.3[e]	69.1[f]

[1]Values represent means from three runs. Means with a common superscript in the same line or column are non-significant ($P < 0.05$).

The values for the untreated pith indicate that cellulose digestibility increases with increasing fermentation time, though the rate of increase was slower after 24 hours fermentation. Cellulose digestibility was approximately doubled between 12 and 24 hours fermentation (8.9 vs. 16.9%) while a further 10 percentage units increase was obtained by an additional 24 hour fermentation (48 hour period). These

Figure 7. In vitro cellulose digestibility of untreated and alkali-treated pith alfalfa and bromegrass



values were all statistically significantly different ($P < 0.05$). Compared with the forage controls (alfalfa and bromegrass) and the treated pith, Figure 7 shows the relatively low plateau of cellulose digestibility achieved using untreated pith.

The data indicate no difference between pith treated in the laboratory in small amounts (25 gm) and bulk treated (15 kg) material used for the feeding trial.

Similar trends of increasing percentage cellulose digestibility with increasing times of fermentation were observed with the alkali-treated pith. Differences between cellulose digestibility obtained after the different fermentation periods were statistically significant ($P < 0.05$) for both bulk treated and laboratory treated pith. Rates of digestion were observed to be slower with further fermentation after 24 hours.

Most striking in this trial was the cellulose digestibility of the treated pith which was approximately three times higher than that of the untreated pith after any of the fermentation periods. This demonstrated the effectiveness of the NaOH treatment in markedly increasing the availability of cellulose for degradation by rumen microorganisms.

Of interest is the comparison of *in vivo* and *in vitro* digestibility of cellulose. The 48 hour *in vitro* cellulose

digestibility coefficient of 69.1 (bulk sample) is almost identical to the average *in vivo* digestibility coefficient of 67.6 as observed in Experiment 4.

The results of the investigation also indicate that the cellulose of treated pith was more available to the rumen microorganisms, as shown by higher levels of digestibility, than that of alfalfa or bromegrass.

The form of the fermentation curves obtained was similar to that reported by Hershberger *et al.* (1958) and Donefer *et al.* (1960). These latter workers suggested that the decreased rate of cellulose digestion of forages after 12 hours was related to the extent of lignification, with the plateau or maximum digestion achieved essentially a reflection of the inability of cellulolytic microorganisms to utilise the residual ligno-cellulose complex.

It has generally been concluded that intake is related to the rate of microbial degradation of the fibrous constituents of the feed in the rumen. The rapid initial rate of *in vitro* cellulose digestion as measured at 12 hours for the treated pith thus suggests that the depressed *in vivo* intake as observed in Experiment 4, was due to factors, e.g. palatability, other than the availability of cellulose to microbial attack.

VI. SUMMARY AND CONCLUSIONS

The experiments conducted in St. Kitts, West Indies using tropically adapted Senepol and Hostein animals showed that fresh sugarcane pith (obtained from mechanical removal of the rind of mature sugarcanes) can provide a substantial portion of the animals' energy requirements. The average daily gains of 1.38 and 1.81 pounds made by the Senepol steers during the 77-day intensive and 21-day extended feeding periods, respectively, indicate that sugarcane pith when supplemented with protein, minerals and vitamins is a satisfactory ration for cattle. Particular care has, however, to be paid to selection of animals with good growth potential under tropical conditions, while attending also to environmental factors, particularly parasite control.

The chemical composition of sugarcane pith is characterised by a very low crude protein content (1.5%) and a cellulose content of 17.5% which could classify it as a borderline source of concentrated energy (concentrate or energy feed). Digestibility trials with sheep in St. Kitts, indicated that the nutrients in a sugarcane pith supplemented ration are all adequately digested, and that despite the high readily available carbohydrate content of the ration,

the cellulose fraction was satisfactorily digested (59.7%). Relative Intake values and Nutritive Value Indices indicate that the ration is similar in its digestible energy intake potential to high quality forages.

Water extraction (diffusion) of sugars from sugarcane pith leaves a fibrous residue designated as pith. The *in vitro* cellulose digestibility of alkali treated acid neutralised pith indicated that increased levels of NaOH treatment resulted in marked increases in the extent of cellulose digested. For practical purposes the 8% NaOH treatment level (8 gm NaOH/100 gm pith) appears to be most satisfactory resulting in an average *in vitro* cellulose digestibility of 70.9%. *In vitro* cellulose digestibility of untreated pith was of a much lower order (22.6%). Increases in cellulose digestibility *in vitro*, were also realised with ammonia treatment of pith; however, the extent of digestion was not as great as with the NaOH treatment.

The possibility of incorporating NaOH treated acid neutralised pith into ruminant rations was tested in an intake and digestibility trial with sheep. Results indicated that despite supplementation of this material with 2.5% urea and 7.5% molasses, low palatability characteristics limited the voluntary intake of the ration and thus its

potential use as an energy feed. Although the apparent energy and cellulose digestibility of NaOH treated supplemented pith was high (54.9% and 67.6%, respectively) approximating that of a good quality forage, the voluntary intake of this ration would have to be substantially increased so that enough digestible energy was available to meet the animals' energy requirements.

The in vitro rate of cellulose digestibility of NaOH treated pith was determined from observations made at 12, 24 and 48 hours. The observed response curves indicated that the extent of cellulose digested increased with fermentation time, the values for treated pith being higher than that of alfalfa or bromegrass forages after any time period. The in vitro cellulose digestibility of the treated pith between 24 - 48 hours (60.3 - 69.1%) was similar to that obtained in the in vivo trial (67.6%), giving validity to the in vitro/in vivo comparisons.

The assumption that the low voluntary intake of the treated pith ration was due to its poor palatability characteristics is substantiated by the observation of the high initial (0 - 12 hour) in vitro rate of cellulose digestion indicating that availability of cellulose to bacterial attack was not a factor limiting the potential nutritive value of

this material.

In conclusion, the *in vivo* trials with fresh sugarcane pith indicate the potential of using a sugarcane crop as the main energy source in a ruminant ration. This indicates the feasibility in tropical areas of using a locally grown product of high available energy content to alleviate the problem of satisfying the energy requirements of cattle. More research would be required to investigate the possible use of sugarcane pith in rations for other forms of livestock to remove the dependence on imported grain for livestock feeds. The use of locally produced protein supplements could markedly increase the economic feasibility of a sugarcane based ration for ruminants.

Whereas the digestibility of diffused sugarcane pith was greatly increased following alkali treatment the observed low palatability characteristics of this material limits its usefullness as an energy source for ruminants unless further research can result in increases in voluntary intake of a treated pith ration.

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APPENDIX TABLES

Appendix Table 1. Liveweight changes of steers during 77-day period

Calf No.[1,2]	Ration	Initial wt.		Final wt.		Total gain		Daily gain	
		lbs.	kg	lbs.	kg	lbs.	kg	lbs.	kg
S1	Sugarcane	354	160.7	489	222.0	135	61.3	1.75	0.79
S2	"	234	106.2	318	144.4	84	31.1	1.09	0.49
S3	"	246	111.7	356	161.6	110	49.9	1.42	0.64
S4	"	274	124.4	370	167.9	96	43.6	1.25	0.57
S5	Control	200	90.8	208	94.4	8	3.6	0.10	0.05
S6	"	402	182.5	472	214.3	70	31.8	0.91	0.41
H1	Sugarcane	178	80.8	248	112.6	70	31.8	0.91	0.41
H2	"	170	77.2	208	94.4	38	17.3	0.49	0.22
H3	"	172	78.1	208	94.4	36	16.3	0.47	0.21
H4	"	206	93.5	282	128.0	76	34.5	0.98	0.44
H5	Control	198	89.9	320	145.3	122	55.4	1.58	0.72
H6	"	160	72.6	262	118.9	102	46.3	1.32	0.60

[1]S - Senepol steers.

[2]H - Holstein steers.

Appendix Table 2. Experiment 1 - Average daily weight gain of Senepols and Holstein steers on sugarcane pith and control rations

Senepol		Holstein	
Sugarcane Pith	Control	Sugarcane Pith	Control
lbs.	lbs.	lbs.	lbs.
1.75	0.10	0.91	1.58
1.09	0.91	0.49	1.32
1.42	-	0.47	-
1.25	-	0.98	-
Total			
5.51	1.01	2.85	2.90
Mean			
1.38	0.51	0.71	1.45

Analysis of Variance

Source	DF	MS		5%	1%
Total	11				
Sub groups	3	0.59			
Breed	1	0.05	1	5.32	11.26
Ration	1	0.02	1	5.32	11.26
Breed X Ration	1	1.72	17.2	5.32	11.26
Error	8	0.10			

Appendix Table 3.

(a) Comparison of average daily gain of breed on sugarcane pith ration

Senepols	Holstein
Mean = 1.38	Mean = 0.71

Observed difference = 0.67

Standard error of difference = 0.163

Observed "t" = 4.11

Expected "t" p = 0.05 = 2.45

Expected "t" p = 0.01 = 3.71

(b) Comparison of average daily gain of breed on control ration

Senepols	Holstein
Mean = 0.51	Mean = 1.45

Observed difference = 0.94

Standard error of difference = 0.425

Observed "t" = 2.21

Expected "t" p = 0.05 = 4.30

Expected "t" p = 0.01 = 9.92

Appendix Table 4. Weight changes of steers on sugarcane pith ration over additional 21-day feeding period

Calf No.[1,2]	Initial wt.		Final wt.		Total gain		Av. Daily gain	
	lbs.	kg	lbs.	kg	lbs.	kg	lbs.	kg
S1	489	222.0	538	244.3	49	22.3	2.29	1.04
S2	318	144.4	348	157.9	30	13.6	1.43	0.64
S3	356	161.6	389	176.6	33	14.9	1.56	0.71
S4	370	167.9	413	187.5	43	19.5	2.05	0.93
S5	208	94.4	248	112.6	40	18.2	1.89	0.86
S6	472	214.3	507	230.2	35	15.9	1.66	0.75
H1	248	112.6	270	122.6	22	9.9	1.05	0.48
H2	208	94.4	238	108.0	30	13.6	1.43	0.64
H3	208	94.4	230	104.4	22	9.9	1.05	0.48
H4	282	128.0	280	127.1	- 2	- 0.9		

[1]S - Senepol steers.

[2]H - Holstein steers.

Appendix Table 5. Average Daily Feed consumed[1] by steers during 77-day feeding period

Calf No.[2,3]	Sugarcane Pith		Supplement Mix		Dairy Ration,		Citrus Pulp	
	lbs	kg	lbs	kg	lbs	kg	lbs	kg
S1	8.4	3.80	1.9	0.9				
S2	5.9	2.70	1.9	0.9				
S3	6.8	3.1	1.9	0.9				
S4	7.0	3.2	1.9	0.9				
S5					2.6	1.2	0.09	0.045
S6					3.5	1.6	5.50	2.5
H1	4.4	2.0	0.9	0.45				
H2	4.2	1.9	0.9	0.45				
H3	4.6	2.1	0.9	0.45				
H4	5.3	2.4	0.9	0.45				
H5					3.5	1.6	3.3	1.5
H6					3.5	1.6	1.9	0.9

[1]Values based on sugarcane pith 28.67% DM and citrus pulp and dairy ration assumed 90% DM, as fed.

[2]S - Senepol.

[3]H - Holstein.

Appendix Table 6. Dry matter and gross energy values of sugarcane pith supplemented ration

Sheep #	Dry matter digestibility (%) Level of Supplementation		Gross energy digestibility (%) Level of Supplementation	
	100 gm	200 gm	100 gm	200 gm
1	81.6	81.8	80.4	81.4
2	73.0	75.4	71.9	74.8
3	77.7	79.4	76.8	78.1
4	81.8	82.2	80.9	81.7
5	81.7	76.9	80.6	75.9
6	71.3	73.7	70.1	72.5
7	74.5	73.0	72.8	72.1
8	76.0	78.9	75.3	78.1
Mean	77.2	77.6	76.1	76.8
	S_d = 1.92		S_d = 1.98	
	obs. t = 0.24		obs. t = 0.35	
	$t_{0.05}$ = 2.145		$t_{0.05}$ = 2.145	

Appendix Table 7. Crude protein and cellulose digestibility values of sugarcane pith supplemented ration

Sheep #	Crude Protein digestibility (%) Level of Supplementation		Cellulose digestibility (%) Level of Supplementation	
	100 gm	200 gm	100 gm	200 gm
1	76.8	84.4	66.4	67.9
2	65.2	78.2	49.2	54.2
3	76.6	80.7	57.4	61.5
4	79.8	84.5	66.1	69.6
5	77.3	80.0	64.1	57.4
6	58.4	77.0	44.0	49.7
7	69.7	78.9	50.2	53.1
8	71.0	82.7	59.7	63.9
Mean	71.8	80.8	57.1	59.7
	S_d = 2.75		S_d = 3.93	
	obs. t = 3.25		obs. t = 0.64	
	$t_{0.05}$ = 2.145		$t_{0.05}$ = 2.145	

Appendix Table 8. Relative Intake and Nutritive Value Index of sugarcane pith supplemented ration

Sheep #	Relative Intake		Nutritive Value Index	
	Level of Supplementation			
	100 gm	200 gm	100 gm	200 gm
1	94.3	100.5	75.9	81.7
2	88.0	96.7	63.3	72.4
3	90.1	124.2	69.2	97.0
4	78.1	93.2	63.2	76.2
5	93.3	103.0	75.2	78.3
6	84.2	91.8	59.0	66.6
7	86.4	95.2	62.9	68.6
8	65.4	88.5	49.2	69.1
Mean	84.9	99.2	64.7	76.2
	$S_d = 5.16$		$S_d = 4.66$	
	obs. $t = 2.74$		obs. $t = 2.46$	
	$t_{0.05} = 2.145$		$t_{0.05} = 2.145$	

Appendix Table 9. Liveweight changes (gm) of sheep on sugarcane pith supplemented ration over 7-day test periods

Sheep #	Level of Supplementation	
	100 gm	200 gm
1	454	908
2	454	794
3	1134	226
4	-340	1702
5	226	680
6	0	908
7	0	226
8	226	680
Av. Total Gain	269	766
Av. Daily Gain	38.4	109.4

$S_d = 206.52$

obs. $t = 2.4065$

$t_{0.05} = 2.145$

Appendix Table 10. *In vitro* digestibility of alkali treated pith

Alkali	Treatment Level gm alkali/100 gm	Neutralisation	Run	Cellulose Digestibility 1	2	3	Avge.
-	0.0	-		22.2	21.0	24.6	22.6
NH_4OH	1.5	air drying		23.7	23.8	27.1	24.8
"	3.0	"		26.9	22.5	27.2	25.5
"	6.0	"		35.2	32.0	29.2	32.1
"	1.5	acetic acid		28.2	18.9	26.0	24.4
"	3.0	"		30.1	27.1	25.4	27.5
"	6.0	"		32.6	27.2	26.6	28.8
NaOH	4.0	"		38.2	34.3	39.4	37.3
"	8.0	"		73.1	68.3	71.2	70.9
"	16.0	"		80.1	75.7	74.2	76.7

Appendix Table 11. Analysis of variance of *in vitro* cellulose digestibility of treated pith

Sources	DF	MS	F value obs.	F value 5%	F value 1%
Total	29				
Treatment	9	1183.77	228.96	2.46	3.60
Reps.	2	38.58			
Error	18	5.17			

SD = 19.32 $Se_{\bar{x}}$ = 1.31

LSR P = 2-10 = 2.97 - 3.41 (P = 0.05 n = 18)

P = 2-10 = 4.07 - 4.71 (P = 0.01 n = 18)

76.7 g 70.9 f 37.3 e 32.1 28.8 d 27.5 25.5 24.8 24.4 22.6 b a

c

Appendix Table 12. *In vitro* cellulose digestibility of alkali treated oat straw

Alkali	Treatment Level gm alkali/100 gm	Neutralisation	Run	Cellulose Digestibility 1	2	3	Avge.
-	0.0	-		28.3	29.2	29.5	29.0
NH_4OH	1.5	air drying		36.8	33.1	34.7	34.9
"	3.0	"		39.3	34.0	36.4	36.6
"	6.0	"		43.2	39.9	42.4	41.8
"	1.5	acetic acid		37.0	30.0	35.9	34.3
"	3.0	"		37.3	37.4	39.9	38.2
"	6.0	"		42.7	36.5	39.3	39.5
NaOH	4.0	"		57.0	52.0	52.5	53.8
"	8.0	"		67.8	62.4	67.5	65.9
"	16.0	"		68.5	63.5	72.1	68.0

Appendix Table 13. Analysis of variance of *in vitro* cellulose digestibility of oat straw

Sources	DF	MS	F value obs.	F value 5%	F value 1%
Total	29				
Treatment	9	556.00	164.98	2.46	3.60
Reps.	2	44.74			
Error	18	3.37			

SD = 13.33 $Se_{\bar{x}}$ = 1.06

LSR P = 2-10 = 2.97 - 3.41 (P = 0.05 n = 18)

P = 2-10 = 4.07 - 4.71 (P = 0.01 n = 18)

68.0 65.9 (g) 53.8 (f) 41.8 39.5 (e) 38.2 (d) 36.6 34.9 34.3 (c) 29.0 (b) (a)

Appendix Table 14. *In vitro* cellulose digestibility of NaOH treated pith

Method of treatment	Rep. No.	Cellulose Digestibility % 12 hrs.	24 hrs.	48 hrs.
None	1	9.5	20.5	32.4
	2	6.5	14.1	23.6
	3	10.6	16.0	24.5
	Mean	8.9	16.9	26.8
Small sample in lab (Expt. 3)	1	38.1	63.2	75.8
	2	29.7	59.4	70.5
	3	38.2	60.9	69.4
	Mean	35.3	61.2	71.9
Bulk sample from mixer (Expt. 4)	1	32.2	62.6	71.9
	2	34.5	57.8	64.3
	3	40.2	60.5	71.0
	Mean	35.6	60.3	69.1

Appendix Table 15. Analysis of variance of *in vitro* cellulose digestibility of NaOH treated pith over 12 - 24 - 48 hours

Sources	DF	MS	F value obs.	F value 5%	F value 1%
Total	26				
Treatment	8	1637.26	228.03	2.59	3.89
Reps.	2	60.63			
Error	16	7.18			

SD = 22.64 $Se_{\bar{x}}$ = 1.54

LSR P = 2-9 = 3.00 - 3.41 (P = 0.05 n = 16)

P = 2-9 = 4.13 - 4.76 (P = 0.01 n = 16)

8.9	16.9	26.8	35.3 35.6	60.3 61.2	69.1 71.9
a	b	c	d	e	f

Appendix Table 15. Analysis of variance of *in vitro* cellulose digestibility of NaOH treated pith over 12 - 24 - 48 hours

Sources	DF	MS	F value obs.	F value 5%	F value 1%
Total	26				
Treatment	8	1637.26	228.03	2.59	3.89
Reps.	2	60.63			
Error	16	7.18			

SD = 22.64 $Se_{\bar{x}}$ = 1.54

LSR P = 2-9 = 3.00 - 3.41 (P = 0.05 n = 16)

P = 2-9 = 4.13 - 4.76 (P = 0.01 n = 16)

8.9	16.9	26.8	35.3 35.6	60.3 61.2	69.1 71.9
a	b	c	d	e	f