THE NUTRITIVE VALUE OF FOUR ARABLE FARM BY-PRODUCTS COMMONLY FED TO DAIRY CATTLE BY SMALL SCALE FARMERS

By

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D E C L A R A T I O N

I declare that this thesis is my original work and has not been submitted for a degree in any other University.

Joseph Esikini E. Kevelenge

This thesis has been submitted for examination with our approval as University Supervisors.

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SUMMARY

Four arable farm by-products were evaluated in a trial conducted at the National Agricultural Research Station, Kitale in 1977. The trial lasted 8 months. Green maize stalks, maize cobs, sugarcane rejects and sugarcane tops were the by-products evaluated. The main objective of the trial was to evaluate the nutritive value of the by-products using both *in vivo* and *in vitro* digestibility techniques.

The by-products were composed of high crude fibre and ash, low ether extracts and crude protein. The gross energy of maize stalks (4.3 kcal/g), maize cobs (4.4 kcal/g), sugarcane (3.9 kcal/g) and sugarcane tops (3.8 kcal/g) were not different ($P > .05$) and their respective digestible energy was 2.8, 2.4, 2.3 and 2.0 kcal/g. Neutral detergent fibre (NDF) of sugarcane was lower ($P < .05$) than that of maize stalks, maize cobs and sugarcane tops. The by-products were highly lignified, with ADL values ranging from 4.4 to 5.8 % DM.

Sheep fed maize stalks and sugarcane tops were in positive nitrogen (N) balance and negative N-balance in those fed sugarcane and maize cobs. This observation emphasized the need for supplementary protein in the by-product based diets.

All by-products were rich in calcium and potassium (except maize cobs) and poor in sodium and phosphorus. Wether sheep fed these by-products were in positive calcium and potassium balances and negative phosphorus balance. There was positive sodium (Na) balance in those sheep fed sugarcane tops while negative Na balance in those fed maize stalks, sugarcane and maize cobs. It was recommended that animals should be supplemented with minerals when fed these by-products.

Mean daily dry matter (DM) intakes of maize stalks (1007.5 g), maize cobs (553.1 g), sugarcane (299.5 g) and sugarcane tops (864.3 g) were different (P <.05). The feeds were readily accepted by sheep. The DM intakes by sheep fed maize stalks, maize cobs, sugarcane and sugarcane tops were 2.6, 1.3, 1.0 and 2.0 % body weight, respectively

Mean daily organic matter intakes of maize stalks (926.9 g), maize cobs (531.4 g), sugarcane (293.3 g) and sugarcane tops (794.8 g) were different (P <.05).

Average daily digestible organic matter intakes of maize stalks, maize cobs, sugarcane and sugarcane tops were 585.0, 329.3, 183.9 and 447.5 g, respectively and were different (P <.05). Liveweight changes of sheep fed these by-products were + 350, - 110, - 510 and - 10 g/day, respectively.

Apparent dry matter digestibility (DMD) of maize stalks (63.8 %), maize cobs (60.1%) and sugarcane (60.8%) were not different (P> .05) but were higher (P< .05) than sugarcane tops (54.3%). Organic matter digestibility (OMD) of maize stalks (63.8%), maize cobs (60.6%) and sugarcane (62.9%) were not different (P> .05) but were higher (P <.05) than sugarcane tops (56.2%). All by-products had positive crude protein digestibility except sugarcane (- 25.1%).

TDN of maize stalks (60.2%), maize cobs (61.6%) and sugarcane (62.3%) were not different (P >.05) but were higher (P< .05) than sugarcane tops (51.4%). SE values of maize stalks, maize cobs, sugarcane and sugarcane tops were .45,,.42, .50 and .32 SE/kg DM and were different (P <.05).

Daily gross energy (GE) intakes of maize stalks (4402.9 kcal) and sugarcane tops (3345.4 kcal) were higher ($P < .05$) than maize cobs (2178.3 kcal) and sugarcane (1160.7 kcal). Digestible energy (DE) and Metabolisable energy (ME) intakes of by-products were different ($P < .05$). GE, DE and ME intakes per kg DM of the by-products were within close range of energy values. Much of the energy was lost through faeces, fermentation gases and urine.

DMD was estimated by Van Soest technique. Results showed DMD of maize stalks, maize cobs and sugarcane tops largely depended on the NDF while DMD of sugarcane depended on NDS. *In vivo* DMD and OMD could not be predicted from NDF, NDS, ADF or ADL.

Two stage *in vitro* DMD of maize stalks, maize cobs, sugarcane and sugarcane tops was 66.5, 58.8, 65.9 and 54.8 %; OMDOM was 64.8, 58.3, 65.1 and 52.9 % and OMDDM (D-values) was 60.1, 57.3, 63.3 and 47.7 percent, respectively. OMDOM and OMDDM were lower than DMD due to ash contents of the by-products. It was recommended that sugarcane be derinded before being fed for optimum utilization by animals. *In vivo* DMD and OMD were accurately predicted from *in vitro* DMD, OMD and OMDDM. Initial screening of these by-products may be carried out by *in vitro* techniques. The most promising by-products may be recommended for final evaluation, using animal feeding trials.

Rate of *in vitro* dry and organic matter disappearance established important factors which need careful consideration when high fibre by-products are fed to livestock. There were highly significant ($P < .05$) and linear relationships between DMD, OMD, OMDDM and time. These suggested that digestion of the by-products is heavily dependant on time of incubation in

the rumen liquor. It was recommended that these by-products need to be physically or chemically treated to make them more acceptable and digestible before being fed to livestock.

It was proposed that in future, research should be directed towards the effects of nitrogen and mineral supplementation. A study to investigate performance of dairy animals fed rations based on these by-products, especially under zero grazing system, should be encouraged.

CHAPTER 1

INTRODUCTION

Man in developing countries has a direct competition with ruminant animals for food from the limited arable land. The competition is likely to be more acute in those high potential areas which are inhabited by the small scale farmers than in the large scale farming communities. Nevertheless the need to increase livestock production is very great in the developing countries where it has been pointed out that the daily consumption of animal protein is sub-normal of protein requirement for growth (FAO, 1972).

The low protein consumption is attributed to the fact that livestock domesticated in these developing countries have a low level of production. It is estimated that 70 percent of livestock resources that are domiciled within these countries produce only 21 percent of the world milk production and 34 percent of the world beef production (FAO, 1972). There are a number of ways in which these low production levels could be improved. Most people are agreeable that, under conditions prevailing in the developing countries, the most immediate strategies should be in breeding, management and nutrition.

In Kenya substantial advances have been made in breeding and management. Regrettably not much improvement in the level of nutrition has been achieved country wide. In their report, Kirkwood (1958/59) and Foot (1965) established that

the major cause for the low production parameters is inadequate feeding of the livestock and particularly failure to supply energy feeds to meet the production requirements.

Under tropical conditions the main diet of the ruminant animals consists of pasture but it has been shown that foraging animals in these countries cannot obtain sufficient nutrients to meet their production requirements from pasture alone.

Tropical pastures are capable of meeting only maintenance and moderate level of production at most times of the year, (Christensen, Ipsen and Soneji, 1973; Glover and Dougall, 1961; Minson and Milford, 1966; Musangi, 1969; French, 1957; Hamilton, Lambourne, Roe and Minson, 1970; Stobbs, 1971; and Lawrence, Mugerwa and Christensen, 1974.

During the dry season, grazing animals may even be at sub-maintenance level of nutrition. Whereas the large scale farmers may be able to supplementary feed their animals with concentrates or conserved fodders to maintain production, it is often not possible for the small scale farmers to do likewise. One commonly sees glaring cases of mal-nutrition in the animals within the small scale farming communities, due to either lack of capital or "know how" to properly feed their livestock. As shown in table 1, wet season milk production per cow per day on the small scale farms is normally higher than that for dry season production. Wet season milk production ranged

Table I Seasonal Milk production on some small scale farms in high potential areas of Kenya

(Extracted from Chuldleigh, 1974)

Province	Wet Season		Dry Season		Average milk production per-centage drop in dry season
	Number of farms studied	Average milk production in litres per cow per day	Number of farms studied	Average milk production in litres per cow per day	
Central	21	10.9	20	8.0	25.0
Eastern	15	10.9	15	7.7	28.0
Western	13	8.2	12	6.3	23.3
Rift Valley	15	8.0	12	6.8	24.8
Nyanza	11	7.4	11	6.0	19.1
Coast	6	6.7	1	4.0	N.K

N.K - not known, data not available.

between 6.7 and 10.9 litres per cow per day as compared to the dry season milk production of 4.0 and 8.0 litres per cow per day. This dry season milk production gave a mean percentage drop of 19.1 to 25.0 percent over the wet season (Chudleigh, 1974). Seasonal fluctuations are associated with erratic plane of nutrition that is common in these small scale farms.

Improving the plane of nutrition of the animals on pastures is commonly done by using conserved fodders and/or concentrates. The other aspect of supplementary feeding which has received very little attention in Kenya is the utilization of high fibrous arable farm by-products such as maize stalks, maize stovers, maize cobs, cereal straws, sugarcane rejects, sugarcane tops, banana stems and leaves, sisal waste, etc. Under the present farming enterprises in Kenya, all these arable farm by-products are readily available and, in fact in most cases, they are considered wastes and are rarely used for livestock feeding. However, available literature indicates that high fibrous arable farm by-products, such as the ones mentioned are at their very best, maintenance supplements due mainly to their high fibre and low protein levels (Laksesvela and Said, 1970).

The high tonnage of available farm by-products in Kenya justifies a study of their potential for livestock production both within the large scale farming communities and more so within the small scale farming areas where some

of those by-products, such as maize stalks, maize stovers, maize cobs and sugarcane tops are important and are readily available (Chuldleigh, 1974; Stotz, 1977).

This study was therefore undertaken to evaluate the nutritive value of some of the available high fibrous arable farm by-products, namely maize stalks, maize cobs, sugarcane rejects and sugarcane tops by using wether sheep and by *in vitro* digestibility techniques.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Definition of arable farm by-products

High fibre arable farm by-products are defined as crop by-product material that still possesses value which until now, can only be realized by recycling them through ruminants. It is not easy to decide when such a material ceases to be the desired product of tangible economic value and becomes a by-product. The actual value of by-products depends on many varying factors, such as the volume of the available material for use, actual nutritive value and the acceptability of the by-product material by the animals (Wilton, 1975; Owen, 1976). There is also the problem of bulk in relation to transport costs and also in relation to net available nutrients.

There are many categories of farm by-products. In these studies, high dry matter content by-product materials i.e. maize cobs and high moisture content by-product materials i.e. maize stalks, sugarcane rejects and sugarcane tops which were identified as being commonly fed to cattle on the small scale farms (Chuldleigh, 1974 and Stotz, 1977) were undertaken.

2.2 Types of arable farm by-products studied

2.2.1 Maize stalks

Maize stalks (*Zea mays*) are green maize plants whose

ears have been removed. In this review, maize stalks are the mature green maize plants. It is a common practice among the small scale farmers to remove the green maize ears for home consumption. The remaining green maize stalks are then by-products that are used as cattle fodder.

Maize as a crop is extensively grown in the high potential areas of East Africa. It is estimated in Kenya that there are about 756 000 hectares of maize grown annually and that over 75 percent of these hectares are grown by small scale farmers (PDA Annual Reports, 1974 to 1976). It is reasonable therefore to expect a fairly large quantity of maize stalks available for livestock feeding on these small scale farms.

However, there has been little research work in Kenya on the utilization of maize stalks by livestock. In most World literature, maize stalks have been tested in livestock feeding as an intact maize plant together with the green maize cobs, unlike the custom prevailing in East Africa by the small scale farmers, as explained above.

Deinum and Dirven (1971) and Deinum (1976) observed that digestibility of maize stalks declines with age and varies according to many other factors, such as environmental temperatures and cultural practices. Young maize stalks are highly digestible and low in percent Cell Wall Constituents (CWC) whereas mature maize stalks are less digestible and richer in percent CWC.

Deinum (1976) also observed that a higher temperature causes a small increase in percent CWC but a sharp drop in digestibility. This is attributed mainly to the large effect of temperature on cell wall digestibility of the mid rib. In the observations of Deinum (1976), the results were related to the lignification of the various tissues of the stems and mid ribs. French (1957), Bredon, Hawker and Marshall (1963), Haggar and Ahmed (1971) and Wilson (1973 a and 1973 b) also reported that temperature and age adversely affect digestibility of tropical grasses.

Ranjan and Kariyar (1969) fed green maize stalks to Hariana cattle of about 14 months old. The dry matter percentage was 29.7. Crude protein, ether extract, crude fibre and nitrogen-free extracts were respectively 7.1, 1.7, 21.8 and 62.5 percent dry matter and phosphorus and calcium contents were .15 and .37 percent dry matter. Average digestion coefficients of dry matter, crude protein, ether extract, crude fibre and nitrogen-free extracts in the work of Ranjan and Kariyar (1969), are quoted in table 2.

TABLE 2: MEAN DIGESTION COEFFICIENTS OF MAIZE STALKS BY HARIANA CATTLE (Ranjan and Kariyar, 1969)

	Dry matter	Crude protein	Ether extract	Crude fibre	Nitrogen-free extracts
	55.6	39.8	59.6	58.3	65.1
Standard error (Se)	±1.35	±2.86	±2.85	±1.91	±1.25

Ranjan and Kariyar(1969) also reported a daily intake by their cattle of 2.2 kg dry matter per 100 kg body weight and that digestible crude protein and starch equivalent values of the maize stalks they used were 2.82 kg and 45.43 kg, respectively per 100 kg dry matter.

A nitrogen and mineral balance trial on calves fed on the maize stalks by Ranjan and Kariyar (1969) gave positive balances for nitrogen and phosphorus but negative balance for calcium as given in table 3.

TABLE 3. AVERAGE NITROGEN AND MINERAL BALANCES IN GRAMS PER HEAD PER DAY (Ranjan and Kariyar, 1969)

	Mean intake (g)	Excretion		Total excretion (g)	Balances (g)	Se
		Faeces (g)	Urine (g)			
Nitrogen	34.00	20.46	6.09	26.55	+ 7.45	± 1.35
Phosphorus	4.76	4.27	.05	4.32	+ .44	± .07
Calcium	11.06	11.83	2.34	14.17	- 3.11	± .22

Beaty, Miller, Brooks and Clifton (1966) used ground and pelleted maize stalks containing 32.0 percent grain dry matter. These diets were compared with pelleted 3 weeks old Coastal Bermuda grass (Star grass) in a feeding trial with 36 lactating cows for a period of 8 weeks. The protein contents of the diets were adjusted in each case to equalize intake and meet the requirements of the cows.

Those cows which were fed on the ground maize stalks, pelleted maize stalks and Coastal Bermuda grass pellets produced 13.50, 12.95 and 13.36 kg milk per day, respectively. Forage dry matter intake was 14.18, 12.81 and 14.95 kg per day, respectively. The dry matter intake for the three forages worked at approximately 3.0 percent body weight.

Milk fat and protein compositions for the cows fed on ground maize stalks, pelleted maize stalks and Coastal Bermuda pellets showed significant differences ($P < .05$) with 3.93, 3.62 and 3.90 percent fat and 3.66, 3.52 and 3.69 percent protein, respectively. The milk SNF compositions for the forages were not significant ($P > .05$) with 8.97, 8.85 and 8.85 percent SNF for ground maize stalks, pelleted maize stalks and Coastal Bermuda pellets, respectively. It was concluded that each of the three forages was a satisfactory feed and that their nutritive values were equal.

Holm (1973) investigated the digestibility of green maize stalks during the rainy and dry season. The maize stalks were cut at 56, 63 and 70 days in the dry season. The green maize stalks were fed to 4 year old sheep with average liveweight of 25.0 kg.

Holm (1973) showed that the digestible protein was greater in the dry season when the temperature and humidity were lower. Green maize stalks were not economic in terms of unit digestible protein and unit starch equivalent when cut and fed in the rainy season.

2.2.2 Maize cobs

Maize cobs are the by-products of maize ears after the removal of mature maize grains. There is a very high tonnage of maize cobs in this country which is not commonly used for livestock feeding. Some small scale farmers and a few large scale farmers (Chuldleigh, 1974) grind maize cobs together with maize grains for livestock feeding. Recently, the Kenya Seed Company, Kitale, Kenya started grinding maize cobs as a commercial by-product and there is currently a limited market by feedlot farmers.

Research in Kenya has not so far attempted to investigate the nutritive value of maize cobs. Research findings from other countries, however show that maize cobs can be a very useful feedstuff, mainly as a source of roughage to the ruminants. Burroughs, Gerlaugh, Shalk, Silver and Kunkle (1945) used maize cobs successfully as a roughage supplement to beef cattle and Fries, Lassiter, Seath and Rust (1955) reported maize cobs as a satisfactory roughage for growing heifers. But Hill, Hatcher, Lundiquist and Crowl (1953) reported that maize cobs were unsatisfactory source of roughage in milking cows, over a 12 week feeding trial. Hill *et al.* (1953) observed a decline of 53.4 percent of milk production in those cows fed on maize cobs and a grain mixture supplement as compared to a decline of 41.5 percent in milk production in the cows which received alfalfa hay and silage plus the same quality and quantity of the grain mixture supplement as the maize cobs group. Those cows fed on maize cobs gained 42.4 kg in weight as compared to 7.3 kg for the

alfalfa hay and silage fed cows. The total dry matter consumption were 2.36 and 2.76 percent body weight per day for the cows fed maize cobs and for the alfalfa hay and silage fed cows, respectively.

Graf and Langel (1953) fed two groups of cows for a period of 30 days. One group of the cows was fed 2.5 kg of maize cobs daily in place of an equivalent amount of alfalfa-grass hay. Both groups received the same amount of maize silage and grain. Cows fed no maize cobs produced 10.0 kg of more milk per group than cows receiving maize cobs.

Lassiter, Huffman and Duncan (1958) concluded that under his experimental conditions, maize cobs were equal to medium quality hay on a per unit weight basis up to the limit of the cow's ability to consume them. In their trials, maize cobs were substituted for hay at the rate of 3.63 and 7.27 kg per day without affecting milk production, butter-fat or body weight. In another trial, maize cobs replaced alfalfa hay from 60 to 80 percent of total roughage intake without seriously affecting milk production (Lassiter *et al.* 1958). There was however an increase in the total roughage consumption as the level of maize cobs feeding increased up to a limit of 80 percent of total roughage intake.

It seems that these observed differences in the foregoing trials were attributed to the type of roughage fed to the animals. However, Lofgren and Warner (1970) noted that sources of fibre did not differ significantly when 21 Holstein cows were fed on hay, maize cobs, beet root

or oat husks as sources of crude fibre. All diets significantly increased milk fat from 2.3 to 3.3 percent and decreased milk protein from 3.71 to 3.63 percent and milk SNF from 8.68 to 8.57 percent.

Elliot (1960) also evaluated maize cobs using 15 Angus yearlings on three treatments: the conventional ration (Control); half conventional and half maize cob meal and entirely maize cob meal ration. Each ration was allocated to 5 Angus yearlings. All the rations were adjusted to provide enough energy and protein required for satisfactory growth. Elliot (1960) obtained .76, .65 and .62 kg daily liveweight gains for those yearlings on maize cob meal ration, half conventional and half maize cob meal ration and conventional ration, respectively. Those yearlings on maize cob meal ration consumed more dry matter than those on half maize cob meal ration (5.66 vs 1.88 kg DM per day). It was concluded here that protein was the limiting factor in maize cobs dry matter consumption. Any addition of minerals such as phosphorus to the maize cob meal gave no significant mineral responses in the growing animals. The limit of energy availability and the small contribution from the protein source of the maize cob meal was sufficient to support only .68 kg gain per day.

2.2.3 Sugarcane and sugarcane rejects

Sugarcane (*Saccharum officinarum*) thrives successfully in the warm humid high potential areas of

Kenya. The crop is grown on both small scale farms and on plantation estates. In 1973, there were 41 140 hectares of sugarcane in Kenya. At the time of writing this review the total hectrage of sugarcane is as shown in table 4.

TABLE 4. BREAKDOWN OF HECTRAGE UNDER SUGARCANE ON NUCLEUS ESTATES, (PARTLY QUOTED FROM PDA NYANZA, 1973)

	Land under cane (Hectares, (1973)	Caneland to be developed (hectares)	Total hectrage in each zone (1978)
Miwani	10213	2600	12813
Chemelil	12610	200	12810
Muhoroni	9317	3600	12917
Mumias	4000	7200	11200
Ramisi	5000	3000	8000
Nzoia	-	-	10200
	41140	16600	67940

A part from the nucleus estates, substantial hectrage of sugarcane is grown by small scale farmers commonly referred to as outgrowers. These small scale farmers either send their sugarcane to sugar processing factories or to their own small scale jaggery factories. Some canes are sold on local markets for chewing. In

industrial processing of sugarcane into sugar, there is some percentage of the canes that do not meet the requirements for sugar processing. Such rejects, which are mainly from outgrowers are thrown out as waste.

The yield potential of sugarcane in Kenya has been estimated to range between 60 to 100 metric tons of dry matter per hectare per year, compared to a good crop of maize turned into silage which produces about 12 tons dry matter per hectare per year (Mulder, 1975). Values ranging upto 160 metric tons per hectare have been reported (N.S.R.S., Kibos, 1972), and at Nzoia Sugar Company, the estimated yield is 120 tons per hectare on the nucleus estate and 100 tons per hectare from outgrowers (Keya, 1978). Calculations based on 100 metric tons per hectare give sugarcane production of about 4.1 million tons cane in 1973; 4 million tons cane in 1975 (technical report, 1975) and 6.8 metric tons cane in 1978.

Sugarcane has been used and is being used for livestock feeding in many parts of the world. The potential of sugarcane and sugarcane rejects as a contributor to livestock development in the tropics is strongly associated with its high energy yields per unit area of land (Bregger and Kidder, 1959; Gooding and Sargeant 1975; Preston, 1975; Lionel, 1975). The total digestible nutrients (TDN) per unit area of land of sugarcane surpasses the yield potential of cereal grains and tubers.

Preston (1975), quoting FAO (1969) and Pigden (1972) reported that sugarcane yields upto 20 tons TDN per hectare. In Kenya, tabulated TDN yield potential of sugarcane and its by-products was reported to be higher than that of maize grain, sorghum grain and cassava tubers (FAO, 1969; Pigden, 1972). Lionel (1975) estimated the energy production per hectare of sugarcane to be equivalent to that from 2.8 hectares under wheat, 8.0 hectares under milk production and over 40.0 hectares under beef production.

It is reported (Lionel, 1975) that sugarcane is normally at its optimal nutritional value in the dry season, hence its use eliminates animal weight losses which coincide with dry season. In view of this spectacular characteristics, sugarcane considerably increases animal off-takes per unit of time. Lionel (1975) thus found out that slaughter weight of beef steers was reached at 1½ to 2.0 years of age, compared with 2½ to 3.0 years of age for steers on pasture. Gooding and Sargeant (1975) noted that a hectare of cane at a yield of 75 tons dry matter could support about 5.5 animals per year at slaughter liveweight of 550 kg, compared to one animal per hectare per year on improved pangola grass.

Sugarcane has been mainly fed with or without the rind (the highly lignified outer skin). Work conducted in Barbados on derinded sugarcane (Gooding and Sargeant, 1975 quoting Donefer, James and Lawriew, 1973) gave average weight gains

in cattle of about .9 kg per day, from 36 kg initial liveweight to 545 kg. Preston (1975) quoting James (1973) reported an improvement of 19.0 percent in voluntary intake of derinded sugarcane by Holstein steers, due to incorporated sugarcane tops. Liveweight gain increased by 12.0 percent when sugarcane tops were fed together with sugarcane stalks. There was a mean liveweight gain of .59 and .66 kg per day on derinded sugarcane and derinded sugarcane plus sugarcane tops, respectively when fed to two groups of 12 and 13 Holstein steers. However, the inclusion of sugarcane tops resulted in a lower feed conversion efficiency (8.0 and 8.5 kg DM/kg gain for sugarcane alone and sugarcane plus sugarcane tops, respectively).

Ferreiro and Preston (1977 a) investigated the effect of supplementary sugarcane tops on digestibility and voluntary intake of derinded sugarcane stalk by zebu crossbred bullocks of about 150 kg liveweight. Basal diets consisted of molasses, urea and minerals, except in one experiment where rice polishings were included. The chopped sugarcane tops were fed at different levels. In one experiment the digestibility of chopped cane stalk alone was 70.7 percent and that of chopped stalk mixed with chopped tops in the ratio of 25:75, respectively was 61.0 percent. Intake increased from 1.68 kg/100 kg liveweight on stalk alone to 2.30 kg/100 kg liveweight when 25 percent of the cane diet was replaced by chopped sugarcane tops and fell to 2.08 kg/100 kg liveweight when chopped sugarcane tops were fed alone. The sizes of chopped tops had no effect on digestibility.

In another trial, Ferreiro and Preston (1977 a) compared chopped underinded to derinded cane stalks with or without 25 percent chopped tops by feeding them to 8 bullocks. The tops increased intake from 1.9 kg/100 kg to 2.2 kg/100 kg liveweight and reduced digestibility from 67.0 to 63.0 percent. However, derinding the stalk increased digestibility from 63 to 67.0 percent but reduced intake from 2.14 to 1.85 kg/100 kg liveweight. Work by Preston, Carcano, Alvarez and Gutierrez (1976) and Lopez, Preston, Sutherland and Wilson (1976) gave similar findings when rice polishings were supplemented to chopped sugarcane and derinded sugarcane.

Dry matter digestibility of mature and immature sugarcane stalk and tops was determined (Ferreiro, Preston and Sutherland 1977 b) using 8 crossbred zebu bullocks of 190 kg. Dry matter digestibility was 65.6, 62.2, 62.1 and 55.6 percent for immature stalk, immature tops, mature stalk and mature tops, respectively. Voluntary intakes of dry matter were 2.06, 2.3, 2.0 and 2.16 kg/100 kg liveweight, respectively.

Derinded whole sugarcane is composed of mainly sugars and structural carbohydrates (Preston, 1975; Pigden, 1974). These nutrients form ideal substrates in the utilization of non-protein nitrogen by ruminal microflora in the synthesis of animal protein. Silvestre, McLeod and Preston (1976) determined the effect on rate of growth of cattle and conversion of different proportions of a protein supplement, with or without maize grain in basal diets of sugarcane. In one experiment where 2 groups of 4 animals received daily, for 84 days, a 30 percent protein

supplement in varying proportions showed significant linear responses to added protein (1.79 g daily gain/g supplementary protein) and to added maize grain. In another experiment where the principal treatment was maize, Silvestre *et al*.. (1976) found higher liveweight gain on sugarcane mixed with molasses and 10 % urea than on sugarcane with urea (622 gagainst 489 g/day). There was a significant response to added maize (202 g/day liveweight gain/kg maize) on the sugarcane with urea diet but not on the diet containing molasses where the response was absent.

Ground whole sugarcane containing 16.0 percent total sugars, 3.2 percent crude protein, 35.0 percent ADF in dry matter and 2.7 Mcal per kg DM were fed *ad libitum* to 28 crossbred cows of 425 kg average liveweight and with average milk production of 8.5 kg per day (Perez and Garcia, 1975). The cows were on dry season pasture and received 1.84 kg per day of a 16.0 percent crude protein concentrate In addition three levels of urea were fed; .32, .64 and .95 percent of fresh ground sugarcane. Intake of ground sugarcane was significantly increased by urea from 1.84 kg fresh weight per cow per day for the control (sugarcane alone) to a mean of 20.1 kg for the three urea diets. There was no significant effects by the levels of urea fed. Milk production increased with dietary urea. Milk yields were 8.21 (on control) and increased significantly to 9.14 kg per day for the cows on the highest urea concentration. It was concluded that ground sugarcane mixed with 1.0 percent urea was a suitable dairy feed

for dry season feeding in the tropics. Silvestre *et al.* (1977) fed *ad libitum* chopped sugarcane, mixed with urea and molasses for 168 days to 6 groups of zebu bullocks with initial mean age of 2.0 years and liveweight of 227 kg. Average daily gain increased from 427 g when urea was 25 g/kg molasses to 531 g at 125 g urea/kg of molasses. At a level of urea supplementation of 100 g/kg molasses and above, intake of dry matter decreased per unit of liveweight gain but there was a linear increase in intake of cane and a decrease in intake of molasses as urea level increased. Ferreiro *et al.* (1977 c) in 4 x 4 latin square trials with no urea or 10, 13 or 16 g urea/kg chopped cane stalk gave dry matter digestibility by cattle of 66.5, 68.9, 67.7 and 71.8 percent respectively for the diets of chopped cane stalk.

Mulder (1975) working in Kenya fed cattle on chopped sugarcane for 70 and 105 days. The rations consisted of 18 to 77 percent chopped underinded sugarcane. Daily liveweight gains of crossbred beef cattle ranged from 1.25 to 1.34 kg per animal on rations containing 18 and 44 percent chopped sugarcane, respectively. Boran cattle gained lowest (.78 and .66 kg per animal per day) on 59 percent chopped sugarcane and were highest (.85 kg per animal per day) on 44 percent chopped sugarcane. At 29 percent, chopped sugarcane liveweight gain by Boran cattle was .70 kg per animal per day.

2.2.4 Sugarcane tops

The leafy residues together with a few aerial nodes of sugarcane after the removal of the cane stalks are broadly defined as sugarcane tops.

Sugarcane tops constitute an important fodder to cattle although at present they are not fully utilized, inspite of the scarcity of green fodder in the country. It is lamentable that inspite of the fairly huge tonnage of cane tops available in Kenya, no work has been done to evaluate their nutritive value and the practicability of feeding them to the ruminant animals.

In the more recent work by Geoffroy and Vivier (1975) the average yield of sugarcane tops in Guadelope and Martinique was 31 tons per 100 tons harvested cane. In Kenya, it has been estimated that 6.8 million tons of cane would be produced from the nucleus complex estates. The anticipated sugarcane tops dry matter yield in 1978 would be 2.1 million metric tons (Calculations based on 31 tons cane tops/100 tons cane), from the sugarcane nuecleus complexes. This implies that the available quantity of sugarcane tops is supposedly much higher than the figure quoted above, when sugarcane tops production from outgrowers is included.

The nutritive value of sugarcane tops does not seem to vary greatly whether they are in ripe or over-ripe stage of the crop (Das Gupta, 1949). Chemical composition of the sugarcane tops together with two common forages is shown in table 5.

TABLE 5. PERCENT COMPOSITION OF THREE FORAGES ON DRY MATTER BASIS (Das Gupta, 1949)

	Dry matter	Organic matter	Protein	Ether extract	Fibre	NFE
Sugarcane tops						
(Madhurikund, Mathura)						
1st February to 7th March	33.7	88.55	4.64	1.96	34.72	47.23
8th March to 11th April	28.40	87.84	4.83	1.95	34.25	46.81
14thApril to 22nd April	39.87	87.54	4.50	3.05	31.87	48.12
Morrison's figure	28.50	92.60	5.30	1.40	31.20	54.70
Jowarfodder (Sorghum)						
(Bharari, Jhansi, average)						
Prime to mature September to November	35.10	88.91	3.90	1.12	29.22	54.67
(Etarrah, average)						
Prime to mature September to November	33.80	90.88	3.15	1.50	30.16	56.07
Madhuri Kund (Mature) - November	46.20	90.20	5.18	1.16	30.74	53.12
Napier grass						
(Bharari, Jhansi, average)						
September to November	28.40	86.13	5.85	1.13	36.91	42.24
(Etarrah, average)						
September to November	30.90	89.24	2.34	1.03	35.63	50.24
Madhurikund (Mathura)						
November	34.10	87.08	2.78	1.36	32.87	50.07

Sugarcane tops were fed *ad libitum* to 3 Hariana cows (Das Gupta, 1949). Daily dry matter intake was 3.0 kg per 100 kg liveweight. It was also reported in the same experiment that sugarcane tops were better digested than *jowar* (Sorghum) forage and were superior to Napier grass and Guinea grass. Digestible nutrients for sugarcane tops were 3.21 for protein and 66.8 for TDN. The nutritive value of overripe sugarcane tops was nearly equal to green maize stalks and compared favourably with that of Napier grass and sorghum. Organic matter digestibility was 71.3, 75.0, 59.0 and 58.0 percent for mixed ration of sugarcane tops and linseed cake, sugarcane tops, Guinea grass and sorghum, respectively. Das Gupta (1949) concluded that sugarcane tops were able to maintain production when supplemented with a little protein.

Sherrod, Campbell and Ishizaki (1968) evaluated 8 months old sugarcane tops and cane strippings for a period of 21 days, using 20 wethers of 49.1 kg liveweight. The wethers were fed these two by-products with or without 100 g soya bean meal per day. The dry matter of the sugarcane tops and sugarcane strippings was 16.4 and 28.2 percent, respectively and their chemical composition on dry matter basis for crude protein, crude fibre and nitrogen-free extractives was 7.4 and 4.4, 37.4 and 36.2, 47.3 and 52.2 percent, respectively. The dry matter intakes of the diets were similar. The supplemented soya-bean meal increased significantly ($P < .05$) the

digestibilities of organic matter, crude protein, crude fibre, ether extract, nitrogen-free extracts and gross energy of the sugarcane tops diet but not those of cane strippings diet, except the ether extract which showed improved digestibility. However, the soya bean supplement increased nitrogen retention on both forages although all sheep remained in the negative nitrogen balance. It is probable then that a protein supplement has a marked effect on the utilization of sugarcane tops.

Fratteggiani (1963) also carried out a trial on sugarcane tops. In his trial, freshly picked sugarcane tops were chopped and fed as the only feed to 4 male cross-bred sheep. The chemical composition of the feed was 67.99, 4.98, 4.08, 8.81, 1.70, 12.87, 3.64 and 1.27 percent, of fresh matter, for moisture, crude protein, true protein, crude fibre, ether extract, nitrogen-free extracts, ash and lignin, respectively. The sugarcane tops were readily eaten and each sheep consumed from .99 to 1.49 kg per day. Average percentage digestibility was 77.06, 74.39, 49.18, 60.72, 58.87 and 5.74 for crude protein, true protein, ether extract, nitrogen-free extractives, crude fibre and lignin, respectively. The calculated starch equivalent value was 13.93 kg per 100 kg for fresh sugarcane tops.

Digestibility of sugarcane tops averaged 60.0 percent and was higher with short than with tall crops. It was lower in humid than in dry zones (Geoffroy and Vivier, 1975). Dry matter content of the cane tops ranged from 30 to 35

percent and crude protein content was reported to be less than 5 percent in DM. Butterworth (1962) also determined the digestibility of sugarcane tops. The sugarcane used in his trial was cut daily, early in the harvesting season, at a time when the crude protein level was expected to be at its highest during the cutting period. Chemical composition of the sugarcane tops tested is shown in table 6.

TABLE 6. THE CHEMICAL COMPOSITION OF SUGARCANE TOPS (Butterworth, 1962)

Constituent, %	Green sugar-cane tops	Dry matter basis
Moisture	74.4	0
Crude protein	1.6	6.3
Crude fibre	8.9	35.0
Ether extract	.6	2.2
Ash	1.6	6.2
Nitrogen-free extracts	12.9	50.3
Organic matter	24.0	93.8

Six sheep were used in the trial. The digestibility coefficients of the constituents of sugarcane tops were 50.6, 64.8, 31.7, 63.3 and 63.3 percent crude protein, crude fibre, ether extract, nitrogen-free extracts and organic matter, respectively. Total digestible nutrients (TDN) were 59.3 percent. Crude fibre digestibility values were larger than those of nitrogen-free extractives, a fact

that was attributed to increased lignification of the cell wall. It was concluded that sugarcane tops do not supply sufficient crude protein for maintenance hence the need for protein supplementation in order to maintain the condition of animals.

Nutritive value of sugarcane tops were evaluated by *in vitro* studies (Chaudhary, Sharma, Ahuja and Bhatia, 1972). The dry matter content of the sugarcane tops ranged from 27.2 to 32.3 percent. Crude protein, crude fibre and water soluble carbohydrates of the cane tops were in the ranges from 4.0 to 4.6, 24.3 to 27.4 and 14.5 to 16.2 percent, dry matter, respectively. *In vitro* dry matter digestibility of the sugarcane tops after 24 and 48 hours was 30.0 to 31.3 percent and 43.3 to 49.6 percent, respectively. However when compared with *in vitro* DMD at the 24 and 48 hours incubation for maize stalks at flowering stage, it was 23.7 and 36.6 percent and for pure cellulose it was 46.0 and 84.0. The *in vitro* digestibility of cellulose after 24 and 48 hours incubation was 27.7 to 29.6 and 30.3 to 34.1 percent for sugarcane tops, 26.2 and 42.5 percent for maize stalks and 76.2 and 98.1 percent for pure cellulose.

In a trial by Rodrigues, Freitas and Lopen (1976), intake of dry matter of a ration based on sugarcane tops was reported to be higher than that of a ration based on whole sugarcane. Liveweight gains of steers on these diets were .74 and .74 kg/day for sugarcane tops and whole sugarcane, respectively.

Pate (1974) investigated the utilization of sugarcane tops in steer finishing rations. The sugarcane tops were

in the form of pellets with 95.4 percent dry matter. Chemical composition was 7.2, 31.3, 1.6, 6.9 and 52.9 percent for crude protein, crude fibre, ether extract, ash and nitrogen-free extracts, respectively. The sugarcane tops pellets were fed to steers as replacements for parts of maize meal and citrus pulp in the control ration, fed *ad libitum* with .91 kg Pangola grass hay per day. The replacement of 17 percent of the ration by sugarcane tops pellets resulted in slight improvement in the rate of liveweight gain and feed conversion efficiency. However, further increases in the contribution of the pellets to the diet reduced gains, feed conversion efficiency and carcass parameters.

CHAPTER 3

MATERIALS AND METHODS

3.1 Location

The trial was conducted at the National Agricultural Research Station (N.A.R.S.) Kitale, Kenya. The station is situated at 1^{o} 01'N and 35^{o} 00' E at an altitude of 1890 metres.

Mean annual temperature is 18.3^{o}C with the highest temperature at 27.1^{o}C in February and lowest at 10.1^{o}C in December. The station has a mean annual rainfall of 1191 mm with peaks falling during April to May and July to August. There is a short period of dry season, normally from December to end of February.

3.2 Experimental diets

The experimental diets were green maize stalks, maize cobs, sugarcane, sugarcane tops and hay.

3.2.1 Green maize stalks

Green maize stalks were obtained from the agronomy trials at N.A.R.S. The crop had been fertilized with 500 kg/ha of single superphosphate during planting time and top dressed with 500 kg/ha of ammonium sulphate nitrate (ASN). The maize ears were plucked off and plain stalks were cut and were chopped by a stationary forage harvester to sizes of 2 to 3 cm. The chopped maize stalks were dried in forced drought ovens at 60^{o}C for 48 hours. They were then packed in gunny bags and kept in dry and well ventilated store.

3.2.2 Maize cobs

Maize cobs were collected from Kenya Seed Company drier at Endebess, Kenya. The cobs were ground in a hammer mill (sieve size 8 mm) to a fine cob meal. It was packed in bags and stored, ready for feeding.

3.2.3 Sugarcane

Sugarcane was obtained from the National Sugar Research Station, Kibos, Kenya. A soft and mature (15-17 months old) variety (CU1001) was chosen. Enough canes were collected and stored in cold room for the feeding trial. They were chopped by a stationary forage harvester to sizes of 2 to 3 cm and fed in that form.

3.2.4 Sugarcane tops

Sugarcane tops of the experimental canes in 3.2.3 were cut and chopped by a stationary forage harvester to sizes of 2-3 cm. The material was dried at 60^{o} C for 48 hours, stored in a well ventilated store and was fed in that form.

3.2.5 Hay

Hay was prepared from Rhodes grass (*Chloris gayana*) at blooming stage. The grass hay was made from a field of Rhodes grass that had been planted with 500 kg/ha of single superphosphate together with 62.5 kg/ha ASN and top dressed with 500 kg/ha ASN. The hay was chopped to 2-4 cm long by Chaff Cutter and stored in that form for feeding.

3.3 Experimental animals, design, feeding and collection of samples

3.3.1 Experimental animals

Twenty Romney Marsh wethers, 1 to 2 years old, ranging from 30.4 to 45.4 kg liveweight were used in the experiments. The animals were kept in individual metabolism cages. The cages were locally made, based on the specifications of Hobbs *et al.* (1950) and Horn *et al.* (1954). Minor modifications were made on the cages by fitting them with rectangular aluminium troughs for separate urine collection.

All sheep were weighed on the first day they were put in the cages, after they had been without food over night. They were weighed again at the end of feeding trial after they had been starved over night.

The twenty wether sheep were divided into 4 groups after they had been balanced for age and weight.

3.3.2 Experimental design and feeding of animals

The experiments were conducted in a randomized block design. There were five treatments, maize stalks, maize cobs and mixed with hay in the ratio of 60:40, sugarcane, sugarcane tops and hay. Hay was used in the experiments to determine the digestibility of maize cob meal. These treatments were randomized within the 4 groups.

Two replicate experiments were conducted for each treatment. In each experiment, there was a preliminary (adjustment) period of 10 days and an experimental period of 14 days.

The sheep were fed twice daily, at 09.00 and 18.00 hours. Each animal was fed a total of 1000 g of experimental diets, divided into 2 feedingsof 500 g, but amounts were increased or decreased according to appetite of the animals, making sure however there was a 10 percent refusal. A comprehensive salt mixture and clean water were provided *ad libitum*.

3.3.3 Collection of samples

A sample of feeds offered to each group of sheep was daily hand picked from different sites of the feedstuffs. Each sample of maize stalks, hay plus maize cobs, sugarcane, sugarcane tops and hay was bulked in separate closed bins through the duration of the experiments. On the last day of the experiment, each bulk sample was divided into 4 equal portions. Several sub-samples were taken from each bulk sample to give 400 g of a representative sample. These representative samples were oven dried over night at 100^{o} C. The samples were weighed after cooling, ground in a Christy and Norris 8 in laboratory hammer mill fitted with a 0.8 mm sieve and placed in individual well labelled plastic bags ready for laboratory analyses.

Feeds left over by the sheep were carefully collected from each feeding trough, weighed and bulked in twenty labelled bins for each sheep. At the e i of the experiment, each bulked sample was sub-sampled as described earlier for feeds offered and oven dried at 100^{o} C over night before weighing them. Each sample was ground in Christy and Norris hammer mill and placed in individual labelled air tight plastic bags ready for laboratory analyses.

The mineral block fed to each sheep was weighed at the beginning and end of the experiment to obtain the amount consumed by each sheep.

Total collection of faeces was done by using plastic faecal collection bags which were attached to the harnesses tied round the abdomen of sheep. The harnesses were tied on the sheep one day before the collection period. The faeces were collected twice daily at 18.00 hours and 09.00 hours on the following day. Faeces collected at 18.00 hours were kept in polythene bags and stored in cold room until the following morning at 09.00 hours when they were finally mixed before a 20 percent sub-sample was obtained.

The 20 percent faecal sub-sample was sub-divided further into two equal parts. One part was bulked daily for nitrogen determination. This sample was preserved with 6.0 mls solution of 96 percent ethanol, 3 percent sulphuric acid and 1 percent toluene. Each sub-sample for each sheep was kept in tightly closed plastic buckets and stored in the deep freezer at $-5^{o}C$.

The second part of the 20 percent faecal sub-samples were weighed and dried at 65^{o} C for 48 hours in forced drought ovens. After drying, they were weighed again and bulked separately for each sheep. At the end of the experiment, the dry faeces were milled in a Christy and Norris hammer mill and stored in air tight plastic bags ready for laboratory analyses.

Total urine collection was done once daily. The urine was collected in stoppered plastic bottles connected to the collection trough by a plastic delivery tube. The volume of urine excreted by each sheep was measured. After measuring the total volume by each sheep, 10 percent of the urine was retained. The daily sub-samples were bulked in stoppered labelled flasks, into which was added 3.6 grains of mercury bichloride, 2 drops of toluene and 6.2 mls concentrated sulphuric acid. The urine samples were deep frozen.

3.4 Analytical procedure

3.4.1 Chemical analyses

Chemical analyses for dry matter, crude fibre, ether extracts, total ash and nitrogen-free extractives were carried out using conventional methods according to AOAC (1970). Nitrogen determination was done in the semi-micro Kjeldahl apparatus, according to Markham's (1942).

3.4.2 Mineral analyses

Sodium and potassium were determined by Flame photometer (Model A Evans Electroselenium Ltd. No. 712700). Calcium was determined by EDTA method due to the fact that the atomic absorption spectrophotometer (SP 191 Atomic Absorption Spectrophotometer) had not been installed at N.A.R.S. Phosphorus was determined by Absorption spectrophotometer (Unicam SP 600 series 2 spectrophotometer).

3.4.3 The determination of heat of combustion (Gross energy)

Calorific value determination for by-products, faeces and urine was done by Automatic Adiabatic Bomb Calorimeter (Gallen Kamp Auto Bomb CB-100). Urine samples were prepared according to the method in Appendix before obtaining solid material required for ignition in the calorimeter.

3.4.4. The determination of *in vitro* digestibility by the two stage technique

Dry matter digestibility on dry matter basis (D.M.D.), organic matter digestibility on organic matter basis (O.M.D.) and organic matter digestibility on dry matter basis (D-value or O.M.D.D.M.) were determined according to Tilley and Terry technique (Tilley and Terry, 1963 and 1968). Rate of *in vitro* dry matter and organic matter disappearance for all experimental feeds was also done by the same technique, whereby the relative rate at which the feeds were digested were observed at 0, 12, 24, 36, 48, 60 and 72 hours (incubation in the rumen liquor), followed by a 48 hour acid-pepsin digestion for each digestion time.

3.4.5 *In vitro* analyses by Van Soest procedure

Neutral detergent fibre (NDF), Neutral detergent solubles (NDS), acid detergent fibre (ADF) and acid detergent lignin were analysed according to the methods of Van Soest (1963), Van Soest and Moore (1965), Van Soest, *et al.* (1966) and Van Soest (1967), as given in appendix.

3.4.6 Statistical Analyses

Analysis of variance (ANOVA) and F-test were done according to the standard procedures outlined by Sokal and Rohlf (1969), Snedecor and Cochran (1967), Goulden (1956) and Steel and Torrie (1960).

Means were compared using Duncan's New Multiple-Range Test (Steel and Torrie, 1960) only when ANOVA revealed significant differences amongst means. Regressions and correlations were tested by a t-test (Steel and Torrie, 1960; Snedecor and Cochran, 1967).

CHAPTER 4

RESULTS

4.1 Chemical composition, performance, comparative digestibilities, Nitrogen and Mineral retentions

4.2.1 Chemical composition of by-products

The chemical composition of the by-products fed to the wether sheep is summarized in table 7. The by-products were characterised by high fibre and low crude protein contents. Maize stalks (8.1 %) and sugarcane tops (9.6 %) were composed of high ash contents whereas maize cobs (1.3 %) and sugarcane (2.2 %) were low in ash. The energy values with a mean of 4.1 kcal/g were in the same range in all of the by-products.

TABLE 7. AVERAGE COMPOSITION OF THE BY-PRODUCTS

Item	Experimental feeds			
	Maize stalks	Maize cobs	Sugar-cane	Sugar-cane tops
Dry matter, %	94.4	94.6	94.0[a]	97.4
Composition of dry matter, %				
Organic matter	91.9	98.7	97.8	90.4
Crude protein	8.5	2.0	2.4	4.7
Crude fibre	25.0	32.8	20.2	32.2
Ether extract	2.0	.9	1.6	2.0
Ash	8.1	1.3	2.2	9.6
NFE	56.4	63.0	73.6	51.5
Gross energy, Kcal/g	4.3	4.4	3.9	3.8
Digestible energy, Kcal/g	2.8	2.4	2.3	2.0

[a]Dry matter as fed was 27.1 %

Average mineral composition of feeds is presented in table 8. The by-products except maize cobs were deficient in sodium. Large amounts of potassium were observed in maize stalks, sugarcane and sugarcane tops. There was no consistent trend in the composition of calcium and phosphorus in the feeds. Maize cobs was low in phosphorus.

Mineral composition of faeces and urine is shown in table 9. It was observed that large quantities of all the minerals were lost through urine. Potassium excretion through urine was high compared to other minerals studied. The excretion of each element in the urine seemed to have a direct relationship with the amount ingested in the feedstuffs.

All sheep had direct access to free mineral lick. The mineral brick that was fed *ad libitum* to all groups was analysed and results compared with those given in the extension mineral handbook, (table 10). Results agreed to some extent, although the calcium/phosphorus ratio obtained at N.A.R.S. was lower than the one supplied to farmers. Sodium was the major component of the mineral brick.

4.2.2 Chemical composition of faeces

Average faecal composition of the by-products fed wether sheep is summarized in table 11. The results showed similar trends of nutrient concentration in the faeces as in the feeds. This observation was more so in the crude protein, crude fibre and ash contents. The gross energy of the faeces was similar to that of feeds. The gross energy of urine was .2, .2, .3 and .2 kcal/g for sheep fed maize stalks, maize cobs, sugarcane and sugarcane tops, respectively.

TABLE 8. AVERAGE MINERAL COMPOSITION OF THE BY-PRODUCTS[1]

Item	Experimental diets			
	Maize stalks	Maize cobs	Sugarcane	Sugarcane tops
Ash, %[2]	8.10	1.30	2.20	9.60
Ca, %	.24	.18	.28	.15
P, %	.13	.06	.24	.43
Na, %	.05	.37	.03	.05
K, %	2.65	.80	2.81	2.31

[1]Means represent data from six replicate samples.

[2]Dry matter basis.

TABLE 9. AVERAGE MINERAL COMPOSITION OF FAECES AND URINE[1]

Item	Experimental diets			
	Maize stalks	Maize cobs	Sugarcane	Sugarcane tops
	Faeces			
Ash, %[2]	8.10	5.60	7.30	14.00
Ca, %	.13	.15	.24	.10
P, %	.82	.38	1.10	1.01
Na, %	.14	.51	.06	.06
K, %	.61	.75	.96	.87
	Urine			
Ca, mg/100 ml	7.55	40.80	35.95	8.15
P, mg/100 ml	18.54	1.53	358.54	7.65
Na, mg/100 ml	56.80	6.72	30.72	9.36
K, mg/100 ml	3550.00	1785.00	1286.00	2712.00

[1]Means represent data from thirty replicate samples.

[2]Dry matter basis.

TABLE 10. MINERAL ANALYSES OF MINERAL BRICKS FED TO THE WETHER SHEEP

	Mineral				
	Ca	P	Na	K	Ca/P
Elemental analyses at N.A.R.S., %[1]	2.1	2.4	31.05	.050	.9/1
Elemental analyses from Cooper, %[2]	2.6	1.4	31.93	.006	1.8/1

[1]Means represent data from 3 replicate samples

[2]Data extracted from Extension Mineral supplement hand book.

TABLE 11. AVERAGE CHEMICAL COMPOSITION OF THE FAECES AND URINARY ENERGY FROM WETHER SHEEP FED BY-PRODUCTS[1]

I t e m	Experimental feeds			
	Maize stalks	Maize cobs[a]	Sugar-cane	Sugar-cane tops
Dry matter (DM), %	95.2	95.0	94.9	96.4
Composition of dry matter, %				
Organic matter	91.2	94.4	93.0	86.7
Crude protein	11.1	7.4	8.1	6.1
Crude fibre	25.8	24.3	34.4	30.7
Ether extract	1.8	1.3	1.4	2.1
Ash	8.8	5.6	7.0	13.4
NFE	52.5	61.4	49.1	47.7
Gross energy (faeces) kcal/g	4.4	4.5	4.1	4.0
Gross energy (Urine) kcal/ml	.2	.2	.3	.2

[1]Means represent data from 10 wether sheep.

[a]Digestibility was determined using indirect methods by feeding maize cobs to hay in the ratio of 60:40

4.3.1 Voluntary feed intake and performance by wether sheep.

Feed intake, feed digestibility and efficiency of utilization constitute the nutritive value components of a feed. Thus, the ability of animals to consume the by-products would initially determine their quality.

Voluntary feed intake values are given in table 12: Dry matter intake was 1007.5, 553.1, 299.5 and 864.3 g per day by sheep fed maize stalks, maize cobs, sugarcane and sugarcane tops, respectively. These dry matter intake values were different ($P < .005$), with maize stalks having the highest ($P < .05$) intake, followed by sugarcane tops, maize cobs and sugarcane.

All feeds except sugarcane were readily accepted by sheep. The sheep on sugarcane showed an initial high appetite but this appetite decreased during the advanced stage of the trial.

Dry matter intake by wether sheep fed maize stalks, maize cobs, sugarcane and sugarcane tops was 65.7, 32.6, 22.5 and 52.7 g/kg$^{.75}$/day, respectively. The intakes were different ($P< .05$). The daily dry matter intake was 2.6, 1.3, 1.0 and 2.0 % body weight in those sheep fed on maize stalks, maize cobs, sugarcane and sugarcane tops, respectively. The dry matter intakes for maize stalks and sugarcane tops were established to be higher ($P< .05$) than those of maize cobs and sugarcane.

The daily organic matter intake by sheep was 926.9, 531.4, 293.3 and 794.8 g of maize stalks, maize cobs, sugarcane and sugarcane tops, respectively. These intake values were

TABLE 12. AVERAGE PERFORMANCE OF WETHER SHEEP FED BY-PRODUCTS[1]

I t e m	Experimental diets				Se of treatment mean and significance Level	C.V. %
	Maize stalks	Maize cobs	Sugar-cane	Sugar-cane tops		
Initial weight, kg.	36.7	44.7	34.5	42.6		
Final weight, kg	39.7	43.1	28.5	42.6		
Mean liveweight, kg	38.2	43.9	31.5	42.6		
Daily gain/loss weight, kg	+ .35^a	- .11^b	- .51^b	- .01^c	± .04***	- 200
Metabolic body weight, kg $^{.75}$	15.4	17.0	13.3	16.5		
DM intake, g/day	1007.5^a	553.1^b	299.5^c	864.3^d	±30.7***	14.0
Feed intake/kg gain or loss, g	346.9	679.5	50.2	659.3		
DM intake/kg $^{.75}$/day, g	65.7^a	32.6^b	22.5^c	52.7^d	± 2.1***	15.0
DM intake kg/100 kg body weight, %	2.6	1.3	1.0	2.0		
Organic matter intake, g/day	926.9^a	531.4^b	293.3^c	794.8^d	±26.8***	13.0
Organic matter intake, g/kg $^{.75}$/ day	60.4^a	31.3^b	22.1^c	48.4^d	± 1.8***	14.0
Digestible organic matter intake, g/day	585.0^a	329.3^b	183.9^c	447.5^d	±17.6***	14.0
Digestible organic matter intake g/kg $^{.75}$/day)	38.3^a	19.4^b	13.9^c	27.2^d	+ 1.1***	15.0

*** P< .005

[1]Means represent data from 10 wether sheep.

^{a,b,c,d} Means in the same row with different superscripts were significantly different (P< .05).

different ($P < .05$), with maize stalks and sugarcane tops having higher ($P < .05$) organic matter intake than maize cobs and sugarcane. These variations in organic matter intake were associated with varying quantities of ash contents of each by-product. Daily organic matter intake values were equivalent to 60.4, 31.3, 22.1 and 48.4 $g/kg^{.75}$, respectively. These organic matter intake values were different ($P < .05$).

Daily voluntary intake of digestible organic matter by sheep fed maize stalks (585.0 g) and sugarcane tops (447.5 g) were higher ($P < .05$) than that of maize cobs (329.3 g) and sugarcane (183.9 g). Daily intake of the digestible organic matter were 38.3, 19.4, 13.9 and 27.2 $g/Kg^{.75}$. These values were different ($P < .05$).

The sheep fed on maize stalks gained while those on maize cobs, sugarcane and sugarcane tops lost weight. The average daily liveweight gain by sheep on maize stalks was .35 kg. The liveweight loss in sheep fed maize cobs, sugarcane and sugarcane tops was .11, .51 and .01 kg, respectively. Liveweight gain per day in sheep fed maize stalks was higher ($P < .05$) than those fed maize cobs, sugarcane and sugarcane tops. However, liveweight losses in sheep fed maize cobs and sugarcane were not different ($P > .05$).

4.4 Apparent *in vivo* digestibility of the by-products

Dry matter digestibility coefficients of the by-products (table 13) were 63.8, 60.1, 60.8 and 54.3 % for maize stalks, maize cobs, sugarcane and sugarcane tops, respectively. The

TABLE 13. AVERAGE APPARENT DIGESTIBILITY COEFFICIENTS OF THE BY-PRODUCTS BY WETHER SHEEP [1]

Item	Experimental Diets				Se of treatment mean and significance level	C.V. %
	Maize stalks	Maize cobs	Sugar-cane	Sugar-cane tops		
Apparent digestibility, %						
Dry matter	63.8^{a}	60.0^{a}	60.8^{a}	54.3^{b}	± 1.1***	6.0
Organic matter	63.8^{a}	60.6^{a}	62.9^{a}	56.2^{b}	± 1.1***	6.0
Crude protein	52.4^{a}	37.3^{c}	- 25.1^{b}	37.7^{c}	± 3.3***	40.0
Ether extract	64.7^{a}	76.6^{b}	68.6^{a}	44.6^{c}	± 2.6***	13.0
Crude fibre	62.3^{a}	69.8^{b}	35.3^{c}	56.5^{d}	± 1.6***	9.0
NFE	66.1^{a}	57.8^{b}	73.0^{c}	56.6^{b}	± 1.2***	6.0
Gross energy	63.9^{a}	54.8^{b}	58.7^{b}	52.4^{b}	± 1.7***	10.0
Digestible nutrients, %						
Digestible organic matter	58.7^{a}	59.8^{a}	61.4^{a}	50.9^{b}	± 1.0***	6.0
Digestible crude protein	4.5^{a}	.8^{b}	.6^{b}	1.9^{c}	± .2***	42.0
Digestible ether extract	1.3^{a}	.7^{b}	1.1^{a}	.9^{b}	± .1***	26.0
Digestible crude fibre	15.6^{a}	22.9^{b}	7.1^{c}	18.2^{d}	± .4***	8.0
Digestible NFE	37.3^{a}	36.4^{a}	53.3^{b}	29.3^{c}	± .8***	7.0
Total digestible nutrients	60.2^{a}	61.6^{a}	62.3^{a}	51.4^{b}	± 1.1***	6.0
Starch equivalent	45.0^{a}	41.6^{b}	50.2^{c}	32.3^{d}	± 1.1***	8.0

***P< .005. [1]Means represent data from 10 wether sheep.

^{a,b,c,d}Means in same row with different superscripts were significantly different (P< .05).

dry matter digestibility of maize stalks, maize cobs, and sugarcane was not different ($P > .05$). These dry matter digestibility values were, however, higher ($P < .05$) than sugarcane tops.

Average organic matter digestibility coefficients of maize stalks, maize cobs, sugarcane and sugarcane tops were 63.8, 60.6, 62.9 and 56.2 %. The organic matter digestibility of maize stalks, sugarcane and maize cobs were not different ($P > .05$). They were however all higher ($P < .05$) than sugarcane tops.

The average crude protein digestibility values for maize stalks, maize cobs, sugarcane and sugarcane tops were 52.4, 37.3, - 25.1 and 37.7 %, respectively. The crude protein digestibility of maize stalks was higher ($P < .05$) than sugarcane tops, maize cobs and sugarcane.

Crude protein digestibility in maize stalks was superior ($P < .05$) to the rest of the feeds whereas sugarcane was lowest, with a large negative crude protein digestibility coefficient. These differences were associated with the quantity of crude protein in the by-products.

Ether extract digestibility coefficients for maize stalks (64.7 %), maize cobs (76.6 %), sugarcane (68.6 %) and sugarcane tops (44.6 %) were different ($P < .05$, CV = 13.0 % and Se = $\pm$ 2.6 %). The ether extract digestibility in maize cobs was higher ($P < .05$) than that of the rest of the by-products. Sugarcane and maize stalks were not different ($P > .05$) although both were different ($P < .05$) from sugarcane tops.

Crude fibre digestibility in maize cobs (69.8 %), maize stalks (62.3 %), sugarcane tops (56.5 %) and sugarcane (35.3 %) were different ($P < .05$).

The average Nitrogen-free extract (NFE) digestibility in maize stalks, maize cobs, sugarcane and sugarcane tops was 66.1, 57.8, 73.0 and 56.6 %, respectively. Sugarcane and maize stalks were higher ($P < .05$) than maize cobs and sugarcane tops. NFE digestibility in maize cobs and sugarcane tops were not different.

The gross energy digestibility of maize stalks (63.9 %) was higher ($P < .05$) than maize cobs (54.8 %), sugarcane (58.7 %) and sugarcane tops (52.4 %). Maize stalks was however higher ($P < .05$) than sugarcane tops while no difference ($P > .05$) was observed between sugarcane and maize cobs, neither was there any difference ($P > .05$) between maize cobs and sugarcane tops.

4.4.1 Estimation of digestible nutrients

The digestible organic matter of maize stalks (58.7 %), maize cobs (59.8 %) and sugarcane (61.4 %) were not different ($P > .05$). However, sugarcane tops (50.9 %) was lower ($P < .05$) than maize stalks, maize cobs and sugarcane.

Digestible crude protein (DCP) was variable, mainly due to the effect of low crude protein conten in sugarcane and maize cobs. The DCP of the maize stalks (4.5 %) was different ($P < .05$) from sugarcane tops (1.9 %). Maize cobs (0.8 %) and sugarcane (0.6 %) were not different ($P > .05$).

The digestible ether extract (DEE) of maize stalks (1.3 %) and sugarcane (1.1 %) were not different ($P > .05$) neither were

the DEE of maize cobs (.7 %) and sugarcane tops (.9 %). The DEE of the latter two by-products were however lower ($P < .05$) than the former two by-products.

All the by-products showed significant differences ($P < .05$) in their digestible crude fibre (DCF). The DCF of sugarcane (7.1 %) was the lowest ($P< .05$) while maize cobs (22.9 %) was the highest of all. The DCF of maize stalks and sugarcane tops were 15.6 and 18.2 %, respectively. The crude fibre of the by-products was digestible only to a limited extent by the sheep. The low digestible crude fibre might have had adverse effects on the available nutrients.

The digestible nitrogen-free extract (DNFE) of sugarcane (53.3 %) was different ($P< .05$) from maize stalks (37.3 %), maize cobs (36.4 %) and sugarcane tops (29.3 %). There was no difference ($P< .05$) in the DNFE of maize stalks and maize cobs. The DNFE of sugarcane tops was the lowest ($P< .05$) of all the by-products. These observed variations in the DNFE were largely associated with the differences in the neutral detergent fibre (NDF) and neutral detergent solubles (NDS) table 17. The contrasting differences in the digestible nutrients were largely caused by these organic structural components.

Starch equivalent values (SE) of the by-products were estimated from their proximate analysis values. The starch equivalent values of maize stalks, maize cobs, sugarcane and sugarcane tops were 45.0, 41.6, 50.2 and 32.3 % respectively. These SE values were different ($P< .05$) and were equivalent to .45, .42, .50 and .32 SE per kg of maize stalks, maize cobs, sugarcane and sugarcane tops, respectively. The SE of sugarcane

was found highest (P <.05) of all while sugarcane tops were lowest (P <.05) in SE of all the by-products.

The TDN of maize stalks (60.2 %), maize cobs (61.6 %) and sugarcane (62.3 %) were not different (P >.05) but were higher (P< .05) than sugarcane tops (51.4 %). TDN values established that the by-products were high in digestible energy that can be potentially available to ruminants.

4.4.2 Intake of digestible nutrients

Digestible dry matter intake was directly related to the dry matter intake by sheep. The average daily digestible dry matter intake was 41.8, 19.9, 13.7 and 28.8 g/kg$^{.75}$ by the sheep on maize stalks, maize cobs, sugarcane and sugarcane tops, respectively.

Digestible protein intake in maize stalks, maize cobs, sugarcane and sugarcane tops was 2.6, .9, - .2, and 1.1 g/kg$^{.75}$ per day, respectively as shown in table 14. The quantity of digestible protein consumed by the sheep appeared to have a controlling effect on the overall intake of the nutrients. Sugarcane with a negative digestible protein intake had the lowest intake of crude protein.

Daily gross energy intake by the sheep was 4402.9, 2178.3, 1160.7 and 3345.4 kcal per day for maize stalks, maize cobs, sugarcane and sugarcane tops, respectively. Maize stalks and sugarcane tops were higher (P<.05) than maize cobs and sugarcane. Gross energy intake was directly related to the amount of organic matter ingested. This intake was equivalent to 286.8, 127.9, 87.2 and 200.1 kcal/kg$^{.75}$ for maize stalks, maize cobs, sugarcane and sugarcane tops, respectively.

TABLE 14. DAILY AVERAGE INTAKE OF NUTRIENTS BY WETHER SHEEP[1]

I t e m	Experimental Diets				Se of treatment mean and significance level	C.V. %
	Maize stalks	Maize cobs	Sugar-cane	Sugar-cane tops		
Dry matter intake, DM g/kg $^{.75}$	65.7^a	32.6^b	22.5^c	52.7^d	± 2.1***	15.0
Crude protein intake g/kg $^{.75}$	5.6^a	1.8^b	$.6^c$	2.6^d		
Dig. DM, g/kg $^{.75}$	41.8^a	19.9^b	13.7^c	28.8^d		
Dig. protein, g/kg $^{.75}$	2.6^a	$.9^b$	$-.2^c$	1.1^d		
Gross energy intake, kcal/day	4402.9^a	2178.3^b	1160.7^c	3345.4^d	±130.2***	15.0
Dig. energy intake, kcal/day	2812.2^a	1201.1^b	683.0^c	1762.3^d	± 88.5***	17.0
Metabolizable energy, kcal/day	2366.8^a	1028.3^b	516.5^c	1439.6^d	± 77.6***	18.0
Gross energy, kcal/kg $^{.75}$	286.8^a	127.9^b	87.2^c	200.1^d		
Digestible energy, kcal/kg $^{.75}$	183.2^a	70.5^b	51.3^c	105.4^d		
Metabolizable energy, kcal/kg $^{.75}$	154.2^a	60.4^b	38.8^c	86.1^d		

***P< .005 [1]Means represent data from 10 sheep.

^{a,b,c,d}Means in the same row with different superscripts were significantly different (P < .05)

There was a similar trend in intake of digestible energy (DE) as was found with the gross energy intake. The DE intake of maize stalks (2812.2 kcal/day) was higher ($P< .05$) than sugarcane (683.0 kcal/day). The DE intake of maize cobs (1201.1 kcal/day) and sugarcane tops (1762.3 kcal/day) were also different ($P< .05$). The digestible energy intakes were equivalent to 183.2, 70.5, 51.3 and 105.4 kcal/$kg^{.75}$ per day for maize stalks, maize cobs, sugarcane and sugarcane tops, respectively. The digestible energy intakes in maize cobs and sugarcane were rather low as compared to maize stalks and sugarcane tops.

Metabolizable energy was estimated by adjusting digestible energy for losses in urine and fermentation gases. Gaseous energy loss (GPD) was calculated as 8.0 % of the gross energy intake (Maynard and Loosli, 1969 and McDonald and Greenhalgh, 1966).

Metabolizable energy (ME) intake corresponded to observed gross and digestible energy intakes of each by-product. The metabolizable energy by sheep fed maize stalks (2366.8 kcal/day) was higher ($P< .05$) than by sheep on sugarcane (516.5 kcal/day), maize cobs (1028.3 kcal/day) and sugarcane tops (1439.6 kcal/day). The metabolizable energy intakes were equivalent to 154.2, 60.4, 38.8 and 86.1 kcal/$kg^{.75}$ per day by sheep on maize stalks, maize cobs, sugarcane and sugarcane tops, respectively. All these ME intakes were different ($P< .05$), with maize stalks having the highest and sugarcane the lowest ME intake.

4.4.3 Comparative average daily energy intake

The gross energy intake (table 15) when corrected and expressed per kg DM of feed intake was 4379.3, 3931.5, 3876.9 and 3885.6 kcal/kg DM intake by sheep fed maize stalks, maize cobs, sugarcane and sugarcane tops, respectively. Maize stalks were higher ($P < .05$) in gross energy intake per kg DM than maize cobs, sugarcane and sugarcane tops. Maize cobs, sugarcane and sugarcane tops GE intake/kg DM were not different ($P > .05$).

The by-products were highly fibrous roughages, consequently all the gross energy intake/kg DM of the by-products was not fully available to the wether sheep. This observation was marked in the digestible energy intake/kg DM of the by-products. The digestible energy intake per kg DM of maize stalks, maize cobs, sugarcane and sugarcane tops was 2798.2, 2149.8, 2276.4 and 2038.9 kcal/kg DM of feed, respectively. The digestible energy intake per kg DM of maize stalks and sugarcane were different ($P < .05$) while there was no difference ($P > .05$) between maize cobs and sugarcane tops. It was therefore possible that much of the gross energy intake per kg DM was lost through gasses of fermentation and undigested plant material in the faeces.

The reduction in the gross energy intake along the gasto-intestinal tract was 36.1, 45.4, 41.5 and 47.8 % in maize stalks, maize cobs, sugarcane and sugarcane tops, respectively. These gross energy losses were less in sheep fed maize stalks compared to those fed maize cobs, sugarcane and sugarcane tops.

TABLE 15· COMPARATIVE AVERAGE DAILY ENERGY INTAKE AND LOSSES BY WETHER SHEEP[1]

I t e m	Experimental diets				Se of treatment mean and significance level	C.V. %
	Maize stalks	Maize cobs	Sugar-cane	Sugar-cane tops		
Gross energy intake, kcal/kg	4379.3[a]	3931.5[b]	3876.9[b]	3885.6[b]	± 64.4***	5.0
Digestible energy, kcal/kg	2798.2[a]	2149.8[b]	2276.4[c]	2038.9[b]	± 71.5***	10.0
Metabolizable energy, kcal/kg	2355.4[a]	1847.2[b]	1706.3[b]	1663.9[b]	± 71.8***	12.0
Energy loss during digestion, %						
Gross energy intake to digestible energy	36.1	45.4	41.5	47.8		
Digestible energy to metabolizable energy	16.0	14.0	25.0	37.0		
Gross energy intake to metabolizable energy	46.0	53.0	56.0	56.5		

*** P < .005

[1]Means represent data from 10 sheep after correcting the daily energy intake to be equivalent to quantity of energy per kilogram of feed, for quantitative comparison.

[a,b,c]Means in same row with different superscripts were significantly different (P< .05).

Metabolizable energy intake per kg DM in maize stalks (2355.4 kcal/kg) was different from maize cobs (1847.2 kcal/kg), sugarcane 1706.3 kcal/kg) and sugarcane tops (1663.9 kcal/kg). However there was no difference ($P > .05$) between ME intake of maize cobs, sugarcane and sugarcane tops.

It was possible to establish that the quality of the by-products was variable in terms of available energy, by comparing the energy losses through fermentation gases and urine. The energy losses between digestible energy and metabolizable energy were 16.0, 14.0, 25.0 and 37.0 % DE by sheep fed maize stalks, maize cobs, sugarcane and sugarcane tops, respectively.

Total energy reduction from gross energy intake to metabolizable energy was 46.0, 53.0, 56.0 and 56.5 % GE intake by sheep fed maize stalks, maize cobs, sugarcane and sugarcane tops, respectively. Faecal, urinal and gaseous energy losses indicated that on average 52.9 % of whole energy intake was not available to the animals for their metabolic activities. Hence about 50.0 % of the gross energy intake of the by-products was lost during the digestion process. The sheep could not derive sufficient energy from these by-products for production purposes. The large energy losses through urine suggested that the sheep lost their body tissues to meet their basic maintenance requirements.

4.5 Predictions of voluntary intake of the by-products by wether sheep.

4.5.1 Prediction of dry matter intake from dry matter digestibility

Voluntary dry matter intake (g DM/$kg^{.75}$/day) regressed over

TABLE 16. REGRESSIONS FOR PREDICTING VOLUNTARY INTAKE (VI) FROM *IN VIVO* DRY MATTER DIGESTIBILITY (DMD) AND ORGANIC MATTER DIGESTIBILITY (OMD)

Item	Correlation Coefficient (r)	Regression	Residual Standard deviation (RSD)
	VI DM $g/kg^{.75}$ from DMD		
Maize stalks	- .51 NS	VI = 92.2 - .4 DMD	± 6.9
Maize cobs	.02 NS	VI = 26.0 + .11 DMD	± 2.9
Sugarcane	.04 NS	VI = 19.5 + .05 DMD	± 5.5
Sugarcane tops	.10 NS	VI = 28.3 + .45 DMD	± 9.9
All feeds combined	.04 NS	VI = 39.8 + .06 DMD	±18.4
	VI OM $g/kg^{.75}$ from OMD		
Maize stalks	.40 NS	VI = 114.1 - .84 OMD	± 5.9
Maize cobs	.20 NS	VI = 24.0 + .12 OMD	± 2.3
Sugarcane	- .01 NS	VI = 23.4 - .02 OMD	± 5.4
Sugarcane tops	.20 NS	VI = 45.5 + .6 OMD	± 7.6
All by-products combined	- .05 NS	VI = 52.8 - .20 OMD	±16.1

NS $P > .05$

apparent dry matter digestibility coefficients (table 16) showed no significant ($P > .05$) linear relationship between them. There was some observable linear relationship, with varied values of residual standard deviations (RSD or Sy.x) for the by-products. The regressions, however failed to establish any significant relationship (correlation and regression coefficients not significant $P > .05$), which indicated that variations in intake of the by-products could not be explained fully by only one factor (apparent digestibility alone).

Dry matter digestibility alone was not successful in predicting voluntary dry matter intake. There were other unexplained factors which along with digestibility contributed towards the observed intakes of the by-products. Factors, such as the physical and chemical properties of the by-products and the physiological status of the animals could have contributed towards the observed intakes. The dry matter intake of maize stalks was negatively correlated to its dry matter digestibility. The rest of the by-products were positively correlated.

In view of these findings, it may be concluded that predictions of dry matter intakes from the dry matter digestibility of the by-products could be erroneous and misleading.

4.5.2. Prediction of organic matter intake from organic matter digestibility

Organic matter intake (g OM/kg $^{.75}$/day) was not significantly ($P > .05$) related to organic matter digestibility of the by-products. Small and not significant ($P > .05$)

correlations were found with these regressions. Maize stalks, sugarcane and all by-products combined were negatively correlated, while sugarcane tops and maize cobs were possitively correlated. Large RSD values (table 16) proved further that the regressions had failed to establish the best fit curve, hence no meaningful predictions of the intakes could be made from this single factor of organic matter digestibility.

4.6 Organic structural components of by-products

Organic structural components of the feeds and faeces are shown in tables 17 and 18, respectively. The analyses showed that a large proportion of these feeds except sugarcane, was composed of neutral detergent fibre (NDF). This implied that the nutritive values of these by-products was largely controlled by the NDF. Sugarcane was largely composed of neutral detergent solubles (NDS).

The NDF of maize stalks (60.9 %), maize cobs (86.7%), and sugarcane tops (63.3%) were higher ($P < .05$) than sugarcane (40.6%). The hemicellulose fractions of maize stalks, maize cobs, sugarcane and sugarcane tops were 24.6, 39.1, 13.1 and 20.2 %, respectively. The cellulose fractions of the by-products were 31.9, 41.8, 22.6, and 38.1 % for maize stalks, maize cobs, sugarcane and sugarcane tops, respectively. The hemicellulose and cellulose are important fractions of plant cell wall that are potentially rich in energy. The high values of hemicellulose and cellulose showed further that the by-products were a potential source of energy to the sheep.

TABLE 17. ORGANIC STRUCTURAL COMPONENTS OF BY-PRODUCTS[1]

Item	Diets			
	Maize stalks	Maize cobs	Sugar-cane	Sugar-cane tops
Composition of dry matter, %				
Neutral detergent fibre (NDF)	60.9	86.7	40.6	63.3
Neutral detergent solubles (NDS)	39.1	13.3	59.4	36.7
Acid detergent fibre (ADF)	36.3	47.6	27.5	43.1
Hemicellulose	24.6	39.1	13.1	20.2
Cellulose	31.9	41.8	22.6	38.1
Acid detergent lignin (ADL)	4.4	5.8	4.9	5.0

[1]Means represent data from 6 replicate samples.

TABLE 18. ORGANIC STRUCTURAL COMPONENTS OF FAECES[1]

Item	Faeces			
	Maize stalks	Maize cobs	Sugar-cane	Sugar-cane tops
Composition of dry matter, %				
Neutral detergent fibre (NDF)	60.1	70.8	73.9	66.0
Neutral detergent solubles (NDS)	39.9	29.2	26.1	34.0
Acid detergent fibre (ADF)	40.4	41.1	49.9	47.8
Hemicellulose	19.7	29.7	24.0	18.2
Cellulose	32.8	28.7	39.4	40.6
Acid detergent lignin (ADL)	7.6	12.4	10.5	7.2

[1]Means represent data from thirty replicate samples.

The ADF of maize stalks (36.3 %), maize cobs (47.6 %) and sugarcane tops (43.1 %) were different ($P< .05$) from sugarcane (27.5 %). All by-products were highly lignified, with acid detergent lignin (ADL) values ranging from 4.4 to 5.8 %. ADL of maize cobs (5.8 %) and sugarcane tops (5.0 %) were higher ($P< .05$) than maize stalks (4.4 %) and sugarcane (4.9 %).

Neutral detergent solubles (NDS) is the only cell fraction of the plant which is unaffected by lignin. The variations noted in the *in vivo* dry and organic matter digestibility of nutrients in maize stalks, maize cobs and sugarcane tops diets could be attributed to the large NDF while in sugarcane diet to the NDS fraction. Lignin could have depressed the digestibility of maize stalks, maize cobs and sugarcane tops. Sugarcane diet digestibility must have been least affected by the lignin due to the presence of high NDS contents.

Faeces of wether sheep fed these by-products were similarly composed of large NDF. The NDF concentration was higher ($P< .05$) in sugarcane (73.9 %) and maize cobs (70.8 %) than in maize stalks (60.1 %) and sugarcane tops (66.0 %). This suggested that much of the NDF in sugarcane and maize cobs was highly indigestible. The cellulose fraction of the NDF appeared to be least affected during digestion in all by-products except in maize cobs. The faecal cellulose concentrations in maize stalks, maize cobs, sugarcane and sugarcane tops were 32.8, 28.7, 39.4 and 40.6 %, respectively. The hemicellulose fraction in faeces of sheep fed maize stalks, maize cobs, sugarcane and sugarcane tops were 19.7, 29.7, 24.0 and 18.2 %, respectively.

TABLE 19. SUMMATIVE AVERAGE DRY MATTER DIGESTION OF THE NEUTRAL DETERGENT FIBRE (NDF) AND NEUTRAL DETERGENT SOLUBLES (NDS)

Diet	Organic structural component % digestibility		Dry matter digestibility %
	NDF	NDS	
Maize stalks	39.0	24.7	63.7[a]
Maize cobs	54.6	3.6	58.2[a]
Sugarcane	11.6	49.4	61.0[a]
Sugarcane tops	32.8	21.6	54.4[b]

CV = 6.0 % Se of treatment mean = ± 1.2 %

[a,b]Means in same column with different superscripts were significantly different (P< .05).

The faecal ADF was 40.4, 41.1, 49.9 and 47.8 % for maize stalks, maize cobs, sugarcane and sugarcane tops, respectively. The faecal ADL subsequently increased in the faeces. The faecal ADL was 7.6, 12.4, 10.5, and 7.2 % in maize stalks, maize cobs, sugarcane and sugarcane tops, respectively.

4.6.1 Estimation of dry matter digestibility by Van Soest procedure

Dry matter digestibility was estimated using Van Soest (1967) procedures. The results (table 19) agreed with those in the *in vivo* digestibility. The dry matter digestibility of maize stalks (63.7%), maize cobs (58.2%) and sugarcane (61.0%) were not differept ($P > .05$). The digestibility of sugarcane tops (54.4%) was lower ($P < .05$) than the rest of the by-products.

The objective of this analysis was to fractionate the DM digestibility of the by-products into their respective organic structural components in order to determine what proportion of the plant cell material (NDF and NDS) contributed to the observed *in vivo* digestibility coefficients. It was possible to show that the DM digestibility of maize stalks, maize cobs and sugarcane tops was largely attributable to the NDF fraction while that of sugarcane was due to its NDS fraction.

4.6.2 Prediction of *in vivo* dry matter digestibility from summative Van Soest dry matter digestion

The regressions of *in vivo* dry matter digestibility over Van Soest dry matter digestibility (table 20) were linear and

TABLE 20· REGRESSIONS RELATING DRY MATTER DIGESTIBILITY BY VAN SOEST PROCEDURE (VDMD) TO *in vivo* DRY MATTER DIGESTIBILITY (DMD)

Diet	Correlation coefficient (r)	Regression	Residual standard deviation (RSD)
Maize stalks	.97***	DMD = 2.0+ .97VDMD	± .7
Maize cobs	.30*	DMD = 43.9+ .28 VDMD	± 3.3
Sugarcane	.99***	DMD = .41+ .99VDMD	± .4
Sugarcane tops	.74***	DMD = 26.1+ .57VDMD	± 1.3
All by-products combined	.97***	DMD = 2.8+ .96VDMD	± 1.1

* P< .05 ***P<.001

significant, in maize stalks ($P < .001$, $r = .97$, RSD = ± .7), maize cobs ($P < .05$, $r = .3$ and RSD = ±3.3), sugarcane ($P < .001$, $r = .99$ and RSD = ± .4), sugarcane tops ($P < .001$, $r = .74$ and RSD = ±1.3) and all by-products combined ($P < .001$, $r = .97$ and RSD = ±1.1). The significant correlations and low RSD values confirmed that *in vivo* DMD could be estimated accurately from Summative Van Soest DMD Values.

4.6.3 Prediction of dry matter digestibility from separate organic structural components

The regression coefficients and correlation coefficients (table 21) were negative in all equations where the organic component factor determinations were NDF, ADF and ADL but positive for NDS. The relationships between DMD and organic structural components, though linear, were not significant ($P > .05$).

It was observed (figure 1) that NDF, ADF and ADL were negatively correlated to dry matter digestibility. It was concluded that dry matter digestibility (DMD) of the by-products declined with increasing NDF, ADF and ADL. The decline in DMD was more gradual with increasing NDF and ADF than ADL. There was a positive correlation between NDS and DMD, which indicated that the DMD of the roughages increased with increasing NDS. This observation was applicable particularly in sugarcane diet.

The low and not significant ($P > .05$) correlations and large RSD values confirmed that organic structural components could not be applied separately to predict the DMD accurately.

TABLE 21. REGRESSION RELATING *IN VIVO* DRY MATTER DIGESTIBILITY (DMD) AND ORGANIC MATTER DIGESTIBILITY (OMD) TO NEUTRAL DETERGENT FIBRE (NDF), NEUTRAL DETERGENT SOLUBLES (NDS), ACID DETERGENT FIBRE (ADF) AND ACID DETERGENT LIGNIN (ADL).

Prediction	Correlation coefficient (r)	Regression	RSD
DMD - All feeds combined			
	- .12 NS	DMD = 61.6 - .03 NDF	± 4.8
	+ .04 NS	DMD = 59.4 + .01 NDS	± 4.9
	- .38 NS	DMD = 66.3 - .17 ADF	± 4.5
	- .56 NS	DMD = 88.5 - 5.88 ADL	± 4.0
OMD - All feeds combined			
	- .31 NS	OMD = 64.65 - .06 NDF	± 4.0
	+ .15 NS	OMD = 59.60 + .04 NDS	± 4.1
	- .57 NS	OMD = 69.34 - .22 ADF	± 3.4
	- .51 NS	OMD = 84.7 - 4.86 ADL	± 3.5

NS P >.05

Fig. 1. Regressions of *in vivo* DMD on NDF, NDS, ADF and ADL

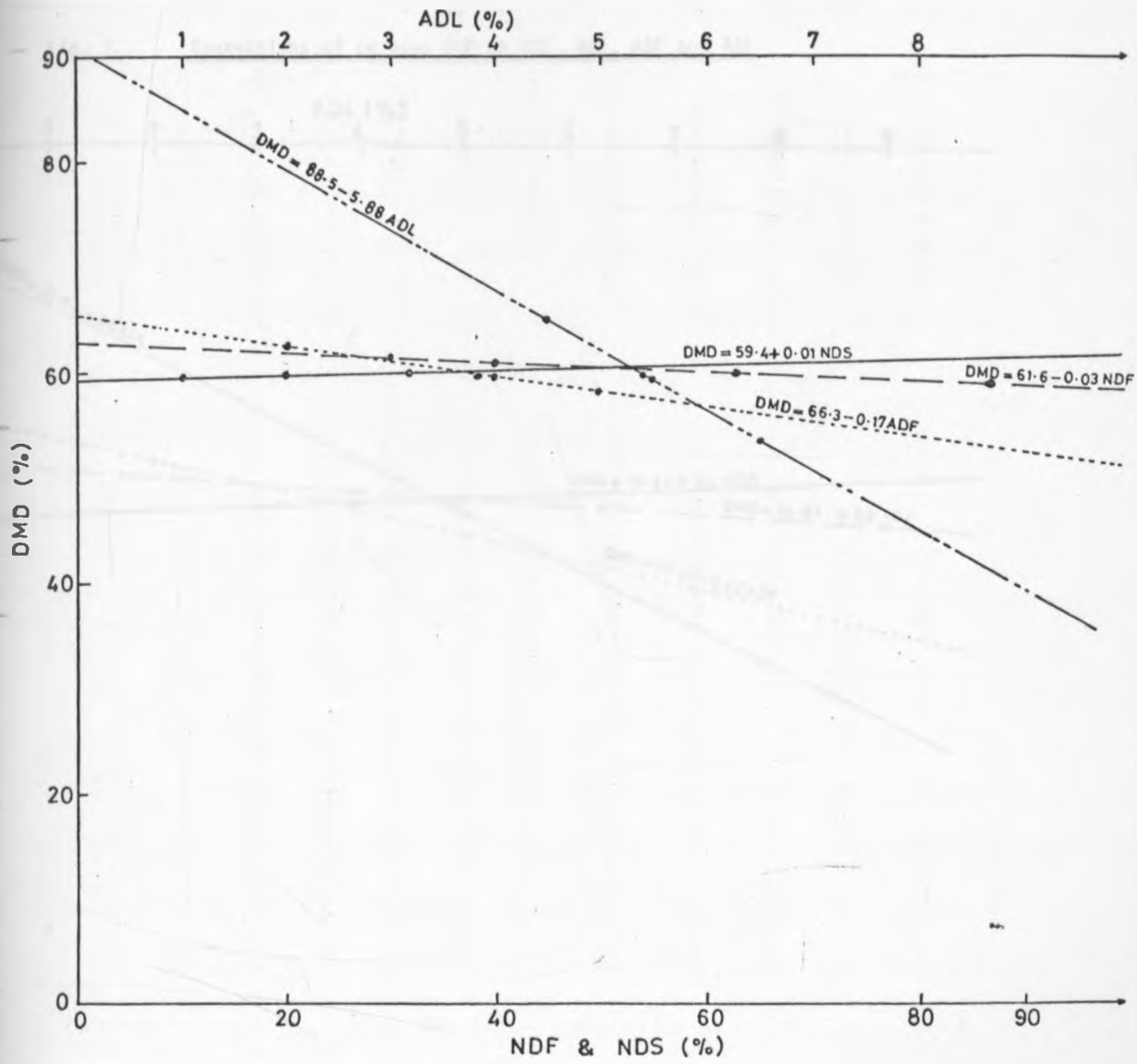
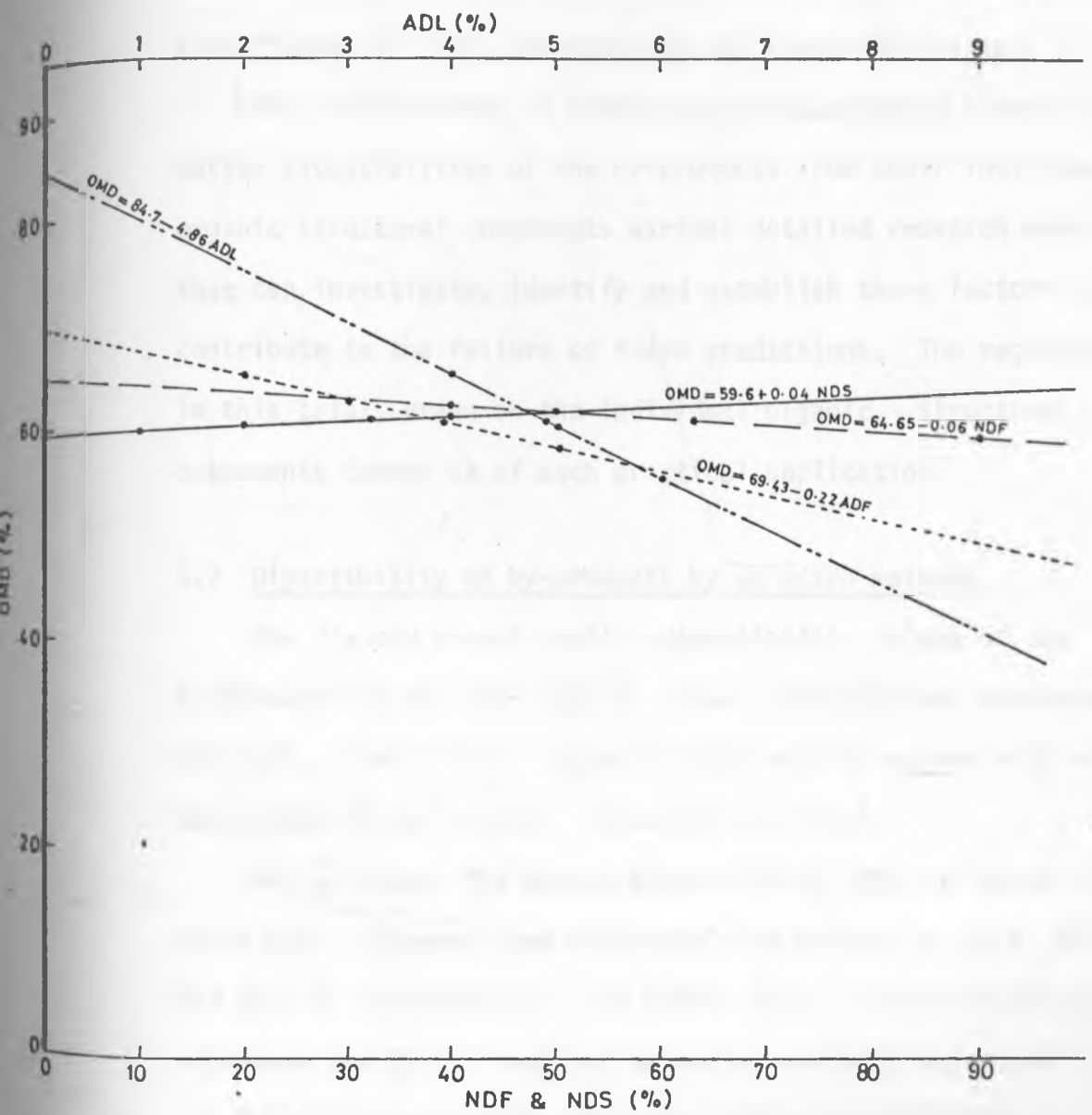


Fig. 2. Regressions of *in vivo* OMD on NDF, NDS, ADF and ADL



4.6.4 Prediction of organic matter digestibility from separate organic structural components

A similar trend as established for DMD was also observed in the results of predicting the OMD from NDF, NDS, ADF and ADL (table 21 and figure 2). None of these organic structural components was found suitable in predicting OMD (Low and not significant, P > .05, correlations and large RSD values).

The shortcomings in predecting *in vivo* dry and organic matter digestibilites of the by-products from their individual organic structural components warrant detailed research work that can investigate, identify and establish those factors which contribute to the failure of these predictions. The regressions in this trial, drawn on the individual organic structural components cannot be of much practical application.

4.7 Digestibility of by-products by *in vitro* methods

The dry and organic matter digestibility values of the by-products by the two-stage *in vitro* procedure are presented in table 22. The *in vitro* digestibility results agreed with values determined in the *in vivo* digestibility trial.

The *in vitro* dry matter digestibility (DMD) of maize stalks, maize cobs, sugarcane and sugarcane tops were 66.5, 58.8, 65.9 and 54.0 %, respectively. Dry matter digestibility in derinded sugarcane was 82.5 % compared to whole undrinded sugarcane (65.9 %). The rind with a mean dry matter digestibility of 40.9 % had a depressing effect on the dry matter digestibility of whole underinded sugarcane diet.

TABLE 22. TWO-STAGE *IN VITRO* DIGESTIBILITY OF THE BY-PRODUCTS[1]

Experimental Diets	*In Vitro* digestibility		
	DDM %	OMD %	OMDDM (D-Value) %
Maize stalks	66.5	64.8	60.1
Maize cobs	58.8	58.3	57.3
Sugarcane (Rind and pith)[2]	65.9	65.1	63.3
Sugarcane rind	40.9	38.3	36.1
Sugarcane pith	82.5	82.5	79.5
Sugarcane tops	54.0	52.9	47.7

[1]Means represent data from six replicate samples.

[2]Results on sugarcane rind and pith were separately included in the table to contrast the various factors that affect the digestibility of whole sugarcane diet (rind and pith together).

Organic matter digestibility on organic matter basis (OMD) were 64.8, 58.3, 65.1 and 52.9 % in maize stalks, maize cobs, sugarcane and sugarcane tops, respectively. There was little difference observed between OMD and organic matter digestibility on dry matter basis (OMDDM normally refered to as D-value). The OMDDM of maize stalks, maize cobs, sugarcane and sugarcane tops were 60.1, 57.3, 63.3 and 47.7 %, respectively.

The low OMD compared to DMD values were attributed to the ash contents of the by-products. The effect was more pronounced in sugarcane tops diet than in any of the other three by-products.

The depressing effect of the rind on the organic matter digestibility of whole underinded sugarcane diet was still conspicuous, although the organic matter digestibility of underinded sugarcane was higher ($P< .05$) than that of maize stalks, maize cobs and sugarcane tops. Sugarcane pith DMD (82.5 %), OMD (82.5 %) and OMDDM (79.5 %) was more digestible than any of the by-products.

OMD and OMDDM of the by-products were similar to their respective *in vivo* organic matter digestibility values.

4.7.1 Prediction of *in vivo* dry and organic matter digestibility from *in vitro* dry and organic matter digestibility

In vitro digestibility values regressed against *in vivo* digestibility values (table 23) gave significant ($P< .05$) linear relationships.

In vivo DMD predicted from *in vitro* DMD gave a linear relationship and was significant ($r = .91$, $P< .05$) with small RSD value (RSD = ±2.0). Minson (1971) reported similar

TABLE 23. REGRESSIONS OF *IN VIVO* DRY MATTER DIGESTIBILITY (DMD) AND ORGANIC MATTER DIGESTIBILITY (OMD) ON *IN VITRO* DRY MATTER DIGESTIBILITY (IDMD) AND ORGANIC MATTER DIGESTIBILITY (IOMDOM AND IOMDDM)

Prediction	Correlation coefficient (r)	Regression	Residual standard deviation (RSD)
In vivo dry matter digestibility			
DMD	.91*	DMD = 22.95 + .6 IDMD	± 2.0
DMD	.91*	DMD = 22.36 + .62IOMD	± 2.0
DMD	.87*	DMD = 30.61 + .511OMDDM	± 2.4
In vivo organic matter digestibility			
OMD	.97*	OMD = 27.16 + .55 IDMD	± 1.0
OMD	.98*	OMD = 26.52 + .57 IOMD	± .9
OMD	.95*	OMD = 33.47 + .48 IOMDDM	± 1.3

* Probability between .05 and .01

digestibility RSD units (RSD = ±2.0) in pasture. The DMD prediction from *in vitro* OMD was the same as that from DMD. The prediction from OMDDM was not as satisfactory as was with *in vitro* DMD and OMD (RSD = ±2.4, r = .87 and P< .05).

In vivo OMD was also predicted from *in vitro* DMD, OMD and OMDDM. The regression of *in vivo* OMD on *in vitro* DMD was significant (r = .97, P< .05 and RSD = ±1.0). The same findings were obtained with OMD (r = .98, P< .05 and RSD =± .9) and OMDDM (r = .95, P< .05 and RSD = ±1.3).

It was concluded that *in vivo* DMD and OMD of the by-products could be predicted from their corresponding *in vitro* DMD, OMD and OMDDM. Digestibility coefficients obtained in the *in vivo* trial and the comparisons made on them through these regressions confirm their reliability. This factor was explained by the observed minimal variations in the *in vivo* digestibility coefficients. The unexplained variations in the *in vivo* apparent digestibility were fully accounted for by the *in vitro* data in the regression analyses (large R^2 and significant correlations).

Theoretically, *in vitro* DMD corresponds to *in vivo* DMD (within limits of digestibility units) and OMDDM to *in vivo* OMD. This was also confirmed by the results of this trial on the by-products.

4.7.2 The rate of *in vitro* dry and organic matter disappearance

The objective of this trial was to study the rate of digestion of each by-product with time of incubation. In all the *in vitro* DMD, OMD and OMDDM determinations, it was established that sugarcane was easily digested in the initial hours of incubation in the rumen liquor, followed by sugarcane tops, maize stalks and maize cobs.

Rate of dry matter disappearance is shown in figure 3a. After 12 hours of rumen liquor incubation and 48 hours acid-pepsin digestion, sugarcane attained 50.3 % DMD while maize stalks, maize cobs and sugarcane tops reached 34.9, 19.2 and 32.1 % DMD, respectively. At 96 hours (48 hours incubation in rumen liquor and 48 hours acid-pepsin digestion), maize stalks, maize cobs, sugarcane and sugarcane tops reached 66.1, 54.4, 66.2 and 53.9 % DMD, respectively. At 120 hours (72 hours incubation in rumen liquor and 48 hours acid-pepsin digestion), all by-products reached a ceiling and levelled off in dry matter digestibility. Rate of organic matter disappearance (figures 4 a and 5 a) followed similar trend as observed in dry matter disappearance.

Regressions of DMD, OMDOM and OMDDM on time of incubation (table 24 and figures 3b, 4b and 5b) indicated, that despite the rapid digestibility of sugarcane initially, the same rate of digestion was not maintained throughout the digestion period. On the other hand, maize stalks and maize cobs, whose initial digestibility was lower than sugarcane, were digested at an increasing rate until eventually digestion was the same level with sugarcane. Rate of digestion in sugarcane tops was similar to that of sugarcane. However, its digestion progressed at a decreasing rate such that by 120 hours, sugarcane tops digestion value was much lower than the rest of the by-products.

The significant and linear relationships between dry and organic matter digestibility and time (table 24) suggested that the digestion of the by-products was heavily dependent on time of incubation in the rumen liquor. It is possible to conclude from these observations that time of incubation of these by-products in the digestion media was an important factor that deserves due consideration.

Fig. 3a. Rate of *in vitro* DM disappearance.

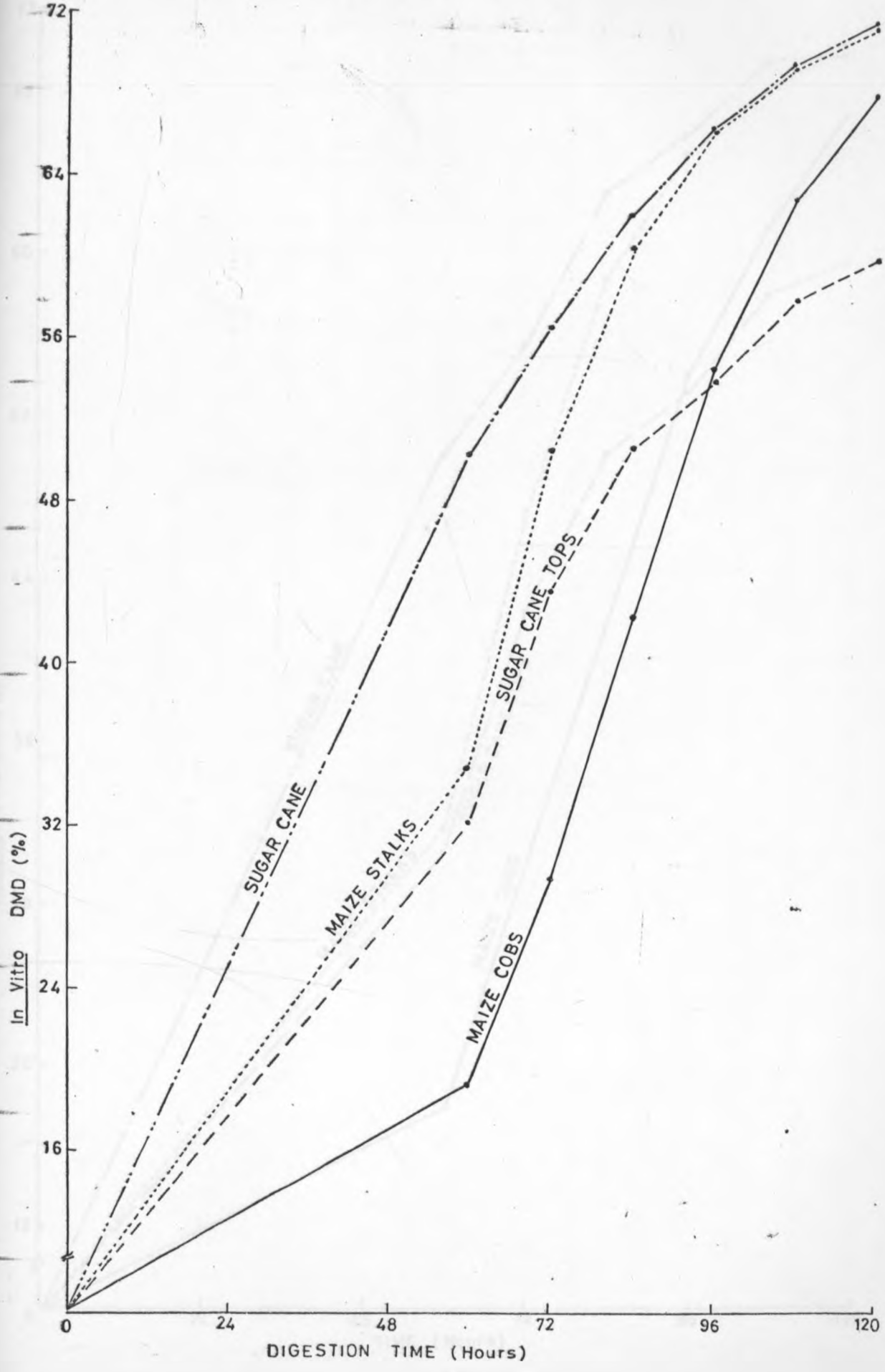


Fig. 4a. Rate of *in vitro* OM disappearance

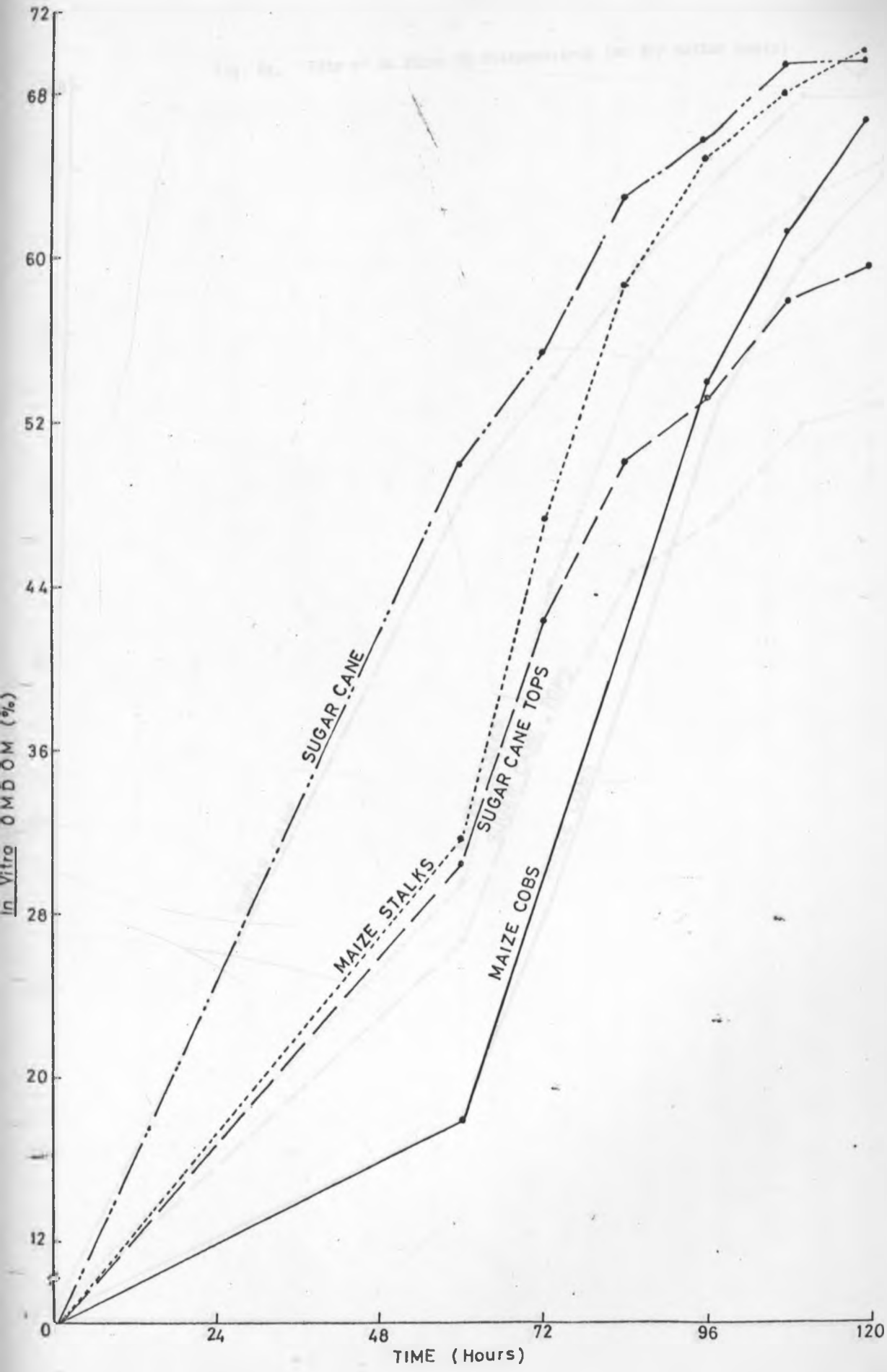


Fig. 5a. Rate of *in vitro* OM disappearance (on dry matter basis)

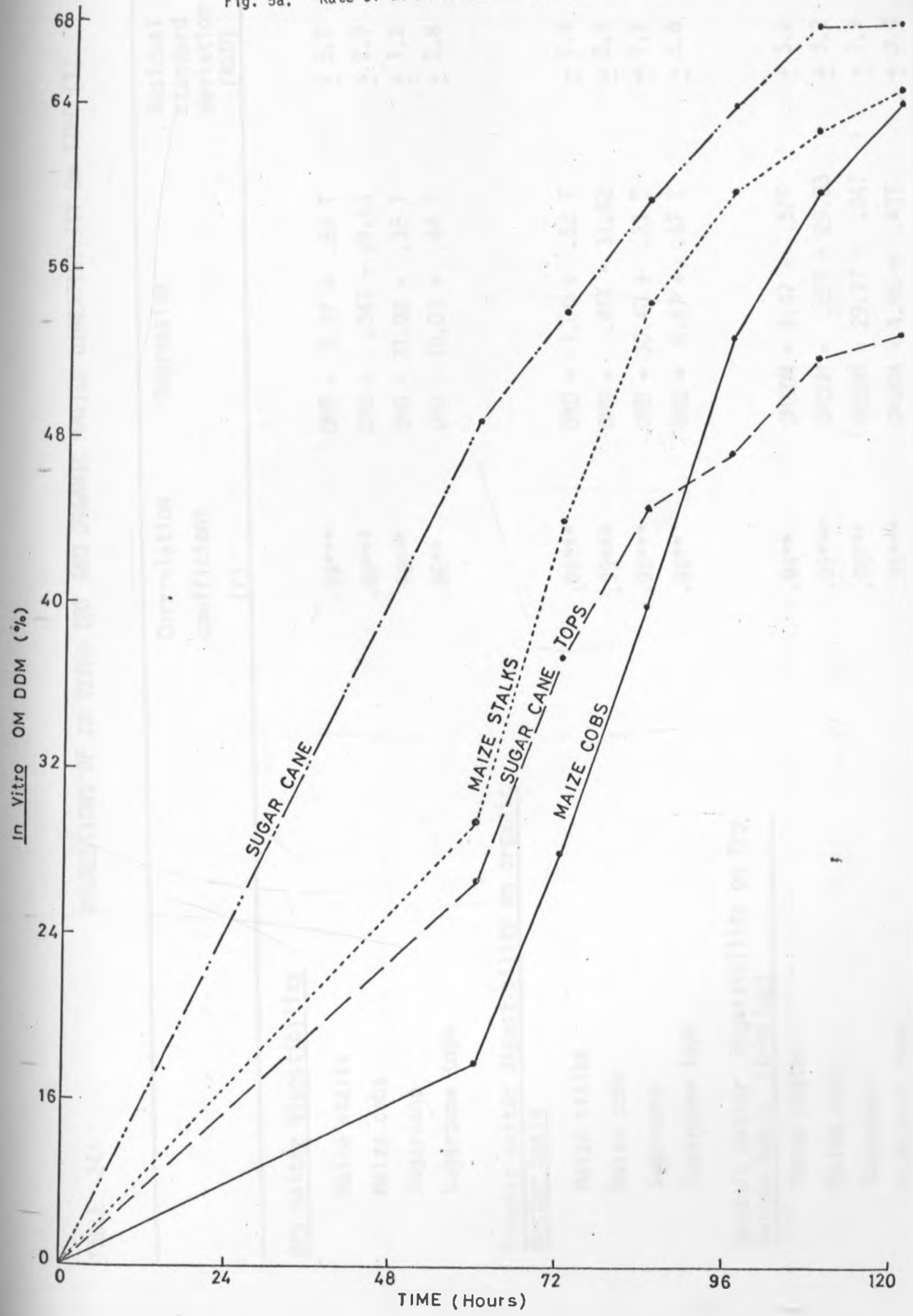


TABLE 24· REGRESSIONS OF *IN VITRO* DRY AND ORGANIC MATTER DIGESTIBILITY ON TIME (T)

	Corrrelation coefficient (r)	Regression	Residual standard deviation (RSD)
Dry matter digestibility			
Maize stalks	.94***	DMD = 5.47 + .59 T	± 5.2
Maize cobs	.99***	DMD = .84T - 29.63	± 2.9
Sugarcane	.98**	DMD = 31.08 + .35 T	± 1.2
Sugarcane tops	.96**	DMD = 10.03 + .44 T	± 2.8
Organic matter digestibility on organic matter basis			
Maize stalks	.94***	OMD = 1.05 + .62 T	± 5.5
Maize cobs	.99***	OMD = .85T - 31.62	± 2.9
Sugarcane	.98***	OMD = 30.40 + .35 T	± 1.9
Sugarcane tops	.96**	OMD = 6.67 + .47 T	± 3.6
Organic matter digestibility on Dry matter basis (D-value)			
Maize stalks	.94**	OMDDM = 1.47 + .57T	± 5.2
Maize cobs	.99***	OMDDM = .82T - 29.83	± 3.2
Sugarcane	.98***	OMDDM = 29.97 + .34T	± 1.9
Sugarcane tops	.95***	OMDDM = 4.95 + .43T	± 3.4

** P< .01 *** P< .001

Fig. 3b. Regressions of DMD on time

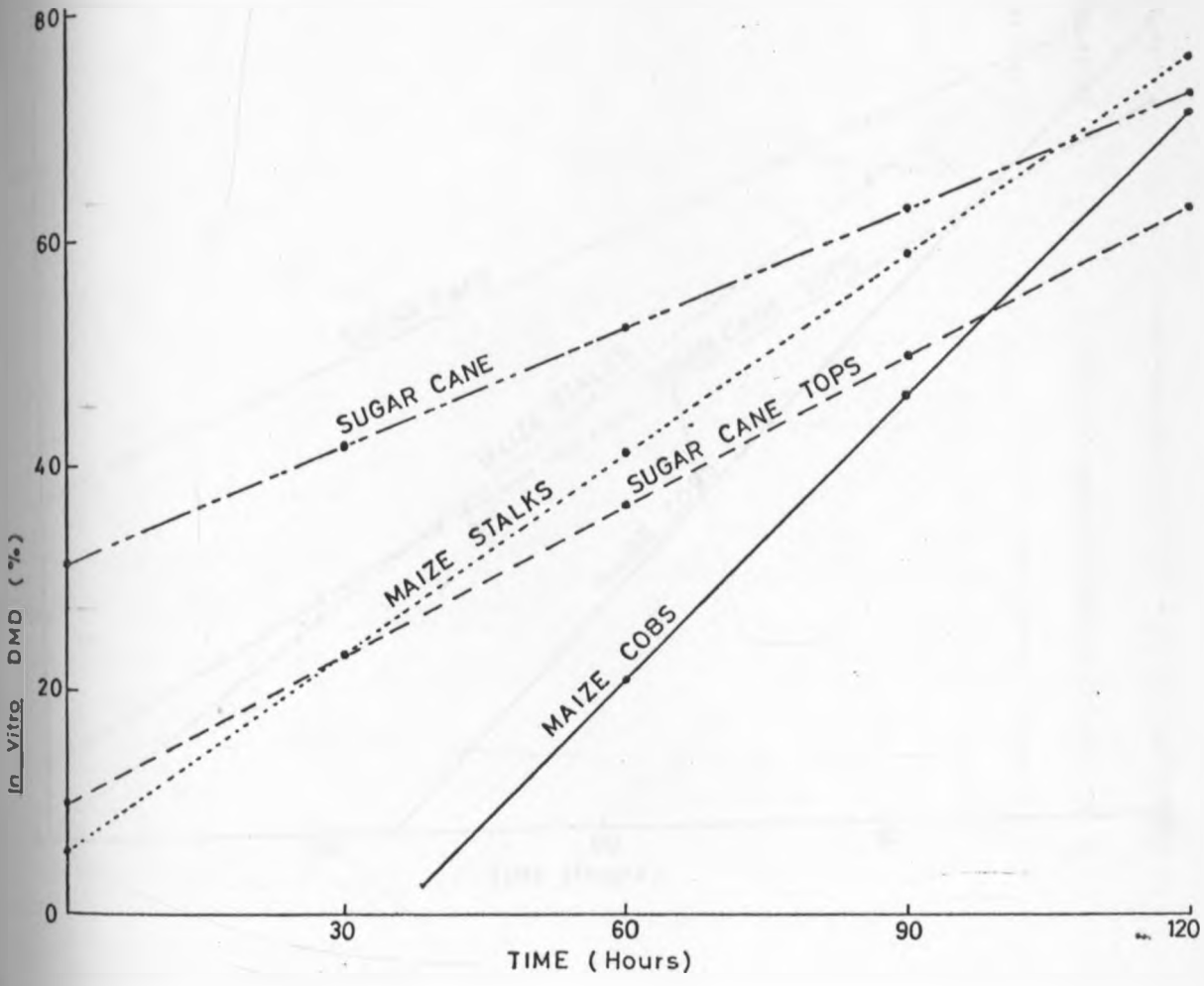


Fig. 4b. Regressions of OMDOM on Time.

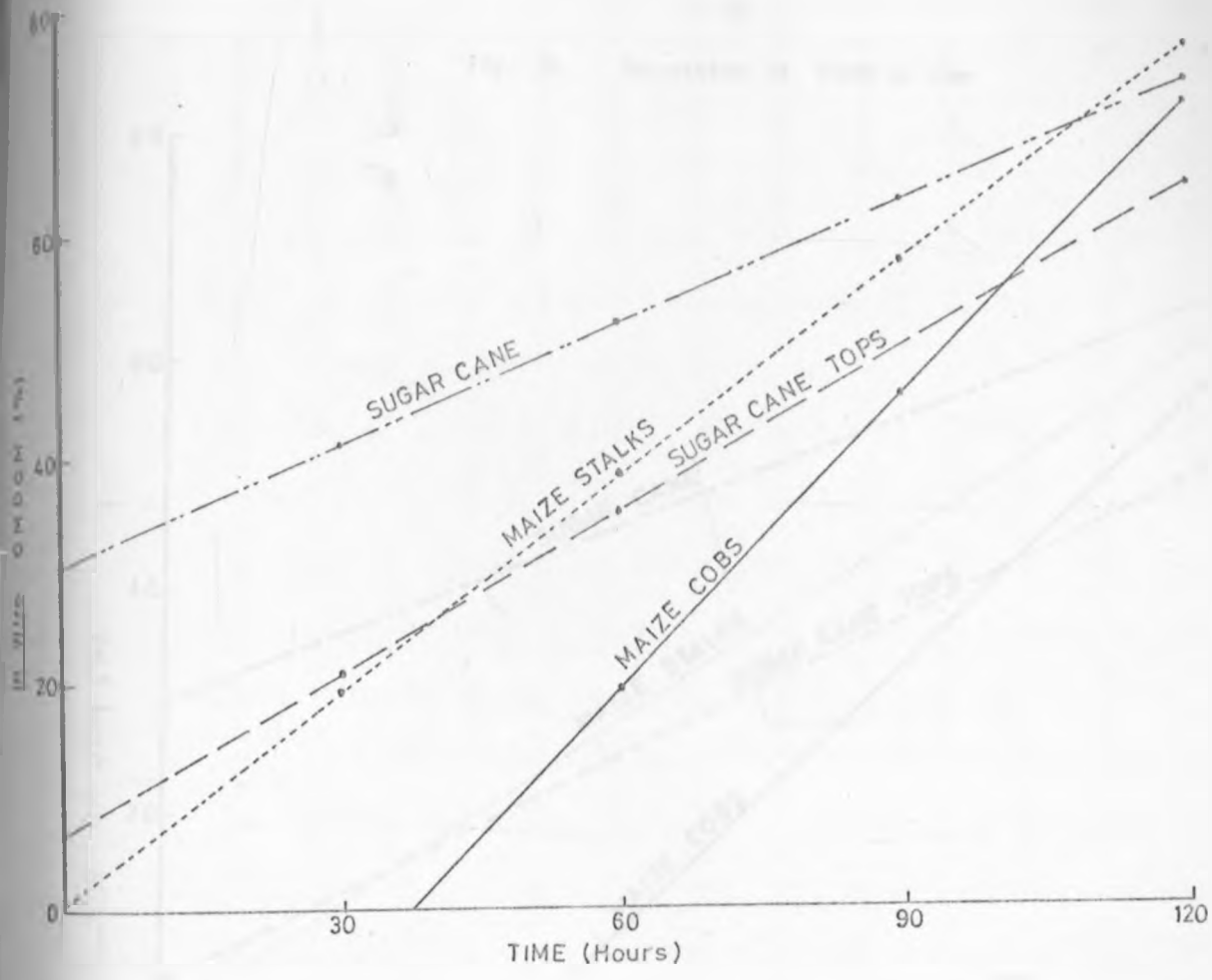
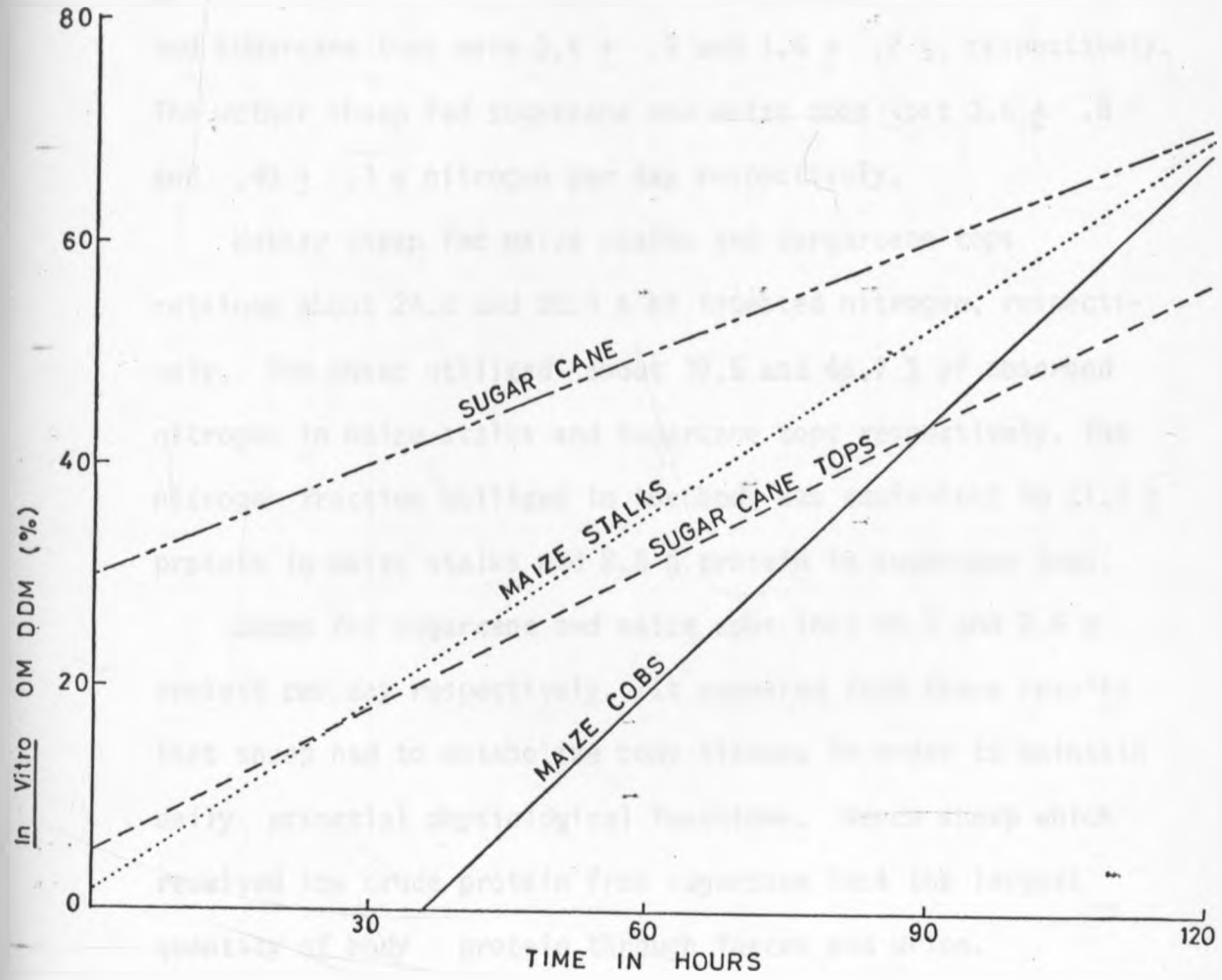


Fig. 5b. Regressions of OMDDM on time



4.8 Nitrogen retention by wether sheep

Nitrogen retention results are summarized in table 25. Sheep fed maize stalks and sugarcane tops were in positive nitrogen balance while those on sugarcane and maize cobs diets were in negative nitrogen balance.

Mean daily nitrogen retentions by sheep fed maize stalks and sugarcane tops were 3.4 ± .5 and 1.4 ± .2 g, respectively. The wether sheep fed sugarcane and maize cobs lost 3.6 ± .8 and .40 ± .3 g nitrogen per day respectively.

Wether sheep fed maize stalks and surgarcane tops retained about 24.8 and 20.3 % of ingested nitrogen, respectively. The sheep utilized about 39.5 and 46.7 % of absorbed nitrogen in maize stalks and sugarcane tops respectively. The nitrogen fraction utilized in the body was equivalent to 21.3 g protein in maize stalks and 8.8 g protein in sugarcane tops.

Sheep fed sugarcane and maize cobs lost 22.5 and 2.5 g protein per day respectively. It appeared from these results that sheep had to metabolize body tissues in order to maintain daily essential physiological functions. Hence sheep which received low crude protein from sugarcane lost the largest quantity of body protein through faeces and urine.

Wethers fed maize cobs lost less body protein than those on sugarcane. The limiting nitrogen quantity in maize cobs was corrected by the associative increase in total crude protein from *Chloris gayana* hay (CP = 10.5 %) which was used in indirect digestibility determination.

TABLE 25. AVERAGE DAILY NITROGEN RETENTION PER SHEEP[1]

	Experimental Diets			
	Maize stalks	Maize cobs	Sugarcane	Sugarcane tops
Nitrogen intake, g/day	13.7	2.6	1.2	6.9
Faecal nitrogen, g/day	5.1	2.1	1.5	3.9
Absorbed nitrogen, g/day	8.6	.5	- .3	3.0
Urinary nitrogen, g/day	5.2	.9	3.3	1.6
Retained nitrogen, g/day	+3.4 ± .5	- .4 ± .3	-3.6 ± .8	+1.4 ± .2
Retained nitrogen, % of intake	24.8	-15.0	-300.0	20.3
Retained nitrogen, % absorbed	39.5	-	-	46.7
Protein gained or lost, g/day	+21.3	- 2.5	- 22.5	+ 8.8

[1]Means represent data from 10 sheep.

4.9 Mineral retention by wether sheep

Mineral retention results are presented in table 26. The sheep were in positive balance for calcium and potassium but negative for phosphorus for all by-products. There was negative sodium balance in those sheep fed maize stalks, sugarcane and maize cobs. Wethers fed sugarcane tops were in positive sodium balance.

Calcium retention by sheep, was + 1.44 ± .1, + .54 ± .22, + .56 ± .1 and + .78 ± .08 g, when fed maize stalks, maize cobs, sugarcane and sugarcane tops, respectively.

Potassium retentions by wether sheep fed maize stalks, maize cobs, sugarcane and sugarcane tops were + 9.27 ± 1.24, + .09 ± .26, + 5.77 ± .75 and + 8.48 ± 1.0 g, respectively.

Wether sheep were in negative phosphorus balance of - 1.5 ± .25, - .44 ± .10, - 1.28 ± .26 and - .20 ± .14 g when fed maize stalks, maize cobs, sugarcane and sugarcane tops, respectively. The sheep fed maize stalks and sugarcane showed a higher negative phosphorus balance compared to those fed maize cobs and sugarcane tops.

The results indicated positive sodium retention of + .16 ± .04 g in sheep fed sugarcane tops while sheep fed maize stalks, maize cobs and sugarcane were in the negative balance of - .17 ± .04, - 2.11 ± .53 and - 4.87 ± 1.20 g, respectively.

A negative phosphorus balance relative to a positive calcium balance in the sheep could have off-set the calcium/phosphorus ratio. This effect may cause imbalances in the

TABLE 26. AVERAGE DAILY MINERAL RETENTION PER SHEEP[1]

Treatments	Nutrients	Nutrient Intake (gm)	Excretion		Total Excretion (gm)	Balances (gm)	Se of treatment mean
			Faeces (gm)	Urine (gm)			
MS[2]	Ca	1.83	.37	.02	.39	+ 1.44	± .10
	P	.87	2.32	.06	2.38	- 1.51	± .25
	Na	.38	.38	.17	.55	- .17	± .04
	K	20.16	1.73	9.16	10.89	+ 9.27	± 1.24
MC	Ca	1.31	.63	.14	.77	+ .54	± .22
	P	.65	1.08	1.01	1.09	- .44	± .10
	Na	.23	2.32	.02	2.34	- 2.11	± .53
	K	6.79	3.10	3.60	6.70	+ .09	± .26
SC	Ca	.93	.29	.08	.37	+ .56	± .10
	P	.66	1.15	.79	1.94	- 1.28	± .26
	Na	.08	4.82	.13	4.95	- 4.87	± 1.20
	K	9.68	1.12	2.79	3.91	+ 5.77	± .75
S C T	Ca	1.29	.48	.03	.51	+ .78	± .08
	P	3.90	4.07	.03	4.10	- .20	± .14
	Na	.43	.24	.03	.27	+ .16	± .04
	K	21.40	3.50	9.42	12.92	+ 8.48	± 1.00

[1]Means respresent data from 10 sheep. [2]MS = Maize stalks MC = Maize cobs SC = sugarcane SCT = Sugarcane tops

utilization of the minerals. The same effect applies to sodium and potassium which require a definite ratio for efficient utilization by the animals.

CHAPTER 5

DISCUSSION

5.0 Chemical Composition

Chemical analysis of the by-products indicated that the feeds were characterized by high crude fibre and low crude protein contents. Crude protein contents were below 7.0 % for all by-products except maize stalks (8.5 % CP). Intake is largely controlled by crude protein content. Milford and Minson (1965 a) and Milford and Haydock (1965 b) found 7.0 % CP to be the critical value below which intake declines significantly.

The low crude protein contents of these by-products partly explained some of the variations which caused the observed voluntary intakes of the diets by wether sheep. The high crude fibre contents of maize stalks, maize cobs and sugarcane tops were in close agreement with their respective neutral detergent fibre (NDF) values. It was possible that the available digestible nutrients of these by-products were heavily dependant on the NDF fraction except in sugarcane. Neutral detergent solubles (NDS) of sugarcane contributed largely towards the digestible nutrients of this diet.

The marked high lignocellulose contents of these by-products could have a depressing effect on the digestibility of the feeds. Higher ash contents of maize stalks and sugarcane tops than those of sugarcane and maize cobs were directly related to the mineral retentions by the wether sheep.

The highly pronounced faecal NDF, particularly in sugarcane was a notable factor that was attributed to the indigestible portion of the rind. Most of the rind remained intact throughout digestion, as was observed in the *in vitro* digestibility. The marked high faecal NDS fraction similarly implied that the sheep had much of their faecal wastes composed of mainly endogenous excretion from the intestinal mucosa, spent enzymes and microflora residues (Van Soest *et al.*, 1966).

5.1 Voluntary intakes

Voluntary intake of any feed is a more important factor than digestibility in determining the quality of feeds. In these studies, voluntary intake measurement was a better determinant of nutritive value of the by-products.

According to Brody (1945) and Milford and Minson (1966), intake was one single factor in determining the feeding value of forages, hence an excellent index for assessing the productive potential by animals.

The intake of maize stalks was found equivalent to any other green fodder. The stems of maize stalks are composed of largely soluble carbohydrates, mainly in the form of sugars. This factor combined with the crude protein (8.5 %), enhanced the highest intake of the maize stalks, as compared to the other by-products, where CP contents were maize cobs (2.0 %), sugarcane (2.4 %) and sugarcane tops (4.7%). The low intakes of maize cobs

and sugarcane might have largely been caused by their low crude protein contents. It was concluded that crude protein was the major limiting factor in the voluntary intake of the by-products.

On the other hand, there would have been factors (Van Soest, 1965 b) other than crude protein, that might have contributed towards the observed low feed intakes. There are indications by Halley and Dougall (1962), that crude fibre plays a role in intake. Maximum levels of feed consumption is associated with a low crude fibre content in addition to a high dry matter content. If this proposition was true, then the intake of the by-products should not have varied greatly, due to the fact that all the by-products contained more-or-less equal crude fibre contents. The marked large differences in DM intakes of maize stalks and sugarcane tops than DM intake of maize cobs and sugarcane tended not to agree with the proposition.

The filling effect of roughages in the reticulo-rumen appeared to be one of the possible explanation to the observed differences in the feed intakes. The contents of the reticulo-rumen exert a direct effect on the voluntary intake of dry matter, whereby there exists an inverse relationship between voluntary intake and dry matter (Campling and Balch, 1961 a; Campling *et al.*, 1961 b). All the by-products studied, could have exerted a filling effect to the reticulo-rumen, due to their bulkiness thus inducing a depressing effect on intake.

The depression in intake may not be associated with exhaustion of the salivary glands or muscles of the jaw. Dodsworth and Campbell (1953) established that these factors were not functional, hence the constant distention of the digestive tracts of the

wether sheep at the end of each meal should have had significant effect on the observed intakes. This conclusion was in full agreement with work by Blaxter *et al.* (1960) and Blaxter *et al.* (1961).

There is usually a slower breakdown of high fibre roughages by the microorganisms in the rumen before optimum particle size is obtained for passage from the rumen. This process enhances a slower digestibility and concurrently a longer retention meantime of the residues in the rumen. Retention time of the residues in the rumen may have been another factor that contributed towards the intakes of the by-products.

Intake is inversely related to retention time (Campling and Freer, 1962 a; Campling *et al.*, 1962 b; Freer, *et al.*, 1962; Freer and Campling, 1963) hence the intake of maize stalks and sugarcane tops could have been associated with shorter mean retention time due to their high leaf to stem ratio. Different plant fractions are eaten in different proportions. Laredo and Minson (1973) found a higher intake of leaf than stem due to shorter retention time of leaf dry matter in the reticulo-rumen.

Higher dry matter intake of both maize stalks and sugarcane tops than that of maize cobs and sugarcane led to improved organic matter intake by the ruminants. This implied that available nutrients from maize stalks and sugarcane tops contributed greatly to the observed performance of the wether sheep. The DM intake of maize stalks (2.6 % body liveweight) and sugarcane tops (2.0 % body liveweight) were higher ($P < .05$) compared to sugarcane (1.0 % body liveweight) and

maize cobs (1.3 % body liveweight). The sheep performed well on maize stalks compared to the rest of the by-products, a fact which among other factors was accounted for by their respective protein contents.

The differences observed in the performance of the wether sheep were consequently caused by the varying DM intakes of the by-products. The observed intake of sugarcane was in addition caused by the moisture content of the diet (sugarcane diet was fed at 30.0 % DM). Large moisture contents of diets inhibit intake.

The sheep had been drenched against parasites before the trial had started to avoid depressions in intake. Parasitism has been reported to depress intake in sheep (Donelly *et al.*, 1974). It was possible to conclude from all these observations that on the basis of dry and organic matter intakes, maize stalks and sugarcane tops were better feeds than maize cobs and sugarcane.

5.2 Apparent digestibility of the by-products

In vivo dry matter digestibility of maize stalks (63.8%), maize cobs (60.0%) and sugarcane (60.8 %) were not different ($P > .05$) but were higher ($P < .05$) than sugarcane tops (54.3 %). These observed DMD values were in agreement with those of Rogerson (1955).

Maize stalks in this trial gave significantly higher ($P < .05$) DMD values than those found by Dysli and Bressani (1969); Ranjan and Kariyar (1969). These differences in the maize stalks digestibility could have been caused due to variations

brought about by the age of the fodder, environmental temperatures, soil factors and changes in cell contents (Deinum and Dirven, 1971; Deinum, 1976).

Sugarcane whose bulk composition is sucrose was high in DMD, despite its low crude protein content. DMD of sugarcane was actually associated with its high neutral detergent solubles which is highly digestible. Organic matter digestibility of all the feeds showed similar trend as the DMD. This similarity reflected the nutrient availability derived by the ruminants from each by-product. Das Gupta (1949) obtained OMD values ranging from 58.0 to 75.0 % when studying the digestibility of maize stalks, sugarcane tops, green sorghum stalks and napier grass. These findings were confirmed by the results of the present trial.

Sugarcane gave a negative crude protein digestibility, a factor that led to very low value of digestible crude protein. Negative crude protein value caused loss in body weight (- .5 kg/day) in wether sheep.

Crude fibre digestibility was lower than N-FE digestibility in most of the by-products. This observation was cantradictory to the established research findings about the magnitude of CF digestibility, being higher than N-FE digestibility, in tropical pastures. Van Soest and Moore (1965) reported digestibility of crude fibre was higher than N-FE digestibility in tropical pastures.

Dry and organic matter intakes were predicted from dry and organic matter digestibility of the by-products. The regressions of DM and OM intake on *in vivo* DMD and OMD

established no significant ($P > .05$) linear relationships (correlation coefficients were small and not significant and RSD values were large). These findings showed that dry matter and organic matter intakes of the by-products were independent of their respective dry and organic matter digestibility. The findings also confirmed that voluntary intakes could not be predicted from only one single factor because factors that cause variations in intake had not fully been accounted for in these analyses (Halley and Dougall, 1962; Campling and Balch, 1961 a; Campling *et al.*, 1961 b; Freer and Campling, 1963; Dodsworth and Campbell, 1953; Blaxter *et al.*, 1960; Blaxter *et al.*, 1961; Laredo and Minson, 1973).

The findings in this trial for predicting voluntary intake (VI) from digestibility coefficients were in agreement with those of Milford *et al.* (1966) but disagreed with those of Blaxter *et al.* (1961). Blaxter *et al.* (1961) and Minson *et al.* (1964) were able to draw significant predictions of intakes from digestibilities by using temperate pastures. The intake of temperate grasses relates very well to *in vivo* DMD and OMD. Tropical grasses have large varietal differences in intake hence there cannot be a generalisation about their intake being accounted for by differences in DMD alone (Minson, 1971 and 1972).

The significant relationships between OM intake and OMD by Osbourn *et al.* (1966) may also not be applicable to these high fibre by-products. Blaxter *et al.* (1961) and Minson *et al.* (1964) reported positive general relationships between VI and digestibility of grasses. These

findingswere in agreement with the results obtained in this trial although some by-products gave negative relationships.

It is possible to conclude from these findings that voluntary intake of the by-products may not be predicted from digestibility alone. There are other numerous factors that contribute towards voluntary intake. These include extrinsic and intrinsic factors associated with the by-products, animal factors arising out of the central nervous system (i.e. hypothalamus, chemostatic and lipostatic regulation) and effective capacity of reticulo-rumen and appetite.

5.3 Intake of digestible nutrients

Estimated starch equivalent (SE) values of the by-products were comparable to good quality hay. The energy derived from these feeds was capable of meeting the maintenance requirements.

Total digestible nutrients (TDN) of the by-products verified further that the feeds were a good source of digestible and estimated net energy.

Protein in the by-products could have induced imbalances in the calorie/protein ratio. This imbalance could cause poor utilization of the available energy from the by-products. Laksesvela and Said (1970) observed similar findings in their trials on sisal waste. Lack of protein in the by-products might contribute to low economic production by animals, inspite of the by-products being capable of supplying energy (only maintenance requirements

satisfied) required by the animals for their basic metabolic activities. Inadequate protein in the by-products may remain a major obstacle in the utilization of local by-products in Kenya.

Intake of gross energy was related to the intake of digestible dry matter. Gross energy values were reflected well by the corresponding digestible energy intake of each by-product. The low digestible energy intake by wether sheep fed maize cobs was a reflection of its nutritive quality. Maize cobs could only be a good source of roughage that could supply some limited energy to animals. Sugarcane diet was low in digestible energy mainly as a result of limited organic matter intake. However, the digestible energy of sugarcane can be increased by increasing the quantity of organic matter intake. This conforms with findings sited in the literature review, whereby other by-products had to be included in the sugarcane based ration to improve sugarcane intake and utilization.

The similarity of energy potential in the by-products was clarified when GE, DE and ME of the by-products were corrected per kilogram of dry matter intake of the respective diet. The GE intake per kilogram dry matter intake of maize stalks still remained higher than sugarcane, maize cobs and sugarcane tops. The overall energy values of sugarcane, maize cobs and sugarcane tops were almost identical, which infact showed that all these by-products could be a good source of energy to sheep, if the dry matter intake of the respective by-products is improved.

Gaseous and urinary losses reduced the digestible energy to an extent that the actual energy available to the ruminant was far much smaller than anticipated. The energy loss of

46.0, 53.0, 56.0 and 56.5 % by wether sheep fed maize stalks, maize cobs, sugarcane and sugarcane tops, respectively, meant that a large proportion of the ingested energy was largely lost along the pathway before being utilized in any useful metabolic activity.

Mulder (1975), Lionel (1975), Preston (1975), Wilton (1975) and Owen (1976) emphasized the importance of by-products, especially sugarcane, as suitable roughages that could be incorporated into intensive animal feeding regimes. The importance of by-products hinges itself on their potential as supplementary energy source for ruminants. The by-products as demonstrated in this trial can only provide sufficient energy to meet the maintenance requirements of sheep.

Arable farm by-products have a major proportion of their cellular material composed of hemicellulose and cellulose (table 14). Ruminants are capable of utilizing such high fibre roughages due to the presence of cellulolytic enzymes secreted by the microphyta and microfauna which co-exist anaerobically in the rumen. It is out of this biological efficiency that ruminants may convert the available local arable farm by-products into usable animal products by employing the cellulases to hydrolyse the complex chains of the structural plant polymers (β-Configuration of the 1 - 4 glucosidic linkages) of cellulose to simpler carbon chains of volatile fatty acids (acetic acid, propionic acid and butyric acid). These organic acids are the major source of energy in ruminants.

Nehring *et al.* (1965) when feeding cellulose to wether sheep were able to establish that ruminants are capable of meeting their digestible and metabolizable energy requirements from high fibrous feed. These results confirmed that ruminants

can utilize the by-products to derive sufficient energy required for their metabolic activities without encountering any adverse effects.

Efficiency of metabolizable energy utilization for all roughage diet was calculated to the magnitude of 68 and 40 % for maintenance and fattening, respectively, (ARC, 1965). Energy requirements by a 30-40 kg sheep (for maintenance) lies between 1.31 and 1.59 Mcal/day (ARC, 1965). The estimated available metabolizable energy in this trial was 2.4, 0.5, 1.0 and 1.4 Mcal per day in the maize stalks, sugarcane, maize cobs and sugarcane tops, respectively. Maize stalks were capable of meeting over and above the maintenance requirements of the wether sheep. Sugarcane tops just barely met the maintenance requirements. Sugarcane and maize cobs could not meet the maintenance requirements of the sheep due to the factors arising out of low protein level. Hence the observed liveweight gain in the animals on maize stalks and sugarcane tops was as a result of both of these by-products being able to provide energy over and above the maintenance requirements. All these by-products may provide sufficient energy for maintenance when all other factors have been corrected (table 12).

5.4 Organic structural components of the by-products

Dry matter digestibility estimated from summative equations confirmed the proportion of organic structural components (NDF and NDS) that contributed to the observed digestible nutrients (table 19). The digestible nutrients of mainly maize stalks, maize cobs and sugarcane tops were

largely attributed to their NDF fractions whereas NDS fraction contributed the largest proportion of DMD in sugarcane.

The similarity between *in vivo* DMD and *in vitro* DMD by Van Soest procedure confirmed the validity of the *in vivo* DMD obtained in this trial. The significant linear relationships and small RSD values suggest that *in vivo* DMD can be predicted accurately from *in vitro* DMD obtained by Van Soest (1967) procedure. This close agreement in predicting *in vivo* DMD gave further validity of evaluating these high fibre by-products in future by the *in vitro* techniques.

In vivo DMD and OMD could not be predicted from separate organic structural components (i.e. the NDF, NDS, ADF and ADL). This failure in the prediction was an additional confirmation that individual organic structural components cannot be applied in determining *in vivo* digestibility of the by-products.

It was recommended that all the cellular organic structural components need to be considered together when predicting *in vivo* DMD and OMD. Combinations of NDF, NDS and ADL have been reported to give accurate results in predicting *in vivo* DMD (Van Soest and Moore, 1965). General linear relationships obtained in this trial were similar to those by Van Soest (1965a and 1967), Van Soest and Moore (1965), Van Soest *et al.* (1966) and Clancy and Wilson (1966). These prediction equations may not be applicable in predicting *in vivo* DMD and OMD of the by-products.

The prediction equations obtained in this trial showed low insignificant correlation and large RSD values. The correlation between organic structural components and *in vivo* DMD or OMD values must be high and the sample standard deviation from the regression (RSD or Sy.x) be low if prediction equations are to be of practical application.

It was assumed that nutrient digestibility of the by-products, was largely affected by the amount of NDF, NDS, ADF and ADL when *in vivo* DMD and OMD were regressed on the structural organic components. ADL, for instance, was used in the regressions of this trial to predict *in vivo* DMD and OMD, on the assumption that the digestibility and availability of DM of each whole by-product was largely influenced by the degree of lignification.

There are many other unrelated factors which may influence the digestibility of a major part of DM. Factors such as the maturity and species of forage and the digestibility of individual organic structural components (Van Soest *et al.*, 1965) and the nutritive uniformity of chemical fraction of dry matter need due consideration if such predictions are to be of any subsequent applicability. The use of individual NDF, NDS, ADF or ADL failed to predict the *in vivo* DMD and OMD largely as a result of these foregoing assumptions. McLeod and Minson (1975-76) however concluded that ADF methods in current use were not suitable for predicting *in vivo* DMD.

5.5 *In vitro* digestibilities and rate of dry and organic matter disappearance

Normally variability observed in *in vivo* digestibility is much larger than it is under controlled conditions of *in vitro* digestibilities (Ivins, 1960; Tilley and Terry, 1963 and Minson and McLeod, 1972). It was therefore preferable to report *in vitro* results in addition to the *in vivo* digestibility results of the by-products, as suggested by Tilley and Terry (1968), Minson and McLeod (1972), Clancy and Wilson (1966) and Van Soest (1967).

The *in vitro* digestibility results obtained in this trial were in close agreement with *in vivo* digestibility data. *In vitro* digestibility results of the by-products were in most cases larger than *in vivo* digestibility values, a factor caused by the absence of metabolic faecal dry matter (Van Soest *et al.*, 1966). *In vitro* dry and organic matter digestibility of maize stalks and sugarcane were higher ($P < .05$) than maize cobs and sugarcane tops. The same results were observed in *in vivo* digestibility studies. This observation confirmed that maize stalks and sugarcane were higher in digestibility than maize cobs and sugarcane tops.

The regressions of *in vivo* digestibility on *in vitro* digestibility data (table 20) established significant linear relationships (large significant correlations and low RSD values). This relationship also confirmed that the *in vivo* digestibility can be predicted accurately from *in vitro* digestibility values. McLeod and Minson (1975-76) had also reported

similar findings. It is, therefore, recommended that any future screening of by-products can be accomplished successfully by *in vitro* techniques.

Those variabilities which arise from *in vivo* digestibilities can be eliminated by the *in vitro* techniques. *In vivo* digestibility is affected by many factors, including variations due to species of animals used - cattle or sheep (Cipolloni *et al.*, 1951), age and health of the animals (Grassland Research Institute Bulletin, 1961) and level of feed intake and manner in which the feed is prepared (Minson, 1962).

The rate of dry and organic matter disappearance in the rumen liquor, revealed that *in vitro* digestibility of these by-products was strongly associated with mean retention time. This observation agreed with conclusions made on the voluntary intake of the by-products. The large and significant correlation coefficients and the low RSD values showed that the DMD and OMD of these by-products were heavily dependant on retention time. A longer time was required before each by-product was fully soaked to facilitate digestion by microorganisms. This was more so in the case of maize cobs which showed the lowest digestibility in the initial hours of rumen liquor incubation.

The relationship between *in vitro* digestibility and time, suggested that the by-products could have been utilized more efficiently if some physical or chemical treatment had been performed prior to feeding them to the sheep. Physical or chemical treatment procedure could have reduced the length of time taken in digesting the by-products. Treatment of by-

products would be more effective particularly in maize cobs diet which required relatively longer retention time than other by-products before achieving the same level of digestibility similar to that of sugarcane diet. Any treatment on these by-products could make plant cellular material more permeable and facilitate a faster digestibility within limited time by the rumen microorganisms than was observed in this trial.

5.6 Nitrogen retention by wether sheep

Wether sheep fed maize stalks and sugarcane tops retained most of the ingested nitrogen, whereas those on maize cobs and sugarcane were in negative nitrogen balance (table 22). These results showed that nitrogen was the major limiting nutrient in the utilization of the by-products.

The negative nitrogen balance would probably explain the observed losses in liveweight of the sheep. The wether sheep had to metabolize their body tissues to produce the energy required for maintenance.

Sheep fed on maize stalks and sugarcane tops retained 24.8 and 20.3 % of the ingested nitrogen and utilized about 39.5 and 46.7 % of the absorbed nitrogen, respectively. These low values of nitrogen retentions need to be corrected for efficient utilization of the by-products, especially in maize cobs and sugarcane. The utilization of by-products would be improved greatly by supplementing the by-products with organic protein or non-protein nitrogen, such as urea. This undertaking would be a more realistic practical approach to improve animal performances.

5.7 Mineral retention by wether sheep

Maize stalks and sugarcane were richer than maize cobs and sugarcane tops in calcium. Comparisons of calcium compositions of the by-products with tabulated values (Crampton and Harris, 1969 and Morrison, 1961) were identical. The sheep were subsequently in positive calcium balance on all by-products. Calcium level is unlikely to be of any problem to livestock fed these by-products.

Phosphorus composition of the by-products agreed with the tabulated values by Morrison (1961) and Crampton and Harris (1969). A negative phosphorus balance was observed in all sheep fed by-products. Ranjan and Kariyar (1969) obtained positive phosphorus balance but negative calcium balance when cattle were fed maize stalks. These findings justify that many other factors may have contributed to observed differences in the nutrient retentions by animals. Agronomic practices and environmental factors, largely play a major role towards the accumulation of any nutrient in the crops. The negative phosphorus balance confirmed the need for phosphorus supplementation in the diets when the by-products are fed to livestock. Phopshorus supplementation would be more effective and advantageous in animals fed maize stalks and sugarcane.

A positive sodium balance was observed in wether sheep fed sugarcane tops. This observation was as a result of high sodium content in sugarcane tops. Sheep fed maize stalks, sugarcane and maize cobs were in negative sodium balance due to the low sodium contents in these by-products.

All wether sheep remained in positive potassium balance on all by-products. An inverse relationship normally exists between the concentration of sodium and potassium in grasses. This relationship was confirmed by this trial. There was more potassium than sodium in most of these by-products. This suggested that those animals fed these by-products would not suffer from potassium deficiency as they would from sodium. It would be advisable to supplement sodium when animals are fed these by-products. Sodium could be supplemented in the form of sodium chloride (Common salt) for efficient utilisation of these by-products.

In conclusion, maize stalks, sugarcane and maize cobs were found poor in phosphorus and sodium whereas sugarcane tops were poor only in phosphorus. All by-products were rich in calcium and potassium. It was recommended that sodium and phosphorus be supplemented when these by-products are fed to animals.

CHAPTER 6

CONCLUSIONS

The by-products contain high levels of crude fibre and very low levels of crude ptotein which greatly influenced their nutritive value.

Voluntary intake of the by-products was controlled to a large extent by crude protein. Maize stalks (8.5 % CP) was highest in intake as compared to the other by-products. It is recommended that protein be supplemented when feeding these by-products.

Maize stalks that showed the highest dry and organic matter digestibility and high intake value was found to be a better feed than sugarcane, maize cobs and sugarcane tops.

The rate of *in vitro* DM and OM disappearance of sugarcane were higher than maize stalks, maize cobs and sugarcane tops. This suggested that sugarcane was easily digested relative to the rest of the by-products. However, the low *in vitro* digestibility of the rind and the low dry and organic matter intake of sugarcane could have affected its nutritive value.

The by-products compared favourably with good quality hay. The by-products were rich in energy although a large proportion of this energy content was lost through faeces, fermentation gases and urine. Starch equivalent values were sufficient to meet the maintenance requirements of the wether sheep. Total digestible nutrients of these by-products confirmed this observation. It is possible to recommend that these arable farm by-products may be incorporated into intensive

livestock feeding regimes in this country. The practice already prevailing in small scale farms in Kenya should be highly encouraged.

Results of this trial on the nutritive value of the by-products indicated that when these by-products are properly supplemented, they contain more feeding value than is commonly recognized. The by-products fed to livestock are a good source of energy and roughage but a poor source of protein. It was therefore recommended that protein be supplemented to the by-products in order to correct their inadequate protein contents. Pre-formed protein, either of animal or/and plant origin or Non-protein nitrogen (N-PN) such as urea may constitute complete protein supplement to the by-products. It was concluded that nitrogen may remain the major drawback for efficient utilization of arable farm by-product based rations.

Phosphorus and sodium were observed to be the most critical minerals in animals fed on these by-products. These minerals may require immediate supplementation. The level of supplementation may vary according to the degree of deficiency of each individual element as determined in this trial.

Results obtained by use of *in vitro* digestibility techniques highly agreed with the *in vivo* data. Experiments conducted by involving animals have been known to be tedious and expensive. It was suggested that any future research work on the screening of by-products could be carried out by *in vitro* evaluation prior to animal trials.

CHAPTER 7

SCOPE FOR FUTURE RESEARCH WORK

The trial demonstrated that arable farm by-products are highly fibrous, low in crude protein and deficient in important major minerals. It was also shown that animals fed on these by-products in most cases cannot derive sufficient nutrients to meet their metabolic requirements.

In order to overcome these problems, it is suggested that any future research work on by-products should concentrate on various ways of improving their nutritive value. These may include all the available techniques of processing by-products to make them more acceptable and digestible. Experiments may concentrate on physical treatments of by-products either by finely grinding or steam heating the by-products. Chemical treatments by use of alkalis, such as sodium or ammonium hydroxide may also be encouraged.

The effects of nitrogen and mineral supplementation may also constitute another important field of research on the arable farm by-products. The research may be directed towards investigating suitable levels at which each of these nutrients may be supplemented.

There has not been any research conducted on dairy cows feeding on maize stalks, maize cobs, sugarcane and sugarcane tops in Kenya. It is suggested that a feeding trial using dairy cows be instituted in the future to investigate the optimum levels at which such by-products could be included in well balanced ration for improved milk

production. This type of research could assist Kenyan Small Scale farmers who currently feed these by-products to their cattle under zero grazing system.

Evaluation of numerous other arable farm by-products must be encouraged. By-products such as brewers' waste, banana stems and leaves and cashew nut waste are a few of the farm by-products which are being fed to dairy cows in this country yet they have received least research attention. The evaluation studies may follow similar trends as proposed for research in optimum utilization of maize stalks, maize cobs, sugarcane and sugarcane tops in livestock production.

CHAPTER 8

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CHAPTER 9. APPENDIX

TABLE 27. INTAKE OF NUTRIENTS BY SHEEP PER DAY DURING COLLECTION PERIOD

Diet	Animal Number	g/day			g/kg$^{.75}$/day		
		Dry Matter	Organic Matter	Digestible Organic Matter	Dry Matter	Organic Matter	Digestible Organic Matter
MS	1	1226.67	1134.83	674.25	71.36	66.02	39.22
	2	1078.50	997.41	624.25	73.27	67.76	42.41
	3	1124.36	1041.65	664.30	74.31	68.85	43.91
	4	793.36	735.31	452.45	58.08	53.83	33.12
	5	843.78	843.78	477.31	61.77	61.77	34.94
	6	1001.74	913.99	605.33	54.88	50.08	33.17
	7	1001.74	908.91	608.34	62.92	57.09	38.21
	8	1001.74	909.91	560.43	65.56	58.55	37.99
	9	1001.72	875.39	601.31	68.14	59.55	40.91
	10	1001.74	907.89	582.06	67.05	60.77	38.96
	MEAN	1007.54	926.91	585.00	65.73	60.43	38.28
MC	1	504.65	483.94	300.80	31.15	29.87	18.57
	2	495.17	475.04	284.69	31.93	30.63	18.36
	3	559.35	537.43	340.11	30.07	28.89	18.29
	4	582.60	560.11	358.56	31.56	30.34	19.42
	5	578.75	556.39	350.85	32.24	31.00	19.55
	6	582.60	560.11	327.77	31.22	30.02	17.57
	7	540.74	520.28	324.30	37.58	36.16	22.54
	8	539.35	517.75	326.57	31.86	30.58	19.29
	9	565.38	543.25	332.92	35.05	33.66	20.63
	10	582.60	560.11	346.78	33.37	32.08	19.86
	MEAN	553.12	531.44	329.34	32.60	31.32	19.41
SC	1	427.06	415.86	275.35	28.04	27.31	18.08
	2	227.02	220.96	138.96	15.60	15.40	9.69
	3	180.74	176.35	113.51	13.81	13.45	8.67
	4	350.89	344.90	233.28	29.27	28.77	19.46
	5	241.63	235.21	151.47	19.79	19.26	12.41
	6	353.13	347.06	183.42	24.34	23.92	12.64
	7	328.37	222.39	185.64	22.96	22.54	12.98
	8	286.25	281.25	187.71	22.00	21.62	14.43
	9	334.86	328.80	200.88	27.92	27.42	16.75
	10	264.90	260.21	168.27	21.29	20.97	13.53
	MEAN	299.49	293.27	183.85	22.51	22.07	13.86
SCT	1	1126.67	1010.75	533.58	69.50	62.35	36.62
	2	845.09	757.53	410.16	62.18	55.74	30.18
	3	893.95	802.73	456.45	57.53	51.66	29.37
	4	691.96	620.33	353.38	43.57	39.06	22.25
	5	1018.64	913.82	486.26	57.42	51.51	27.41
	6	919.65	837.24	499.95	55.53	50.56	30.19
	7	747.55	638.23	356.91	48.92	31.77	23.36
	8	789.66	715.38	381.21	48.48	43.93	23.40
	9	698.05	816.64	470.69	38.63	45.19	26.05
	10	911.85	835.45	466.45	45.52	41.71	23.29
	MEAN	864.31	794.81	447.50	52.73	48.35	27.21

MS = Maize stalks MC = Maize cobs SC = Sugarcane SCT = Sugarcane tops

TABLE 28 INTAKE OF ENERGY BY SHEEP PER DAY DURING COLLECTION PERIOD

Diet	Animal Number	Kcals/day			Kcals/kg of feed ingested		
		G E	D E	M E	G E	D E	M E
MS	1	5390.66	3290.97	2796.00	4420.34	2698.60	2292.72
	2	4749.71	2878.67	2436.22	4417.23	2677.16	2265.68
	3	4944.89	3151.13	2694.01	4400.95	2804.51	2397.67
	4	3485.02	2168.45	1889.65	4391.13	2732.25	2380.96
	5	3709.09	2296.54	1921.16	4413.82	2732.88	2286.18
	6	4347.52	2903.88	2431.18	4347.52	2903.88	2431.18
	7	4347.52	2802.98	2332.71	4347.52	2802.98	2332.71
	8	4347.52	2782.65	2314.27	4347.52	2782.65	2314.27
	9	4359.13	3032.53	2540.44	4359.13	3032.53	2540.44
	10	4347.52	2814.62	2312.16	4347.52	2814.62	2312.16
	Mean	4402.86	2812.24	2366.78	4379.27	2798.21	2355.40
MC	1	1856.93	1001.11	848.93	3676.72	1982.20	1680.88
	2	1784.23	646.31	484.37	3604.14	1305.55	978.43
	3	2241.15	1322.24	1127.20	4011.66	2366.81	2017.69
	4	2409.98	1410.67	1209.30	4145.17	2426.35	2080.00
	5	2357.91	1391.68	1190.60	4079.18	2407.61	2059.74
	6	2402.52	1212.03	1044.06	4132.33	2084.69	1795.78
	7	2071.65	1208.59	1041.05	3832.55	2235.89	1925.94
	8	2060.96	1219.51	1075.30	3812.78	2256.09	1989.31
	9	2274.82	1259.89	1086.65	4026.43	2230.01	1923.37
	10	2322.32	1338.92	1175.12	3994.39	2202.94	2021.21
	Mean	2178.25	1201.10	1028.26	3931.54	2149.81	1847.24
SC	1	1660.65	1084.79	872.70	3885.92	2538.41	2042.12
	2	881.08	510.32	408.04	3876.75	2245.41	1795.38
	3	700.80	403.20	253.13	3875.42	2229.67	1399.81
	4	1341.43	855.92	664.57	3823.08	2439.37	1894.02
	5	936.15	567.67	420.81	3875.66	2350.15	1742.17
	6	1369.02	692.21	503.45	3874.33	1958.95	1424.76
	7	1273.54	665.15	531.48	3884.30	2028.71	1621.01
	8	1116.36	679.89	496.58	3896.10	2372.82	1733.06
	9	1295.20	737.41	534.85	3872.65	2204.86	1599.20
	10	1033.05	633.72	479.11	3904.93	2395.46	1811.04
	Mean	1160.73	683.03	516.47	3876.91	2276.38	1706.26
SCT	1	4552.85	2652.68	2210.81	4052.04	2360.89	1967.62
	2	3185.36	1562.70	1264.85	3758.72	1843.99	1492.52
	3	3379.26	1819.95	1505.17	3784.77	2038.34	1685.79
	4	2613.75	1343.77	1069.83	3789.94	1948.47	1551.25
	5	3821.38	1891.07	1542.60	3744.95	1853.25	1511.75
	6	3473.81	1943.87	1583.19	3786.66	2118.82	1725.68
	7	2812.43	1519.49	1251.48	3768.66	2036.12	1676.98
	8	2785.43	1304.74	1037.47	3537.50	1657.02	1317.59
	9	3392.66	1784.26	1448.01	4851.50	2551.49	2070.65
	10	3437.33	1800.17	1482.55	3781.06	1980.19	1638.81
	Mean	3345.43	1762.30	1439.60	3885.56	2038.86	1663.86

MS = Maize stalks MC = Maize cobs Sc = Sugarcane SCT = Sugarcane tops

TABLE 29. APPARENT DIGESTIBILITY COEFFICIENTS FOR EXPERIMENTAL DIET COMPONENTS BY SHEEP

Diet	Animal Number	Component[a]						
		Dry Matter	Organic Matter	Crude Protein	Ether Extracts	Crude Fibre	N-Free Extractives	Gross Energy
		%	%	%	%	%	%	%
MS	1	59.34	59.41	45.86	75.99	58.33	61.18	61.05
	2	62.45	62.59	49.46	81.01	60.05	64.86	60.61
	3	63.32	63.77	52.79	60.71	61.49	66.37	63.72
	4	61.53	61.53	49.84	72.15	59.33	63.83	62.22
	5	60.80	61.11	47.25	69.09	58.62	63.77	61.92
	6	65.77	66.23	55.02	57.52	65.54	68.47	66.79
	7	66.44	66.93	56.38	60.52	66.39	68.95	64.47
	8	63.93	63.79	54.54	63.46	59.87	66.96	64.01
	9	68.45	68.69	58.85	56.29	68.09	70.77	69.58
	10	65.92	64.11	53.82	50.00	65.00	65.64	64.74
	Mean	63.76	63.82	52.38	64.67	62.27	66.08	63.91
MC	1	58.39	59.01	32.89	78.77	68.52	56.53	53.77
	2	54.87	55.30	30.56	91.90	63.83	52.62	36.22
	3	62.42	62.87	39.95	85.88	71.69	60.19	59.00
	4	62.96	63.73	28.60	84.39	73.84	61.73	58.53
	5	62.13	62.89	35.66	64.92	70.24	62.15	59.02
	6	54.09	54.65	36.72	74.95	64.94	50.14	50.45
	7	61.52	62.26	45.95	72.25	70.27	59.48	58.34
	8	62.83	63.22	48.20	63.38	71.99	60.14	59.17
	9	60.37	60.76	39.85	80.34	71.63	56.41	55.38
	10	60.57	61.22	34.98	69.13	70.71	58.42	57.64
	Mean	60.02	60.59	37.34	76.59	69.77	57.78	54.75
SC	1	65.26	66.21	-13.13	75.21	39.39	75.96	65.32
	2	60.70	62.89	-23.98	68.90	35.15	73.26	57.92
	3	62.36	64.48	-30.30	59.78	37.28	75.34	57.53
	4	66.00	67.64	-17.67	75.11	40.23	77.44	63.81
	5	62.09	64.39	-26.56	66.28	34.00	73.32	60.64
	6	50.62	52.85	-33.33	60.05	20.32	64.61	50.56
	7	55.42	57.58	-33.00	67.26	30.95	67.93	52.23
	8	64.14	66.74	-28.57	72.69	44.60	75.81	60.90
	9	59.06	61.09	-24.46	65.43	30.72	72.36	56.93
	10	62.52	64.67	-20.09	75.09	40.27	74.24	61.35
	Mean	60.82	62.85	-25.11	68.58	35.29	73.03	58.72
SCT	1	56.83	58.73	54.09	59.99	62.45	57.83	58.26
	2	52.38	54.14	49.93	47.98	61.82	48.95	49.06
	3	55.26	56.86	53.43	63.01	56.07	57.83	53.86
	4	54.63	56.97	50.86	45.69	59.00	57.17	51.41
	5	51.24	53.21	52.36	39.14	54.50	53.32	49.49
	6	57.35	59.71	32.78	45.28	59.0	64.00	55.96
	7	54.19	55.92	14.20	37.35	54.08	56.33	54.03
	8	51.71	53.29	20.01	18.51	50.46	54.74	46.84
	9	55.61	57.64	25.16	46.54	51.78	56.75	52.59
	10	53.71	55.83	24.10	42.55	56.19	59.19	52.37
	Mean	54.29	56.23	37.69	44.60	56.54	56.61	52.39

[a]Dry matter basis.

TABLE 30. APPARENT DIGESTIBLE NUTRIENTS FOR EXPERIMENTAL DIET COMPONENTS BY SHEEP

Diet	Animal number	Component[a] DOM	DCP	DEE	DCF	DNFE
MS	1	55.02	3.90	1.87	14.59	34.65
	2	57.96	4.20	1.99	15.02	36.73
	3	59.06	4.49	1.49	15.39	37.59
	4	56.98	4.24	1.78	14.84	36.15
	5	56.59	4.02	1.70	14.67	36.11
	6	60.43	4.71	.82	16.41	38.49
	7	61.07	4.83	.87	16.62	38.76
	8.	58.20	4.67	.91	14.99	37.64
	9	62.67	5.04	.80	17.05	39.78
	10	58.49	4.61	.72	16.28	36.90
	MEAN	58.65	4.47	1.30	15.59	37.28
MC	1	58.25	.66	.73	22.50	35.60
	2	54.59	.61	.85	20.94	33.13
	3	62.06	.80	.80	23.53	37.90
	4	62.91	.57	.78	24.23	38.87
	5	62.08	.71	.60	23.05	39.14
	6	53.95	.73	.70	21.31	31.57
	7	61.46	.92	.67	23.06	37.45
	8	62.40	.96	.59	23.62	37.87
	9	59.98	.80	.75	23.50	35.52
	10	60.43	.70	.64	23.20	36.79
	MEAN	59.81	.75	.71	22.89	36.38
SC	1	64.46	- .34	1.23	7.82	55.66
	2	61.22	- .62	1.12	6.98	53.69
	3	62.77	- .79	.97	7.40	55.21
	4	65.85	- .46	1.22	7.99	52.35
	5	62.68	- .69	1.08	6.75	53.73
	6	51.89	- .76	.98	4.16	47.68
	7	56.54	- .76	1.10	6.33	50.13
	8	65.53	- .65	1.19	9.13	55.95
	9	59.98	- .56	1.07	6.29	53.40
	10	63.50	- .46	1.23	8.24	54.79
	MEAN	61.44	- .61	1.12	7.11	53.26
SCT	1	52.67	3.19	1.34	20.27	28.40
	2	48.55	2.94	1.07	20.07	24.03
	3	50.99	3.15	1.41	18.20	28.40
	4	51.09	3.00	1.02	19.15	28.07
	5	47.72	3.08	.87	17.69	26.18
	6	54.44	1.14	.75	18.83	34.64
	7	50.99	.49	.62	17.26	30.49
	8	48.59	.69	.31	16.11	29.63
	9	52.56	.87	.77	16.53	30.72
	10	50.91	.84	.71	17.94	32.04
	MEAN	50.85	1.94	.89	18.21	29.26

MS = Maize stalks MC = Maize cobs SC = Sugarcane SCT = Sugarcane tops

[a]Dry matter basis.

TABLE 31. ESTIMATION OF DRY MATTER DIGESTIBILITY BY VAN SOEST PROCEDURE

Diet	Animal Number	Digestibility of organic component, %		Summative dry matter Digestibility coefficient %
		NDF	NDS	
MS	1	34.48	24.87	59.35
	2	36.23	26.22	62.45
	3	36.81	26.51	63.32
	4	35.71	25.37	61.08
	5	35.15	25.64	60.79
	6	42.68	23.09	65.77
	7	42.81	23.82	66.63
	8	40.75	23.32	64.07
	9	44.23	24.78	69.01
	10	40.87	23.49	64.36
	Mean	38.97	24.71	63.68
MC	1	56.04	4.00	60.04
	2	48.95	4.93	53.88
	3	50.26	5.78	56.04
	4	54.95	7.59	62.54
	5	57.48	5.15	62.63
	6	51.95	4.47	56.42
	7	56.40	- .85	55.55
	8	56.55	- 3.37	53.18
	9	56.95	4.30	61.25
	10	56.82	3.23	60.05
	Mean	54.64	3.52	58.16
SC	1	12.06	53.07	65.13
	2	10.70	50.00	60.70
	3	11.35	51.03	62.38
	4	12.47	53.51	65.98
	5	10.98	51.10	62.09
	6	5.77	45.15	50.92
	7	9.49	45.93	55.42
	8	16.70	48.44	65.14
	9	11.06	48.01	59.07
	10	15.65	47.65	63.30
	Mean	11.62	49.39	61.01
SCT	1	35.99	20.84	56.83
	2	32.76	14.72	47.48
	3	34.86	20.52	55.38
	4	36.13	18.50	54.63
	5	32.09	20.62	52.71
	6	33.12	24.29	57.41
	7	32.42	24.69	57.11
	8	27.79	24.68	52.47
	9	32.16	23.56	55.72
	10	30.01	23.80	53.81
	Mean	32.73	21.62	54.35

MS = Maize stalks MC = Maize cobs SC = Sugarcane SCT = Sugarcane tops

TABLE 32. ANALYSIS OF VARIANCE SUMMARY TABLE FOR DRY AND ORGANIC MATTER DAILY INTAKE

		M S					
		Intake g/day			Intake $g/kg^{0.75}$		
Source	df	DM	OM	DOM	DM	OM	DOM
Replications	9	13166.34	10901.98	4103.55	29.70	24.97	8.84
Treatments	3	1007111.30*	794142.78*	291533.90*	3796.38*	2942.33*	1120.94*
Residuals	27	9418.29	7162.86	3083.71	43.73	31.59	12.88
Total	39						

*Statistically significant ($P < .05$)

TABLE 33. ANALYSIS OF VARIANCE SUMMARY FOR APPARENT DIGESTION COEFFICIENTS

Source	df	MS						
		DM Dig.	OM Dig.	CP Dig.	EE Dig.	CF Dig.	NFE Dig.	GE Dig.
Replications	9	8.55	7.77	35.25	158.98	12.17	10.00	25.21
Treatments	3	156.85*	114.07*	11908.57*	1851.89*	2193.24*	591.74*	254.23*
Residuals	27	12.26	12.27	106.53	69.33	24.65	14.76	29.86
Total	39							

*Statistically significant ($P < .05$)

TABLE 34. ANALYSIS OF VARIANCE SUMMARY FOR DIGESTIBLE NUTRIENTS

Source	df	MS				
		Dig. OM	Dig. CP	Dig. EE	Dig. CF	Dig. NFE
Replications	9	7.54	.18	.18	.69	4.33
Treatments	3	220.88*	46.54*	.66*	438.67*	1026.60*
Residuals	27	10.43	.48	.07	1.67	6.57
Total	39					

*Statistically significant (P< .05)

Determination of Calorific values of Urine samples

10 mls of urine from individual sheep was pipetted in round steel dishes and evaporated in fume chambers, using UV lamps, for 24 hours. Each sample was done in triplicate.

The dried sample was scrapped into weighed gelatine capsules, without leaving any speck of the dried material in the dishes. The normal procedure for determining heat of combustion was then adapted after this operation.

Calorific value of capsule alone was calculated (Weight of Campsule mg x Calorific value of capsule Kcals/g). The calorific value of capsule plus urine (thermal capacity of the Auto Bomb in Kcals x corrected temperature rise in ^{o}C) was also calculated. The calorific value of urine alone was then found by difference and was expressed in terms of Kcals per ml of sample taken. The mean of the three determinations was taken as the calorific value of the sample.

In vitro digestibility of the feeds by the two stage *in vitro* technique

Tilley and Terry technique has consistently shown highest correlation with *in vivo* digestibility (Tilley, Deriaz and Terry, 1960; Tilley and Terry, 1963). This technique was developed for temperate pastures but of late, it has been shown to be satisfactory for tropical sp cies (McLeod and Minson 1969 a) and grass-legume mixtures (McLeod and Minson 1969 b). Hence the *in vitro* method has been accepted as a useful technique in the feeding value evaluation process.

Minson and McLeod (1972) made various modifications to the original *in vitro* technique in order to increase the weekly estimations output, but the basic technique developed by Tilley and Terry (1963) still remained unchanged. N.A.R.S. adapted the original two stage technique by Tilley and Terry, (1963), as such all the experimental samples were analysed by the procedure of Tilley and Terry (1968).

Results of these analyses are normally expressed in three major forms, dry matter digestibility on dry matter basis (DMD), organic matter digestibility on an organic matter basis (OMD) and organic matter digestibility on a dry matter basis (D-value).

DMD or DDM uses the smallest weight of a sample hence it is the method of choice where the samples are small.

OMD or DOM involves more analytical work, separate ash determinations have to be carried out. It is unaffected by the level of soil contamination, hence it is preferable in conditions where the level of such contamination may vary.

D-value involves the same analytical procedure as OMD but is affected by the level of soil contamination, just as DMD. Thus OMD and OMDDM, any one of them can be calculated from the other. However, the D-value form is highly recommened for all data quoted to the farmers, because it gives a nutritional evaluation of the feed in terms of digested nutrients per unit of moisture free feed. Hence it is numerically very similar to the total digestible nutrients (TDN) on a dry

matter basis. However, results obtained with the D-value form tend to be lower (ca 5%) than those of DMD or OMD, although in the absence of soil contamination, DMD and OMD are usually within 1 or 2 percent of each other.

In view of this, the *in vitro* digestibility expressed in either form (DMD, OMD or D-value) is an arbitrary figure. It is dependant on the conditions of analysis. It can thus be varied by changing time or temperature of fermentation; the pH of the added buffers, variation in the digestible efficiency of rumen liquor; if the diet of the donor animals is not constant and if the nitrogen content of the rumen liquor is inadequate i.e. if N is less than 1.5 percent (10% CP). The results thus can be only defined as the results of a particular treatment.

Preparation of experimental reagents

4 reagents were prepared for the experiments viz. a phosphate - bicarbonate buffer, Mercuric chloride solution, Sodium Carbonate Solution (2N) and pepsin solution.

A phosphate-bicarbonate buffer solution was prepared by dissolving 18.5 g di-sodium hydrogen carbonate in distilled water. 47.0 g sodium chloride, 57.0 g potassium chloride, 12.0 g magnesium chloride ($6H_2O$) and 4.0 g anhydrous calcium chloride were also dissolved separately to give 2 litres of acqueous solution. 100 mls of this chloride solution were then mixed with the solution of distilled water. The cloudy solution was then saturated with carbon dioxide until it was clear at about pH 6.9-7.0.

Mercuric chloride solution was made by dissolving 5 g mercuric chloride in distilled water and made to a volume of 1000 c.c.

Sodium carbonate solution (2N) was made from 106 g sodium carbonate anhydrous dissolved in distilled water to give a final volume of 1 litre.

Pepsin solution was prepared lastly by dissolving 2 g of 1:10,000 pepsin powder (Chas, Zimmerman and Co. Ltd., perivale, Middlesex, England) in 850 ml of water. 100 ml normal hydrochloric acid were added and solution made up to 1 litre. The solution was made for each experiment because it deteriorates much faster.

Analytical Procedure

Rumen liquor was obtained from fistulated sheep. The animals were in good health and well fed on Rhodes grass of about 10-12 percent crude protein. The sheep had been supplemented with 100 g of high protein dairy cubes. The sheep were fed 1 day prior to the extraction of the rumen liquor and remained without being fed until the liquor had been taken (Monday at 09.00 hours). The fluid was strained and squeezed through four layers of muslin cloth and stored in a closed vessel for a short time under Carbon dioxide at $38^{o}C$.

0.500 g of oven dried herbage samples were placed into 100 ml centrifuge tubes. The samples were finely ground in Christy Norris 8 in laboratory mill fitted with a 0.8 mm screen. The centrifuge tubes were then closed with rubber stoppers, fitted with gas release valve and were pre-warmed to $38^{o}C$ in an incubator before adding the inoculum.

Rumen liquor and carbon dioxide mineral solution were mixed in 1 part to 4 parts producing a mixture of pH 6.9. After the agitation of the mixture and then gassed with Co_2, the mixture was dispensed in 50 ml aliquotes using the dispenser that is fitted with a tube. Anaerobic conditions during incubation were maintained by passing continuously Co_2 through this tube to displace air from the dead space above the liquid level in the tube.

4 tubes were left blank (Blanks that had no herbage for determining the weight of indigestible residue contributed by the rumen liquor). 2 tubes containing standard herbages of known digestibility were also included in each trial. Thus, 25 tubes (1 blank + 1 standard + 23 samples) in a box, were placed in the incubator at 38°C after dispensing and careful shaking. The temperature of 38°C was maintained throughout the experiment.

The tubes were placed in the incubator at 10.00 hours on Monday. Each tube was then mixed by inversion at 17.00 hours that same day. The process was repeated at 09.00 and 17.00 hours on Tuesday. Any tubes with loose corks and appreciable amounts of mould were rejected. The pH was constantly checked because some samples like sugarcane, were rich in sugars that would cause the pH to drop below 6.7 due to the action of acid fermentation products.

The depression of the pH would interfere with the final stages of fermentation because cellulose and hemicellulose digestion would be slowed considerably. The pH was checked at 24th hour and each tube that showed any discrepancies in pH was adjusted with normal sodium carbonate.

The initiation of second stage was after 47 hours from the beginning of incubation. The boxes were taken out of the incubator at 09.00 hours on the Wednesday, 1 ml of 5 percent mercuric chloride solution and 1 ml of 2 N sodium carbonate were added to each tube from burettes. Each tube was shaken and left for 30 minutes until all material had sedimented The corks were removed and any solid material was washed off the stopper with a jet of water. Material deposited on the inner walls of the tubes was loosened with a glass rod covered with a rubber sleeve or "policeman". Each tube was then centrifuged at 2,500 r.p.m. for about 7 minutes and the supernatant was poured off through a funnel covered with a fine nylon cloth.

Solids collected on the cloth were returned to the tube. The tubes were marked at approximately 50 ml capacity. Fresh pepsin solution warmed to 38^{o}C was then poured into each tube up to the 50 ml mark and the contents stirred with a metal spatula. The tubes were re-corked and returned to the incubator. The tubes were again mixed by inversion at 09.00 hours and 17.00 hours on the Thursday. Digestion in this second stage was carried out in the presence of traces of mercury. The traces of mercury have been found to have no effect on the pepsin but they inhibit microbial activity during the first stage.

End of second stage and recovery of undigested residues started on Friday at 09.00 hours. The tubes were taken from the incubator, the stoppers removed and adhering solid material washed off into the tubes. The tubes were centrifuged and the supernatants poured off through a cloth filter. Solid material

that remained on the filter was returned to the tubes.

The insoluble residue from each tube was then washed out into an alumina crucible fitted to a filter flask under vacuum. The tube walls were scrapped with glass rod, fitted with "policeman". The crucible was dried at 100°C for 3 days. The crucibles were then weighed and the residue weight of dry matter was calculated from the original empty weight of the crucibles. The residual weight of organic matter was determined by comparing the weight of crucible plus dry matter with the weight of the crucible plus ash, after incineration over night at 650°C in a muffle furnace.

Rate of *in vitro* dry and organic matter disappearance

The procedure for this experiment was similar to the ones above. All samples were placed in the incubator at the same time (0. hours). Two tubes for each sample were removed from the incubator at 12, 24, 36, 48, 60 and 72 hours. All tubes received similar treatment in the second stage of acid-pepsin digestion as described in the last section. Thus 1 ml of 5 percent mercuric chloride solution and 1 ml of 2 N sodium carbonate were added, each tube centrifuged, filtered and fresh pepsin solution added. All precautions necessary for second stage of *in vitro* digestion were observed. All samples remained in the incubator for 48 hours before being removed out.

Calculation of results for *in vitro* digestibility

The digestibility results were expressed as a percentage. The formulae used were developed from the basic equation given below.

$$\text{Percent digestibility} = \frac{100 \times \text{Sample weight-undigested residues}}{\text{Sample weight}}$$

The insoluble residues consisted of a mixture of undigested forage together with insoluble material derived from the rumen liquor. The residues from the blank tubes (rumen liquor inoculum only) were calculated. This average blank weight was subtracted from the insoluble residue weights before digestibility was calculated.

FORMULAE

1. % DMD = (.500 - (Undigested residue less blank) x 200

   This formular is similar to:-

   $$\%DMD = \frac{\text{Weight of sample - (Wt. residue-blank residue)} \times 100}{\text{Weight of sample}}$$

   i.e. Blank + Sample weight - residue) x 200

2. % DOMD or "D" (i.e. digestible OM as a % of the total sample)

   = (.500 - (ash content of herbage ÷ 200) - (undigested organic matter residue less organic blank) x 200

   This is equal to organic matter digestibility on an organic matter basis x (100 - ash content)

   $$DOMD = \frac{\text{Organic matter digested from sample} \times 100}{\text{Dry matter (.50)}}$$

3. $$\%\ OMD = \frac{\text{OM digested from sample} \times 100}{\text{OM in sample}}$$

   i.e. Digestible organic matter as a percentage of the total OM in the sample.

4. $$\%\ \text{ash (on total sample)} = \frac{\text{Weight of ash}}{\text{Weight of sample}} \times 100$$

5. $$\text{OM in sample} = \frac{.5 \times (100 - \%\ \text{ash})}{100}$$

6. OM digested = Weight of organic matter - Weight of residue from digestion

   i.e. (Residue blank - ash blank) + OM in sample - (residue + Crucible - ash + Crucible).

In vitro analyses by Van Soest procedure

Dry matter is divided into two major divisions: - The Cell Wall Constituents (holocellulose and lignin) and cell contents (water solubles, lipids and protein). The digestibility of cell wall constituents is controlled by the concentration of lignin in lignocellulose whereas the cell contents are highly digestible and unaffected by lignin.

It has been suggested that the division of the carbohydrates of forages by Weende System into crude fibre and nitrogen-free extractives is not realistic either chemically or nutritionally (Van Soest and Moore, 1965 and Crampton and Harris, 1969). Weende system fails to provide adequate theory of fibre digestion by ruminants because it is believed here that crude fibre represents the indigestible portion of the plant. However, this has been shown not to be the case with herbivores. Literature also shows that fibre is digestible in the chemical determination of crude fibre hence a considerable part of the indigestible lignin passes into the nitrogen-free extractives which is supposed to represent only available carbohydrates. Many grasses have been found to have crude fibre more digestible than nitrogen-free extractives, although crude fibre use is rather preserved due to the fact that crude fibre content is negatively correlated with the nutritive value.

It was therefore necessary to investigate the proportion of each component of the cell together with characteristic and nutritional behaviour of these high fibre experimental feeds. There are various analytical methods available

currently for such analyses (Crampton and Maynard Cellulose Method, 1938; Griffith and Jones, 1963; Clancy, 1964 and Clancy and Wilson, 1966). These methods were believed to be simple and rapid in predicting the digestibility of small samples of ground dried herbage plants. However, none of these methods was used in these analyses.

The analytical procedures adopted in these experiments were those put forward by Van Soest (1963), Van Soest and Moore (1965), Van Soest, Wine and Moore (1966) and Van Soest (1967).

Determination of plant cell-wall constituents by use of detergents

Preparation of reagents

Neutral-detergent solution was used in this analysis to fractionate dry matter into Neutral Detergent Fibre and Neutral Detergent solubles.

The neutral detergent solution was prepared from 150 g sodium lauryl sulphate, 93.05 g EDTA (disodium ethlene-diamine-tetracetic dihydrate reagent grade) 22 g sodium hydrogen phosphate anhydrous reagent grade (Na_2PO_4-Na_2HPO_4), 50 ml 2-ethoxyethanol and 34.05 g sodium tetraborate (Sodium borate decahydrate reagent grade - $Na_2B_4O_7.10H_2O$). The EDTA and $Na_2B_4O_7.10H_2O$ were added to 2 litres of distilled water, boiled and kept separate. Sodium lauryl sulphate was mixed with 50 ml 2-ethoxyethanol in 1½ litres of distilled water. Disodium hydrogen phosphate was heated in a beaker containing distilled water until it dissolved.

Finally, all the three solutions were mixed simultaneously in distilled water and made up to 5 litre mark with water. EDTA + $Na_2B_4O_7.10H_2O$ and sodium lauryl sulphate + 2-ethoxyethanol were not mixed together because these two solutions form crumbs when mixed.

The analytical procedure

100 mls of cold neutral detergent solution were added to 1 g of each sample in refluxing apparatus (600 ml beakers). 0.5 g anhydrous sodium sulfite (Na_2SO_3) were added to each (in this order) and lastly 2 mls of decalin (decahydronaphthalene) as an antifoamant.

The contents were heated to boiling in 10 minutes then the boiling was reduced to an even level and refluxed for 60 minutes, timed from the onset of boiling. Each beaker was swirled and the contents filled in previously tared sintered glass crucibles. The contents were filtered through the crucible using vacuum while being rinsed with hot water (80-90^{o}C). The vacuum was then removed, mat broken up using glass rod and the crucible filled with hot water.

The liquid was filtered and the washing procedure repeated. The contents were finally washed twice with acetone in the same manner and sucked dry. The crucibles were dried at 100^{o}C over night in an oven. They were cooled in an efficient desiccator and weighed. The material was ignited to be ashed for 3 hours at 450^{o}C, cooled in a desiccator and weighed. The ash content of the neutral detergent fibre was recorded.

Calculation of results

Neutral-detergent fibre

The Neutral detergent fibre was calculated thus:-

$$\% NDF = (Wo + NDF - Wt)(100)/S$$

Where Wo = Weight of oven-dry crucible.

NDF = Neutral Detergent fibre

Wt = tared weight of oven-dry crucible

S = oven-dry sample weight

Oven-dry weight was obtained by conducting a separate dry matter determination and multiplying the dry matter percentage by the air-dry weight. The NDF represents lignin, cellulose, hemicellulose and some fibre bound protein.

Neutral-Detergent Solubles

$$\% NDS = 100 - \% NDF$$

Where %NDS = percent Neutral-detergent solubles;

% NDF = percent Neutral-detergent fibre.

The determination of fibre and lignin by use of detergents

The reagents used in these analyses were:-

Acid-detergent solution which was prepared from 20 g cetyl trimethyl ammonium bromide (CTAB) technical grade dissolved in 1 litre N H_2 SO_4 that had previously been standardized.

Decalin - reagent grade decahydronaphthalene.

Acetone - grade of acetone free colour on evaporation.

Sulphuric acid (72 %) - Reagent grade H_2SO_4 was standardized to specific gravity of 1.634 at 20°C.

Apparatus used - Refluxing apparatus and sintered glass crucibles.

The analytical procedure

Acid-Detergent fibre

2 g air dry samples that had been milled in a Christy and Noarris 8 in laboratory mill (8 mm screen) were prepared for refluxing. 100 ml room temperature of acid-detergent solution (CTAB) and 2 ml decalin were added to each sample. The contents were heated to boiling for at least 10 minutes and the heat was reduced to avoid foaming as boiling began. The contents were refluxed for 60 minutes from onset of boiling. Boiling was always adjusted to a slow even level.

The contents were filtered on a tared crucible using light suction. The filtered mat wasbroken up with a glass rod and washed twice with hot water, while rinsing the sides of the crucible. Washing was repeated with acetone, until it could remove no more colour. The acid-detergent fibre was sucked free of acetone and dried at 100^{o}C over-night. Crucibles plus contents were cooled in a desiccator over phosphorus pentoxide and weighed.

The separation of acid-insoluble lignin

The crucible containing the acid-detergent fibre was placed in a 50 ml beaker for support. 72% H_2SO_4 (cool ca 15^{o}C) was added to cover contents. The ADF was stirred with a glass rod to smooth paste while breaking all the lumps. This procedure was repeated while refilling with 72% H_2SO_4. The contents were stirred at hourly intervals as acid was drained away. The acid was filtered off with vacuum after 3 hours.

The contents were washed with hot water until free from acid, after which the material was rinsed and stirring rod removed. The crucibles were dried at 100°C, cooled in a desiccator over phosphorus pentoxide and weighed. The crucibles were ignited in muffle furnace at 450°C for 2 hours placed in desiccator while still hot, cooled and weighed.

Calculation of Acid-Detergent Fibre and Acid-Detergent lignin

Acid-Detergent Fibre

$$\% \text{ ADF} = (Wo + F - Wt)\ (100)/S$$

where % ADF = percent acid-detergent fibre

Wo = Weight of oven-dry crucible

F = Fibre

Wt = tared weight of oven-dry crucible

S = Oven dry sample weight

Acid-detergent lignin

$$\% \text{ ADL} = (L \times 100)/S$$

Where L = loss upon ignition after 72% H_2SO_4 treatment

S = Oven dry sample weight

Oven dry sample weight was obtained by conducting a separate dry matter determination and multipying the dry matter percentage by the air dry weight.