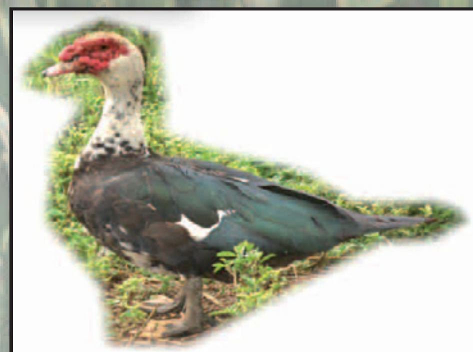
A Guide to the Use of Sugarcane and its By-Products as Animal Feed:

A Manual for Farmers and Livestock Production Specialists

By: Harry ARCHIMÈDE and Gary Wayne GARCIA








INRA

MIC

Sugarcane Feeds Centre

With inputs from:
Xavier XANDE, Jean Luc GOURDINE, David RENAUDEAU, Edouard DESPOIS, Caroline ANAIS, Ode COPPRY, Jérôme FLEURY, Maurice MAHIEU, Marilyne BOVAL, Gisèle ALEXANDRE, Rémy ARQUET, Floyd NECKLES , Cicero LALLO and Alexander BENN

FOOD AND NUTRITION • AGRICULTURE • ENVIRONMENT

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INRA -Institut National de la Recherche Agronomique
Petite Bourg, Guadeloupe, French West Indies

OTF-APL - Open Tropical Forage-Animal Production Laboratory, Department of Food Production, Faculty of Science and Agriculture, The University of the West Indies

MIC - Metal Industries Company Limited.
Macoya Industrial Estate, Trinidad, Trinidad and Tobago

SFC - Sugarcane Feeds Centre
Pokhor Road, Longdenville, Trinidad, Trinidad and Tobago

UWI - The University of the West Indies
St Augustine, Trinidad and Tobago

DEDICATION

Dedicated to ....

Alain XANDE

[1946-2006]

Alain Xande worked tirelessly for the improvement of "Animal Production" (domestic and non-domestic) within the Caribbean and Latin America. He transcended nationality, culture, social and economic status and language. He kept Caribbean Animal Science and Production united through the following publications (1) Xande, Garcia Trujillo and Ceceres (1985), *Tableau de la valeur alimentaire des forages tropicaux de la zone caraibe* and (2) Xande and Alexandre (1989) (Editors), *Paturages et al.imentations des ruminants en zone tropicale humide.* These stand testimony to this achievement. To these is now added the contents of this manual. He is missed and will continue to be missed by his colleagues.

Foreword & Acknowledgements

The primary objective of this **“manual for farmers and livestock production specialists”** is as a reference in formulating tropical non-conventional animal feeds with sugarcane derived ingredients (SDFs) as the basal feed resource(s) within the diets. This manual attempts to take into account the diverse farm situations that exist within the Caribbean region and elsewhere in the tropics. Practices must be adjusted according to the specific farm situation and new information generated. This guide suggests alternatives for the possible use of the entire sugarcane plant and its by-products (bagasse, straw, stem/stalk, juice, and molasses) for animal feeding (to pigs and ruminants). The First Edition was initially written in French for distribution within the French Farming Environment. This English Edition was translated from the French version and then modified and adapted to suit the needs of the farmers within the English-speaking Caribbean. One thousand copies of this first edition have been printed **[500 in French and 500 in English].**

This guide is the output from research carried out as part of three projects done within the French-speaking Caribbean at the Institut National de la Recherche Agronomique [INRA] of the Antilles-Guyane, in Guadeloupe, French West Indies. The projects were:

1] The livestock support sector of Martinique 2001-2006 (funded by the European Agricultural Fund for Rural Development EAFRD and Region of Martinique);

2] Alternative Support 2001-2006 (funded by EAFRD and Region of Guadeloupe); and

3] Enrichment of Sugarcane as Animal Feed (funded by the Regional Cooperation of Guadeloupe, EAFRD, and Regions of Martinique, Guadeloupe and French Guyana).

These projects demonstrate the interest and commitment of the Government of the French Republic regarding Caribbean Agricultural Development. In addition to the experiments conducted at INRA, the projects were assisted by the experiences of other researchers engaged in the use of sugarcane as animal feed. Their experiences have also provided previously undisclosed inputs. These data assisted the manual to remain faithful to its primary objective within a realistic tropical agricultural farm production context.

In this English version of the manual attention of the reader is directed to the websites of the **“Open School of Tropical Animal Science and Production”** as follows:

1] **www12.brinkster.com/ostasp/index.aspx; and**

2] **http://ostasp.rizontt.com/**

to access the presentations made at the **"Sugarcane Feeding Conference"** held at INRA, Petit Bourg, Guadeloupe in June, 2008. Therein the experiences of the use of SDFs in Cuba, at the Sugarcane Feeds Centre (SFC) in Trinidad and Tobago [1976 to the present], Colombia and Vietnam were exchanged. In addition this English version of the manual has been slightly rearranged to bring it in keeping with the needs of the English-speaking Caribbean and the special circumstances of the livestock industries therein.

In this English version there are three (3) additional items that are included that are not in the original French version. These are "**The partitioning of feeds/feed ingredient(s) into its nutrients", "Protein utilization of feeds by ruminants"** and a **"Flow chart of energy metabolism in the ruminant animal"**. These were considered relevant to this manual as the understanding of these concepts by livestock technicians in the English-speaking Caribbean was considered essential. In particular "Protein Utilization" is the limiting constraint to the use of SDFs and the protein input into the diets of animals is the most costly nutrient component. This manual also reproduces the output of the salient experiences of the Sugarcane Feeds Centre (SFC), 1976 to the present.

The SFC in Trinidad and Tobago was initiated and established in 1976 by Professor Eugene Donefer [Professor of Animal Nutrition, Mc Donald College, Mc Gill University, Canada] and Professor Holman E. Williams [Professor of Livestock Science, Department of Livestock Science, Faculty of Agriculture, The University of the West Indies, Trinidad and Tobago]. The SFC was originally called the **UWI – Mc Gill Sugarcane Feeds Centre [1976-1981].** It was initially funded by the Canadian International Development Agency (CIDA 1976-1980) then jointly with the Government of the Republic of Trinidad & Tobago (1980-1981). It has been fully funded by the Government of the Republic of Trinidad and Tobago from November 1st, 1981 to the present. This project has "operated" and "demonstrated" the feeding of SDFs 24 hours/day, 7 days/week, 365 days/year for the last thirty four (34) years. This scientifically operational animal production platform was made possible by the "Vision and Management Genius" of Eugene Donefer, the "Vision and Patience" of Holman E. Williams, the "Agricultural Engineering Skills" of Robert Broughton (Professor of Agricultural Engineering, Mac Donald College, Mc Gill University), the "Dedication and Commitment" of Floyd A. Neckles (employed by the SFC from 1976 to 2008 – 32 years) and all the employees of the SFC from 1976 to the present. Mr. George Muirhead a Canadian (first Project Manager), Mr. Clifford Poon (first Project Foreman), Mr. Sam Seegulam (first livestock and dairy foreman) and Frank Roopnarinesingh (an unlettered mechanical genius), must be particularly commended along with Messers Bharat Jaikaran (Oysterman), Eynath Hosein (Breed), Errol Boodoo, Suresh Benny (now Acting Project Director), Stanley Mollon, Tadil Hosein (Old Oak), Baldeo Sooklal, Deo Ragbir (Papa Blakes), Sooknanan Sankar (Nigger), Mrs. Shira Mohamdally, Mrs Janice Fleming-Scott, Mrs. Sookmin Tanoo, Mrs. Shamela Boodoo, Mrs. Choonilal Ragbir (Caje Lady) and the cane cutters. A special respect must be paid to Mr. Radhay Kisson (a watchman) who lost his life protecting the SFC property.

Many scientists, technicians, administrators and farmers have contributed to this manual. All cannot be cited, the following are among the collaborators that deserve special mention:

The research collaborators – Mr. Cicero Lallo [The Open Tropical Forage-Animal Production Laboratory, Department of Food Production, Faculty of Science and Agriculture, The University of the West Indies formerly Animal Productionist, SFC], Mr. Floyd Neckles [SFC & UTT] and Mr. Alexander Benn [formerly of the SFC and the Agricultural Development Bank of Trinidad and Tobago, Agricultural Consultant, Mausica, Trinidad, Trinidad and Tobago].

The technicians and administrators of INRA (Guadeloupe) - (Unite de Researches Zootechnique (URZ) Platforme Tropicale de Experimentation sur l'Animale, Service Communication du SDAR).

The INRA Scientific Staff who participated in the Sugarcane Feeding Project at INRA, Guadeloupe - Félix Quenais, Christelle Benoist, Valérie Gauthier, Libby Onieka, Caroline Assoumaya, Moise Magdeleine, Audrey Fanchone, Xavier Xande, Séverine D'Alexis, Léticia Limea.

This Foreword must also make mention of the "Herculean" contribution that Dr. Thomas Reginald Preston has made in the sugarcane feeding literature through the publications Livestock Research for Rural Development and Tropical Animal Production Journal which are both online. Additionally, much of the sugarcane feeding work was assembled by Sansoucy, Aarts and Preston (1988). The paper by Garcia, Neckles, Archimedè, and Xande (2008) elaborated on Preston's contribution. Intensive animal production systems since the 1950's have relied heavily on the feeding of maize and soyabean meal-based diets. The production of these crops or feed resources is heavily based on the use of fossil fuels. This will most likely not be sustainable beyond the next decade. This manual attempts to provide the livestock farming innovators, within the Caribbean and the wider tropics, with information to better integrate both crop and livestock production systems for optimal vs. maximal output of animal products as visualized by Xande (2008).

In closing we would like to publicly commend the efforts of Emeritus Professor Holman E. Williams for (i) first identifying the need for a Beef Cattle Demonstration Feedlot for the Caribbean in 1975, which then led to the UWI-Mc Gill Sugarcane Feeds Centre (SFC) and (ii) the final editing of this manual that has attempted to put the work of the SFC (1976 to 2010) into perspective. Thus the embryo produced in 1975 has now matured into this manual that can be used by all in the tropical world.

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List of Acronyms

INRA	Institute Nationale de la Recherche Agronomique [French National Institute for Agricultural Research]
SDF	Sugarcane-derived feeds
EAFRD	European Agricultural Fund for Rural Development
SFC	Sugarcane Feeds Centre
CIDA	Canadian International Development Agency
UTT	University of Trinidad & Tobago
URZ	Unite de Researches Zootechnique
DMI	Dry matter intake
WCS	Whole chopped sugarcane
ADG	Average daily gain
CP	Crude protein
AA	Amino acids
DM	Dry matter
NRC	The National Research Council
OM	Organic matter
VFAs	Volatile fatty acids
N	Nitrogen
NPN	Non-protein nitrogen
VDMI	Voluntary dry matter intake
NDF	Neutral detergent fibre
ADF	Acid detergent fibre
CF	Crude fibre
DE	Digestible energy
DOM	Digestible organic matter
DPI	Digestible proteins in the intestine
ARC	Agricultural Research Council of the United Kingdom
MCP	Microbial crude protein
EAA	Essential amino acids
RDP	Rumen degradable protein
RDN	Rumen degradable nitrogen
USA	United States of America
TDN	Total digestible nutrients
UFP	Urea fermentation potential
DEE	Digestible ether extract
TCP	Total crude protein
ME	Metabolisable energy
PBM	Poultry by-product meal
SBM	Soyabean meal

FCM	Fat corrected milk
FCR	Feed conversion ratio
UDN/UDP	Undegraded dietary nitrogen/protein
GE	Gross energy
FU/UF	Fodder unit
MJ	Mega joules
IE	Intake energy
FE	Faecal energy
UE	Urinary energy
DE	Digestible energy
ADL	Acid detergent lignin
NDS	Neutral detergent soluble
VFI	Voluntary feed intake
WSC	Water soluble carbohydrate
UF/FU	Fodder unit
NE_M	Net Energy for maintenance
CMV	Vitamin and mineral mix
SAA	Sulphur amino acids
SAPS	Sustainable animal production systems
CARDI	Caribbean Agricultural Research and Development Institute
M_tE	Maintenance energy

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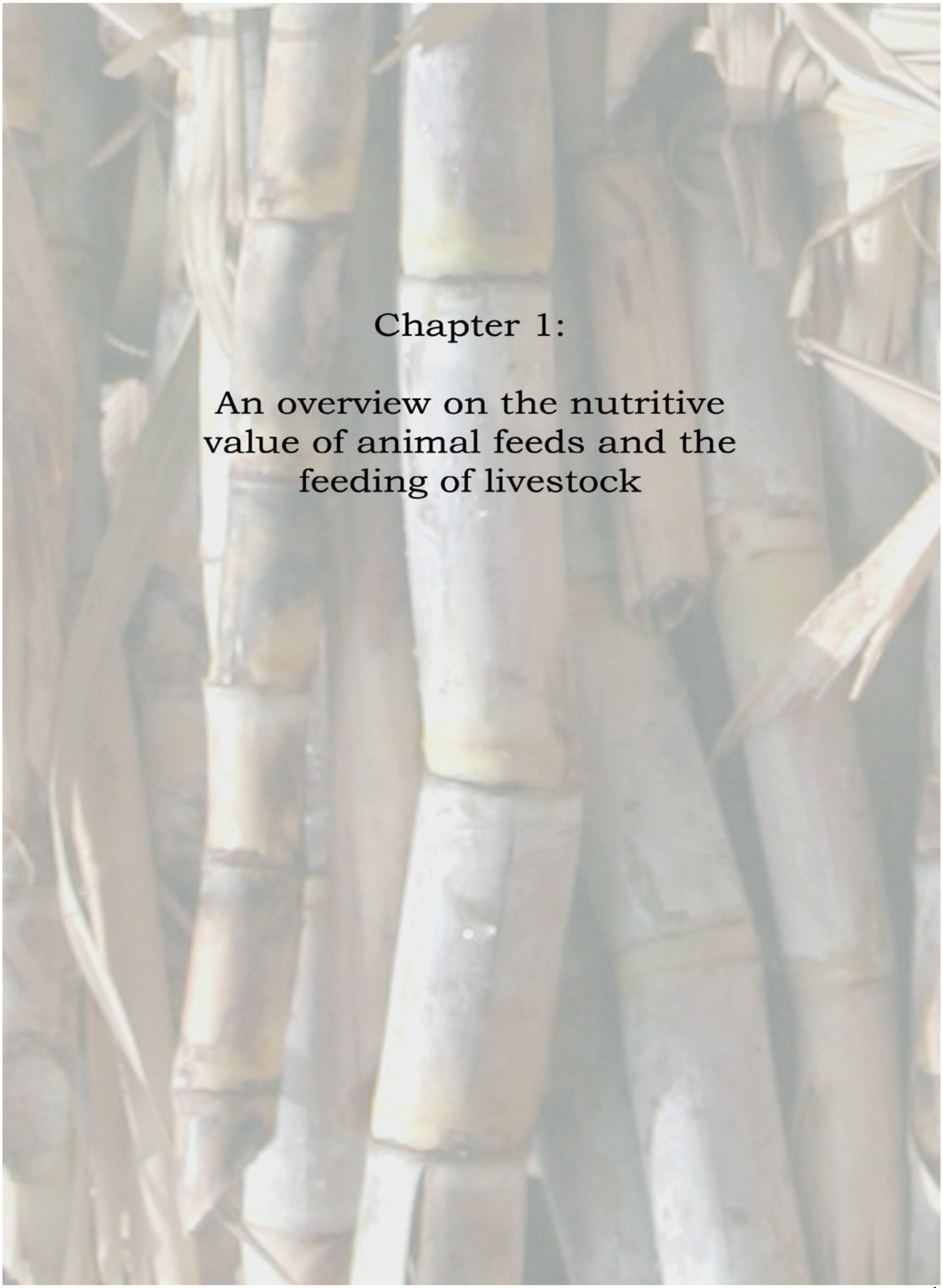


Chapter 1:

An overview on the nutritive value of animal feeds and the feeding of livestock

Chapter 1.0: An overview on the nutritive value of animal feeds and the feeding of livestock

1.1 Meeting the nutritional needs of animals

The nutritional needs of livestock are generally divided into maintenance and that for production. **Maintenance needs** refer to the amounts of energy, proteins, minerals and vitamins necessary for the basic metabolism of the animal (cell renewal, muscle tone, functioning of vital organs, synthesis of enzymes and hormones). These are what are needed for the survival of the animal with zero live-weight gain or loss. **Production needs** refer to the additional quantities of these same nutrients that would allow for growth and fattening (meat production), milk production and work from the animals under systems of intensive animal production. In order to fulfil these requirements, the animals must use the nutrients that they extract from their daily feed intake. These nutrients in the animal feed can be classified into 3 groups based on the manner in which they are utilized by the animals following intake and digestion. These nutrients can be grouped as follows: (1) Energy-giving nutrients; (2) Plastic/Structural (protein) nutrients; and (3) Catalytic (enzyme) nutrients.

1.1.1 Energy-giving nutrients

These provide energy to meet the animal's requirements. How the nutrients are used or needed by the animal would vary according to the animal species. **Glucose** is the main energy supplying nutrient in **monogastrics** (pigs and poultry), whereas **volatile fatty acids (VFAs)** predominate in ruminating or weaned **ruminants** [sheep, goats, cattle). However, ruminants also have need for glucose which they synthesise following production of certain VFAs in the rumen. These VFA's are called glucose precursors. The main glucose precursor is propionic acid. **Fats [lipids]** are also used as sources of energy when they are plentiful in the feed. When the animal does not consume enough energy giving nutrients/energy dense feeds, the fats and proteins (muscles) are transformed into energy, resulting in weight loss and the wasting away of muscle mass.

In the feeding of **monogastrics** (pigs and poultry) and secondarily of **polygastrics** (ruminants - beef, young goats, sheep) the energy-giving nutrients are those feed ingredients that are rich in starch (cereals, tubers, fruits) and sugars (sugarcane juice and molasses) that supply glucose. The main sources of volatile fatty acids for ruminants are plant/forage fibres. But in the case of ruminants VFAs can also be obtained from the digestion of fibre in the reticulo-rumen.

1.1.2 Plastic/Structural nutrients

Plastic/Structural nutrients make up the "structure" of living matter, animal products, tissues and body fluids (that is, milk, meat, bones, hormones, enzymes). Among the several plastic /structural nutrients are water, minerals, amino acids and lipids (fatty acids). Water and amino acids (the basic components of proteins) and, to a lesser extent fatty acids, are the main components of meat and milk. Minerals are the main components of bones.

Amino acids are present in significant quantities in forage/plant resources that are rich in nitrogen (grains, legume leaves and soya beans). Minerals are also found in high concentrations in forages and in plant-storage-organs (fruits and tubers such as cassava). There are twenty (20) **essential amino acids** that cannot all be synthesized by monogastrics and must be supplied in the feed. Consequently, the right balance (mix) of amino acids (the amino acid "profile") of a feed ingredient and the consumed intake in relation to the needs of the monogastric animal are important for good maintenance and production. These criteria are even more important when high levels of animal performance are desired.

1.1.3 Catalytic nutrients

Catalytic nutrients facilitate the biological machinery to function. "They are the lubricant of the motor." Vitamins and certain minerals are the main catalysts. They are often present in lower quantities in old, very mature forages but are plentiful in young, green vegetative material.

1.1.4 The partitioning of feeds/food ingredients into their nutrients

The food of farm animals typically consists of plants and plant products, although some foods of animal origin [such as fish meal and milk] are fed in limited amounts. Animals depend upon plants for their existence and, consequently, a study of animal nutrition must necessarily consider plant composition. The main components of foods, plants and animals [from an animal nutrition point of view] are itemized in Figure 1.

Water

The water content of the animal's body varies with age:

➲ the **newborn animal** contains from 750 to 800 g water/kg body weight but this decreases with age; and

➲ the **mature, fat animal** contains about 500 g water/kg body weight.

Water is vital to the life of an organism and the water level in the body must be maintained.

NOTE: An animal will die more rapidly if deprived of water than if deprived of food. That is why water-supply-management is one of the most important components of any production system.

Water functions in the body as:

- a solvent in which nutrients are transported through the body;
- a solvent in which waste products are excreted from the body; and
- the regulator of animal body temperature.

Many of the chemical reactions brought about by enzymes take place in solution and involve *hydrolysis* (any decomposition involving the addition of water). Because of the high specific heat of water, large changes in heat production can take place within the animal with very little alteration in body temperature.

Water also has a high latent heat of evaporation and its evaporation from the lungs and skin regulates animal body temperature. **Clearly, water is of paramount importance to animal welfare and culture.**

The animal obtains its water from three (3) sources:

- drinking water;
- water present in its food; and
- metabolic water (formed during metabolism by the oxidation of hydrogen-containing organic nutrients).

The water content of food is very variable and can range from 60 g per kg in fresh material in concentrates to over 900 g per kg in some root crops. Therefore, root crops and tubers are high in water or moisture content. The water content of growing plants is related to their stage of growth — younger plants contain more water than older plants. There is no evidence that, under normal conditions, an excess of drinking water is harmful. Animals normally drink what they require.

Dry Matter

The dry matter ("DM") of foods is conveniently divided into:

- Organic; and
- Inorganic materials (see Figure 1).

In living organisms there is no such sharp distinction.

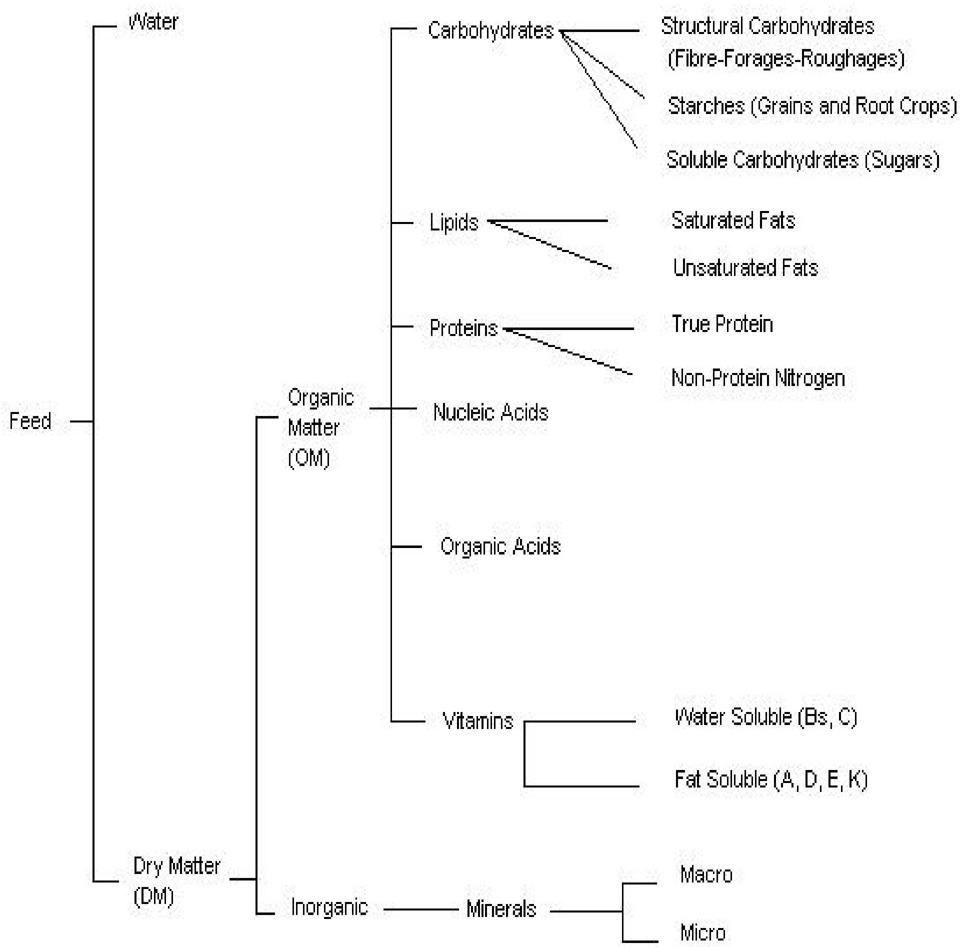


Figure 1: Components of Foods/Animal Feed Ingredients [of plant and animal origin]

Organic compounds

Many of the following organic compounds contain mineral elements as structural components:

Carbohydrate

The main component of the DM of pasture grass is carbohydrate. This is true of all plants and many seeds — the oilseeds, such as groundnuts, being exceptional in containing large amounts of protein and lipid material in the form of fat or oil.

In contrast, the carbohydrate content of the animal body is very low. Two main reasons for the differences in carbohydrate content between plants and animals are that:

- the cell walls of plants consist of carbohydrate material (mainly cellulose); and
- the cell walls of animals are composed almost entirely of protein.

Furthermore, plants store energy largely as carbohydrates, such as starch and fructans (fruit sugars), whereas an animal's main energy store is as fat.

Fat

Fat is the most important lipid present in both plants and animals. The fat content of the animal body is variable and is related to age, the older animal containing a much greater proportion of fat than the younger animal. The lipid content of plants is relatively low, (*i.e.*, pasture grass contains 40 to 50 g per kg DM). Many of the lipids and carbohydrates in plants and animals contain phosphorus.

Nitrogen Compounds

1. *Proteins* — In both plants and animals, proteins are the major nitrogen (N) compounds. In plants, where most of the protein is present as enzymes, the concentration is high in the young, growing plant and falls as the plant matures. In animals, muscle, skin, hair, feathers, wool and nails contain protein. Proteins are made up of amino acids.

NOTE: The expression of the quantity of crude protein (CP) in a feed or compound is the %N x 6.25.

1. *Nucleic acids* — Like proteins, nucleic acids are also nitrogen compounds and they play a basic role in the synthesis of proteins in all living organisms. They also carry the genetic information of the living cell.

1. *Non-Protein Nitrogen (NPN)* – This is a nitrogen-containing compound which, because of its CP equivalent (%N x 6.25), is included in the diets of ruminants. Microbial activity in the rumen ('stomach') breaks down the NPN into ammonia.

The utilization of CP and N by the ruminant animal will be described in detail later in this chapter.

Organic Acids

Although organic acids are normally present in small quantities, they nevertheless play an important role as intermediates in the general metabolism of the living cell.

The organic acids that occur in plants and animals include: citric acid, malic acid, fumaric acid, succinic, and pyruvic acid.

Other organic acids that occur are volatile fatty acids (VFAs) as fermentation products in the rumen or in silage and these include: acetic acid; propionic acid; butyric acid; and lactic acid.

Vitamins

Vitamins are present in plants and animals in minute amounts and many of them are important as components of enzyme systems. Important differences between plants and animals are:

➲ Plants can synthesise all the vitamins they require for metabolism; and

➲ Animals cannot synthesise all the vitamins they require or have very limited powers of vitamin-synthesis and are dependent upon an external supply.

Vitamins are described based on their solubility in either water or fat. They are therefore classified as follows:

Fat-Soluble Vitamins: A [retinol], D_2 [ergocalciferol], D_3 [cholecalciferol], E [tocopherol], K [phylloquinone];

Water-Soluble Vitmins: B_1[thiamine], B_2[riboflavine], B_6[pyridoxine], B_{12}[cyanocobalamine], nicotinamide (niacin), biotin, panthotenic acid, folic acid, choline, vitamin C [ascorbic acid].

Inorganic matter

Inorganic matter contains all those elements present in plants and animals other than carbon, hydrogen, oxygen and nitrogen. The major components of the ash of animals are calcium and phosphorus. The main inorganic elements in plants are potassium and silicon. These inorganic substances are called macro- and micro-minerals. The macro-minerals are calcium (Ca), phosphorous (P), potassium (K), sodium (Na), chlorine (Cl), sulphur (S) and magnesium (Mg). The micro-minerals are iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), iodine (I), cobalt (Co), molybdenum (Mo), selenium (Se), fluorine (Fl), bromine (Br), barium (Ba) and strontium (St).

In the formulation of diets for ruminants or polygastrics three important mineral ratios are the C:N, Ca:P and the S:N. In the formulation of diets for Non-ruminants or monogastrics an important mineral ratio is that of Ca:P.

1.2 The main differences between "ruminants/polygastrics" and "monogastrics"

Livestock convert plant biomass into animal body mass, products [meat, milk, hair, wool, eggs, products of conception] and work. The digestive capacity of animals and the type and quantity of their final products are the direct consequences of the anatomy and physiology of their respective digestive systems.

1.2.1 Ruminants/Polygastrics

Digestion in ruminants uniquely involves the activities of a multitude of micro-organisms [bacteria, protozoa and fungi] living symbiotically within the digestive tract. These populations live in the reticulo-rumen (paunch) of ruminants wherein the ingested feed is fermented and converted into **microbial protein** which is used in growth and multiplication**, ammonia** and **VFAs.** Dead microbes are eventually utilized in the animal's lower digestive tract.

It is then due to these microbes, that the ruminants (unlike mono-gastrics) can obtain energy from fibre (cellulose and hemicelluloses). Additionally, microbes allow ruminants to use non-protein-nitrogen (NPN) to synthesise amino acids into microbial protein. The microbial protein [that is produced in the reticulorumen] are then digested in the small intestine of ruminants (as stated above). This microbial protein could contribute between 40 to 60 % of all the animals' protein needs according to the level of production. The ruminant also benefits from the synthesis by the microbes of B vitamins.

1.2.2 Monogastrics

Monogastrics have microbial fauna, but only to a limited extent within the caecum [or hind gut]. Pigs, rabbits, horses, Guinea pigs and capybaras are mono-gastrics with a caecum. In the case of pigs the caecum is not well developed until the animal is well grown, thus microbial digestion is often limited and insignificant. Monogastics digest cellulose and hemicelluloses to a limited extent only in the caecum. The main sources of energy for the monogastrics are starches and sugars. Unlike the ruminant, there is no microbial protein production. The monogastric then must have the amino acids present in the proteins fed and the amino acid profile of the feed has to be similar to the needs of the animal.

Ruminants and the monogastric pigs have different constraints as far as feeding is concerned even if certain feeds can be shared between the two groups of animals. Ruminants can use feed consisting of highly fibrous products (grasses, sugarcane, bagasse) with "reasonable" production output and maintenance status.

Rations that contain high levels of low-fibre products (concentrate feeds, molasses, banana, potato, cassava tubers and, cereals) can result in digestive disorders and consequently reduce the ruminant animal's performance. In contrast, the rations that are high in fibrous products do not allow pigs to attain high levels of productivity. The pig**'s** feed must be rich in starch and/or sugars and must contain the needed high quality proteins.

1.3 Formulation of diets

1.3.1 General considerations

An animal's diet can comprise of a single feed, e.g. grass forage, but it is most often a mixture of feed ingredients either produced on the farm or bought from a feed mill. The proportion of different feeds and the total distributed quantities of the feed composition will depend on:

1) Biological / Nutritional and

2) Economic and/or Financial considerations.

The highest limit of feed use is fixed by the animal's production potential and its intake capacity. It is wasteful to offer an animal more feed than it is capable of converting into useful animal products (milk, meat). An excess of energy intake can lead to wasteful subcutaneous fat deposition or fat around the digestive tract and internal organs. An excess of protein intake increases losses of nitrogen in the urine and increases the risks of pollution. **Dietary nitrogen and protein sources are generally the most expensive components of the animals' diet.**

The highest levels of animal production performance may not always be the farmers' objective. The type of diet and the level of feeding will be influenced by cost. With animals of high production potential the best results are obtained with feeds of high nutritive value but this also incurs a high feed cost. Therefore, designing a good diet is to search for an optimum between: 1) the level of animal performance required; and 2) the cost of the feed.

1.3.2 Formulation of ruminant diets

Ruminant feeding must meet certain standards.

The ruminant requires fibre intake in its diet, this fibre intake must fulfil two requirements:

1) chemical (nutritional) composition (cellulose, hemicelluloses) and

2) physical characteristics linked to the length of long grass leaf blades (> 5 mm) ingested by the animal.

Figure 2: Grazing creole goats in Guadeloupe [INRA, Gardiel Experimental Station]

The fibre or "roughage **in the diet**" comes from forages or forage-like substances. When the diet does not have an adequate fibre-level diet intake is lowered and metabolic problems are encountered. One of the indicators of a ruminant animal's good health is the act of "**ruminating"** or the apparent "chewing of the cud" when in a resting position. Rumination stops when the animal does not get enough roughage in its diet (and in many forms of ill health). Roughage must account for at least 30 % of the **voluntary dry matter intake [VDMI]** by the animal. The quantity and profile of the nutritional elements in the diet are the sum of products extracted directly from feed and those resulting from the activity of micro-organisms in the rumen. The micro-organisms in the rumen produce a group of essential amino acids from mineral nitrogen. The rest of the essential amino acids must be supplied in the form of edible digestible proteins in the intestine. This may be in the form of **by-pass pre-formed proteins** that have not been digested in the reticulorumen. Other nutrients, such as VFAs, mainly come from the breaking down of organic matter by micro-organisms in the animal's rumen. These must match up with the protein profile in order to have efficient energy use. All the energy-supplying nutrients are not interchangeable. It is thus imperative that glucose or glucose precursors (propionate/propionic acid) be present in sufficient quantities in the digested diet.

In excess, certain nutritional elements become toxic to the animal. Such is the case with nitrogen (N) that is very fermentable in the rumen. This highly fermentable N is plentiful in the leaves of legumes. The excess of certain substances such as urea (non-protein-nitrogen) can create irreversible metabolic problems and ultimately lead to the animal's death. Likewise, excess energy from feeds rich in starch may cause acidosis.

Only young grass contains the quantities, the qualities, and the balance of nutrients that are compatible with the animal's needs for production. Hence, good quality grass is the only raw material in the diet of a ruminant. Besides grass, the feed must incorporate several other raw materials in order to fulfil nutritional requirements.

In practice, ruminants' diets must be formulated so that they provide nutrients to both the animal and the micro-organisms in their digestive tract (the reticulo-rumen). The microbes are nourished by feed containing highly digestible energy (sugar, starch, fibres from very young forages), highly degradable N (contained in urea or sulphate of ammonia or 30 to 40% N contained in legumes), minerals and vitamins. These allow for the development of the population of micro-organisms that breakdown the less digestible fibres in the diet.

Along with the rapidly digestible N, the other portion of total N in the diet (50 to 80 %) must be supplied in the form of proteins digestible in the small intestine (bypass proteins). This portion will be more important for those animals having special needs. Similarly, the energy arising from the breakdown of fibres (the less costly part of the diet) must be complemented with "starch" that degrades very slowly in order to meet the increased needs (like those of producing milk or of late gestation) of certain animals.

1.3.3 Formulation of diets for pigs

Figure 3: A mature pig eating forage

Under modern-day intensive pig production systems the feed used generally comes in the form of concentrates that are formulated by the feed-milling industry. Such concentrates consist mainly of cereals, by-product feeds and soyabean meal. The diets are formulated taking into account: **1) the intake capacity of the animal**, and **2) the quantity and quality of different nutrients**. The feed must not be bulky and must therefore be limited in fibre.

Under tropical farm conditions, farm-produced materials used for feeding pigs are often low in protein, "bulky" or high in fibre, or high in moisture content (banana fruit, tubers, sugarcane juice). It is thus necessary to include feeds high in protein. Grass, the most available resource (leaves with more than 20%CP), is also high in fibre. Overall, the rations formulated on such farms is more likely to be more "bulky" than those supplied by commercial feed mills (concentrate feed). A feed based on farm resources can be markedly improved by moderate gain supplementation especially in pigs not selected for high levels of animal production. Elite, "improved" breeds merit expensive feed regimes based on maize and soyabean meal.

1.4 Nutritive value of the feed

The nutritive value of a feed ingredient is evaluated by its potential to meet the nutrient needs of animals. It is recommended that farm feeding minerals, vitamins and trace elements be supplied independently of the main farm based feed ingredients used. They are a small part of the total ingredients in the final feed mix, i.e., less than 5%. Therefore, they need to be carefully dispersed if in powdered form. This is achieved by mixing the total mineral-vitamin-trace elements required in a small amount of a chosen ingredient and then spreading the mixture all over the large remainder of feed while mixing the total ration/diet. Minerals can also be in the form of ground limestone mineral mixes and salt licks. Fresh, clean water must be available to the animals at all times.

1.4.1 The fibre content of the feed

The fibre content of feed can be determined by laboratory analysis using one of the following analytical procedures: neutral detergent fibre (NDF), acid detergent fibre (ADF) and crude fibre (CF).

1.4.1.1 What is roughage?

A feed ingredient or resource can be described as roughage if it falls under the following categories:

1) the average length of the grass blades is more than 0.5 cm;

2) the fibre content is more than 450 g of NDF/kg of dry material or Dry Matter Intake (DMI) (45%NDF) or

3) the fibre content is more than 220 g of ADF/kg of DMI (22% ADF); or

4) if the fibre content is more than 220 g of CF/kg of DMI (22% CF).

The diets of pigs (unlike those of ruminants) will be lower in nutritive value if they are high in fibre (more than 15 % NDF) as this would lead to the feed being low in digestible energy (DE) content.

1.4.2 The nitrogen content of feeds

The **CP content (%CP)** indicates the potential of the feed to provide the animal with amino acids. The CP value is generally estimated by **the % N multiplied by a factor of 6.25** (this figure being an average value indicating that the molecular-mass of an amino acid is, on average, 6.25 times higher than that of nitrogen). However, all the N or CP contained in the consumed feed is not in the form of amino acids.

The ideal feed must contain highly fermentable N in the rumen [about 25g/kg of digestible organic matter (DOM)] as well as indigestible proteins (amino acids). The indigestible amino acids become digestible in the small intestine. With regards to pigs, the feed must always be composed almost exclusively of amino acids of a specific amino acid profile. Pigs and other monogastrics are not able to digest NPN, such as urea and sulphate of ammonia.

All the nitrogenous matter in the diets of animals is not protein; also the content of the CP is not an exact reflection of the amino acid content of the diet.

In the modern systems of ruminant feeding, the nitrogenous value of the feed is reflected in the digestible proteins in the intestine (DPI). With respect to pigs, this is based on the availability of amino acids in the small intestine.

1.4.3 Feed protein and nitrogen utilization by ruminants

1.4.3.1 Introduction

Nitrogen utilization involves digestion, absorption and assimilation. Nitrogen digestion in the ruminant is a two-step process—first by the microbial population in the reticulorumen and secondly by the enzymatic digestion posterior to the reticulorumen National Research Council [(NRC) 1985b]. The N content of feeds is expressed as %CP (i.e., %N x 6.25). The National Research Council (1985b) has suggested that this convention ignores the differences that exist among feedstuffs both in respect of the form of the N in the feeds and the fate of N following ingestion.

Reports on N utilization by the ruminant may be examined in three historical periods:
1) the early phase;
2) the radioactive N time; and
3) the post radioactive N era. The early phase was characterized by accounts on how dietary N utilization occurred in the ruminant (Hobson, 1963; and Chalmers, 1963). Pilgrim et al. (1970), in Australia, began the radioactive N phase with the use of $^{15}N_3$. During this period quantitative data on N cycling were obtained. Other major reports of this period were by Mathison and Milligan (1971), in Canada, and also, in Australia, by Nolan and Leng (1972), Nolan, Norton and Leng (1973, 1976). These workers all contributed to the understanding of how much of the N was digested in the different locations in the digestive tract and what quantities therefrom went into producing body tissue and excretory products.

This review of N utilization covered sheep [*Ovis aries*] (NRC 1975, 1985a), goats [*Capra hircus*] (NRC, 1981), dairy cattle [*Bos taurus*] (NRC, 1978), and beef [*B. taurus, B. indicus*] (NRC, 1976a; 1984b), cattle (NRC 1975, 1985a, 1981, 1978; 1976a, 1976b). The ARC (1980 and 1984) and NRC (1985b) have produced comprehensive reviews embracing all ruminant species except the water buffalo [*Bubalus bubalis*]. In the review herein, most of the references cited on N utilization have been from work done on the first three ruminant species mentioned above. However, based on the work of Ludri and Razdan (1980) it may be assumed that the generalized N utilization concepts developed for other ruminant species may be applicable to the water buffalo.

1.4.3.2 Sources and forms of nitrogen or protein for the ruminant

Dietary N or CP for feeding to ruminants may be obtained from plant and animal material or from crystalline organic and inorganic compounds. However, regardless of the source of the N there are two broad chemical forms of dietary nitrogen fed to the ruminant. These are **protein N** (or true protein or pre-formed protein) and **NPN**.

Protein N or true protein refers to N-containing compounds consisting of molecules made up

of amino acids linked by peptide bonds. These macromolecules are called polypeptides and may contain hundreds of amino acid molecules. Some proteins contain only one polypeptide chain while others contain two or more (Lehninger 1977). Protein N or true protein is required by the ruminant animal:
1) to furnish the rumen microbes with a N source for the manufacture of microbial protein in the rumen and
2) to survive the rumen undegraded and be digested in the small intestine. In this way the ruminant is provided with a source of amino acids (Mercer and Annison, 1976).

Non-protein-nitrogen is defined by Church (1977) as any compound that contains N which is not presented in the polypeptide form of precipitable protein. Organic NPN compounds include ammonia, amides, amines, and some peptides. The NRC (1976b) has listed as NPN sources - urea, ammonium salts of both organic and inorganic acids, biuret, cyanuric acid, and triuret. Some feed N sources, contain variable amounts of NPN in particular plant protein sources may contain some of their N in the form of NPN (Van Soest, 1982; Church 1984b).

In formulated feeds NPN usually refers to urea (or, to a lesser extent, such compounds as biuret, ammonium phosphate, and ammonium sulphate) or any inorganic form in N which can be incorporated into ruminant diets as a source of dietary N or CP (NRC, 1976b; Church, 1984b). Non-protein-nitrogen is usually used in formulating ruminant diets in instances where N content of the feed ingredients used is low, or to balance dietary N concentration.

1.4.3.3 Nitrogen utilization by the ruminant

A number of authors (Annison and Lewis, 1959; Chalmers, 1963; and Hobson, 1963) developed an early understanding of the pathway of N and protein in the ruminant. They held that, in ruminants, much of the food N, whether protein or non-protein in nature, is synthesised by bacteria into their own cellular proteins, the protozoa utilize bacterial protein for their growth, and the ruminant host animals digest the symbiont protozoal animal protein and remaining bacterial protein.

Pathways of N utilization by the ruminant have been described by Annison and Lewis, 1959; Preston, 1970; Mercier and Annison, 1976; and NRC, 1985b. They are outlined in Figure 4. Quantitatively, N metabolism differs for each animal species depending on their physiological states and level of production. Owens and Bergen (1983) stated that 40 to 80% of the CP reaching the duodenum is microbial CP (MCP), the quantity of which is dependent on several dietary and host animal factors to be explained later.

Loosli et al. (1949), Oltjen (1969), and Virtanen (1966) showed that amino acid synthesis took place in the rumen which made it possible for ruminants to grow and to give milk when fed on rations that were devoid of amino acids. However, ruminants require the same essential amino acids (EAA) as other mammals, and the balance of EAA absorbed from the gastro-intestinal tract may, at times, determine the relative importance of one or more of the known pathways (Preston, 1970). Further, the EAA pattern of MCP has a biological value of 66 to 87% and sometimes the ruminal MCP yield may not meet the EAA needs of high-producing ruminants (ARC, 1980 citing Weller 1957; and Huber and Kung, 1981). However, under the conditions of integrated and intensive animal production systems on small family farms within the tropics, higher levels of animal production performances (as characterize the industrialized countries) can be traded off. This can be done if value is given to farm by-products when used as animal feeds.

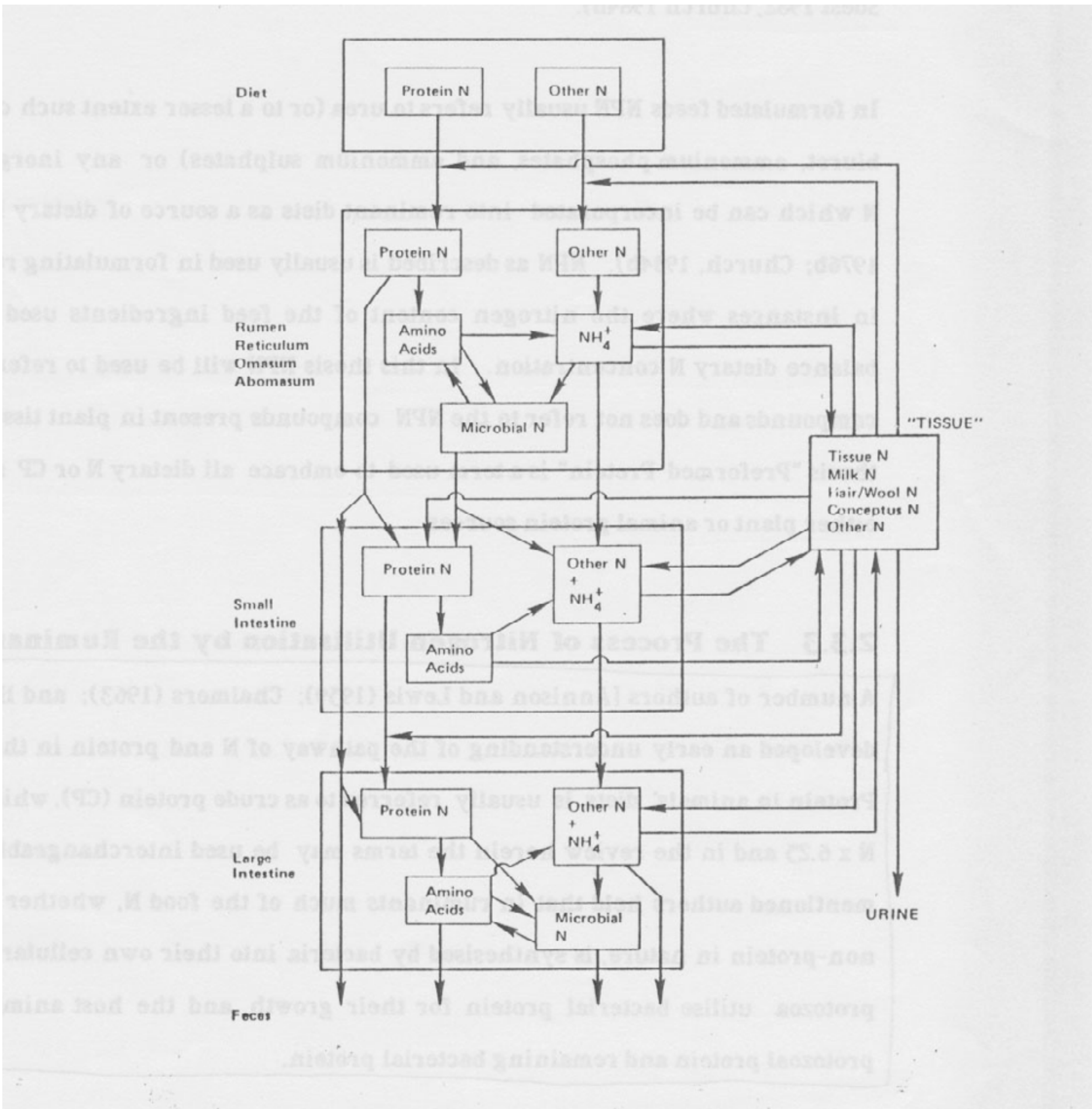


Figure 4: The Pathways of nitrogen in the ruminant (from NRC,1985b)

1.4.3.4 Factors affecting feed nitrogen utilization by the ruminant

Factors affecting feed N utilization by the ruminant are divided into animal and feed factors.

Animal factors are:

(i) The stage of growth and development/physiological maturity;
(ii) Intake
(iii) Species
(iv) Breed; and
(v) Sex

II Feed factors are:

(i) Degradability of dietary protein in the rumen;
(ii) The CP content of the diet
(iii) The energy content of the diet (energy-protein interaction); and
(iv) The NPN content of the diet (as formulated)

1.4.3.4.1 Animal Factors

1.4.3.4.1.1 The stage of growth and development/physiological maturity

1.4.3.4.1.1.1 *The pre-ruminant*

The pre-ruminant (milk-subsisting) calf has little rumen function so protein nutrition parallels that in the non-ruminant (NRC, 1984b). In these animals, N digestion takes place in the small and large intestines shown in Figure 4. In the pre-ruminant amino acid requirements can be met through the intake of protein from milk or milk replacers (Roy and Stobo, 1975). Pre-ruminant calves utilize their feed more efficiently than ruminants, faecal losses are lower and there are no fermentation losses, hence no ruminal ammonia losses. At this stage of development the usefulness of urea and/NPN are limited (Morrill and Dayton, 1978). After the rumen becomes functional at six to eight (6-8) weeks of age, the need for N for microbial fermentation in the reticulo-rumen and the need for post-ruminal amino acids for the tissues of the host must be met from forages and non-milk feeds (NRC, 1984b).

The metabolic faecal N in the pre-ruminant is reported to be 1.65gN/kgDMI for lambs (ARC, 1980 citing Walker and Cook 1967) and 1.9gN/kgDMI for calves (Roy, Gaston, Shillman, Thompson, Stobo and Greatorex, 1964; and Roy, Stobo, Gaston and Greatorex, 1970). These represent less than 5% of the N intake from milk. In the pre-ruminant, the N is utilized for growth (N, retained for body gain/wool growth), endogenous urinary N and metabolic faecal N (ARC, 1980).

1.4.3.4.1.1.2 *The growing ruminant*

Growth in young animals is almost invariably associated with a high rate of protein deposition in relation to intake of available energy. Although the actual rate of protein deposition is influenced by the adequacy of dietary protein and energy, the limits depend upon the genetic potential of the animal. Orskov (1976) indicated that the most important factors affecting the capacity of the young ruminant to synthesise tissue protein are the genetic potential, sex, stage of maturity of the animal, and the level of feed energy input. Balch (1967) and Andrews and Orskov (1970a, b) indicated that, for lambs, optimum CP concentration in the diet for early growth was related to the level of feeding and that female animals, at similar weights to males, retained less N.

Orskov (1976) pointed out that microbial protein synthesis in the rumen was strongly related to the amount of fermentable carbohydrate available. The evidence presented also indicated that, in the early stages of growth or during high growth rates, microbial protein production was insufficient to ensure maximum N retention and that this insufficiency depended largely on the level of feeding. At a particular stage of development, N retention can be met and exceeded by microbial proteins (Orskov, 1976). The stage of development (or the live-weight) at which this occurs depends on the level of performance required of the animals. Orskov (1976) concluded that, for sheep, the maximal attainable rate of protein deposition from 10 to 35kg live-weight followed the relationship

$$y = 2.3 - 0.037x$$

where x = liveweight (kg); y = gN deposited/100g DOM

After 35kg live-weight for lambs and 200kg for cattle, the maximal rate of N deposition was 0.88gN retained per 100gDOM and, from this point, microbial N produced was able to sustain growth. However, Geay (1984) concluded that protein retention reached its inflection point for cattle at about 275kg liveweight or at less than 30% of the mature body weight. But in reality, under conditions on mixed farms practicing intensive and integrated animal production (as exist in tropical countries) fattened lambs and kids are slaughtered and marketed before attaining 35kg live-weight and cattle are usually slaughtered before reaching 200kg live-weight.

1.4.3.4.1.1.3 *Lactating ruminant*

In the lactating ruminant dietary N intake must meet

i) the maintenance N requirements of the host;
ii) the nitrogen requirements for milk production (the milk proteins);
iii) for tissue growth of the dam and foetus and
iv) for gluconeogenesis and energy production
(Jacobson, Van Horn, and Sniffen, 1970; Van Es and Boekholt, 1976; NRC, 1978; ARC, 1980; and Holter, Byrne, and Schwab, 1982).

The utilization of the dietary nitrogen by the cow or ewe in the lactation cycle therefore depends on the:

i) stage of lactation;
ii) level of milk production;
iii) age of cow, ewe or doe or lactation number;
iv) reproductive status (or stage of pregnancy);
v) intake of all dietary nutrients; and
vi) breed (ARC, 1980).

A cow which has to maintain itself with zero body weight change has to meet its tissue protein requirements which are the sum of endogenous urinary N, dermal N loss, the protein secreted in the milk, and foetal tissue N retention. Milk protein production could result in the cow (a high milk producing animal) having to assimilate from 0 to 1.75kg milk CP/day with a milk production ranging from 0 to 50kg/day. van Es and Boekholt (1976) calculated that the protein utilized for maintenance of a 550kg live-weight cow was about 0.3 kg/day (or 48gN/day). When the amino acid supply from the gastrointestinal tract is too low, milk protein production may fall and/or amino acids (N) from the tissues may be mobilised (van Es and Boekholt, 1976 citing Lenkeit, 1972). This has been demonstrated to occur in high-producing cows in the first half of lactation when fed 11% CP diets (Holter, Byrne and Schwab, 1982). They also reported an association between negative N balance, low level of blood urea N and a high percentage (72%) of the apparently digested N in the milk. Their work has also indicated that the preferential way in which the nitrogen is utilized is dependent on nitrogen intake. Between 33 to 62% of the apparently digested N might be in the urine, while 38 to 72% and -5 to 25% could be distributed in the milk and tissue, respectively, for high producing cows fed diets ranging in CP from 11.1 to 20.9% in the first 22 weeks lactation (Holten *et al.*, 1982). However, during the dry phase, Van Es and Beokholt (1976) citing Lenkeit (1972) reported that up to 1kg N/day may be retained from the beginning of the dry period to just after parturition. On the other hand, dry, non-pregnant (open) cows could draw from their reserves up to 2.7kg N when the energy supply of the diet was severely reduced [Paquay, de Baere, and Lousse (1972)]. Therefore the utilization of nitrogen by the lactating ruminant is also very much dependent on the balance between protein and energy supply.

1.4.3.4.1.2 Intake

Dry matter intake data reviewed by the ARC (1980) indicated that, for both cattle and sheep, intake of coarse diets was positively related to the metabolisability of dietary energy. In addition, intake and metabolisability were affected by the form if the feed and type of the feed in terms of coarse vs. fine silage and the intake of fine diets were negatively related to metabolisability. Its recommendations indicated that, for growing cattle of 100kg live-weight and with a high level of metabolisability of dietary energy (Q=0.7) DM intake of coarse diets could be predicted to be 98.65 g/kgW^{75} and for a 100kg live-weight animal that is equivalent to about 3.12% of live-weight.

With respect to the effect of intake on protein utilization it has been shown that, for coarse diets (roughage) low in protein, the addition of N to the diets stimulates increased DM intake. The ARC (1980) also suggested that when concentrates were added to low protein roughages there was usually an increased rather than reduced intake by virtue of their higher protein content. If the intake with a low protein diet is depressed, then protein intake is also expected to be depressed. Thus, at low levels of protein intake, it can be expected that protein would be utilized to meet only maintenance needs (i.e. maintenance of the microbial population) but as zero N retention is achieved the N intake is utilized to make good metabolic faecal N, endogenous urinary N, and dermal and hair/wool N losses.

1.4.3.4.1.3 Species and breed

Ludri and Razdan (1980) reported that non-lactating (dry) water buffalo cows (*B. bubalis*) tended to show better or more efficient N retention on low protein diets than Holstein cows (*B. taurus*). At the SFC in Trinidad and Tobago, water buffalo (Buffalypso type) bulls on similar diets with grade Holstein bulls and steers tended to show lower levels of intake as a percentage of live-weight, but better feed conversion efficiencies (Garcia et al.., Neckles, Lallo and Bennett, 1991). In addition, the DE and CP intakes observed were in agreement with the recommendations of the NRC (1978 and 1984b).

The ARC (1980) suggested that there is no apparent difference in endogenous urinary N loss between pre-ruminant and young ruminant animals whether sheep or cattle (European breeds). The results presented indicated that in the young pre-ruminant the endogenous urinary N at birth and in early life appeared to be quite similar for sheep and cattle (0.06 and 0.07 gN/kg live-weight, respectively). However, it was observed that zebu cattle (*B. indicus*) had a lower endogenous urinary N excretion rate than European breeds. No data were presented to support this statement.

1.4.3.4.1.4 Sex

The ARC (1980) and the NRC (1984b) have reported that net protein gain is a multiple of the weight gain and the composition of the gain, and these are influenced by physiological maturity, sex and use of hormonal adjuvants (NRC 1985b). The effect of physiological maturity has already been discussed. A review and simulation by Fox and Black (1984), Rhor and Daenicke (1984), and Geay (1984) have shown that N utilization for meat production and N retention exhibited an interaction of species, breed and sex. The reviews of the ARC (1980), NRC (1985b), and NRC (1984b) have all suggested that the mature body size of cattle (which is heavily influenced by the breed) and the sex (intact male, steer, or female) of the growing animal are the two most important factors governing protein deposition and empty body weight gain. The reports indicate that kg CP/kg empty body weight gain is highest with intact males of large breeds and that it is lowest with females of small breeds (ARC, 1980). This suggests that within breed intact males would deposit more CP daily/kg empty body weight gain. It is also suggested that at the same live-weight an intact male would deposit more than a steer.

1.4.3.4.2 Dietary factors

1.4.3.4.2.1 Degradability of the protein in the rumen

Rumen degradable protein (RDP) or rumen degradable N (RDN) is that part of the protein or N intake which is degradable or digested by the rumen microbes. The ARC (1980) stated that RDP should be expressed as:

$$\text{RDP} = 1 - \frac{\text{Dietary Protein Entering the Duodenum}}{\text{Dietary Protein Consumed}}$$

Chalupa (1974) emphasised that the degradation of protein in the rumen can be affected by: feed processing and temperature; chemical treatment of proteins; the encapsulation of amino acids; use of amino acid analogues; the manipulation of rumen metabolism; and oesophageal groove closure. He also observed that degradability of proteins in the rumen depended on the solubility of the protein and the rate of passage through the rumen. Sniffen (1974) defined solubility as a measure of the protein (or N) which would go into solution in the rumen fluid, consisting mainly of albumins and globulins. Sniffen, Hoover, Junkins, Crooker, and Macgregor (1979) gave a conceptual approach to describing ruminant protein feeds as follows:

(a) soluble proteins, totally degraded in the rumen;
(b) insoluble proteins, partially degraded in the rumen, escape or insoluble available protein; and
(c) bond protein, lignified N not available to the ruminant animal.

Sniffen *et al.*. (1979) indicated that protein feeds formulated for ruminants varied widely in their relative composition of the above three forms of protein. Rumen degradable protein is important as it forms the source of N for microbial protein synthesis. An increase in soluble N (and RDN) intake was reported by Sniffen (1974) to result in a significant ($p<0.05$) increase in N excretion, resulting in a significant ($p<0.01$) decrease in N retention largely due to increased urinary N excretion. Additionally, the soluble N must be matched with rumen soluble or digestible dietary carbohydrate for the rumen microbes to make efficient use of the soluble dietary N in the rumen.

1.4.3.4.2.2 Methods of feed processing

Man has been able to influence the N utilization of ruminant feeds through feed processing techniques. The feed processing factors affecting N utilization are heat treatment, ensiling, protection by the use of "tannis", protection by the use of formaldehyde, coating of proteins to withstand rumen degradation, pelleting and milling.

Heat treatment

The exposure of feed materials to heat has been reported by Ferguson (1975) to make the protein more resistant to degradation. It was also suggested by Orskov (1982) that the rate of degradation of heat-dried forages in the rumen is slower than that of fresh herbage.

Ensiling

Merchen and Satter (1983) have suggested that the elevated temperatures experienced by feeds during the ensiling process may make the protein more resistant to degradation. In addition, Bergen et al., Cash and Henderson (1974) and Goering and Waldo (1974) reported that the ensiling process could also convert large portions of true protein into NPN. This may lower the amount of protein potentially available for passage from the rumen.

Use of tannins

Orskov (1982) indicated that the use of tannins as a deliberate method of protecting proteins, was attempted. Tannin forms cross-linkages between proteins and other molecules which render protein resistant to degradation. However, the use of tannin as a deliberate means of protecting proteins has received little commercial interest.

Use of formaldehyde

Protection of proteins by treatment with formaldehyde, as proposed by Orskov (1982), is probably the most widespread method of reducing the rate of rumen degradation of proteins. Orskov also suggested that different protein supplements require different amounts of formaldehyde for adequate protection and the excessive use of formaldehyde in fibrous roughages was likely to decrease both the rate and extent of rumen fermentation of carbohydrates as well as proteins.

Coating of proteins

Orskov (1982) reported that when blood was sprayed to different protein sources and the mixture was dried at 100 C there was a marked reduction of the protein degradation of the treated protein sources.

Pelleting, Steam Rolling, Flaking and Milling

These feed-processing methods, NRC (1985b) suggested, generate sufficient heat to alter the feed protein and thus affect utilization.

1.4.3.4.2.3 Feed additives

Feed additives may cause a reduction in rumen degradation of proteins. Orskov (1982) suggested that this was achieved by limiting the hydrolysis of peptides and also by limiting the subsequent deamination of amino acids. Monensin is one such substance.

1.4.3.4.2.4 The CP content of the diet

The ARC (1980), citing the work of Glover and Dougall (1960), Moir and Harris (1962), and Orskov et al.., Fraser, and Mac Donald (1972), concluded that, if insufficient degradable N was available, the rate of digestion of feeds in the rumen would be reduced. This, in turn, would result in a reduction in voluntary intake (Campling, Freer and Balch, 1962, and Orskov *et al.*, 1972) and the combined effects of a reduction in digestibility and intake would lead to a decreased energy supply and inefficient feed utilization by the ruminant animal.

Rhor and Daenicke (1984) also examined the effects of increasing the % CP of the diet, over different liveweight ranges, on liveweight gain and their findings were in agreement with the above. Therefore, as the N content of the diet increased intake and N utilization (at a given level of energy, with a given protein source, and at a given animal's physiological state) improved since the dietary % CP improved the level of animal performance obtained. However, performance was limited by the energy density of by the diet or the genetic potential of the animal.

1.4.3.4.2.5 The energy content of the diet (energy-protein interaction)

The deliberations of the ARC (1980) confirmed that animal performance at increasing levels of protein intake was limited by energy intake. Put another way, high levels of average daily gain required high intakes of protein and energy. However, as has arisen from the review by Geay (1984) the efficiency of utilization of the energy retained in the form of protein by growing cattle concluded that as the:

(a) gross energy intake increased, total energy retention increased almost linearly while energy retained as protein also increased but at a decreasing rate;
(b) total energy retained increased, energy retained as protein decreased and
(c) total energy retained increased, energy retained as fat increased.

Fox and Black (1984) described (b) and (c) above indicating that as the daily empty body weight gain (kg/d) increased, both fat and protein gain/day increased; but fat gain increased at a faster rate than protein gain/day. Rhor and Daenicke (1984) reviewed data which suggested that an increase in energy intake increased carcass gain as well as the % carcass fat in growing cattle and therefore lower % CP.

Garrett and Johnson (1983), in a review of energy utilization by ruminants, stated that research has resulted in several major advancements in the understanding of nutritional energetic of ruminants. These developments have resulted in the existing feeding standards in English-speaking countries. Garrett and Johnson (1983) forecasted that, in spite of the complexity of the ruminant animal's digestive system, continued development of the quantitative models of animal metabolism should, eventually, make the present-day feeding standards and feed evaluation schemes obsolete. In an effort to develop models Fox and Black (1984) produced one which prescribed a format for summarising, evaluating, and applying factors influencing the performance of growing cattle and for refining adjustments as new information becomes available.

Lallo (1996) concluded that DMI and N-utlization in goats were influenced by levels of energy and protein in the diet. He also asserted that N-requirements for maintenance of Caribbean goats appeared to be in general agreement with those recognized by the NRC and ARC.

Garrett and Johnson's (1983) review indicated that the efficiency of use of metabolisable energy protein synthesis was higher than that for fat synthesis. However, fat deposition (the net result of synthesis and degradation) is more efficient than protein deposition. This finding is consistent with the earlier review by Broster (1973).

1.4.3.4.2.6 NPN content of the diet

Virtanen (1966) citing Zunt (1891), indicated that, as early as 1891 it was thought that part of the protein in the feed for ruminants could consist of simple N compounds. Later, Hendricke (1976), citing Krebs' (1937) review on the basic research into NPN, in

Germany, stated that, at that time, NPN-use had few possibilities. Hendricke (1976), however, noted that, after the time of Krebs, NPN use had become accepted in the United States of America mainly because its feeding standard was based on grains while the European standard was based on roughage or green fodder. The few possibilities for NPN use by ruminants was later explained by Conrad and Hibbs (1968) who discovered that the utilization of N from NPN was a linear function of the DE intake within a wide range, regardless of the body weight of the animal. **This therefore is one of the predicaments that one is faced with when one has to feed high fibre sugarcane forage based diets.** This is why recommending farm based diets, the use of root-crop farm residuals (as sources of starch and energy), become important in satisfying and achieving animal growth performances when feeding NPN.

Virtanen (1966) reported that:

(a) urea and ammonium salts (NPN) could be the sole source of N in the diets of lactating dairy cows with no deleterious effects on the animals' health;
(b) the synthesis of bacterial protein in the rumen of lactating cows fed urea and ammonium salts, as the sole source of N, could be increased through feed adaptation to a level not only for maintenance of the cows but also for a relatively high level of milk production, with no effect on milk composition; and
(c) up to 1966, the utilization of NPN in the rumen was still not well understood.

However, Campling, Freer, and Balch (1962) observed that the administration of urea increased voluntary intake and also that urea and sucrose increased the apparent digestibility of OM and the CF content of straw in the reticulo-rumen but not in the remainder of the gastrointestinal tract. **Moreover, urea-addition to straw diets improved N retention. The effect of added urea on increasing forage intake and animal performance on sugarcane-based diets was also reported by Alvarez and Preston (1976b) and Silvestre, MacLeod, and Preston (1977a,b).** Holter, Colovos, and Urban (1968) and Holter, Colovos, Davis, and Urban (1968) observed that the inclusion of urea in diets of dairy cows significantly reduced N retention while effecting a parallel increase in the conversion of dietary N to urinary N and milk N, but milk quality and production were not affected in mature Holstein cows between 5 and 22 weeks of lactation.

Reviews of NPN utilization in ruminants in the 1970's helped to bring together the various facets of the research work and enabled the development of a better understanding of the subject. Lampilla (1972) found that, since the only known effect of urea was to increase ammonia production in the rumen, the advantage of using urea was limited to conditions where ammonia ruminal concentration would be below optimal concentrations for the rumen bacteria. **NRC (1976b) concluded that NPN supplementation was only beneficial when the %N content of the basal diet was less than 1.6% N (or about 10% CP on a DM basis).**

The literature suggests that NPN utilization is mainly a function of:

(a) **ruminal ammonia nitrogen concentration;**

(b) **the energy density of the diet, including the source of the DE and the ratio of fermentable energy in the rumen to NPN;**

(c) **the level of CP of the basal (or urea supplement part of the) diet; and**

(d) **the source of the true or preformed protein and the extent to which it is degraded in the rumen.**

With respect to (a), Satter and Slyter (1974) found that a ruminal ammonia-nitrogen (NH_3-N) concentration of 5mg/100ml of rumen fluid were sufficient to support maximal rates of microbial growth and that increasing the NH_3-N above this amount resulted in no further increase in microbial protein production. In sheep, this maximal rates of microbial growth would occur with a diet of about 13% CP but inbeef cattle Nikolic (1976) indicated that this occurred with a diet of about 10 % CP. Roffler and Satter (1975a) observed that ruminant NH_3-N could be reduced if there was an increase in:

a) feed intake;

b) animal production; and

c) the rate of passage of the ingesta through the digestive tract.

They recorded that 5mg NH_3-N/100ml of ruminal fluid was reached sooner on low energy diets or diets that were high in fibre.

Regarding the energy density of the diet, Bines and Balch (1973) were able to demonstrate that, for growing heifers, even though urea or NPN was used to supply up to at least 45% of the N in the ration (with an N intake equivalent to an ADG of >1.2kg/day), **the limit on growth was set by the DE value of the diet. Additionally, Conrad and Hibbs (1968) reported that N utilization from NPN was a linear function of the DE intake. They also pointed out that each 100g of dietary urea required 1kg of readily fermentable carbohydrate, two-thirds of which should be starch**. Therefore, the practical use of this information in developing farm-based feeding systems, would be to include root crop wastes in such circumstances. Burroughs, Nelson, and Mertens (1975) proposed that the amount of urea that was useful in any given cattle ration was a function of Total Digestible Nutrients (TDN) (or energy content of the diet) and was as follows:

$$\text{Urea Fermentation Potential (UFP)} = (1.044\text{TDN} - \text{B})/2.8$$

where UFP = g Urea/kg feed DM consumed; and B = g protein in 1kg of feed consumed and degraded the rumen.

This can be expressed by one of three formulae as follows:

$$\text{TDN (\%)} = \frac{\text{DE (k.cals/kg)}}{3.616} \times 100 \text{ or } \text{TDN (\%)} = \frac{\text{ME (k.cals/kg)}}{4.409} \times 100$$

(Source: Ensminger and Olentine, 1978)

Or TDN (%) = %DCP + %DOM + (2.25 x % DEE)
Digestible ether extract (DEE)
[Source: NRC (1981a) citing Maynard (1953)]

With respect to the CP level of the basal diet, Roffler and Satter (1975a and b) determined that the addition of NPN to rations, resulting in predicted ruminal ammonia N concentrations greater than 5mg NH_3-N/100ml of rumen fluid were without effect. **This finding was supported by Nikolic (1976) who showed that NPN added to basal diets upward of 10 to 11% CP (on a diet DM basis) did not result in an increase in microbial protein N**. Roffler and Satter (1975a and b) also reported that the addition of NPN to low protein high energy rations caused an improved rate of gain. **However, in a lactation study, NPN supplementation did not improve milk production either from a ration that contained more than 12.5% CP prior to supplementation or one with a predicted ruminal ammonia-N concentration greater than 4mg NH_3-N/100ml rumen fluid.** Further, the source of animal or plant protein and the extent to which it is degraded in the rumen determine ruminal NH_3-N concentration as the extent to which the protein was degraded in the rumen determined the concentration of the rumen ammonia-N.

What can be learnt from the above with respect to NPN use with low energy and low protein feeds under intensive mixed and integrated small farms situations within the Caribbean and the wider tropics?

a) Best use can be made of NPN will be to bring the % CP of the diets [on a DM basis] to 10 or 12 % CP.

b) Such diets are best fed to ruminant animals which require maintenance (eg. sheep or goats in early to mid gestation in production flocks/herds or dairy cows in late gestation, if the cows are in body score 4).

c) Cows in early to mid lactation may not make good use of urea/NPN.

d) Animal selection strategies will have to be revisited, i.e., animals will have to be selected based on rapid growth, good reproduction and increased lactation in response to high-fibre and high-NPN diets. Animal selection has been based on animals' performance on high DE and high good quality CP diets [i.e., diets that have been grain-based].

e) Animal selection strategies will have to be revisited also to match the animal products with the intended cuisine of the region.

1.4.3.5 Methods of estimating the protein requirements of ruminants under production

Feeding standards for estimating the N or CP needs of ruminants have been developed in different parts of the world. The most commonly used ones in the English-speaking world are from the USA: the NRC (1984b) for beef cattle, the NRC (1978) for dairy cattle, the NRC (1975 and 1985a) for sheep, and the NRC (1981b) for goats; and from the United Kingdom the ARC (1980 and 1984) for all ruminants.

The principal approaches used in the NRC publications for determining the protein requirements of each class of cattle have been derived from the factorial method suggested by Mitchell (1929) cited by NRC (1978).

The simplified expression is as follows:

$$TCP = \frac{U+F+S+G+C}{Ep} + \frac{L}{Ep}$$

where TCP = the total CP requirement

U = Urine N x 6.25

F = Metabolic Faecal N x 6.25

S = Protein lost in skin secretions, scurf, and hair

G = Growth-deposited protein

C = Protein deposited in products of conception

L = The net protein required for the synthesis of milk protein

Ep = Represents those factors necessary to convert the sums of the net protein requirements to their equivalents in terms of dietary CP.

The NRC (1978) used the factors for the maintenance components which were calculated by Swanson (1977) for cattle. The NRC (1984b) for beef cattle has expressed the equation differently

$$CP = \frac{U + F + S + G + C + M}{D \times BV \times CE}$$

where U = Endogenous urinary-loss protein

F = Metabolic faecal-loss protein

S = Scurf-loss loss protein

G = Tissue growth protein

M = Milk proteins produced

C = Foetal growth protein

D = The true digestibility of the proteins fed

BV = Biological value

$$= \frac{\text{retained protein + metabolic + endogenous protein loss}}{\text{true digestibility of the feed}}$$

CE = Conversion of dietary to post-ruminal protection

The feeding standards developed by the NRC are formatted to be easily used by ruminant producers in North America. They appear to be very useful for the conventionally formulated feeds used in that region. However, the expanded use of NPN and unconventional feed ingredients has required some reconsideration in feed formulation. This has been attempted by the NRC (1984) for beef cattle. What proves to be useful is that all the predictive equations for estimating nutrient requirements and feed intake for cattle are given in a reference manual. Considerations have also been given to the use of NPN.

The ARC (1980) recommendations for protein requirements of ruminants were reassessed in the light of new information and the ARC (1984) supplement produced. Essentially, the recommendation of the ARC (1980) and its protein requirement tables remain the same. However, the ARC (1984) recognizes a need for further evaluation of the scheme, as feeding trials with high-producing dairy cows indicated that the ARC (1980) scheme predicted N requirements that were less than those determined by Miller (1980) and Oldham and Smith (1982) cited by ARC(1984). The ARC's (1980 and 1984) approach for predicting the protein needs of ruminants is an all-embracing one and an attempt is made to link the N needs of the ruminant to the DE and metabolisable energy (ME) contents of the diets fed. The NRC (1985b) reviewed the equations for CP retention/kg empty body weight gain proposed by ARC(1980), Robelin and Daenicke (1980) and NRC(1984b) and drew attention to the following:

a) in the 250-400kg animal weight range all three approaches resulted in similar estimates of net protein requirements;
b) the NRC (1984b) approach gave high estimates at lighter live-weights and very low estimates at heavier body weights; and
c) the ARC (1980) approach resulted in low estimates for animals of lighter weights and high estimates for those of heavier weights.

The NRC (1985b) report on ruminant N usage has built upon the concepts of the ARC (1980) and found that differences exist between the protein recommendations from the ARC (1980) and the NRC (1984b), with the ARC approach resulting in low estimates for live-weights less than 250kg and higher estimates for live-weights greater than 400kg. Both systems still adopt the principles of the factorial approach. Emphasis, however, is now placed on the ruminal and post-ruminal digestibility characteristics of the feeds.

Garcia (1988) reported that intakes of ME, calculated for growing cattle fed sugarcane based diets, compared favourably with the ARC (1980) and the NRC (1978). However, the intakes of CP did not compare favourably with those recommended by the ARC (1980).

Lallo and Garcia (1994) reported that poultry by-product meal (PBM) (the rendered product obtained from the processing of broilers consisting of meat, blood, heads and bones rendered with a high proportion of feathers) fed in association with urea was an excellent source of protein for hair-sheep fed WCS. It was able to displace 100% of the soyabean meal (SBM) required in the diets with no decrease in animal performance. They further concluded that the nutritional guidelines of the NRC (1985) for sheep seemed appropriate for confined, tropical hair-sheep provided that adjustments are made for levels of intake.

Brown (1991) found that the DE and CP intake recommendations of the NRC (1978) for lactating crossbred Holstein dairy cows were much lower than those observed in a 180-day lactation and feeding trial. The diets consisted of WCS, dehydrated leucaena forage, SBM and urea. The diets were 12.9 to 20.4 % CP on a diet DM basis and contained between 39 and 42% of total CP as NPN. It may have been likely, therefore, that the NPN was not utilized by the animal for the conversion into animal products. The average milk production/ cow was 11.4 kg/day, the mature, equivalent milk production/cow was 13.1 kg/day and the fat corrected milk (FCM) was 10.2 kg/day. Dry matter intake was 3.6% of live-weight, the average live-weight of the cows was 407 kg and the feed conversion ratio (FCR) was 1.3 kg DMI/ kg milk.

The ARC (1980) has advanced its then new approach for predicting the protein needs of ruminant livestock as a framework for future research efforts and as a means of focusing attention on factors for which additional data were required. This approach has been a very useful one for animal nutrition investigations in the tropics involving the use of unconventional forages and feedstuffs, and for helping to improve the understanding of N utilization of under-exploited tropical animal feedstuffs (e.g. cassava and leucaena forages). A limitation of the ARC's (1980) approach is that the term undegraded dietary nitrogen/protein (UDN or UDP) could lend themselves to some confusion. It is assumed that the UDN/UDP is available or digested in the small intestine. This may not happen if the feed protein, after leaving the rumen, is not digested in the small intestine. The N pathway outlined by the NRC (1985b) indicates that it is possible for the UDN/UDP not to be digested post-ruminally. In such a case the UDN/UDP calculated will not be of any use to the animal. This is borne out in the summary and recommendations of the ARC (1984) Supplement as it recommended that a correction for the N bound to indigestible fibre may have to be made in the future if it can be shown, by animal experimentation, that such a correction would give a better prediction of the UDN/UDP requirements. It would be enlightening, therefore, to determine the digestibility of UDN/UDP for the unconventional tropical forage protein feedstuffs.

1.4.3.6 Conclusion

Knowledge of protein requirements of ruminants has advanced but, at the same time, an understanding in some areas is still nebulous, for example, the N utilization of some of the high-fibre, high-protein tropical feedstuffs. These tend to be nutritional paradoxes, in that they are high in CP (>15% CP), moderate to low in DE and high in fibre (e.g. cassava, leucaena). However, it is safe to use the nutritional guidelines of the NRC (of the USA) for growing cattle, goats and tropical hair-sheep. The guidelines for lactating dairy cattle must be used with some caution.

1.4.4 The energy value of feeds

This is a feeding or nutritional concept that is sometimes difficult to explain. In practice, laboratories use bomb calorimeters to quantify the **gross energy (GE)** contained in feed. However, this value for the feed (the GE) does not represent the animal's potential to extract (ingest, digest and assimilate) this energy and convert the energy into animal products.

Forages or feed resources contain highly lignified cell walls, may resist extraction of the energy by the consuming ruminant.

The contents of **cellular carbohydrates**, especially those of starch, reflect the potential of the feed to provide **precursors of glucose** necessary for the metabolic functioning of the animal.

The real indicator of the energy value of the feed measures the energy that may be available to the animal on its digestion, that is, the fraction of the feed retained by the animal relative to the quantity of ingested feed.

Dietary values are often shown in table presentation which take various forms. The energy value of ruminant feed is expressed in **fodder unit (FU),** (by INRA the official guide on animal nutrition in France). **The FU is a reference unit, it is useful energy contained in one kg of cereal (barley).** This is a nutritional evaluation system used in France (Demarquilly, Xande and Chenost, 1978).

Within the English Language System, National Research Council (NRC) of the USA and the Agricultural Research Council (ARC) of the UK, the energy value of feeds is expressed as DE and ME. In respect of pigs and ruminants energy value is expressed in mega joules (MJ) of ME /kg of feed dry matter intake. Metabolisable energy is expressed in MJ/kg diet dry matter intake. Figure 5 describes how the feed energy intake is partitioned within the ruminant animal after the model by NRC (1981).

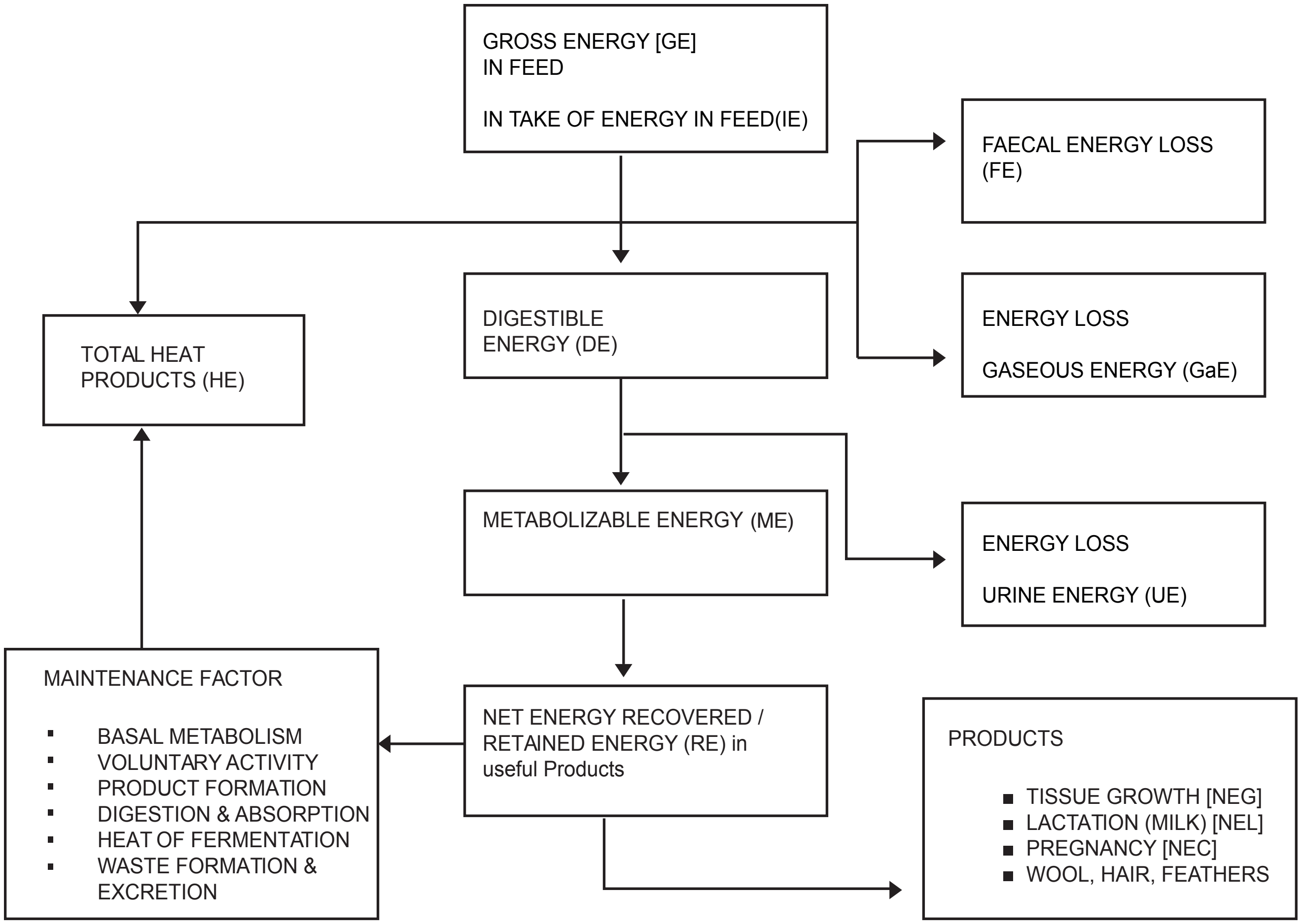


Figure 5: Flow chart of energy metabolism in the ruminant animal

[Based on the concepts proposed in NRC (1981)]

Feed expenses account for about 50 to 75% of the total cost of producing animals under intensive systems of management. Thus, factors that affect the efficiency with which animals convert feed to product have a major effect on the financial and economic considerations within an animal production enterprise or system. Under optimal conditions of environment and nutrition, the animal ingests just as much feed energy as needed for maintenance and production, and the protein taken in at the same time is also available for use. However, when an animal is kept under sub-optimal environmental conditions, its feed intake may not meet its energy and protein needs. When this happens, feed conversion efficiency, and thus overall efficiency of animal production varies considerably.

Earlier the scheme of energy utilization as developed by committees of the NRC of the USA and the ARC of the United Kingdom was described in Figure 5 attributed to NRC (1981) only. The following is an elaboration on this.

➲ Gross intake energy (IE) = the total combustible energy in the feed that an animal eats.

Feedstuffs vary in their gross energy content. Not all of it is useful to the animal, and that which is not useful represents wastage.

- Faecal energy (FE) = the undigested feed plus metabolic and microbial products in faeces. Ruminants lose up to 50% of the gross energy of roughage as faecal energy. Non-ruminants lose only around 20% of the gross energy of concentrate diets in the faeces.
- Apparent digestible energy (DE) equals IE minus FE. DE = IE - FE

This may sound more complicated than it actually is. The amount of DE can be computed by taking the total combustible IE available from feed the animal eats less the undigested or waste energy in faeces (FE) eliminated by the animal.

- Metabolizable energy (ME) is the apparent DE minus the energy in gaseous digestive products (mostly methane) (GE) and in urine (unused nutrients and from normal tissue breakdown) urinary energy (UE).

ME = DE - GE + UE

Gaseous products of digestion contain around 6% of IE in ruminants, and usually less than 1% in non-ruminants. Both kinds of animals lose less than 10% of the DE in urine.

Hence, the ME value of a diet is roughly 82% of the apparent DE content for ruminants and roughly 94% for non-ruminants.

The animal's conversion of its diet into useful energy is influenced by factors that affect the feed value of the various feeds, feed availability and voluntary intake by the animal.

The way in which intake of energy of feed is partitioned within the ruminant is further schematically outlined below.

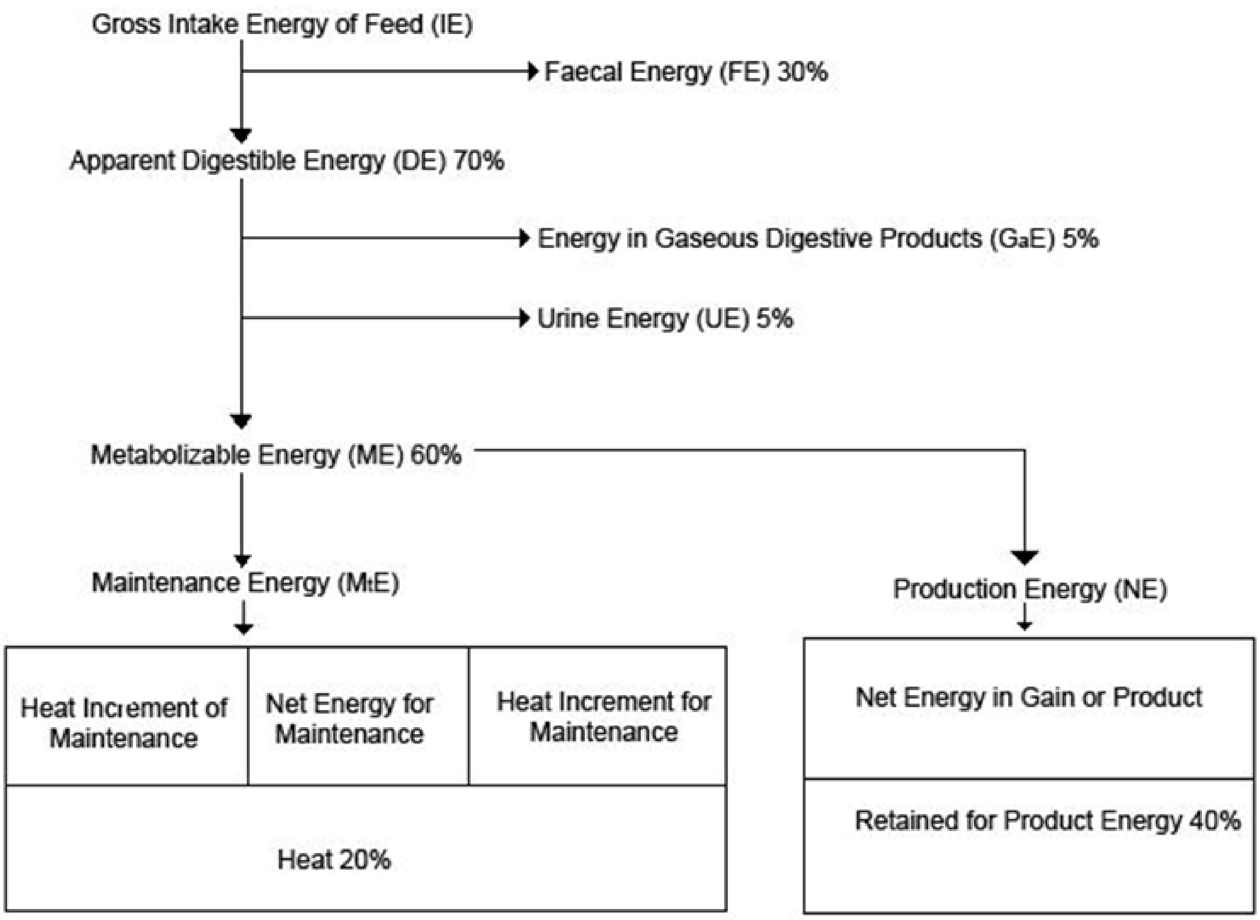
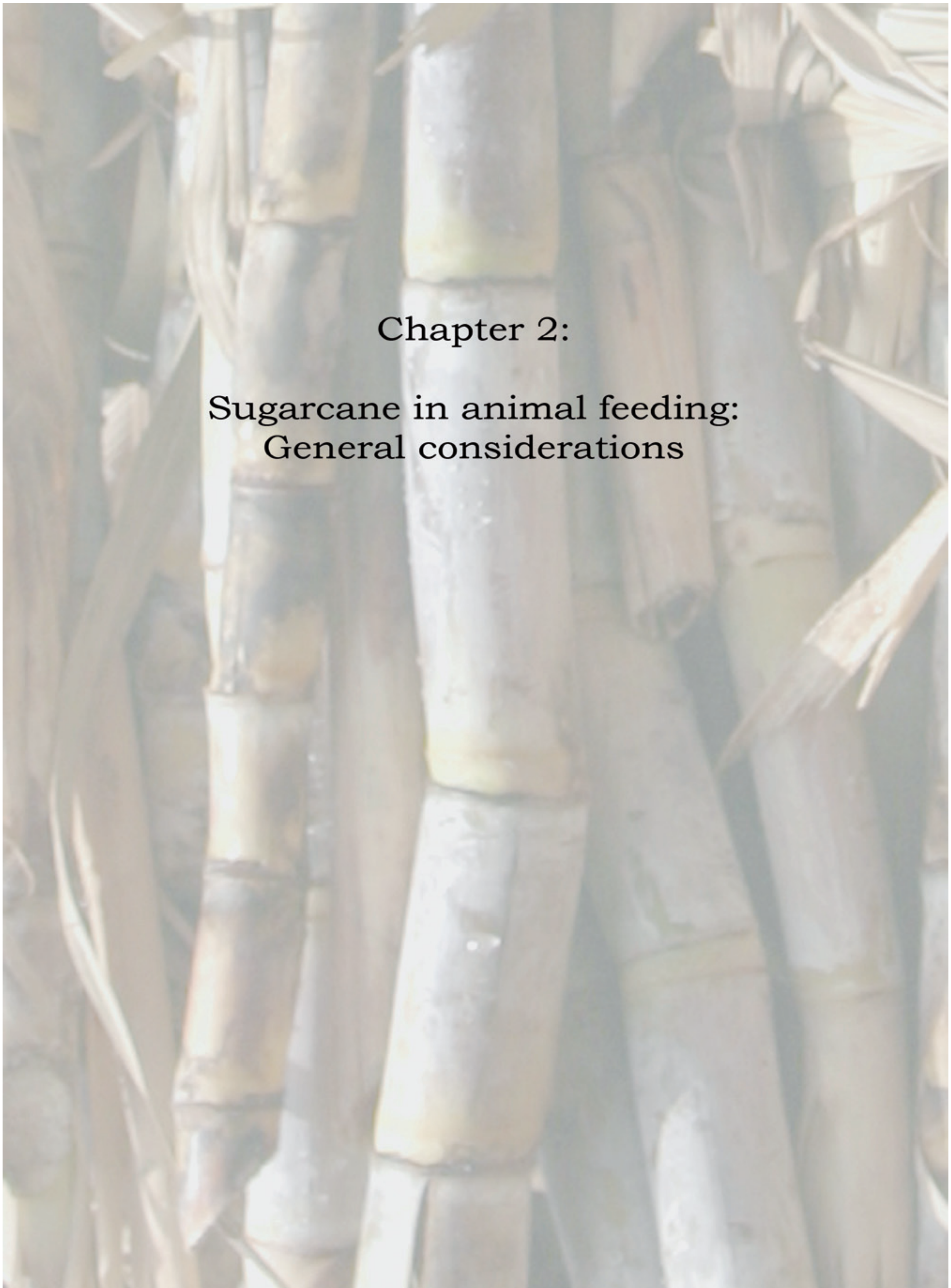


Figure 5a: A quantitative example of how the Gross Energy Intake of a ruminant is partitioned within the animal.



Chapter 2:

Sugarcane in animal feeding: General considerations

Chapter 2.0: Sugarcane in animal feeding:

General considerations

2.1 Sugarcane as a feed resource for livestock

Sugarcane (*Saccharum officinarum*) is a grass that is widely grown in the tropics and sub-tropics. Compared with other fodder grasses, it is a feed high in energy as it contains sugars stored in the stalk. It has a high biomass productivity and is able to yield up to 50 tonnes of DM/ha/annum (on Class IV soils, pH 4 and with low OM), as work at the SFC, in Trinidad, has shown. The varieties of sugarcane that have been developed were primarily for the production of sugar, no variety has been developed for use as a forage or animal feed. The traditional forages, mainly grasses, produce less than 30 tonnes of DM/ha/annum. These data are simulated and presented in Table 1. If sugarcane is to be produced and sold (either fresh chopped or ensiled as a service to farmers) the financial cost of production would be important. Therefore, this information is presented in Appendix #3.

Figure 6: Forage harvester used for harvesting and chopping standing sugarcane and erect type forages.

Table 1: Output of sugarcane relative to other forages

Method of Production		Annual Biomass Yield (tonnes DM/hectare)				
		Dichanthium **(hay)**	**Pangola Grass (*Digitaria decumbens*)**	**Maize (*Zea mays*)**	**Erect Grasses (Fodder, elephant grass)**	**Sugarcane**
Irrigated	**Fertilized**	25	30	45	60	70
Irrigated	**Un Fertilized**	12	15	20	30	45
Non Irrigated	**Fertilized**	16	20	30	40	45
Non Irrigated	**Un Fertilized**	8	10	12	20	40

(Simulated from data at INRA, Guadeloupe)

Sugarcane is also available during the dry season and it is during this period of the year that its dietary value is at its highest (King, 1985). In fact, the crop grows during the rainy season and the ripening of sugarcane (accumulation of sugars) occurs during the dry season. It is therefore strategic to feed ruminants this forage during the dry season. Unlike other forages that decrease in nutritive value with age, sugarcane's value increases with age (King, 1985). As this occurs during the dry season or the periods of the year when other forage resources are scarce, sugarcane thus becomes a "standing" forage resource or silo. In the dry season it is not absolutely necessary to dry it as it can be preserved or conserved in the same way as other grasses, in the form of silage.

Sugarcane, as its name indicates, can produce between 5 to10 tonnes of sugar/ha, annually. Sugar, like most cellular carbohydrates, are effectively used by non-ruminant livestock (pigs, ducks, geese) and can replace some of the starch in the traditional cereal-based feeds (Parris, 1976). With regards to the DE value, the production of sugars per hectare from sugarcane is higher than the production of cereal-based starch.

2.2 The dual role of sugarcane as a livestock feed

There are at least **two [2]** possible alternative strategies for using sugarcane in animal feeding:

> **1) In ruminants: the plant, as forage, can be used as a significant source of energy for ruminants during the dry season [Dry season feeding to ruminants]** (Neckles and Garcia, 1989).

Table 2 outlines different strategies for using sugarcane forage (fresh chopped and ensiled) in ruminant production systems. The different strategies for growing beef and dairy cattle are premised based on the Feeding Models outlined in Appendix #2.

On average, 0.08 hectare of planted sugarcane is necessary on 1.0 ha of pasture land when the dry season is two months in duration. Table 2 simulates different scenarios (developed by INRA) in relation to the length of the dry season, the area devoted to pasture and that to be planted in sugarcane. In this simple strategy sugarcane is used as supplement to the reduced forage production exhibited by other grass species. In general the proportion of sugarcane in the diet depends on the desired animal performance objectives.

2) In pigs and ruminants: the sugarcane plant fractions and/or processed products as the main feed resource.

This role is more complex than the first as it involves year-round feeding of sugarcane to species with different digestive systems (as discussed earlier). This case will be developed in the "conceptualization of the farming system" Chapter 3, Figures 19 and 20. It will thus be necessary to reduce the concentration of sugars in the sugarcane at certain periods in the year (rainy season) or opt for certain forage conservation technologies.

Table 2: Suggested ruminant animal production systems using sugarcane as the forage

Feeding System	Age cane included in diet	Liveweight range (kg)	Forage Feeding Regimes		Notes
			Dry Season	Wet Season	
I. CATTLE PRODUCTION SYSTEMS USING SUGARCANE AS FORAGE*					
1. Zero-grazing (SFC system)	35 days (fed to early-weaned calves)	50kg to slaughter	Fresh chopped	Ensiled	Beef from dairy-bulls
2. Finishing only	6 months more	150kg to slaughter	Fresh chopped	Ensiled	Based on a feeder bull industry
3. Dry-season supplementary use	All animals >5-6 months	>150kg	Fresh chopped or ensiled	Pasture	Sugarcane fed until pasture production is adequate
II. COWS MILK PRODUCTION SYSTEM USING SUGARCANE AS FORAGE					
1. Zero-grazing (SFC system)			Fresh chopped	Ensiled	Suited to land limited areas
2. Sugarcane/pasture systems			Ensiled or fresh chopped in dry season	Grazing or ensiled sugarcane	Relative importance depends on climate/individual farm circumstances.

* A system for the production of mutton would be similar to this one.

Source: Neckles and Garcia (1989)

Table 3: Area (ha) requirements of planted sugarcane in response to forage on different sized farms related to the average length of the dry season.

1		Proportion of forage area to be planted in sugarcane, in ha				
		2	3	4	5	
Total area of forage on the farm (ha)	1	0.04	0.08	0.12	0.16	0.20
	2	0.08	0.16	0.24	0.32	0.40
	3	0.12	0.24	0.36	0.48	0.60
	4	0.16	0.32	0.48	0.64	0.80
	5	0.20	0.40	0.60	0.80	1.00
	6	0.24	0.48	0.72	0.96	1.20
	7	0.28	0.56	0.84	1.12	1.40
	8	0.32	0.64	0.96	1.28	1.60
	9	0.36	0.72	1.08	1.44	1.80
	10	0.40	0.80	1.20	1.60	2.00

2.3 Sugarcane products for use in animal feeding

By fractionating, sugarcane offers a range of component products for feeding, some better suited to different species. Donefer (1981) outlined the experiences with the Canadian Sugarcane Separation Technology that produced “comfith” or “sugar-fith” (stem pith containing sugars) and the sugarcane fibrous rind. The sugarcane separation or fractionating has two distinct approaches. These are:

1) Fractionation or separation by pressing or squeezing the whole sugarcane stalk **[Simple Technology]** to produce **(a) sugarcane juice** and **(b) fibre or bagasse**;

2) Fractionation or separation by the use of “Derinding Machines”**[Complex Industrial Technology]** to produce **(a) “comfith**” or “sugar-fith” and **(b) rind or long sugarcane fibres**.

The latter technology seems appropriate to locations or situations where the rind could be made use of in the making of particle board. As this is a manual specifically for small to medium scale farmers the latter sugarcane separation technology will not be given any attention herein.

The range of animal feed products that can be obtained from sugarcane includes:

- whole sugarcane/Whole Chopped Sugarcane (Figure 6 shows a sugarcane forage harvester)
- tops, forage
- juice (sugars) (Figure 7)
- molasses (residual sugars often from the sugar factory processing)

- straws
- bagasse and
- “comfith” or “sugar-fith”.

The relative value of these products in comparison with other feed resources is shown in Figure 8. The chemical composition of the main sugarcane products are presented in Tables 4 and 6. Appendix #1 also contains a description of “sugarcane feeds” that includes nomenclature and nutritional information assembled by Donefer and Latrille (1980).

Figure 7: Sugarcane roller juicer at the SFC, Trinidad

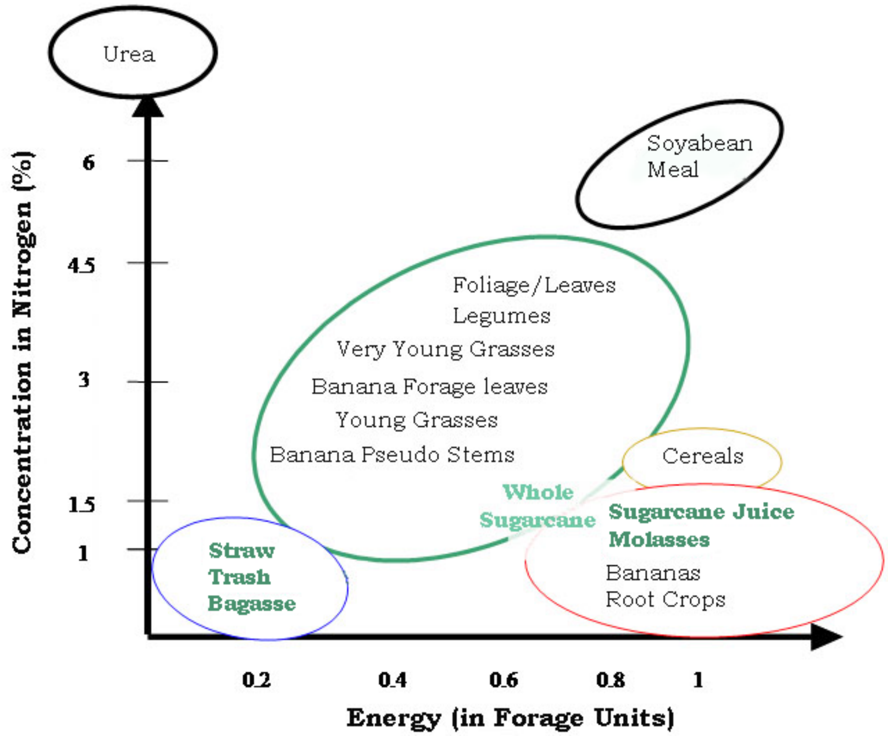


Figure 8: The relative value of sugarcane and its by-products compared to other feeds.

Table 4: Chemical composition of SDF feed resources

Analysis	Whole sugar-cane	Stalk	Sugar-cane tops	Juice	Bagasse	Molasses
Dry Matter (%DM)	30-33	30-32	27-32	18-20	50-70	72-76
#Organic Matter (%OM)	92-94	94-95	90-93			
#Minerals (%DM)	6-8	5-6	7-10	1.5-2.5		14-16
#Total CP (%DM)	2.5-3	1.5-2	4-7	1.2-1.6	2-4	2 to 4
#Crude Fibre (%CF)			33.5			
#Neutral Detergent Fibre/ (NDF) (%DM)	58-65	47-48	62-68		86-88	
#Acid Detergent Fibre/(ADF)(%DM)	31-33	28-38	38-42		54-56	
#Acid Detergent Lignin/(ADL)(%DM)			4-6		9-11	
#Neutral Detergent Soluble/(NDS)(%DM)			32-37	73-75		73-75

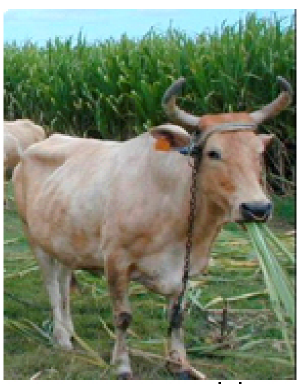
#On a dry matter basis

Feedstuffs directly derived from sugarcane are poor to very poor in **N** content and therefore are very low in **CP**. Some are very high in fibre (bagasse, sugarcane tops, stalks, and whole sugarcane), while others have no fibre (juice and molasses) [Tables 4 and 6].

Ruminants, through their digestive system and associated microfloral population, are capable of converting WCS, sugarcane tops, sugarcane straw and bagasse to animal products. Non-ruminants are better able to utilize sugarcane juice and molasses.

However, these alternative product choices are not the only options for utilization. For example, mixtures of whole sugarcane and molasses; whole sugarcane and juice; sugarcane tops and juice; sugarcane tops and molasses; and bagasse and molasses can lead to diets high in DE that promote production from ruminants. In pigs, the opportunity for leeway is limited; but the sugarcane stalks can be incorporated to a limited extent into the sugarcane diets.

In summary, sugarcane and its various products can be utilized by both ruminants and non-ruminants.



Source: INRA Guadeloupe

Source: Lylian Rodríguez y Thomas R Preston, University of Tropical Agriculture- TOSOLY – Colombia

Figure 9: Pigs being fed sugarcane juice and cows being fed sugarcane tops

These two classes of animals have complementary capabilities in utilizing the two main fractions of the sugarcane plant (the sugars and the fibre). The ideal use of sugarcane would be to fractionate the plant and offer each class of animal the parts of the sugarcane that it can best use.

The consumption of bagasse by livestock, except at low levels, is not the best way to use this product as its low available energy renders it very deprived of nutritive value. However, it can be used as bedding litter and organic manure for fertilizer or for producing energy on the farm.

Figure 10: Pig eating whole sugarcane and the uningested sugarcane fibre being utilized as litter or bedding to absorb the urine and faeces.

Figures 10 and 11 demonstrate how whole sugarcane can be offered to pigs with some concentrate feeds. The pigs chew the whole sugarcane stalk, swallow the juice containing the sugars and spits out the fibre. The fibre then becomes the bedding to absorb the urine and the faeces. After the pigs have been marketed the bedding can be removed and used as organic matter for the sugarcane and other crops.

2.4 Limitations of sugarcane-derived feeds (SDFs)

Regardless of the animal species selected, the main limitations of SDFs are low CP, minerals and vitamins content. It is then necessary, for successful feeding, to complement SDFs with other ingredients high in N, minerals and vitamins. The bagasse, sugarcane straw and sugarcane tops are also low in energy but high in indigestible fibres or CF. This is the reason why the whole sugarcane stalks fed to the pigs, as described earlier, can help to generate another product, i.e., organic matter (OM).

Figure 11: Pigs eating whole sugarcane and the uningested sugarcane fibre being utilized as the litter or bedding to absorb the urine and faeces.

Figure 12: Piglets suckling sow fed sugarcane on the litter of bagasse.

2.5 Feed supplements for ruminants

As stated earlier the feeding of ruminants entails first the feeding of the microbes.

The strategy for the microbe nutrition

The strategy for ruminants is to enable or to facilitate the microbes in the ruminoreticulum, to be able to produce the maximum amount of microbial protein from NPN (urea and sulphate of ammonia). Simultaneously, however, it is necessary to supply high quality **by-pass protein**, indigestible in the ruminoreticulum but digestible in the small intestine. By-pass protein can be in the form of SBM, leaves and forages high in N, e.g., legumes such as gliricidia (*Gliricidia sepium*) and leucaena (*Leucaena leucocephala*), tricantera (*Tricantera gigantea*), Acacia (*Acacia mangium*), and other forages such as sweet potato (*Ipomea batatas*), cassava (*Manihot esculenta*), and moreria/ mulberry forage (*Morus sp.*) (Figures 13, 14, 15 & 16).

Urea diluted in water can be mixed at the rate of 35 g /kg of bagasse, straw and sugarcane tops. An energy supplement (molasses, banana, potato, rice flour, and/ concentrates) and a N supplement (soy or its equivalent) are also essential.

CAUTION*!!* ***An animal must not ingest more than 3g/day of urea for every 10 kg of their body weight. The reason is that the urea or NPN is rapidly converted into ammonia in the ruminoreticulum by the microbes. If there is insufficient VFAs available the microbes will be unable to utilize the ammonia and the excess ammonia will be absorbed into the bloodstream and the animal will die from urea or ammonia toxicity***.

Urea can also be mixed with the WCS at the rate of 10g of urea/kg of fresh sugarcane matter. Once the urea is incorporated it is also necessary to supply 30 to 100 g of SBM/kg of fresh sugarcane.

The substitutes for SBM are potentially numerous. These are all the available materials that are high in N: the leaves of gliricidia, leucaena, erythrina, sweet potato, sweet or bitter cassava, peas, rice polishings, fish meal and other agro-industrial by-products. There is an abundance of fish waste and waste fish throughout CARICOM fishing villages. However, fish meal cannot be used in the French West Indies [which is part of the European Union] as the use of animal by-products or animal waste as animal feed is prohibited by law.

On average, 300g of commercial feed concentrate [15% CP] must replace 100g of SBM. About 1 to 2 kg of fresh leaves that are high in N could replace 100g of SBM.

Figure 13: Gliricidia [*Gliricidia sepium*] planted in pure stand hedges and from which forage is harvested every eight weeks.

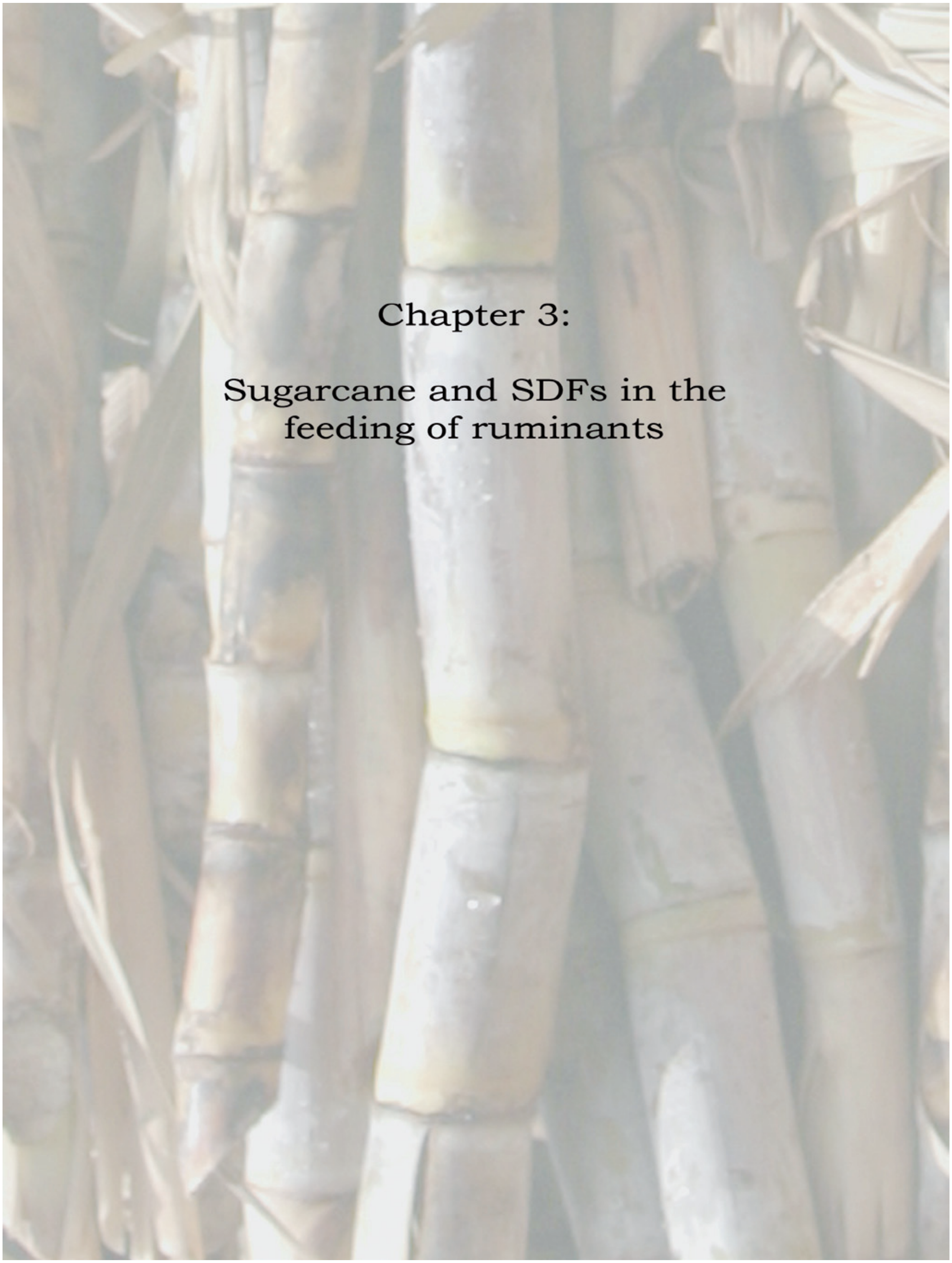
Figure 14: Tricantera [*Tricantera gigantea*] planted in pure stands at Centeno Livestock Station in Trinidad, Trinidad and Tobago; it withstands drought, flooding and fire.

Figure 15: Dr. Francis Davis and *Acacia mangium* hedge at Centeno Livestock Station in Trinidad, Trinidad and Tobago

2.6 Feed supplementation for growing pigs

Molasses and sugarcane juice are the products likely to be best utilized by pigs. Sugarcane juice can be used to replace cereals as a source of energy in the diet of pigs after 25kg live-weight is attained. Molasses is only a partial substitute. It is also necessary to supply high quality proteins to pigs and SBM is a reference feed as its profile includes amino acids that correspond to the needs of pigs. It is necessary to supply 200 to 400 g/day of SBM to achieve satisfactory ADGs. The soya bean meal can be replaced by other sources of proteins but the possibilities are limited. These are, for the most part, products of the agro-industry and certain leaves (cassava, potato, erythrina, moreria or mulberry forage). It is necessary to use younger leaves that are highest in protein and that are the least lignified.

Figure 16: Cassava leaves



Chapter 3:

Sugarcane and SDFs in the feeding of ruminants

Chapter 3.0: Sugarcane and SDFs in the feeding of ruminants

3.1 Whole chopped sugarcane

3.1.1 General considerations

The composition of the WCS varies with the stage of maturity (Figure 17). The N content is highest when the plant is very young (growing, vegetative stage), but, the highest sugar (energy) content is found in the mature plant. On the other hand, the voluntary feed intake [VFI] and digestibility vary very little with age/stage of maturity of the sugarcane (Figure 18). Mature sugarcane (10-12 months of age) should be used for feeding to ruminants because of its higher DE level.

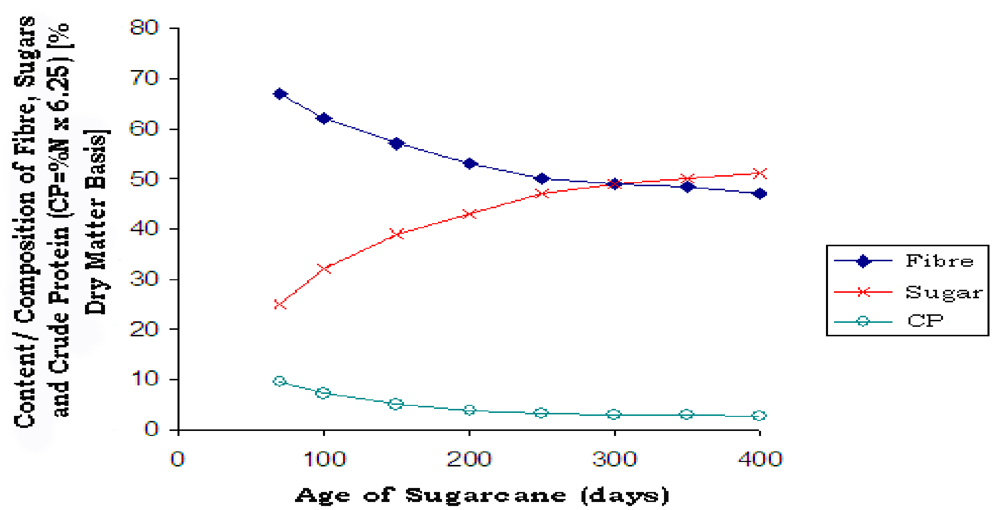


Figure 17: Changes in the composition of sugarcane at different ages [stages of growth] (Preston, 1976)

If the farm only has ruminants, the whole sugarcane with its leaves can be fed (dry season feeding to ruminants). If pigs or poultry (particularly ducks and geese) are to be fed, it is best to reserve the sugarcane tops with the uppermost quarter of the stalk, which is unripened and has less sugar for the ruminants (Figure 19) while the juice extracted from the remainder of the stalk will be of higher value and better feed to the pigs.

Figure 20 schematically displays how sugarcane, agro-industrial by-product feeds and farm-grown feed resources could be integrated to produce animal products. In this way a crop-producing farm could engage in the feeding of sugarcane to animals to obtain added value from the nonmarketable products.

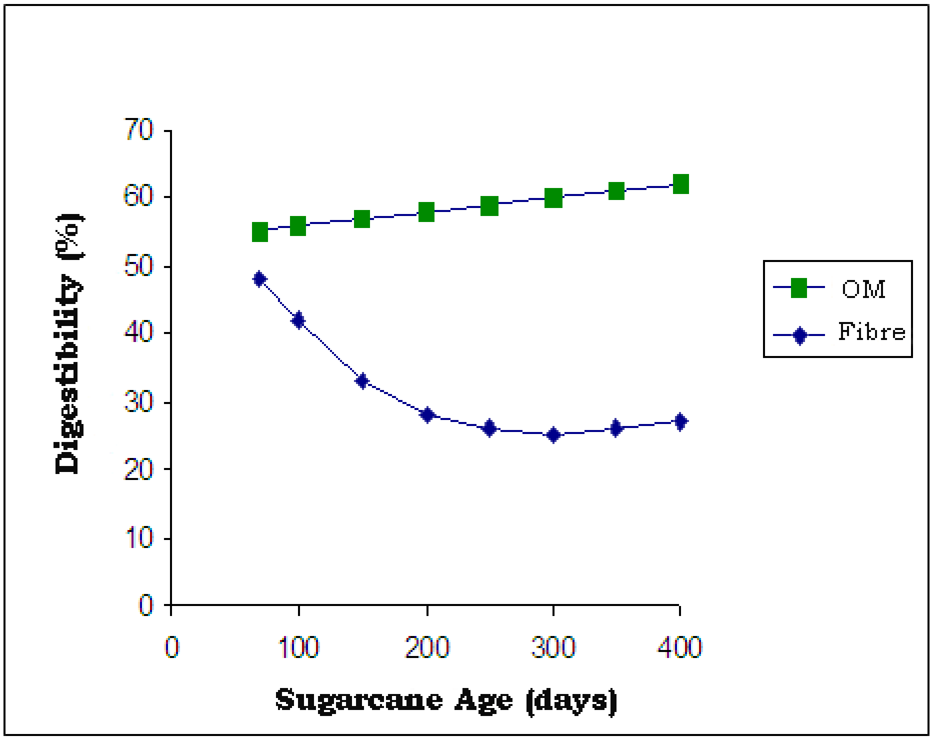


Figure 18: Changes in the organic matter [OM] and fibre digestibility of sugarcane (energy fractions) with age (Preston, 1976)

Sugarcane is of best nutritive value when mature and freshly harvested. In order to avoid the loss of sugar, it must be crushed or chopped in less than three days after harvest. Once chopped, the sugarcane must be used the same day.

There are different types/sizes of machines that can be used for chopping/grinding sugarcane. They all need to be rugged enough to deal with the hard rind of the sugarcane stalk, grinding or chopping at least 2 to 4 stalks at a time.

Any chopper used must be powerful (speed of the rotation of the knives) so that the whole plant is cut into particles (instead of being shredded), especially when it is intended as feed for small ruminants. Choppers are typically operational in stationary mode (in a “feed processing area”) with the sugarcane or other forage material brought to the machine for chopping. They may be powered by diesel, gasoline or electricity. In some suitable situations, in areas where the sugarcane has been planted on land suited to mechanization, the forage may be harvested and simultaneously chopped by an infield tractor-drawn forage chopper.

A supply of NPN in the form of urea or sulphate of ammonia, must be mixed with the sugarcane in order to promote optimal digestion.

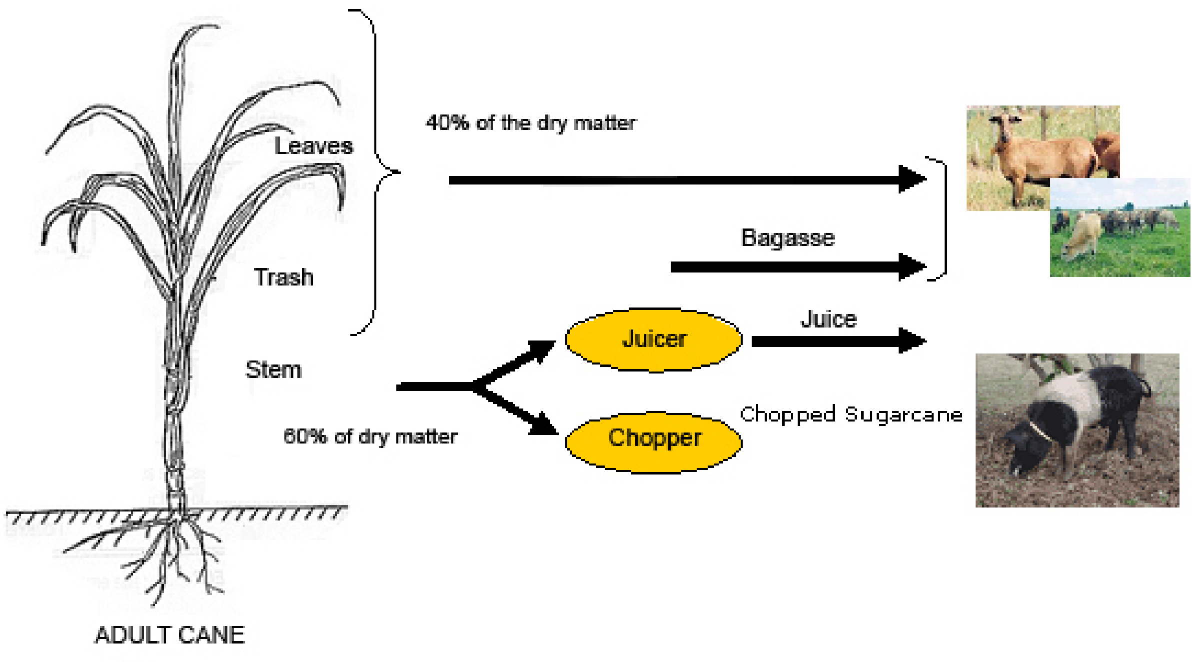


Figure 19: Fractionation or separation of the sugarcane plant and the feeding of the plant fractions to different animal species.

Sources of protein supplying N (soy, concentrate feeds), a source of starch, mineral and vitamin supplements must be available and fed before the distribution of the sugarcane in order to prevent wastage.

The NPN can be supplied in the mix earlier described above. The following forages can be used as sources of protein in sugarcane based diets: cassava (*Manihot esculenta*), potato (*Ipomea batatas*), gliricidia *(Gliricidia sepium*), erythrina/immortel (*Erythrina* sp), and leuacaena (*Leucaena leucocephala*). This is also the case with certain fodders crops (fodder peanut, Stylosanthes…). In this case, it is not necessary to distribute urea. In the absence of forages, the least expensive source of NPN is urea. Other sources of proteins can be produced on the farm, such as different types of peas. This is elaborated on in section 5.7.

Soyabean meal is the most balanced source of protein supplying N. There arealso factory-blended commercial supplements. These are high in proteins (18 to 20% CP). Special supplements can also be formulated for use with sugarcane derived feeds. When traditional concentrate feeds high in proteins or sugarcane supplements are used, they already contain sources of starch.

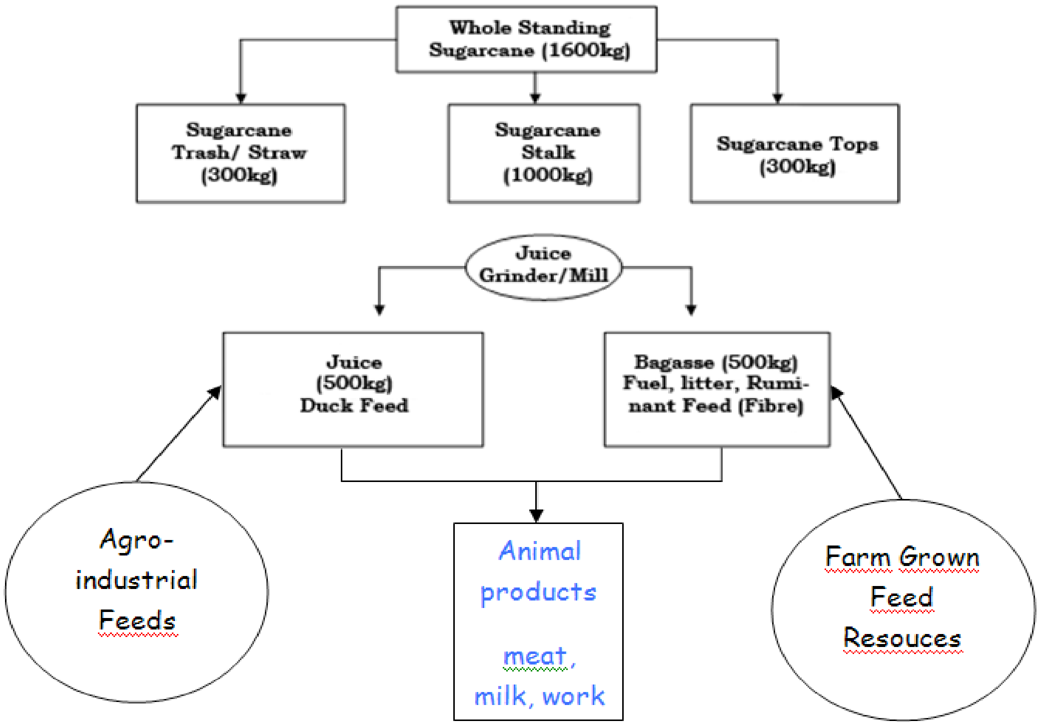


Figure 20: Linkages between sugarcane feeds, agro-industrial by-product feeds, farm grown feeds and animal products.

Figure 21: A stationary chopper for processing small quantities of sugarcane.

Rice bran is a good supplement for sugarcane as the bran supplies both proteins and starches, but this may be only readily available in Jamaica and the Guyanas. **Sources of farm-grown starch could come from rejected green bananas, cassava and sweet potato, tubers and breadfruit.**

The N or protein supplement is the most expensive ingredient in the diet. The quantities of N or CP to be supplied in the diet will depend on the desired animal growth rates, the source of N itself, the characteristics of the sugarcane and the nature of the concentrates available.

The most favourable source of N is NPN in order to make the best use of the microbes in the reticulo-rumen. Non-protein-nitrogen must, however, be supplied only in limited quantities [e.g., 10g urea/kg of fresh sugarcane]. The quantity of by-pass protein needed is of the order of 0.25g/ 1g of growth with cows and 0.75 g/ 1 g of growth in goats. The proportion of sugarcane in the diet depends on the animal performance objectives. The potential for growth in creole animals can be achieved with more than 60% of sugarcane in the diet (Figure 22 and 23)

Pate (1981) working in Florida, USA, showed the relationship between quantity of sugarcane in the diet DM and the ADG of growing cattle (Figure 22).

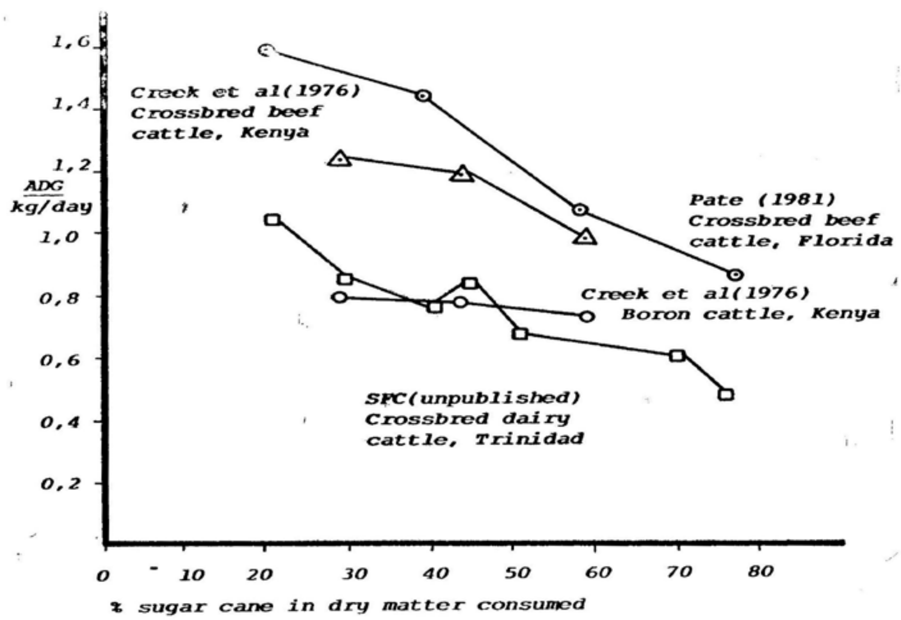


Figure 22: The relation between the quantity of sugarcane in the diet (% DM) and the average daily gain (kg/day) of growing cattle Source: Garcia, Neckles and Lallo (1990).

The results at the Sugarcane Feeds Centre [SFC], Trinidad and Tobago, with the year-round feeding of sugarcane to dairy and beef cattle and water buffalo also demonstrated this inverse relationship between level of sugarcane in the diet and daily milk production and live-weight gain (Neckles and Garcia, 1987, Brown, 1991). This has also been observed with dairy goats as the inclusion of WCS linearly decreased milk yield, without affecting milk composition when the level of sugarcane went from 0, 10, 20, 30, and 40% of the diet (Cabral *et al.* 2009). With tropical hair sheep Lallo *et al.* (1991 a, b) reported similar experiences. At levels of 29, 41.9, 48.3 and 56.7% WCS in the diet DM intake the average daily gains were 190, 200, 160 and 120 g/day (Table 5). This suggested that WCS could be included to form about 40% of the diet DM intake in the diet of growing tropical hair-sheep. Archimedè (2008) had similar results of declining live-weight gain with increasing energy levels in the diet. In this instance the animals were sheep of the local Matinik breed (Figure 23).

Table 5: Dry matter intake (DMI) and growth performance of crossbred lambs fed four (4) levels of WCS.

	A	B	C	D
WCS offered (g/kg DM)	290	419	483	567
Feed intake:				
WCS (g/kg DMI)	281	391	451	551
DMI (kg/d)	1.42	1.19	1.10	1.05
DMI (kg/100 kg wt.)	4.27	3.70	3.70	3.78
Feed (kg/kg gain)	8.80	8.50	6.90	10.50
Initial wt. (kg)	20.1	20.4	20.3	20.8
Final wt. (kg)	41.2	42.2	37.0	33.4
Daily gain (g/d)	190	200	160	120

Source: Lallo, Garcia and Neckles (1991b)

When animals of higher growth potentials are being fed and are properly housed to reduce environmental (thermal) stress, farmers can expect to obtain higher levels of performances as shown in Figure 22.

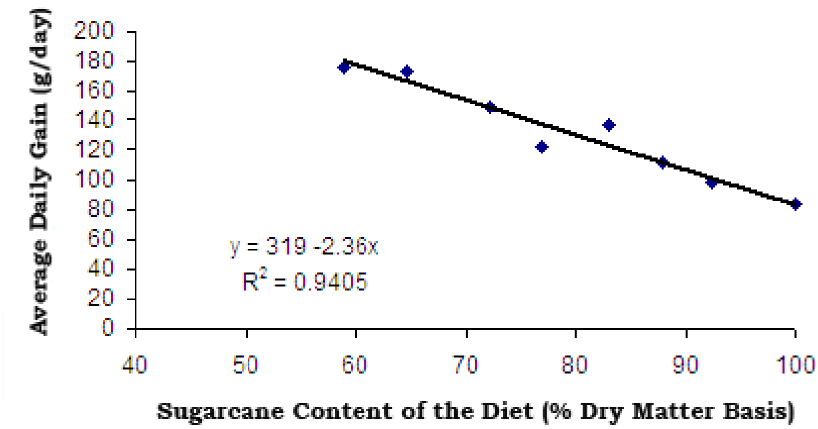


Figure 23: The relation between the quantity of sugarcane in the diet (% dry matter basis) and the average daily gain (g/day) of Martinique sheep. Source: Archimedè (unpublished).

A practical limitation when feeding sugarcane to ruminants is that it must be chopped daily. There are two solutions: the drying the sugarcane or turning it into silage. It has been reported that sugarcane silage is being extensively used in the state of Minas Geiras, Brazil, Anon (?). In 1998, 15,000 dairy farmers cropping 21,500 ha of sugarcane eliminated the seasonal declines in milk production using sugarcane plus urea and sulphur. The use of the sulphur was to balance the ration in order to have a 10:1 S:N ratio.

During the severe dry seasons experienced during the last five (5) years in Jamaica (2005-2010) the Surge Island Dairy, milking about 1600 cows/day, has resorted to the use of sugarcane in the diets of lactating cows to avoid low biomass availability and intake from pastures. The sugarcane was offered fresh, chopped daily (Lloyd Wiggan, Personal Communication).

Whichever option is chosen, it must be a choice for an extended period. It is not recommended that frequent changes be made in the basic diet, as a period of adaptation is necessary.

The drying process must be rapid (24 hours) in order to avoid fermentation and the reduction of the quantity of sugars. Drying is technically possible but costly if the farm does not use renewable energy. The simplest solution entails drying by the sun. In order for the drying process to be quick, it is necessary to spread (e.g., on a tarpaulin) the chopped sugarcane in a layer no deeper than 4 cm. Turning 2 to 3 times daily is necessary and the material needs to be brought inside at night to prevent condensation of moisture. The process is repeated the following day if the material is insufficiently dried. Storage is then done in a covered, secured area. The drying process can also be done through the use of biogas that can be produced on the farm. The benefit of sugarcane over other grasses is that it is available during the dry season. During that season the sugarcane's nutritive value is at its highest.

Athanassof (1917) reported on the use of sugarcane in the feeding of dairy cattle at the Escola Agricola Luiz de Quieroz, in Piracicaba, Brazil. He also advised feeding fresh, chopped sugarcane during the dry season to dairy cows (Athanassof, 1940 as reported by Gurria, 1978). Quesenberry (1925), in the USA, also recommended the use of sugarcane silage for feeding to steers during the winter. The above two experiences were reported on by Gurria (1978). At the SFC [Republic of Trinidad and Tobago], from 1976 to the present, fresh chopped sugarcane has been used as the forage source for the year-round feeding (zero-grazed) of beef cattle, water buffaloes, dairy cows and small ruminants. The annual rainfall is approximately 1900mm, 90% of which falls between June and December. **The significant experiences of the SFC were as follows:**

1) the harvesting of the sugarcane that was easy in the dry season proved to be difficult during the wet season;

2) the sugarcane was contaminated with the mud during the wet season harvesting resulting in high ash content on analysis;

3) efficiency of labour and mechanical and equipment use was low during the wet season increasing the cost of sugarcane when its value was lowest;

4) the nutritive value of the sugarcane was low during the wet season;

5) the mature sugarcane forage in the dry season had the highest DE & ME values.

King (1985) indicated that mature sugarcane forage harvested during the dry season had the highest DE and ME values (Table 6). This led to the development of silage-making harvesting the mature sugarcane during the dry season when full mechanization of harvesting was possible. Silage could then be fed in the wet season or even the year-round.

The main disadvantages of silage in relation to fresh sugarcane are declines in nutritive value (with some sugars being used to produce alcohol in the process), an increase in the concentration of alcohol in the ensiled product and reduced voluntary intake of the animals. The technique of ensilaging will be outlined later in this manual (section 5.6). The chemical composition of sugarcane silage is presented in Table 7.

Table 6: Energy contents of sugarcane molasses, flint corn kernels, whole plant dent corn, sugarcane sugar and fresh sugarcane whole plant.

Reference	Item	Species	Energy content (MJ/Kg DM)	
			DE	ME
NRC 1971	Sugarcane Molasses	Cattle	17.69	14.52
Mc Dowell et al, 1974	Sugarcane Molasses	Cattle	17.69	14.52
Ensminger & Olentine, 1978	Sugarcane Molasses	Ruminant	13.47	11.05
NRC 1982	Flint corn Kernels	Ruminant	17.32	15.65
NRC 1982	Whole Plant dent corn - mature cured	Ruminant	12.72	10.96
NRC 1982	Sugarcane Sugar	Ruminant	18.07	16.36
Mc Dowell et al, 1974	Whole plant sugarcane (fresh, chopped)	Cattle	12.84	10.50
-do-	Whole plant Sugarcane (fresh)	Cattle	11.17	9.16
NRC 1971	Whole plant sugarcane (fresh, mature)	Cattle	10.71	8.79
Present Experiment	Whole plant sugarcane (fresh, chopped)			
	a	steers	9.57	7.85
	b	steers	15.76	12.92
	c	steers	10.72	8.79
	d	steers	12.33	10.11
Present Experiment	mean		$\bar{x}$ 12.10	$\bar{x}$ 9.92
Present Experiment	Standard Error		SE = 0.63	SE = 0.52

a mature cane fed during the wet season
b mature cane fed during the dry season
c young cane fed during the wet season
d young cane fed during the dry season.

Source: King (1985) citing the above mentioned references.

Table 7: Chemical composition of sugarcane silage

Chemical Fraction	Fresh Material	Ensiled Material	Type of silo	Reference
DM (%)	27.5*	22.8*	Lab silo	** (1982, 1983)
	36.6	31.5	Drum silos	** (1983)
		31.0	Hrizontal	** (1982)
	31.5	22.4	Lab silo	***(1982)
ADF (%)	29.1*	40.4*	Lab silo	** (1982, 1983)
	32.1	42.3	Drum silos	** (1983)
		42.4	Hrizontal	** (1982)
	34.2	44.3	Lab silo	***(1982)
pH	5.7	3.48*	Lab silo	** (1982)
	5.25	3.49	Drum silos	** (1983)
		3.49	Hrizontal	** (1982)
		3.59	Lab silo	***(1982)
ETHANOL (%)		9.70*	Lab silo	** (1982, 1983)
		8.70	Drum silos	** (1983)
		0.80	Hrizontal	** (1982)
		17.52	Lab silo	***(1982)
ACETIC ACID (%)	0.86*	1.70*	Lab silo	** (1982, 1983)
		1.33	Drum silo	** (1983)
		1.15	Hrizontal	** (1982)
		1.40	Lab silo	***(1982)
WSC (%)	49.7*	2.28*	Lab silo	** (1982, 1983)
	34.2	1.27	Drum silos	** (1983)
		7.29	Hrizontal	** (1982)

* Means of values reported
**Alli et al
***Kung & Stanley

Source: Garcia, Neckles and Chan Yen (1989), Alli, Baker, and Garcia (1982), Alli, Fairbrain, Baker, and Garcia (1983), and Kung and Stanley (1982).

3.2 Some sugarcane-based diets

Tables 8 and 9 outlines a framework for estimating ruminant livestock nutrient needs. This can be used in the formulation of rations for different production levels. These are approximations as the precise needs of animals, under Caribbean conditions, have not been so determined. However, studies conducted at the SFC in Trinidad, have substantiated that the Nutrient Requirements Tables of the NRC can be relied on in regard to ruminants (Garcia, 1988 working with growing bulls; Lallo, 1985 with goats, Lallo *et al.*, 1991 a,b with sheep; and Brown (1991) with lactating crossbred Holstein dairy cows). It is suggested that livestock technicians and informed farmers access these guidelines from the internet. One word of advice, however, is that the live-weights of dairy animals given may be heavier than those of their counterparts in the Caribbean.

Tables 10 to 14 are some examples of diets tested on animals and animal performances obtained.

Table 8: An estimation of the nutrient needs of growing cattle

Cattle live-weight (kg)	Growth rate (g/day)	UF (J)	Digestible protein intake (DPI) (g/d)	Animals' dry matter intake (DMI) capacity (kg DMI/day)
150	0	1.9	140	3.5
150	400	2.4	240	
150	600	2.8	285	
150	1000	3.6	370	
200	0	2.4	175	4.6
200	400	2.9	280	
200	600	3.3	325	
200	1000	4.2	415	
250	0	2.8	205	5.6
250	400	3.4	415	
250	600	3.8	365	
250	1000	4.8	450	
300	0	3.2	235	6.6
300	400	3.9	350	
300	600	4.3	400	
300	1000	5.4	485	
350	0	3.6	265	7.5
350	200	4.9	330	
350	400	4.3	385	
350	600	4.8	435	
350	1000	5.9	520	
400	0	4	290	8.5
400	400	4.7	420	
400	600	5.2	470	
400	1000	6.5	555	
450	0	4.3	320	9.5
450	400	5.1	455	
450	600	5.7	510	
450	1000	7.1	585	
500	0	4.7	345	10.4
500	400	5.5	495	
500	600	6.2	545	
500	800	6.9	585	
500	1000	7.7	615	

The average need of a lactating cow weighing 500 kg is 6.0 UF and 550 g DPI/d

Table 9: An estimation of the nutrient needs of Small Ruminants

Nutritional need			Ruminant			
Development Stage	Physiological stage UF		Goats		Sheep	
			PDI	UF	PDI	
Adult female	Maintenance		0.43	30	0.52	41
	Maintenance + Gestation		0.48	65	0.62	82
	Lactation					
Immature	Growth	10-15 kg	0.40	65	0.53	63
		15-20 kg	0.48	65	0.65	67
		25-30 kg	0.55	63	0.84	70
		30-35 kg	0.62	50	0.97	73
		35-40 kg	0.66	50	1.22	73
		40-45 kg				
		45-50 kg				

An adult mother 30 kg kid, 40 kg ewe

Table 10: Fattening diets for growing zebu or creole cattle (250 kg liveweight) (Preston, 1976)

Item	Level of rice polishings				
	Ration 1	Ration 2	Ration 3	Ration 4	Ration 5
Chopped sugarcane (kg)	30	30	30	30	30
Urea (g)	150	150	150	150	150
Rice polishings (kg)	0	0.30	0.60	0.90	1.200
Multinutrient block	Free choice	Free choice	Free choice	Free choice	Free choice
ADG (g/day)	200	450	700	775	800

Table 11: Fattening diets for growing creole cattle (250 kg)

Item	Level of sugarcane			
	Ration 1	Ration 2	Ration 3	Ration 4
Chopped sugarcane (kg)	11.0	15.0	18.0	22.0
Maize (kg)	1.4	1.4	1.4	1.4
Soyabean meal (g)	1.1	1.1	1.1	1.1
Multinutrient block	Free choice	Free choice	Free choice	Free choice
ADG (g/ day)	500	600	800	900

SBM: 0.25 kg of SBM can be replaced by 70 g of urea

Maize: 1.1 kg of maize can be replaced by 5 kg of green banana or 4 kg or fresh cassava chips and put to dry

3.2.1 Sheep growth diets

Table 12 itemises some diets that are used for growing lambs in Martinique.

Table 12: Fattening diets for Matinik lambs (15-20 kg)

Item	Level of soyabean meal			
	Ration 1	Ration 2	Ration 3	Ration 4
Chopped sugarcane (kg)	2.5	2.5	2.5	2.5
Green banana (kg)	0.5	0.5	0.5	0.5
Urea (g)	10	10	10	10
Soyabean meal (kg)	0.5	0.15	0.25	0.35
Multinutrient block	Free choice	Free choice	Free choice	Free choice
ADG (g/day)	80	150	174	176

Banana: can be replaced by 400 kg of potato (away from triage), 400g of cassava in the form of chips after a drying period of 24 hours, or 400 g of breadfruit.

Table 13: Fattening diets for Matinik lambs (15-20 kg)

Item	Ration 1	Ration 2	Ration 3	Ration 4
Chopped sugarcane (kg)	1.7	1.7	1.7	1.7
Urea (g)	5	5	5	5
Commercial concentrate(g) (15-16% total protein matter)	525			
Rice polishings(g)		150	300	
Soyabean meal (g)		250		
Alfalfa/ leucaena forage			0.35	
Forage peas ????				150
Multinutrient block	Free choice	Free choice	Free choice	Free choice
Expected ADG (g/day)	180	150	150	140

Alfalfa: the 300g of alfalfa can be replaced by 1500 g of young potato leaves, cassava leaves preferably dried, fresh gliricidia, fresh erythrina, fresh leucaena or stylosanthes.

Table 14: The diet of zebu-type heifers of an average live-weight of 250 kg

Item	Ration 1	Ration 2
Fresh chopped sugarcane (kg)	25	25
Commercial concentrate 15% protein(kg)	1.200	
Commercial concentrate 20% protein (kg)		1.300
Urea (g)	120	80
Multinutrient block	Free choice	Free choice
Expected ADG (g/day)	770	640

Source: Youssef (1987)

3.3 Sugarcane tops-based diets

Sugarcane tops are the highest tip of the sugarcane stalk and the leaves that surround it. The quantities of sugarcane tops produced are linked to the production of stalks. When the stalks are being harvested for sugar production, the tops are cut off and left in the field. Some farmers collect the sugarcane tops and use them as forage for the animals or may tether the animals directly in the field after the harvest.

The sugarcane tops represent the main by-product of the harvest. The average availability is about 24 tonnes of fresh products (8 tonnes of dry biomass) per ha. In reality, the available quantities and chemical composition of sugarcane tops are variable, particularly according to the quantity of young tips of sugarcane stalk to which the leaves are attached.

Sugarcane tops are composed of 3 different "organs": the green stalk, the green leaves and the dry leaves in varying proportions. The green tip of stalk is the part that is the most palatable to the animal.

Sugarcane tops can only be used as a "Maintenance Feed". As the only ingredient in the diet, it allows animals to maintain body weight during the dry season

3.3.1 Estimated intake of fresh sugarcane tops

Voluntary intake of sugarcane tops by ruminants is between 1.8 to 2.5 kg of dry material (about 7kg of fresh biomass)/100kg of animal live-weight.

The chemical composition is shown in Table 4. Tops are high in fibre and relatively poor in N. Its digestibility is average to poor. It must be supplemented with low-fibre ingredients. Molasses is a product of choice but quantities must not exceed 1.5 % of the animal's live-weight or the digestibility is severely reduced. Generally molasses must be limited to 1%.

Some guidelines for sugarcane top-based diets:

- Young bulls, 22 months of age and 300 kg live-weight, receiving sugarcane tops as required with 1.3 kg of wheat bran gained 300 g/day (Gendley *et al.*, 2002)
- Similar bulls fed with 1kg rice flour, 3.5kg molasses and 115g urea can grow 350g/ day (Salais *et al.,* 1977).

Sugarcane tops can be conserved in the form of silage. The procedure is conducted in the conventional fashion for making silage. After chopping and spraying with diluted molasses at a rate of 1 to 5 litres/100kg of sugarcane tops. The mass is packed down in a silo in open air.

3.4 Bagasse

Figure 24: A stack of bagasse

Bagasse is the fibrous residue obtained after the extraction of juice from the sugarcane stalk. The yield of bagasse is about 300kg of dried material/ton of crushed sugarcanes.

It is the sugarcane by-product with the "poorest" nutritive value. Results from the literature indicate that animals use more energy digesting the crude bagasse than they derive from it (Kirk *et al.*, 1962). Its average chemical composition is presented in Table 4 and Appendix #1.

The dietary value of bagasse can be improved by treatments that range from the very simple to the very complex.

- The simplest treatment is natural hydrolysis (pre digestion) by fungi with piles left to "decompose" under ambient conditions for 6 to 12 months. This results in the improvement of the digestibility and thereby the energy value to the animal. However the N value remains poor.

- Bagasse can also be treated with ammonia and/urea. Urea is dissolved in water and the solution sprayed on the bagasse. The treated bagasse is then kept in plastic bags or tightly covered. The optimal conditions are: 9% urea, 60% humidity and 6 weeks of treatment (Hassoun et al., 1987). The digestibility of the bagasse and its energy value increases by 20% with the N content increasing by 40%. The inexpensive and simple treatment is a useful on-farm technique.

- The most effective treatment of bagasse is a hydrolysis (pre digestion) by industrial technology under pressure and steam (13kg/cm², 200 °C). Unlike the previous treatment, this is an industrial technology formulated at a factory, in Brazil. This significantly increases the digestibility of the bagasse from 30 % to nearly 70%, but it is not an on-farm process.

Under farm conditions the use of bagasse must be accompanied by nutrients and highly digestible supplements (N, energy, and vitamin). These increase the cost of the diet. However, under farm conditions, using resources such as banana waste, potato and cassava leaves, and tubers, inexpensive diets can be formulated. Low-cost molasses can also be used. Untreated bagasse can be used in emergency dry season diets in order to limit the weight loss of animals in a crisis period.

On the farm, the use of bagasse as litter (then organic manure) or as a source of energy seems to be a more economically useful solution.

Bagasse is often used with molasses in urea-treated bagasse diets. Naidoo *et al.* (1977) reported weight gains of 168 g/day in cattle ingesting a diet composed of 89% hydrolysed bagasse, 6% molasses, 2% urea and 3% minerals. Table 15 shows 2 diets based on bagasse and green bananas.

In Trinidad and Tobago Singh, Sankat, Osuji and Lauckner (1987) developed a complete commercial ruminant feed based on sodium hydroxide [NaOH] and/ammonia [NH_3] treated bagasse. Dry matter intakes by sheep were reported to be high, ranging from 3.56 to 4.19 kg DM/100 kg body weight. The treatment process was an industrial type one involving the pelleting of a completely mixed diet consisting of 16% CP, 19% CF, 0.4% Ca, 0.26% P, 0.8% K, and 0.255% NaCl on a diet DM basis. The diet also contained NPN and the net energy for maintenance (NE_m) was 1.32 M cals/kg diet DM.

Table 15: Bagasse-based diets for goats

Item	Ration 1		Ration 2	
	Fresh Quantity or as fed (g)	% As Fed (fresh feed offered)	Fresh Quantity (g)	% As Fed (fresh feed offered)
Banana	3400	79	3700	81
Bagasse	60	3	60	3
Maize	50	5	65	6
SBM	120	13	90	9
Urea			6	1
ADG (g/day)	125		140	

Bagasse-based broiler litter has also been successfully fed with chopped sugarcane to tropical hair sheep lambs, ADGs ranges from 99.5 to 196 g/day (Lallo, Neckles and Harper, 1988 and 1992).

3.5 Molasses

Molasses contains non-crystallized sugars with other materials obtained following the boiling of the sugarcane juice when making sugar. It contains about 25% water, or, 75% DM and is a high-energy food containing non-crystallized sugars (30% dry material), reducing sugars (25% dry material), and other glucogenic substances. Molasses is also very low in N: 25 g N /fresh weight kg of crude molasses. Since the fibre content is insignificant, for successful consumption by ruminants it must be fed with forages.

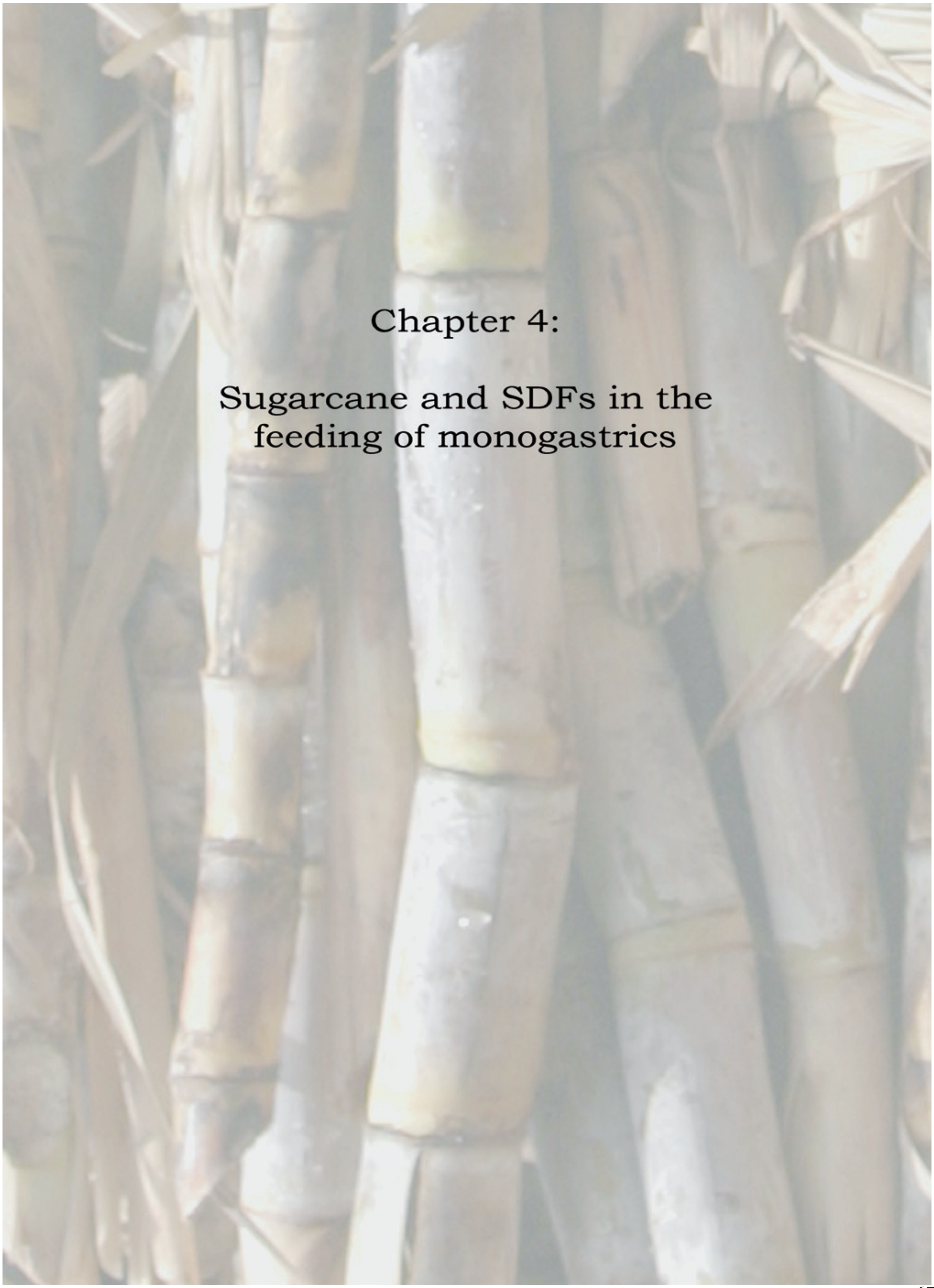
Several studies were carried out on the use of molasses by ruminants. Tables 16 and 17 present molasses-based diets complemented with supplements with and without urea. Average daily live-weight gains of up to 1034 g/day [1.034 kg/day] were obtained.

Table 16: Bagasse based Broiler Litter diets and Molasses with and without urea fed to cattle (Zebu 200kg) (Meyerles and Preston, 1982a)

	Rations							
	1 **Control** **+ Urea**	**2** **Wheat** **Bran** **+Urea**	**3** **SP** **Leaves** **+Urea**	**4** **WB** **+SP** **+Urea**	**5** **Control** **-Urea**	**6** **Wheat** **Bran** **-Urea**	**7** **SP** **Leaves** **-Urea**	**8** **WB** **+SP** **-Urea**
Daily Fresh Matter Intake (FMI) [kg/day]								
Bagasse Based Broiler Litter [84%DM & 14.2%CP]	**1.0**	**0.97**	**1.49**	**1.48**	**1.26**	**1.34**	**1.49**	**1.49**
Wheat bran (WB) [86%DM & 14%CP]	-	0.95	-	1.0	-	0.96	-	1.0
Sweet Potato (SP)leaves [15%DM & 11%CP]	-	-	12.01	12.00			10.03	11.61
Molasses [80%DM]	**4.92**	**4.80**	**5.01**	**6.32**	**3.49**	**3.2**	**4.29**	**4.36**
Urea [100%DM & 288%CP]	0.13	0.13	0.13	0.17	0.0	0.0	0.0	0.0
Vitamin Mineral Mix	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Calculated Daily DM Intake [kg/day]	**4.83**	**5.53**	**7.11**	**8.99**	**3.82**	**4.48**	**6.13**	**7.27**
ADG(kg/day)	**0.234**	**0.643**	**0.774**	**1.034**	**0.055**	**0.368**	**0.557**	**0.855**

Table 17: Rice Hulls Based Poultry Litter, Sugarcane Tops and Molasses based diets with and without urea fed to cattle (Zebu 208kg Live-weight) (Meyerles and Preston, 1982b)

	Ration 1 **Molasses & Sugarcane Tops** **-No Urea** **Control**	**Ration 2** **Molasses, Rice Hulls Poultry Litter and Sugarcane Tops- No Urea**	**Ration 3** **Molasses-Urea, and Sugarcane Tops**	**Ration 4** **Molasses-Urea, Rice Hulls Poultry Litter Sugarcane Tops + extra Wheat Bran**
Daily Fresh Matter Intake (FMI) [kg/day]				
Sugarcane Tops [26%DM]	4.79	5.07	5.25	7.13
Molasses [80% DM]	2.99	3.27	4.78	4.46
Urea [100%DM & 288%CP]	-	-	0.12	0.11
Poultry Litter [84%DM & 14.4%CP]	-	1.49	-	1.47
Wheat bran (WB) [86%DM & 14%CP]	1.0	1.0	1.0	2.0
Vitamin Mineral Mix	0.07	0.07	0.07	0.07
Calculated Daily DM Intake [kg/day]	**4.76**	**6.31**	**6.52**	**8.04**
Average Daily Gain (kg/day)	**0.19**	**0.52**	**0.73**	**1.01**
Feed Conversion **[kg DMI/kg ADG]**	**26.5**	**13.1**	**9.11**	**8.14**



Chapter 4:

Sugarcane and SDFs in the feeding of monogastrics

Chapter 4.0: Sugarcane and SDFs used in the feeding of mono-gastrics

4.1 Basic concepts in pig nutrition

Unlike ruminants, pigs do not digest fibre well, what little fibre they digest is done in the caecum, and this becomes functional only when the pigs becomes mature. Their diets must contain less than 15% CF. Pigs are able to use feeds high in sugars and starch efficiently. These animals, however, require high quality N sources, that is to say, proteins with the required amino acid profiles. The nutritional needs of creole pigs (at different physiological stages), based on the work done at INRA, are summarized in Table 18.

CAUTION!! Non-protein-nitrogen as a source of N or CP is toxic to pigs!!!!

Sugarcane juice and molasses are the most important SFDs for pigs but WCS can be used. The high fibre content of chopped sugarcane strongly limits the animals' performances. The pigs just crush the sugarcane between their teeth, extract the juice and discharge the fibre from the mouth forming part of the litter for the production of organic matter.

Whichever sugarcane product is used, it is characterized by its low content of protein, lipids, and fibre (except whole sugarcane). These products require supplementation with balanced proteins (150 to 200 g of soy proteins/day for growing pigs) plus minerals and vitamins.

The SDFs that can be used for feeding to pigs are fresh and conserved sugarcane juice, dehydrated juice [panela/gur], raw and refined sugarcane sugar, integral, high test, A & B and final/blackstrap molasses (Garcia *et al.,* 2008). However, the leading authority in the world on the feeding of SDFs to pigs is Julio Ly of Cuba. He did an excellent presentation at the Sugarcane Feeding Conference in Guadeloupe in 2008 [Ly (2008]. The websites for that presentation can be found in the "Closing" at the end of this Manual.

4.2 Sugarcane juice in pig nutrition

Sugarcane juice is characterized by a low concentration of DM (on average 20%), a high content of soluble sugars (75 to 92% of dry matter), and a low content of proteins. Among the soluble sugars, sucrose is the main component (70 to 88% soluble sugars), followed by glucose and fructose, each representing 2 to 4% of the total sugar content. The sugar content is strongly linked to the quality of the sugarcane (estimated by the degree brix) that varies according to the season. The sugar content is highest during the dry season.

Table 18: The nutritional needs of creole pigs.

PHYSIO-LOGICAL STAGE	ENERGY				PROTEIN	
	Metabolizable Energy [ME] (MJ/day)	Equivalence in kg of Fresh Material [4]			Digestible Lysine (g/day)	Equivalence in kg
		Molasses	Sugarcane juice	Chopped sugarcane		Soya bean meal 50[5]
Gestating sow [1]	30	3.2	8.8	24.3	10	0.380
Lactating sow [2]	60	6.4	17.5	48.7	32	1.200
Post weaning piglet [3] 8-20 kg[3]	15	1.6	4.4	12.2	6.5	0.250
Pig growth 20-60 kg[3]	26	2.8	7.6	21.1	10	0.380

[1] – Calculated by the fractional approach, the needs of a gestating sow that would give 9 piglets at birth, sow back fat thickness of 25mm at birth and a weight gain during gestation of 40kg (INRA, pig production).

[2] – Calculated by the fractional approach, from the results of average performances during lactation of Creole sows obtained at URZ (Guordine *et al.*., 5\2006; average weight of the sow = 180, GMQ from the litter = 1500g/day and size of the litter = 8.5piglets/litter.

[3] – Calculated by the factorial approach, considering that the composition of weight gain between 8-60kg is the same as between 30-60 kg (Renaudea *et al.*, 2006). Estimated from a growth potential of 400/day between 8 to 20kg and 750g/day between 30 to 60kg liveweight.

[4] - Theoretical optimum quantity in order to provide for the maximum energy needed. Does not take into account the possible limitation of the rate of assimilation in order to avoid digestive problems (eg: molasses). In the case of molasses, it is recommended to limit 40% inclusion rate in the diet; the supplement can be supplied by a product rich in starch (e.g bananas or roots). This calculation does not equally take into account the energy supplied by the protein supplement; e.g in the case of growing pigs, the contribution of 380 g/day of soyabean meal reduces the quantity of juice to be distributed to 6.0 kg instead of 7.6 kg/day.

[5] - 50 Soyabean meal containing 26.5g of digestible lysine/kg

The sugarcane juice is an excellent source of energy that can be used to replace the starch from cereals in formulated pig diets. There have been reports in the literature that when sugarcane juice was fed to pigs average daily live-weight gains ranging from 450 to 750 g were obtained. The variations in growth were linked to:

1) the quantity and quality of the distributed juice;

2) the quantities and the nature of the protein supplementations;

3) the animals' physiological stages; and

4) breed of pigs.

During some growth trials between 30 and 65 kg live-weight, creole pigs consumed 7L of sugarcane juice a day, with 400g/day of SBM and a mineral and vitamin supplement; animals achieved a growth rate of 700g/day (Mena, 1988). The best growth rates with sugarcane juice fed to pigs were from fish meal since sugarcane juice does not bring any amino acids to the diet profile as would a cereal-based diet.

4.2.1 The ideal protein concept and the use of fish meal

One of the major advances in examining the pattern of dietary amino acid (AA) utilization and the understanding of their requirement in mono-gastric animals is the concept that there is an 'ideal' protein. This 'ideal' protein would contain all the essential AA in the correct balance or proportions and includes the correct ratio of essential to non-essential AA. Much of the developmental work on the 'ideal' protein was done in pigs [Lallo (1998) citing Cole, 1978; ARC, 1981; and Wang and Fuller, 1989]. The concept was however proposed in the early 1950s, but was largely passed over until the mid-1960s in the USA and in the late 1970s in the UK (Dean and Scott, 1965; Cole, 1978; ARC, 1981 cited by Lallo, 1998).

The original ratio of AAs was essentially based on the hypothesis that the ration of AAs in lean tissue would reflect the pig's requirement for AAs (Table 19). ARC (1981) advocated the application of the 'ideal' protein for maintaining a minimum balance of AAs, relative to lysine. Thus, the 'ideal' protein concept uses lysine as a reference AA, with the requirements for all other indispensable AAs expressed as a percentage of lysine. Lysine was chosen as a reference AA for several reasons.

1) It is required in major proportions for lean deposition; in practical cereal-based diets it is normally the first and major limiting AA for pigs and the second limiting AA after the sulphur amino acids (SAAs) for broiler (chickens); lysine supplementation is economically feasible.

2) Lysine analysis in feedstuffs is straightforward.

3) Dietary lysine is used only for protein accretion and maintenance (i.e. it has no precursor role).

4) Lysine requirement data for a variety of dietary, environmental and body conformational circumstances are readily available.

While the concept has probably been best developed in pigs, it is equally applicable to other species such as chicken, ducks and turkeys. This may be the reason why such good results were obtained with pigs fed fish meal and sugarcane juice, since the latter does not bring any amino acids to the diet profile as would a cereal-based diet while the juice contains sugars that can be immediately absorbed.

4.2.2 Other considerations for the feeding of sugarcane juice to pigs

A feeding system based on sugarcane juice can replace cereals at all stages in the pig production cycle. The main difficulty linked to the use of sugarcane juice could be in its preservation. The juice must be extracted daily. The juice can be preserved at 4°C or without a preservative, for up to 4 days without causing harm to the pigs. It is also possible to use additives to stop fermentations (e.g., malic acid). For longer lasting conservation, one solution can be partially or completely evaporating the water and making syrup or a sugar-loaf (panela). This solution depends on the level of energy available on the farm.

The protein supplementation depends on the level of performance required as illustrated in Figure 25.

The SBM is the most appropriate protein material because of its high N content and its AA composition which corresponds well with the needs of pigs. Further, the protein supply must correspond to the needs of the animals during their various physiological stages (Table 20). Another approach can consist of rationing the protein supply in order to better increase the value of the energy-supplying resource present on the farm without necessarily aiming to maximize the performance of the animals. This is often the favoured approach with the use of unconventional feeds such as sugarcane juice.

In order to increase the dietary independence of farms, it is possible to replace up to 30% of SBM protein with that from the leaves of forages (cassava, potato, stylosanthes…), without adversely affecting the pigs' growth rates.

Table 19: Earlier Ideal Pattern of Essential Amino Acids for Growing Pigs and the Illinois Ideal Protein for Pigs.

Amino Acid	Cole 1978	ARC 1981	Fuller et al.., 1989			NRC, 1988	Illinois Ideal Protein Baker et al.., 1993		
			Maintenance	Tissue Accretion	Both			20-50kg	50-
Lysine	100	100	100	100	100	100	100	100	100
Methionine	-	-	33	28	28	-	30	30	30
Methionine + Gystine	50	50	150	53	56	55	60	65	70
Threonine	60	60	142	69	72	64	65	67	70
Tryptoplan	18	14	29	18	19	16	18	19	20
Isoleucine	50	54	46	63	63	61	60	60	60
Leucine	100	100	71	115	113	80	100	100	100
Histidine	33-55	33	-	-	-	29	32	32	32
Phenylalanine	-	-	63	60	61	-	-	-	-
Phenlyalanine + Tyrosine	100	96	125	124	123	88	95	95	95
Valine	70	70	54	76	75	64	68	68	68
Arginine	-	-	-	-	-	33	42	36	30

Source: Lallo (1998)

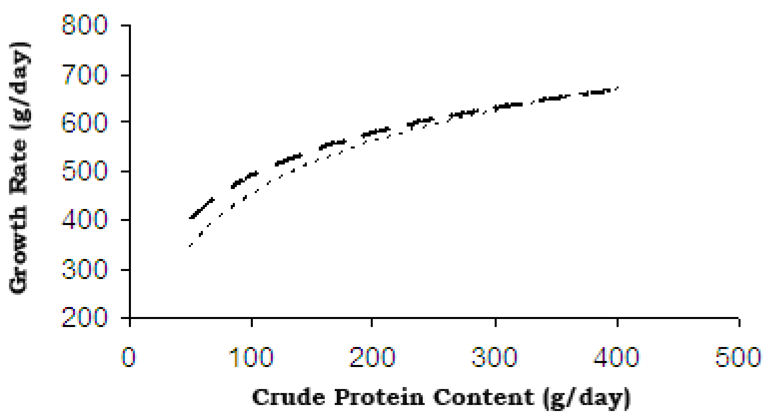


Figure 25: Effect of the level of protein supplied on pig's growth rate (g/day) on a basal diet of sugarcane juice (---) or cassava tubers (---) *ad libitum.*

Tables 20 and 21 illustrate sugarcane juice-based diets.

Table 20: Sugarcane juice-based diets

Physiological Stages	Soyabean Meal*	Sugarcane juice*
Dry sows	0.5	10
Gestating sows	0.5	11
Lactating sows	1.5	18
Suckling Piglets	0.05	
Piglets 30 to 60 days	0.45	
Piglets 60 to 90 days	0.5	5
Growing Pigs	0.4	12

*The diets contained 500 g of chopped sugarcane.

4.3 Molasses in pig nutrition

There are several "types" of molasses, ranging from rich molasses or "high-test" to the "final" molasses that is relatively poorer. The types of molasses are linked to the sugarcane manufacturing process. They differ in their chemical composition due to the progressive extraction of sugar during the sugar manufacturing process. The molasses that is available in Guadeloupe, Martinique, Trinidad and Tobago and the rest of the Caribbean (with the exception of that from Cuba) is the least rich in sugars (Table 22). This is called "final molasses". The common characteristic of all molasses is that they are high in sugars but low in proteins (like all other SDFs). Molasses is also high in industrial impurities (non-digestible organic materials) and minerals. The GE and the DE of molasses are lower than those of cereals.

Molasses however was a very available energy which is relatively inexpensive in contrast to cereals. But molasses is now only available in Cuba, Jamaica, Barbados and Guyana. The viscous consistency of molasses poses problems in texture and of homogeneity of the complete diet. In addition, there is an incorporation rate that is not passed. High levels of molasses inclusion in the diets may lead to digestive disorders that are reflected in diarrhoea. In pigs, this effect is attributed to the increased levels of minerals in molasses particularly potassium as well as the significant non-identified organic fraction.

The literature suggests that molasses can be fed at levels ranging from 55 to 83% of the diet with the growth rates varying between 414 to 742 g/day. Christon and Le Dividich (1978) fixed 30% molasses [from Guadeloupe] as the limit of inclusion rates in pig diets. Beyond this limit, the authors reported a fall in growth performances. Molasses should not be fed at levels in excess of 20% of the diet for piglets and 30% for gestating gilts and sows. Pig performances will depend on the type of supplements used. Sugarcane juice has given better performances than molasses.

Table 21: Sugarcane juice-based diets for growing pigs (the diets contained 500 g of chopped sugarcane with a growth or average daily gain (ADG) target of 600 to 700g/ day).

	Creole pigs (1)			Large White (2)		
Weight	Week	Juice (kg)	Soya (g)	Week	Juice (kg)	Soya (g)
25	1	8.0	400	1	6.0	500
30		8.5	400	2	6.5	500
35	3	8.5	400	3	7.0	500
40		9.0	400	4	7.5	500
45	6	9.0	400	5	8.0	500
50		9.5	400	6	8.5	500
55	8	9.5	400	7	9.0	500
60		10.0	400	8	9.5	500
65	11	10.0	400	9	10.0	500
70			400	10	10.5	500
75			400	11	11.0	500
80			400	12	11.5	500
85			400	13	12.0	500
90			400	14	12.5	500
95			400	15	13.0	500
100			400	16	13.5	500

(1) Xande (2008); (2) Perez (1997)

Table 22: Chemical composition of molasses (Christon and Le Dividich, 1978)

Composition %	Mean	Range
Dry material (DM)	76.8	71.0-80.0
Mineral materials	8.4	5.5-11.3
Fat	0.1	0.0-0.3
Proteins (N x 6.25)	3.6	1.5-10.2
Nitrogen Free Extract	64.6	51.7-69.0
Soluble sugars	58.7	50.0-69.7
Sugar reducers	16.2	13.9-17.0
Glucose	8.6	5.5-14.0
Fructose	9.9	1.3-16.0
Gross Energy (MJ/kg of MS)	12.2	10.7

4.4 Whole chopped sugarcane in pig nutrition

The use of the whole or chopped sugarcane stalk in fattening pigs is not frequently done. Their use in this way may appear absurd, considering the high GE content of the products and the poor capacity of the pigs to digest the fibres. However, there exists an important gap between the sugarcane offered to the pigs and the food that they consume (Table 23). This gap varies according to the physiological stage of the pig, the cultivation of the sugarcane and the means used for mechanically chopping the sugarcane. In fact, the pigs extract the sugars from the chopped sugarcane and reject a large part of the fibres in the oral cavity. As a consequence, the quantity of energy ingested by the pigs depends on their capacity to extract the sugar from the sugarcane. The extraction rate is higher than 50% and a limited quantity of the sugarcane fibres is ingested by the creole pig.

Studies have indicated that the extraction level of sugar from the chopped sugarcane is 67% by pigs between 35 and 55 kg live-weight (Bravo *et al.,* 1996). This value is superior to the classic juice extractors used in a traditional way. The extraction level varies with the size of the pieces of sugarcane offered to the pigs. Thus, the daily quantity of ingested sugars diminishes from 410 to 283 g/day when the length of the chopped sugarcane increases from 3 to 40 cm (Mederos *et al,*. 2004). However, it is necessary to avoid over chopping or pulverization which can lead to significant ingestion of fibre particles which restrict the oral extraction of the juice by the pigs (Mederos *et al.,* 2004; Xande *et al.,* 2008).

Table 23: Composition of chopped sugarcane diets consumed by pigs

Analysis	Expression of value	Chopped sugarcane offered	Chopped sugarcane consumed
Dry materials	% Raw material	43.7	25.8
Ash	% Dry material	1.1	1.5
Total nitrogen	% Dry material	0.0	1.2
NDF	% Dry material	23.2	40.3
ADF	% Dry material	14.9	26.6
ADL	% Dry material	0.0	4.4
Soluble sugars	% Dry material	80.2	51.5
Organic Matter	Digestibility %	30.4	68.6
Nitrogen/Crude Protein	Digestibility %	70.3	73.7
Energy	Digestibility %	31.9	68.6
Digestible energy (MJ/kg DM)	Digestibility %	5.7	12.3
Metabolized energy (MJ/kg DM)	Digestibility %	5.6	11.8

The extraction of sugars increases when the quantity offered is less but the total quantity of daily extracted sugars can be proportionally decreased (Bravo *et al.*, 1996)

The practice of sugarcane use (fed sometimes whole) exists among small pig farmers. In Haiti, the average daily gain of 325 g was observed in pigs fed chopped sugarcane from 20 to 80 kg live-weight (Bien-Aime and Francois, 1990). In Guadeloupe, the Creole pigs have demonstrated ADG of 200 g with 400g of SBM/cotton seed meal and 7 kg of chopped sugarcane.

4.5 Recommendation for feeding pigs

Unlike sugarcane juice, chopped sugarcane cannot be the only energy source in pigs' diet if the objective is for high levels of daily live-weight gains. One of the limits linked to the utilization of chopped sugarcane is the low intake of sugars and the importance of dietary energy use for their extraction. This poor intake leads to an energy restriction that can perhaps be useful for the pregnant sow or gilt which may need to have a restricted diet during this stage in its or her life cycle.

Pig-growth performances ranging from 600 to 700 g/day are possible by including chopped sugarcane as another energy source since it is necessary to supply the blend without the sugarcane. The ration can be commercially blended pig feed containing 20% of CP or a product such as rice flour or wheat bran (1.5kg).

The non-concentrate feed can also be sweet potato, dried bitter cassava, bread-fruit, banana, or potato at the rate of 1kg dried; this is equal to about 4kg of green produce. The protein supplement (400g of SBM) cannot be replaced by fresh forage because of the bulky nature of the diet. The forage protein can be included into the diet only if the leaves are dried and converted into a meal.

Freshly chopped sugarcane is bulky and is also high in moisture and low in dry matter. This imposes a limit on the quantity of dry matter intake, thereby limiting as well the quantity of DE intake by the ruminants. It is therefore recommended to feed along with the freshly chopped sugarcane a concentrate with a 20% CP content. This complements the sugarcane fibre and soluble sugars with starch and protein.

Table 24 shows a diet consisting of chopped sugarcane as the base.

Table 24: A chopped sugarcane diet for a estimated growth rate of 500g/day by creole pigs.

Live-weight	Chopped sugarcane		Commercial concentrate 20% crude protein [2]		Refusal (bagasse)[3]
	Fresh quantity	Equivalent Sugars extracted [1]	Fresh quantity	Consumed protein	
25-30	6.5 kg	0.290 kg	1.0 kg	0.200 kg	3.300 kg
30-35	7.0 kg	0.310 kg	1.0 kg	0.200 kg	3.600 kg
35-40	7.5 kg	0.340 kg	1.0 kg	0.200 kg	3.800 kg
40-45	8.0 kg	0.360 kg	1.0 kg	0.200 kg	4.000 kg
45-50	8.5 kg	0.380 kg	1.0 kg	0.200 kg	4.300 kg
50-55	9.0 kg	0.400 kg	1.0 kg	0.200 kg	4.600 kg
55-60	9.5 kg	0.430 kg	1.0 kg	0.200 kg	4.900 kg
60-65	10 kg	0.450 kg	1.0 kg	0.200 kg	5.100 kg

(1) Base calculation: Extraction rate of sugar 50% and the sugar represents 9% of the fresh sugarcane. However this rate can be inferior for the young animals and/ or if the animals are offered increased quantities.

(2) Commercial feeds must be distributed before the sugarcane.

(3) The bagasse or the refusal represents 50% of the sugarcane offered

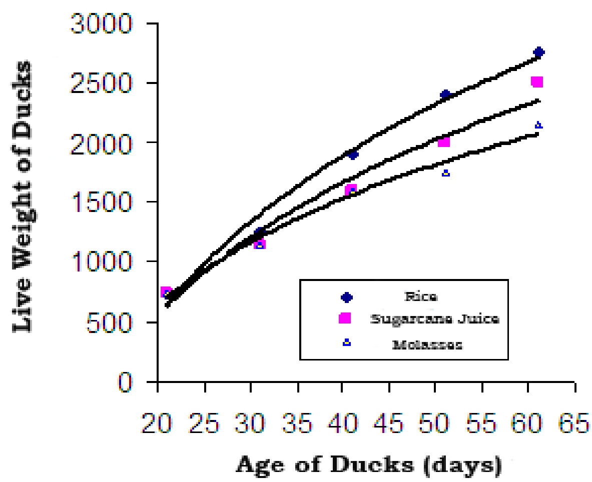
4.6 Sugarcane in poultry nutrition

The driving objective in the poultry nutrition utilizing molasses or sugarcane juice is to be able to replace starch from cereals.

Figure 26: Peking and Muscovy ducks

Chicken hens are not receptive to liquid feed unlike aquatic poultry (ducks and geese) (Figure 26). The duration of the life of the broilers is too short to allow them to adapt to liquid feed. Further, their beaks are not adapted to consume liquid foods. There are significant losses of liquid and splatters of sugar-substance on the feathers which predisposes to cannibalistic behaviour. With broilers, the sugarcane juice and the molasses-based diets have always produced inferior results with regards to the animals' potential.

Ducks and geese are better adapted to consuming liquid feed. Satisfactory performances, which were equivalent to 80-90% of their genetic potential, were obtained with sugarcane juice. This is illustrated in Figure 27 and Table 25.



Source: Bui Xuan Van and Su Vuong Van (1992)

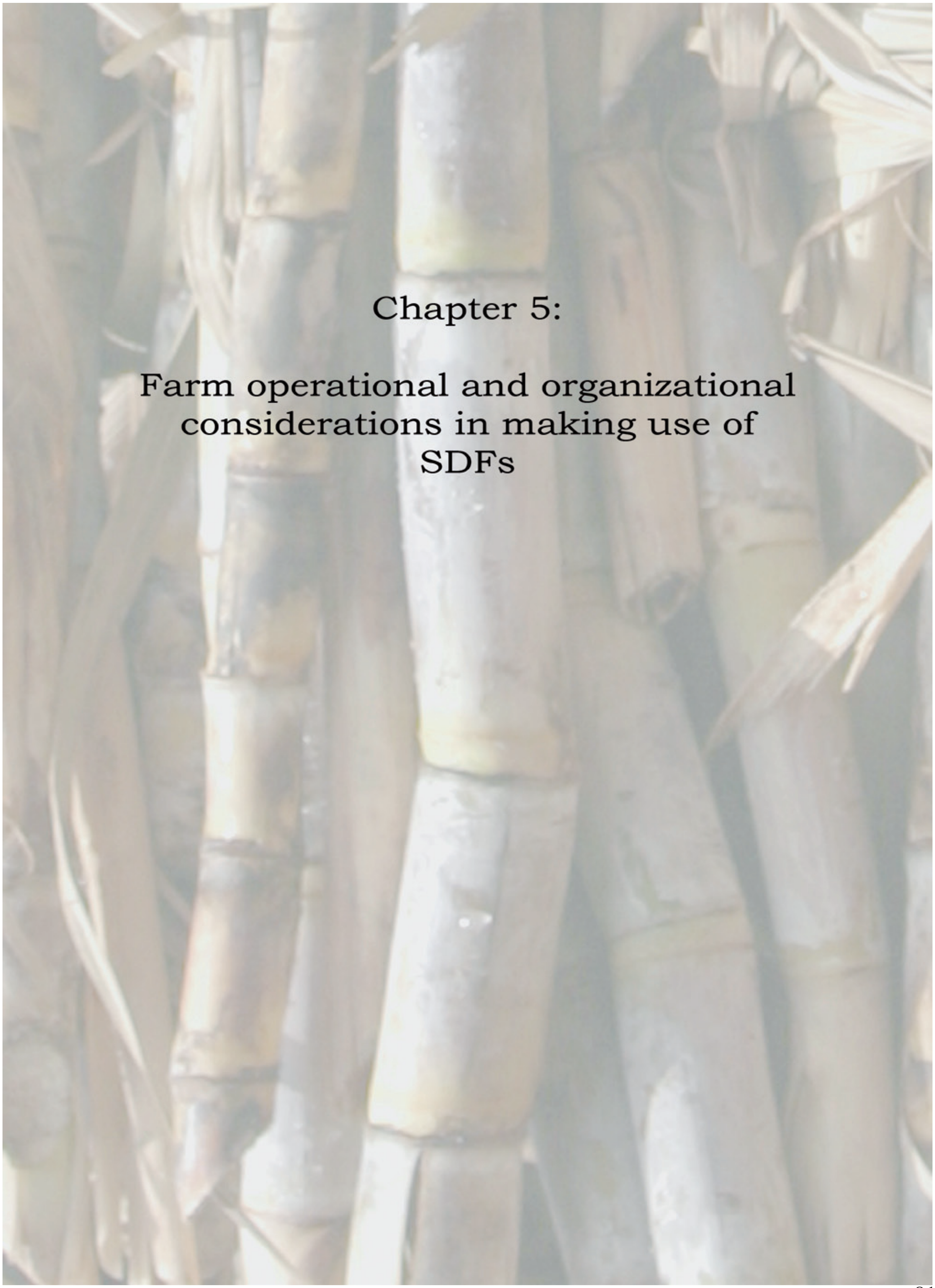
Figure 27: Comparison of the growth rate of ducks fed diets of rice, sugarcane, juice and molasses.

Table 25: Sugarcane juice- or molasses-based diets for ducks). The proportions of ingredients are expressed as % of the dry matter intake.

Item	Duration (days) on control diet	Duration (days) on sugar-cane juice				Duration (days) on "A" Mo-lasses			
	22-68	22-28	29-35	36-40	41-60	22-28	29-35	36-40	41-60
Broken rice	54	28	-	-	-	37	17	6	-
Rice polishings	24	10	19	9	-	-	-	-	-
Soyabean meal	20	30	29	29	28.6	31	31	32	28.5
	3	8	6	3	5.7	9	8	8	5.7
Fish Meal	17	22	23	26	22.8	22	23	24	22.8
Bone meal	1	1	1	1	0.5	1	1	1	0.5
Vitamins premix						30	50	60	70
	1	1	1	1	1	1	1	1	1
Sugarcane juice		30	50	60	70	-	-	-	-
"A" Molasses		-	-	-	-	30	50	60	70

Source: Bui Xuan Van and Su Vuong Van (1992)

The average growth rate of the ducks was 52g/day on the rice-based diet, 46g/day on the juice-based diets and 38g/day on the "A" molasses-based diets. The consumption of sugar-cane juice was, on average, 436g/day compared with 106g/day of the "A" molasses.



Chapter 5:

Farm operational and organizational considerations in making use of SDFs

Chapter 5.0: Farm operational and organizational considerations in making use of SDFs

5.1 General considerations

Sugar sugarcane as the basis for animal feeding is an option that allows for the development of sustainable and productive agriculture.

Sugarcane is recommended because it is one of the most productive plants that farmers can use in the tropics and subtropics and it has been traditionally and successfully grown in the Caribbean for the last 300 years. The high productivity of sugarcane is achieved with the maintenance of the fertility of the soil, when cultivation is of a high standard and when its organic matter is recycled.

No matter what part of the sugarcane is considered, sugarcane is above all, an energy-supplying feed. The farmer must utilize complementary feed ingredients from the local agricultural sector. The farmer can increase his autonomy if he accepts to rethink the choice of crops on his farm and his crop rotation management.

5.2 Choice and rotation of crops

The most productive crop is not necessarily the best in terms of feeding or budgeting. The choice of a variety of sugarcane is a compromise between the quantity of biomass produced, the resistance against diseases and the ease of harvest and of the separation of the different fractions useable by different animal species.

It is necessary to introduce legumes on the farm. The combination of short-cycle plants and long-cycle plants is also a good option.

Therefore, short-cycle (less than 4 months) legumes (peas, nuts) can be planted in the inter rows of the sugarcane. This allows the development of a supplementary space and aids in the fight against weeds. The legume contributes to the enrichment of the soil by fixing protein (N). The leaves and grains of the legumes can also be used in the feeding of animals.

Long-cycle legumes can be introduced in the form of tree-paths 20-30 meters long between the plots of sugarcane. These short trees have several functions. They contribute to the management of the soil's fertility as legumes and also because they draw nutrients from the deep layers of the soil which they bring back to the surface. The leaves can be harvested on a 6 to 8-week cycle and can be used as protein supplements while the woody fraction can be used as fuel. Fodder trees can be used as a high proteins source.

5.3 Fractionation of sugarcane (separation of the sugarcane into its various parts) in order to maximize the use of its different components

The fractionation of sugarcane allows for the use of each section in the best way (as feed, fertilizer, litter, energy). Therefore, the sugarcane tops combined with the young uppermost part of the stalks is made the best use of by the ruminants. The sugarcane juice is well valued by the pigs and secondly by certain poultry (ducks).

The best recommended use for the fibre fraction is as litter to yield fertilizer or as an energy source. Secondly, the fibre fraction can also be used for feeding ruminants, in the case of a feed shortage (extreme drought, for example). It is necessary to limit the sampling of the trash in the field but to recycle, as much as possible, the organic matter stemming from livestock feeding in order to maintain the soil's fertility.

5.4 Increasing or optimizing the value of local types of animals

Local types of farm animals (with the exception of chickens) are the best adaptedto increasing the value of resources produced on the farm. Compared with specially bred species, local races or types were not selected based on production results (high levels of meat and milk production) to the detriment of adaptation to their environment. This has made them more adapted to the local conditions on farms (higher resistance to pathogens, by their availability, and increasing value of tropical crop resource). This results in a decrease in production costs. Their low production potential makes them more apt to valuing the diets that are poor in terms on nutritional density, as the need for supplementary feed supply may be lower. This, however, may be debatable.

5.5 Increasing the farm's energy independence

With mechanization, energy becomes a significant source of expenditure on the farm. The farm however has the possibility of increasing its independence, even via the production of electricity.

Bagasse, produced on the farm, as well as woody fractions of fodder trees are potential fuel sources which allow for the production of electricity by different technologies.

The development of small biogas digesters on the farm fuelled by livestock effluent, allow the production of methane that can be put to many uses on the farm.

5.6 Sugarcane silage

Silage preparation may become necessary to ensure the availability of fibrous animal feed for ruminants year-round.

5.6.1 The general principle

This is a method of conserving the forage resource from the wet/fresh state. The basic principle consists of placing the feed in an anaerobic environment (absence of oxygen) which does not allow the development of "microbes" to cause feed-spoilage.

The feed (sugarcane, grass, banana, breadfruit) is chopped, then introduced and packed tightly in a silo (a container above- or under-ground, or pit) rendered airtight with a plastic sheeting. The objective is to take most of the air and oxygen out of the biomass. In the first hours, the pockets of air are consumed by the activity of the microbial population present in the silo. Furthermore, this population initiates the beginning of the breaking down of the feeds thus causing the development of acidity of the biomass environment. The absence of oxygen and the increasing acidity lead to a retardation of and then a halt to the activity of the microbes. The resultingsilage is thus stabilized and can remain preserved as is for several months in its new air-deprived acidic environment.

5.6.2 The construction of the silo

The silo is constructed either:

- by digging a simple trench in a hillside; the earth walls must not have major asperities (rocks, roots…) that can tear the plastic sheeting.
- by constructing the silo in wood or in concrete on the surface of the ground.

The construction must be sturdy taking into account the pressures exerted on the walls during compression. Whichever option is selected, the base of the silo must have both a 5% slope in order to ensure adequate drainage and a limited entrance for multiple removal of silage and "resealing" of the silo.

The dimensions of the silo would have to be in keeping with the silage needs of farm as determined by the farmer. It is best that the silo be long and only as wide as necessary. This limits silage losses at the silo's opening. After opening the silo, it is necessary to use a layer of at least 20 cm thickness of silo per day in order to avoid an occurrence of unwanted fermentations in the remaining ensiled feedstuff.

The basic equipment, apart from the silo, is: a special plastic "silage" tarpaulin adapted to the silo's dimensions, and a device for chopping the feed.

The tarpaulin is used to cover the floor walls of the trench; the sides must overlap broadly.

The feed is mixed or chopped according to its form of distribution.

The chopped mass is spread out and packed down or compressed frequently by trampling in the case of small silos.

Once the silo is full, the plastic tarpaulin is folded over the silage while ensuring complete air-tightness.

After covering weights (e.g. old tyres or logs) are placed on the covering in order to ensure that it is well covered and compacted as this allows a better compaction of the silage mass.

The tarpaulin is punctured at the lowest point of the silo in order to ensure out drainage.

5.6.3. The use of silage

5.6.3.1 The opening of the silo

Silage is useable as animal feed one month after its making, but it can be conserved, without a problem, for several months if necessary.

5.6.3.2 Silage use

Silage extraction begins through a limited entrance to the silage mass. Silage is removed in successive layers (like a slice of bread) with the help of, for example, a shovel- spade with sharp edges in order to have a distinct layer removed in order to decrease losses. After each removal, the plastic tarpaulin is folded carefully over the limited entrance.

5.6.3.3 Cost of producing sugarcane silage

Taylor (1987) estimated the cost of producing sugarcane silage at the SFC, in Trinidad and Tobago. The cost of sugarcane production, harvesting, ensiling and feeding were 40%, 30%, 18% and 12%, respectively of the total cost of silage use. Details of this are given in Appendix #3.

5.7 Supplementary feeds produced on the farm that can be used with sugarcane and SDFs

The complementary needs of farm-grown feed (other than sugarcane) fall into three [3] categories:

1) **sources of fermentable protein (N) (protein or nitrogen that is digested in the reticulo-rumen);**

2) **sources of by-pass protein (protein that is not digested in the reticulo-rumen) and**

3) **starch sources.**

In order to produce these resources the farmer can use different strategies and these could include the following that will be outlined further in more detail.

1) **growing a mix of plants that produce starch, fermentable protein (N), by-pass protein. These are derived from foliage from cassava, sweet potatoes and peas (vines and Canavalia a legume).**

2) **the production of forage legumes that supply fermentable protein (N) and by-pass protein.**

3) **the cultivation and use of fodder trees that, like the forage legumes, supply fermentable protein (N) and by-pass protein.**

The farmer may choose to combine these different strategies which do not have the same limitations. The choice of forage legumes to supply protein (N), matches up with traditional practices of the farmer who is accustomed to gathering forages. This choice must take into account the general layout and organization of the farm. **The starch sources could be produced for both human use and animal feed, with only the culled (non-marketable) starch based crops going towards the feeding of animals,** thereby adding value to crop farm waste through the use of animals. Further, the animals would give the farmer animal products and organic matter. This is **intelligent, integrated, intensive and sustainable animal production systems** (**IIISAPS**). Examples of these crops are:

Root crops: cassava (*Manihot esculenta*) and sweet potato (*Ipomea batatas*), **Forage legumes**: stylosanthes (S*tylosanthes guyanensis*) and beans (   ), **Fodder trees** (some of which are perennial legumes): gliricidia (*Gliricidia sepium*), leucaena (*Leucaena leucocephala*), erythrina/immortel (*Erythrina* spp) and tricantera (*Tricantera gigantea*).

5.7.1 Cassava

Cassava can be an important resource on the farms that value/use sugarcane in the feeding of animals, regardless of the animal species. This plant is both an energy (starch from the tubers) and protein (N from the leaves) source. The composition of the products from cassava is presented in Table 26. The cassava crop can produce large amounts of leaves/forage when planted at high plant population densities. Cassava forge productivity and protein quality were reported on by Garcia (1988). Figure 28 visually displays the standing quantity of cassava forage. Cassava leaf and forage production vary greatly according to the variety and stage of maturity. If the leaves are harvested at the same time as the roots (12 months or more after planting), the yield of leaves could vary from 1 to 4 tonnes of dry material/ha. If a partial harvest of leaves is obtained during the vegetative phase before the harvest of the tubers [at about six months growth] the leaf yield could be up to 7 tonnes dry matter/ha. If the first harvest is made at 4 months and then at 2-3 month intervals leaf yields could be increased at the expense of tuber yields. The frequency of possible harvests will be dependent on the variety of cassava used and the level of soil fertility.

Figure 28: Standing cassava forage

If the cassava is cultivated for the production of forage and not for tubers, the production of leaves could be 20 tonnes of dry material/ha/year and this level of production could continue for many years. Under this system of management the forage can be harvested every 60-75 days, but the first harvest can only be made as early as 4 months after planting. When attempting to cultivate the cassava as a dual purpose plant, the production of tubers can be 15 to 20 tonnes of fresh produce/ha.

The energy value of the flour from cassava leaves (cassava flour) is estimated at 7.53 (6.65-7.95) MJ/kg DM for poultry and 9.04 MJ/kg DM for pigs.

The leaves and tubers must undergo partial drying so that they can get rid of the hydrogen cyanide which, when ingested in large quantities, can lead to the death of animals.

Table 26: Yield, chemical composition and utilization of cassava fractions

Analysis	Leaves + yellow stalk	Leaves	Stalks	Tubers
Fresh material yield/ ha	25-30	20-25	30	15-20
Dry material yield/ha	5-7	4-5	13	4-5
Dry material (%)	18.2	19.4		
Mineral material (%)	6.8	11.4		
Organic material (%)	93.2	88.6		
Total CP (%)	20.2	21.8		
Soluble nitrogen (% total protein)	45.0	41.0		
DM digestibility (%) (young goats)	75.6	71.2		
CP digestibility (%) (young goats)	75.9	79.5		

Figure 29: Cassava tubers

5.7.2 Sweet potato

Sweet potato has been primarily cultivated for human consumption. Tuber production is about 22 tonnes of fresh potato per hectare containing 25% DM.

Sweet Potato tubers

Sweet potato forage

Figure 30: Sweet potato tubers and leaves

In order to increase the production of leaves a partial defoliation strategy before the harvest was tested in an exploratory trial. The results depended on cultivation, plant population density and the defoliation interval. Leaf yield was on average 4 tonnes of DM/ha (22 tonnes of fresh material) and it contained up to 18% CP.

Chemical composition of leaves and tubers are presented in Tables 27 and 28.

Table 27: Chemical composition and utilization of leaves and roots of the sweet potato

Analysis	Forage	Tuber
DM %	14.2-15.0	29.2
CP [%DM]	18.2-18.5	4.0 -6.4
NDF [%DM]	26.2	6.9
ADF [%DM]	22.3-23.5	4.2-5.5
DM Digestibility (pigs) %		90.4-95.3
OM Digestibility (pigs) %		91-96
CP Digestibility (pigs) %		27.6-52.3

Compiled from Dominguez (1992)

Table 28: Profile of amino acids (g/kg CP) of sweet potato forage and tubers

Amino Acid [AA]	Ideal Protein	Forage	Tubers
Lysine	70	62	42-72
Total Sulphur AAs	35	28	28-39
Tryptophan	10		8-12
Isoleucine	38	49	42-110
Leucine	70	96	62-92
Phenylalanine	67	106	72-136
Threonine	42	53	51-61
Valine	49	63	49-83

Compiled from Dominguez (1992)

5.7.3 Forage legumes

These are perennial legumes. They can be harvested for the first time in less than 2 years after planting and can then be regularly harvested for about 4 to 5 years. Among these, S*tylosanthes guyanensis* is well adapted to the humid conditions of the tropical Americas.

Planting is by direct seeding at a rate of 5 kg of seed/ha. The establishment period takes about 4 to 5 months, which is relatively long. Also, it is preferable to arrange the seedlings in lines in order to reduce the maintenance (hoeing) during the germination period.

Once planted, harvesting can be carried out every 6 to 7 weeks for a production of 2 to 3 tonnes of dry material/ha/harvest. Annual production varies between 12 and 20 tonnes/ha.

Like all forages, the chemical composition and nutritional value of stylosanthes varies with age (Table 29).

Stylosanthes can be used as supplements for ruminants and pigs. For pigs, only the leaves are used. Pigs weighing 15kg can consume 400g of fresh leaves.

Table 29: Chemical composition of stylosanthes

Age at harvest	DM%	OM%	CP%	NDF %	ADF %	ADL %DM
4 weeks	27	90	17	46.7	41.8	10
8 weeks	27	88.8	13	53.9	46.3	10.5

The amino acid profile/100g of protein

Arginine : 5.3 ; Cystéine : 1.2 ; Glycine : 4.5 ; Histidine : 1.6 ; Isoleucine : 3.8 ; Leucine : 6.1 ; Methionine : 1.7 ; Phenylalanine : 4.1 ; Theonine : 4.1 ; Trytophane : 1.4 ; Tyrosine : 3.8 ; Valine : 5.2.

5.7.4 Peas/beans

Of the numerous peas/beans that have been studies, they are certainly an incomplete form of animal feed. Generally, the big grains consumed by animals in a raw state are not used to the maximum effect due to the presence of anti-nutritional factors. In order to improve their use, it is necessary to roast (thermal shock) them. This constitutes an additional investment that one can avoid by limiting the incorporation rate of beans in the diet.

Furthermore, with grains, the foliage can also be included in the food. Table 30 gives the composition of two peas/grains used in tropical zones.

Table 30: Chemical composition of canavalia and vigna

Analysis	**Canavalia grains**	**Vigna**
Protein (% DM)	27-35	25-30
Amino acids (% DM)		
Arginine	1.56	1.52
Histamine	0.80	
Isoleucine	1.12	0.92
Leucine	2.00	1.78
Lysine	1.43	1.57
Methionine + cysteine	0.50	0.62
Phenylalanine + tyrosine	2.42	1.19
Threonine	1.09	0.88
Trytophane		0.34
Valine	1.26	1.09
Digestibility %		
Energy		74-80**
Nitrogen		66-78**

** highest level of digestibility (74 *versus* 80 and 66 *versus*78)

Vigna has a short-cycle. Its digestibility is improved when it is boiled for 40 minutes.Pigs consuming boiled vigna flour obtained identical performance as those fed SBM.

Contrary to the vigna, the effect of heat is less efficient on the canavalia which cannot represent more than 5% of the pigs' diet. Toasted canavalia can be retained in the ruminant's feed.

5.7.5 Fodder trees

The practice of establishing fodder trees specifically for animal feeding is not common in Guadeloupe and Martinique. However, this has been recommended in the English-speaking Caribbean through the initiatives of the SFC, Caribbean Agricultural Research and Development Institute (CARDI) and the UWI, Faculty of Agriculture (now Science and Agriculture), St Augustine, Trinidad and Tobago (Proverbs, 1985; Thompson, 1986; Paterson, Philip and Maynard,1986; Batson, Ferguson and Archibald, 1987; and Paterson, Keoghan and Proverb, 1988). In the French speaking Caribbean when the forage plants (gliricidia, leucaena, erythrina) were planted on farms, they were placed on the borders of paddocks to mark the boundary of the plots of land. They have also been planted as shade trees for the animals.

However, there exist, in the English-speaking Caribbean and in South America, the practice of planting protein banks that offer the opportunity of yielding 20 to 30 tonnes/ha of fresh forage containing between 200 and 300g of protein/kg of dry matter [20 to 30% CP]. This productivity is possible with plant population densities of 15,000 to 20,000 plant/ha. The fodder plants are superior in productivity to the herbaceous legumes. They are less sensitive to pathogens and are better adapted to dry conditions as they have deep rooted systems. Table 31 presents the chemical composition of the edible fractions of 3 fodder trees and Table 32 compares the nutritive value of leucaena, Cassava and Gliricidia leaf meal with Guinea grass hay.

Table 31: Chemical composition on a DM-Basis, of the leaves of the gliricidia, erythrina and leucaena plants

Forage	OM %	CP %	NDF %	ADF %	ADL %
Gliricidia	89.5	26.4	52	33	14
Erythrina	90.5	28.6		31	
Leucaena	90.3	23.5		31	

There is no "all purpose" formula for the management of fodder trees. The results have been very variable and have depended on the soil type and location. The production of forage and the persistence of the fodder trees will depend on the frequency and method of defoliation/harvesting. The sustained experience at the SFC, in Trinidad, on an acid ultisol [pH 4 to 5] has been that leucaena can be repeatedly harvested at an 8- to 12-week harvesting cycle continuously for about 20 to 25 years and *Acacia mangium* can be harvested for about 20 years [Gary Garcia personal experience and observations].

Table 32: Chemical composition of leaf meal made from Gliricidia, Leucaena and Cassava.

Analysis	Guinea grass hay	Cassava leaf meal	Leucaena leaf meal	Gliricidia leaf meal
Dry matter [DM %]	92.4	87.	84.6	81.2
CP % DM basis	7.63	26.81	30.2	28.4
NDF % DM basis	68.1	26.1	30.2	34.4
ADF % DM basis	47.2	13.4	17.3	16.4
Ca % DM basis	0.38	1.74	2.09	1.93
P % DM basis	0.17	0.36	0.18	0.22

The practical experience gained at the SFC over the last 30 years and the observations made by Gary Garcia suggest that the basic management principle is to avoid the flowering of the forage plant. This is because there is a competition within the plant's physiology between the production of flowers (which would lead to the production of the fruits or pods) and the production of leaves. **It is the leaves that are desired for feeding to the animals**. **Therefore, the "rule of thumb" is to defoliate or harvest the forage just before the onset of flowering.** In the case of leucaena this would be 6 to 8 weeks, and in the case of the gliricidia this may be 8 to 12 weeks. Tables 33, 34, 35, and 37 present some data on the nutritive value of leucaena forage and harvesting. Table 36 demonstrates that leucaena forage can be successfully ensiled with the inclusion of 10% molasses. The paper by Garcia *et al.* (1996) describes particulars of the nutritive value and forage productivity of Leucaena.

Table 33: The chemical composition (g $100g^{-1}$ DM) of leucaena forage harvested at different ages grown on an acid ultisol in Trinidad, West Indies

Chemical composition	Month of harvest/Age (months)					
	February	March	April	May	June	Average
	(3)	(4)	(5)	(6)	(7)	
DM (g 100 g^{-1} DM)	33.2	24.3	34.3	35.5	28.7	31.2
CP	34.2	25.8	20.5	19.4	20.5	24.1
NDF	56.8	49.3	58.2	60.0	64.4	57.8
Ash	8.6	7.6	6.3	5.5	6.1	6.8
Estimated DE (MJ kg^{-1} DM)	10.6	10.4	6.3	6.0	7.1	8.1

Source: Garcia (1988)

Table 34: Effect of ageing (months) between regrowth harvests of leucaena forage on CP content (g 100^{-1} DM)

Months of regrowth	% CP of leucaena forage					
	3 months [a] 1st harvest	4 months [a] 1st harvest	Takahashi and Ripperton (1949) [b]	Average [c] wet and dry season	Wet season	Dry season
1	27.90	26.10	–	–	–	–
2	23.70	19.70	22.21	18.72	18.25	19.18
3	18.10	21.10	17.58	18.05	18.83	17.28
4	–	–	14.60	–	13.26	–
4.5	–	–	–	–	–	15.79

[a] Material harvested during establishment at Sugarcane Feed Centre (SFC), Longdenville.
[b] Averages of repeated harvests over 3 years.
[c] Material harvested in a wet and dry season of the same year at the SFC, Longdenville with the leucaena fully established.

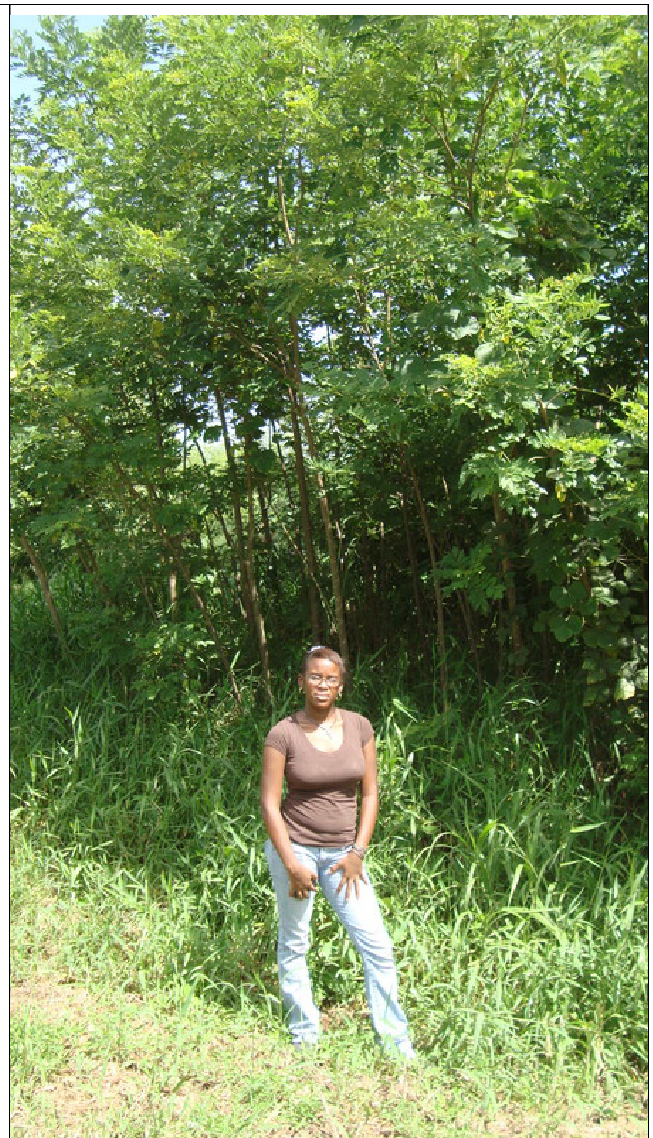
Source: Garcia (1988)

Table 35: Effect of ageing (months) between regrowth harvests of leucaena on the forage yield (kg ha^{-1}) of CP

Harvesting interval (months)	Age of first harvest					
	3 month 1st Harvest	4 month 1st Harvest	Takahashi and Ripperton (1949) Hawaii	Logan (1979) Jamaica	Devers and Keoghan (1978) Antigua	SFC dry season
1	142.37	116.93	–	–	–	–
2	135.64	373.50	640.0	–	–	432.75
3	371.19	797.77	972.5	250.00	458.00	371.36
4	–	–	986.7	–	–	–
4.5	–	–	–	–	–	955.19

Source: Garcia (1988)

Gliricidia leaves and green stems



Gliricidia planted at high population densities

Figure 31: Gliricidia [*Gliricidia sepium*]

In the establishment of a plot of fodder trees forage cannot be harvested for the first 12 months. This is to afford the plants to become fully established. Then it is necessary to practice a harvesting sequence that will allow regrowth (from 2 to 6 months, depending on the species). The necessary height for harvest varies (25 to 150cm).

Table 36: Chemical composition of silages of leucaena forage (at flowering, variety CF 95)

Treatment	DM ($g\ 100\ g^{-1}$ DM)	pH	CP ($g\ 100\ g^{-1}$ DM)	Ethanol ($g\ 100\ g^{-1}$ DM)	Acetic acid ($g\ 100\ g^{-1}$ DM)	Lactic acic ($g\ 100\ g^{-}$ DM)
Fresh [a]	34.5	6.3	20.7			
Control [b]	33.2	5.2	21.0	0.5	0.4	0.7
5% molasses [c]	33.4	4.4	18.6	0.9	0.6	1.0
10% molasses [d]	33.7	4.4	26.0	1.7	0.7	1.8

Source: Pouchette (1988) (unpublished).

[a] Leucaena harvested about eight weeks regrowth (at flowering).

[b] The control silos contained the chopped forage ensiled on its own.

[c] Leucaena forage ensiled with 5% molasses.

[d] Leucaena forage ensiled with 10% molasses.

Source: Garcia *et al.* (1996)

In protein banks gliricidia must be harvested every 3-4 months in order to maximize the forage. Its production is able to reach 15 to 20 tonnes of edible dry material/ ha or 60 tonnes of fresh product. The protein production is 5 tonnes/ha and/ year.

Gliricidia and leucaena are mainly destined for the ruminants to consume. Erythrina is well suited for the pigs to consume.

Table 37: The chemical composition of leucaena forage (leaf (petiole and blade) and stem) and leaf meal

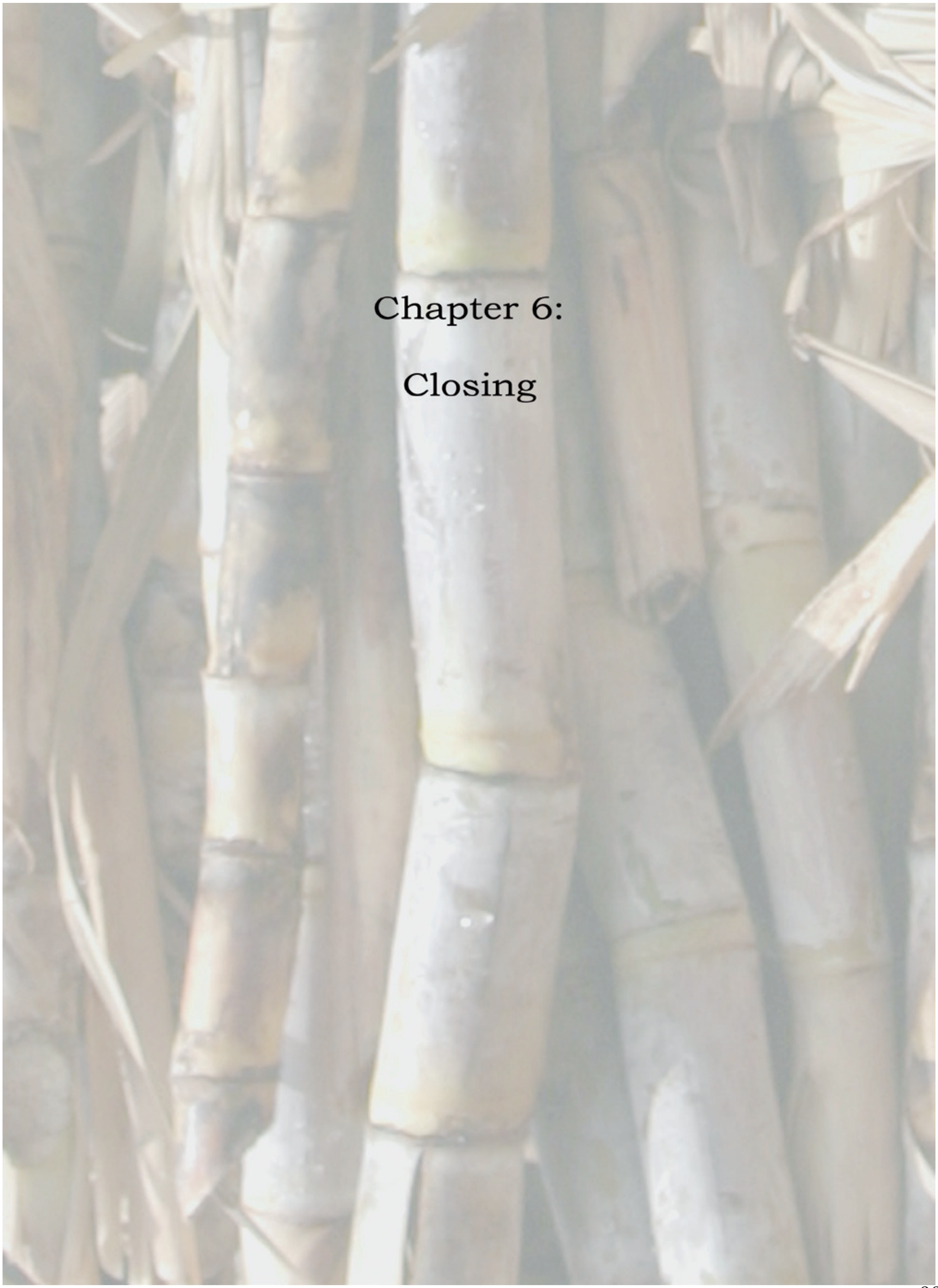
Chemical fraction dry matter basis % dry matter (DM)	Forage		Leaf meal	
	Range 27.00–34.00	Median 30.50	Range	Median
	% DM basis (g 100 g^{-1} DM)			
Nitrogen (N)	2.24–4.80	3.52	4.00–4.30	4.15
Crude protein (CP)	10.00–30.05	22.03	24.00–34.40	29.20
Mimosine	0.70–3.59	2.14	1.40–7.19	4.30
Crude fibre (CF)	32.00–28.00	35.00	18.00–20.40	19.20
Neutral detergent fibre (NDF)	34.00–42.00	39.50		
Acid detergent fibre (ADF)	34.10–36.10	35.10		
Hemicellulose	2.01–7.40	4.71		
Cellulose	11.00–25.70	18.30		
Lignin	4.20–11.70	7.90		
Ash	6.62–9.46	8.04	10.00–11.00	10.50
Tannin	0.51–1.60	1.05		1.01
Sulphur	0.14–0.29	0.22		
Calcium	0.80–2.90	1.80		1.90
Phosphorus	0.14–0.38	0.26		0.23
Magnesium	0.17–0.48	0.33		0.34
Sodium	0.02–2.66	1.34		0.02
Potassium	0.79–2.11	1.45		1.70
	(mg kg^{-1} DM)			
Copper	2.00–32.00	26.00	8.00–11.40	9.70
Iron	187.58–575.00	381.30		907.40
Zinc	30.00–308.95	169.50	19.20–32.80	26.00
Manganese	55.16–875.00	465.08		59.90
Iodine	33.00–90.00	61.50		
Chloride	0.15–0.09	0.17		
Oxalate		881.6		
Xanthrophyll			741.00–766.00	753.00
Leutein			529.00–557.00	543.00
Zeaxanthin			110.00–146.00	128.00
Carotene			227.00–248.00	237.50

Source: Jones (1979); D'Mello and Taplin (1978); Brewbaker and Hutton (1979); Pillot et al. (1976); Meulen et al. (1979); Hulman et al. (1978); Alvarez et al. (1978a); Akbar and Gupta (1984a and Akbar and Gupta, 1984b); Adeneye (1991); Aletor and Omodara (1994).

Source: Compiled by Garcia (1988)

Figure 32: Erythrina/immortel [*Erythrina* spp. mountain immortelle (English); bois immortelle (French); pito, poro (Spanish)]

Figure 33: ***Tricantera gigantea*** **[5-year-old stand that has withstood fire, flooding and extreme dry seasons]**



Chapter 6:

Closing

Chapter 6.0: Closing

This manual was developed to be used by livestock technicians and progressive, innovative and informed farmers to improve the nutrition of animals within the Caribbean and the wider tropical world using their "available feed resources" [Thomas R. Preston]. However, the manual is not the final word as the livestock farmers and animal scientists of the tropical world are all still in the process of getting a better understanding of the nutritive value, nutritional characteristics and productivity of many tropical feed resources for use by domestic and non-domestic animal species. In the manual it was highlighted that the complementary needs of farm-grown feeds (other than sugarcane) fell into three [3] categories:

1) **sources of fermentable protein (N) (protein or nitrogen that is digested in the reticulo-rumen);**

2) **sources of by-pass protein (protein that is not digested in the reticulo-rumen) and**

3) **starch sources.**

In order to produce these resources it was recommended that the farmer could employ different strategies as outlined below.

1) **A mix of plants that would produce starch, the fermentable protein (N) and by-pass protein.**

2) **The production of forage legumes that supply fermentable protein (N) and by-pass protein.**

3) **The cultivation and use of fodder trees.**

The starch sources could supply both human use and animal feed, with only the non-marketable starch-based crops going into the feeding of animals, thereby adding value to crop farm waste via food animals. This would return to the farmer animal products and organic matter. This is an **intelligent, integrated, intensive and sustainable animal production system** (**III SAPS**). In order to achieve this, intelligent decisions will have to be taken based on available information. In this regard readers are invited to consult the following web-based links:

1] Livestock Research for Rural Development:

http://www.lrrd.org

2] Tropical Animal Production:

http://www.utafoundation.org/

3] CIPAV: Centro para Investigacion en Systemas Sostenibles de Produccion Agropecuaria

http://www.cipav.org.co/

4] The Open School of Tropical Animal Science and Production:

Website: **www12.brinkster.com/ostasp/index.aspx**

http://ostasp.rizontt.com/

http://vcnaw.rizontt.com/

http://ejneaw.rizontt.com/

5] UNIVERSITY OF TROPICAL AGRICULTURE **:** UTA FOUNDATION **www.utafoundation.org**

The review of the literature on Nitrogen Utilization by ruminants suggested some practical steps that must be taken [with respect to NPN use with low energy, high fibre and low protein feeds] under intensive, mixed and integrated small farms situations within the Caribbean and the wider Tropics. These were listed as follows:

1) the best use can be made of NPN will be to bring the % CP content of the diets [on a DM basis] up to 10 or 12 % CP;
2) these types of diets should best be fed to animals that require maintenance [eg. sheep or goats in production flocks in early to mid gestation or dairy cows in late gestation, if the cows are in Body Condition 4];
3) cows in early to mid lactation may not make good use of the Urea/NPN;
4) **animal selection strategies** will have to be revisited, i.e. animals will have to be selected based on rapid growth, good reproduction and lactation **in response to high fibre and high NPN diets,** in the past and in the developed countries agricultural systems, animal selection has been based on animals' performances on high DE and high good quality CP diets [i.e. diets that have been grain based];
5) animal selection strategies will have to be revisited also to match the animal products with the intended cuisine of the region.

Therefore in closing it would be safe to suggest that the use and feeding of SDFs and the available feed resources of the tropics will only be hugely successful if we marry it with animal selection practices away from using animals that have been selected for performance on grain based diets [corn and soyabean meal] as has been done by the developed agriculture from the industrialised countries fossil based grain production and grain fed animal production systems.

The authors of this manual also look forward to hearing from readers at the following email address:

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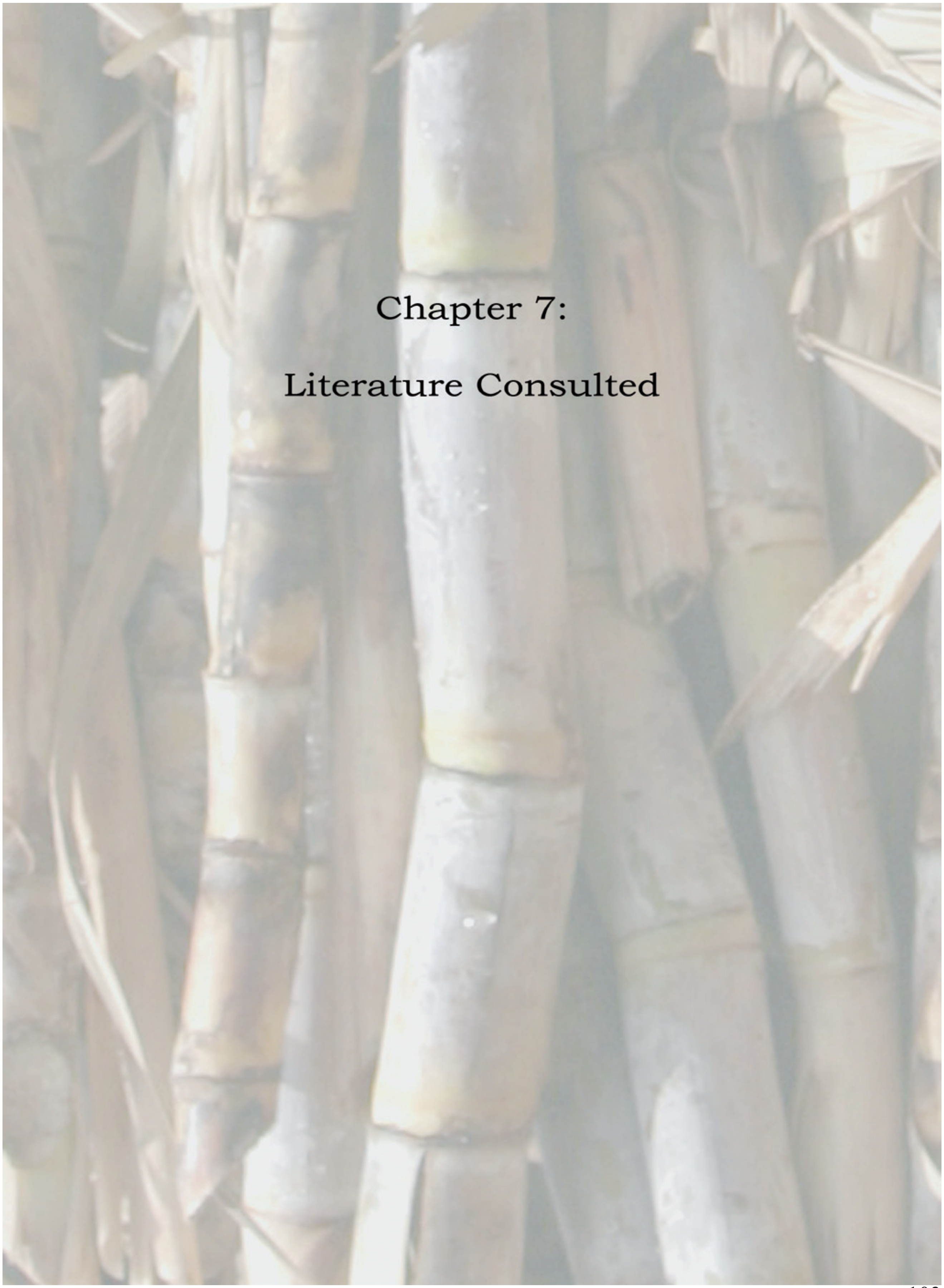
July 2010



Chapter 7:

Literature Consulted

Chapter 7.0: Literature Consulted

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APPENDIX #1

Description of sugarcane feeds: nomenclature and nutritional information, Donefer and Latrille (1980)

This Appendix comprises of six tables taken from the above publication. They concern:

Table 1: The nomenclature applied to the various parts of sugarcane and its derivatives; and

Tables 2-6: The feed analysis and energy content of sugarcane:

- Molasses (Tables 2 and 3)
- Bagasse (Table 4)
- Tops (Table 5); and
- Whole plant, aerial (Table 6)

It should be noted that the energy data (Tables 2-6) were determined in cattle/ruminants.

Int. Feed Name	Int. Feed No.	Common Names
aerial part	(2-04-689)	whole plant
→ top of aerial part	(2-13-568)	cane tops
→ stems or stalks	(2-13-248)	cane stalks
(B) → pith (stalks wo rind)	(2-13-564)	derinded stalks, sugarfith, Comfith
→ rind	(2-20-761)	rind
(A) → bagasse or pulp	(2-09-909)	bagasse
→ pulp, sifted	(1-04-700)	bagasse pith, bagacillo
→ molasses	(4-04-696)	cane, blackstrap or final molasses
→ molasses, dehy	(4-04-695)	dry (dehydrated) molasses
→ sugar, raw	(4-13-569)	raw sugar
→ sugar, brown	(4-13-578)	brown sugar
→ sugar	(4-04-701)	white (refined) sugar

Appendix #1, Figure 1: International and common names for sugarcane-derived feeds

Source: Donefer and Latrille (1980)

Appendix #1, Table 1: Feed analysis and energy content: sugarcane, molasses (sugarcane molasses) (4-04-696)

Reference	Chemical composition (% DM)						Species	Energy content (Mcal/kg DM)					
	DM	Ash	CF	EE	NFE	CP		DE	ME	NE_m	NE_g	NE_l	TDN
NRC 1971a	77.0	10.1	0	0	84.0	5.9	Cattle	4.23	3.47	2.27	1.48	2.60	96.0
NRC 1971b	—	—	—	—	—	4.3	Dairy	4.01	3.43	2.27	1.48	2.42	91.0
McDowell et al. 1974	77.2	10.3	9.9	0.3	74.0	5.4	Cattle	4.23	3.47	2.49	1.57	(2.59)	96.0
NRC 1976	75	—	—	—	—	4.3	Beef	—	2.75	1.91	1.20	—	72.0
NRC 1978	75	—	—	—	—	4.3	Dairy	3.17	2.76	1.60	1.03	1.64	72
Ensminger & Olentine 1978	75	10.3	—	0.1	85.7	5.2	Ruminant	3.22	2.64	1.64	1.06	1.67	73
SFIS No.[a]	*Literature values — levels in ration (%)*												
568	—	—	5–15	—	—	—	Beef heifers	—	—	1.37	0.78	—	—
31	—	—	10	—	—	—	Beef steers	2.86	—	—	1.52	—	62.5
32	—	—	10	—	—	—	Dairy cows	—	—	—	—	1.50	—
568	—	—	20	—	—	—	Beef heifers	—	—	1.23	0.70	—	—
31	—	—	25	—	—	—	Beef steers	2.77	—	—	0.83	—	62.0
32	—	—	30	—	—	—	Dairy cows	—	—	—	—	0.51	—
31	—	—	40	—	—	—	Beef steers	2.60	—	—	0.77	—	59.3

[a]31 = Lofgreen and Otagaki 1960a; 32 = Lofgreen and Otagaki 1960b; and 568 = Lofgreen 1965.

Source: Donefer and Latrille (1980)

Appendix #1, Table 2: Feed analysis and energy content: sugarcane, molasses, dehydrated (4-04-695)

Reference	Chemical composition (% DM)						Species	Energy content (Mcal/kg DM)					
	DM	Ash	CF	EE	NFE	CP		DE	ME	NE_m	NE_g	NE_l	TDN
NRC 1971a	93.5	14.4	2.9	0.6	71.5	10.7	Cattle	3.76	3.08	—	—	—	85.3
NRC 1971b	96.0	—	5.2	—	—	10.7	Dairy	—	—	1.78	1.18	—	68
McDowell et al. 1974	94.7	(23.5)	(3.6)	(2.7)	(52.2)	(18.0)	Cattle	(0.92)	(0.76)	(0.63)	(−1.33)	(0.00)	(20.9)
NRC 1976	96.0	—	5.2	—	—	10.7	Beef	—	2.81	1.78	1.18	—	68
Ensminger & Olentine 1978	90	12.3	5.0	1.0	72.3	9.3	Ruminant	3.00	2.46	1.49	0.92	1.55	68
NRC 1978	96	—	5	—	—	10.7	Dairy	2.99	2.58	1.49	0.92	1.54	68

Source: Donefer and Latrille (1980)

Appendix #1, Table 3: Feed analysis and energy content: sugarcane, bagasse (pulp), dehydrated (1-04-686)

Reference	Chemical composition (% DM)						Species	Energy content (Mcal/kg DM)					
	DM	Ash	CF	EE	NFE	CP		DE	ME	NE_m	NE_g	NE_l	TDN
NRC 1971a	91.5	3.1	48.6	0.7	45.9	1.7	Cattle	1.24	1.02	—	—	—	28.1
McDowell et al. 1974	93.6	4.5	41.6	1.2	50.8	1.9	Sheep	0.98	0.80	—	—	—	—
McDowell et al. 1974[a]	46.4	4.2	49.2	3.7	37.0	5.9	Cattle	2.18	1.79	1.06	0.26	0.99	49.5
NRC 1978	92	—	48	—	—	1.8	Dairy cows	1.24	0.80	0.71	0	0.57	28
Ensminger & Olentine 1978	92	3.3	47.9	0.8	46.3	1.8	Ruminant	2.09	1.72	1.02	0.17	1.04	47
NRC 1971[ab]	90.3	7.9	45.0	1.0	44.2	1.9	Cattle	2.00	1.64	—	—	—	45.4

[a] Dehydrated, ground (1-09-757).

[b] Bagasse pulp, sifted (bagasse pith) (1-04-700); mistakenly cited as (4-04-700).

Source: Donefer and Latrille (1980)

Appendix #1, Table 4: Feed analysis and energy content: sugarcane, top of aerial part (sugarcane tops)

Reference	Chemical composition (% DM)						Species	Energy content (Mcal/kg DM)					
	DM	Ash	CF	EE	NFE	CP		DE	ME	NE_m	NE_g	NE_l	TDN
NRC 1971a[a]	29.6	9.5	35.8	2.0	47.6	5.1	Cattle	2.24	1.84	—	—	—	50.8
McDowell et al. 1974[b]	32.6	8.7	32.1	1.4	52.2	5.5	Cattle	2.40	1.97	1.16	0.45	1.16	54.4
McDowell et al. 1974[c]	30.0	5.8	28.5	4.0	56.0	5.7	Cattle	3.45	2.83	1.80	1.19	1.98	78.2
McDowell et al. 1974[d]	55.5	11.2	31.8	2.5	48.7	5.7	Cattle	2.45	2.01	1.18	0.50	1.20	55.6
McDowell et al. 1974[e]	85.5	5.4	39.3	2.0	51.0	2.3	Cattle	2.34	1.92	1.13	0.40	1.11	53.0
Ensminger & Olentine 1978[f]	26	11.8	33.1	1.7	48.1	5.2	Ruminant	2.14	1.76	1.05	0.22	1.07	49
McDowell et al. 1974[f]	25.9	5.9	30.4	3.4	56.3	3.5	Cattle	2.91	2.38	1.43	0.85	1.55	65.9
		Literature values											
SFIS summary	—	7.0	32.6	1.8	50.3	—	Cattle	—	—	—	—	—	52.6

[a] Ensiled (3-08-528).
[b] Fresh (2-13-568).
[c] Chopped (2-13-563).
[d] Ensiled (3-08-528).
[e] Dehydrated (1-13-565).
[f] Leaves with top of aerial part (2-04-692).

Source: Donefer and Latrille (1980)

Appendix #1, Table 5: Feed analysis and energy content: sugarcane, aerial part (whole plant), fresh (2-04-689)

	Chemical composition (% DM)							Energy content (Mcal/kg DM)					
References	DM	Ash	CF	EE	NFE	CP	Species	DE	ME	NE_m	NE_g	NE_l	TDN
NRC 1971a	25.1	6.8	31.3	2.2	53.5	6.2	Cattle	2.52	2.07	—	—	—	57.2
NRC 1971a[a]	27.2	6.0	32.0	2.1	52.7	7.3	Cattle	2.56	2.10	—	—	—	58.0
McDowell et al. 1974	20.3	3.2	30.5	2.5	60.1	3.5	Cattle	2.67	2.19	1.30	0.67	1.37	60.5
McDowell et al. 1974[b]	25.5	4.5	24.2	1.6	67.0	2.5	Cattle	3.07	2.51	1.51	0.96	1.68	69.6
McDowell et al. 1974[c]	20.9	13.9	34.0	1.5	38.2	12.4	Cattle	2.57	2.11	1.25	0.60	1.30	58.4
Ensminger & Olentine 1978	26.0	6.1	30.9	2.1	54.9	5.9	Ruminant	2.59	2.12	1.27	0.60	1.32	59
			Literature values										
SFIS summary	—	4.9	28.2	2.1	61.1	3.3	—	—	—	—	—	—	55
U. of Florida[d]	—	4.3	28.1	1.2	64.0	2.3	In vitro	—	—	—	—	—	56.6

[a] Mature (2-04-687).
[b] Chopped (2-09-700).
[c] Late vegetative (2-10-258).
[d] Pate and Coleman 1975.

Source: Donefer and Latrille (1980)

APPENDIX #2

Feeding models [% diet dry matter] utilizing WCS for growing beef and dairy cattle, and lactating dairy cows as suggested by Garcia, Neckles and Benn (1982)

Appendix #2, Table 1: Proposed model for feeding freshly chopped sugarcane to zero grazed cattle, with an expected average daily gain (ADG) of 0.6 to 0.9 kg/day

Liveweight [kg]	% of Diet Dry Matter			DE [M.Cal/kg]	%CP	NPN as a % of Total CP
	Chopped sugarcane	Protein/ energy source	Molasses			
50-100	30	60	10	3.4	18.0	20
100	30	55	15	3.3	17.0	30
150	40	45	15	3.2	14.2	30
200	45	35	20	3.2	12.4	40
300	50	25	25	2.9	10.0	45
400	55	20	25	2.7	9.3	50

Appendix #2, Table 2: Proposed model[1] for feeding dairy cattle freshly chopped sugarcane, assuming a 500kg cow at various stages of lactation and various lactation yields.

Proposed/ recommended composition of diet	Stage of lactation (wks) and potential milk yield (kg/day)			
	Wk. 1 - 10	Wk. 11 - 20	Wk. 21 - 30	Wk. 31 - 44
	>23 kg/day	17 - 23 kg/day	11 - 17 kg/day	<11 kg/day
%CP	16	15	14	13
NPN as a % of total CP	20	20	20	20
% Chopped sugarcane (% diet dry matter)	25 to 30	30 to 35	40	45
% Molasses (% diet dry matter)	15 to 20	20	20	20
% Protein energy supplement source(% diet dry matter)	60 to 50	50 to 45	40	35
DE (M.Cal/kg)	3.3	3.1	2.9	2.9

APPENDIX #3

Cost of producing sugarcane silage at the SFC, Longdenville, Trinidad and Tobago in 1986-87

Appendix #3, Table 1: Itemization of sugarcane silage production and feeding cost

ITEMS OF COST	**Cost/ha OR Cost/tonne OR Cost/hour TT$**	**Cost per kg sugarcane as fed (Cost per kg sugarcane DM) TT$**	**% of Cost at point of Feeding**
1. SUGARCANE PRODUCTION	**Cost/ha**		
a) Establishment (20% of cost of production)	674.08		
b) Maintenance (80% of cost of production)	4105.45		
Total Sugarcane Production Cost	4779.53	0.056 (0.17)	**40**
2. HARVESTING	**Cost/hr**		
a) Tractors (2)	105.73		
b) Equipment - trailer and harvestor	27.33		
c) Labor: 2 tractor drivers	20.00		
1 laborer	7.5		
Total Harvesting Cost (at 3.7 tonnes/hr)	160.56	0.043 (0.13)	**30**
3. ENSILING	**Cost/tonne**		
a) Transportation and off-loading (0.05 hrs/tonne @ $108.84/hr)	5.44		
b) Spreading and compacting (0.22 hrs/tonne @ $50/hr)	11.00		
c) Use cost of silo and covering	9.71		
Total Ensiling Cost	26.15	0.026 (0.08)	**18**
4. TOTAL COST OF CHOPPED ENSILED SUGARCANE		0.125(0.38)	**88**
5. FEEDING COST		0.017 (0.05)	**12**
6. COST OF ENSILED SUGARCANE AT FEEDING		0.142 (0.43)	**100**

6TT$ = 1US$ [Source: Taylor (1987]

Appendix 3 Table #2: Summary of the Timing (mins) of Mechanical Sugarcane Harvesting on a per tonne basis

	Clearing Harvester[1]	Cutting[2]	Turn Around[3]	Total Time[4]
Avg. Time Taken/Tonne	4.28	5.96	5.88	16.21
Time Taken as a % of Total Harvesting Time	27	37	36	100

Clearing Harvester[1] – Time taken to unclog the harvester.
Cutting[2] – Time taken for actually cutting sugarcane.
Turn Around[3] – Time taken for the equipment, on completion of one row, to turn around and begin the next.
Total Time[4] – Time taken to harvest one tonne of sugarcane.

[Source: Taylor (1987]

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A Pictorial Memoir from The Visit of Dr. Bertrand Hervieu Chairman of the Board/ President Institut National de la Rercherche Agronomique [INRA] Republique Française to the UWI and SFC, facilitated by the Ministry of Agriculture, Land and Marine Resources of the Republic of Trinidad and Tobago and the French Embassy June 28th and 29th 2002

Cooperation through Collaboration INRA-UWI St Augustine:

Photographed at the University of the West Indies, St. Augustine Campus, Trinidad.

(Left to Right) Dr. Gary W. Garcia [Presdent, UWI French Scientific Language Club], Dr. Ranjit Singh [Head, Department of Agricultural Economics and Ectension] , Dr. Richard Brathwaite, [Head, Department of Food Production], Dr. Mamy, Dr. Durant, Dr. Ferlin [INRA Paris], Dr. Bertrand Hervieu [Chairman of the Board, INRA Paris], Prof. Bridget Brereton [Deputy Campus Principal], Dr. Alian Xande [President INRA Antilles-Guyane], Prof. Baldwin Mootoo [PVC Research], Mr. Cicero Lallo [Lecturer in Animal Production], Prof. Charles Mc David [Dean Faculty of Agriculture and Natural Sciences], Prof. Frank Gumbs [Campus Coordinator for Research].

Dr. Keith Archibald [Chairman CARDI], Dr. Bertrand Hervieu, Emeritus Prof. Lawrence A. Wilson [Former Dean, Faculty of Agriculture] and Mrs. Wilson.

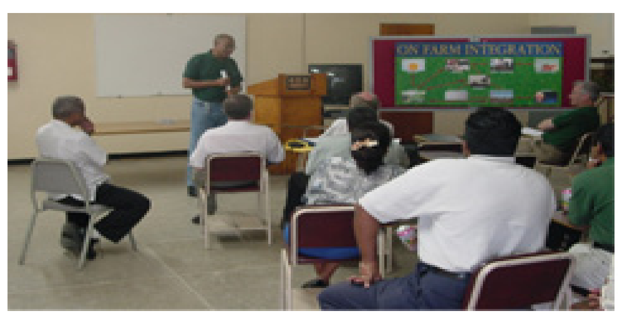
The Honorable John Rahael receiving from Dr. Hervieu a bottle of **INRA's Vintage.**

Last day visit to the Sugarcane Feeds Centre, Longdenville

Dr. Ferlin, Prof. Norman Girvan [Dir. General Associan of Caribbean States], His Excellency the French Ambassador Mr. Alain Germain, Dr. Bertrand Hervieu

Dr. Bertrand Hervieu, Chairman of the Board of INRA, Delivering the lecture on "The Multifunctionality of Agriculture" at the Learning Resource Centre, UWI St Augustine, 28th June 2002

Dr Alain Xande, Dr. Bertrand Hervieu, His Excellency the French Ambassador Mr. Alain Germain, Prof. Charles Mc David, Dr. Keith Archibald and Honorable Minister John Rahel

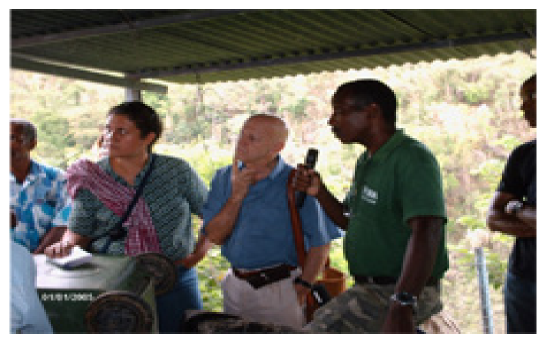


Floyd Neckles [Project Director SFC]

A Pictorial Memoir of the Sugarcane Feeding Conference Institute Nationale de la Rercherche Agronomique [INRA] Guadeloupe, Republique Française Petite Bourg, Guadeloupe, 24-25 June 2008

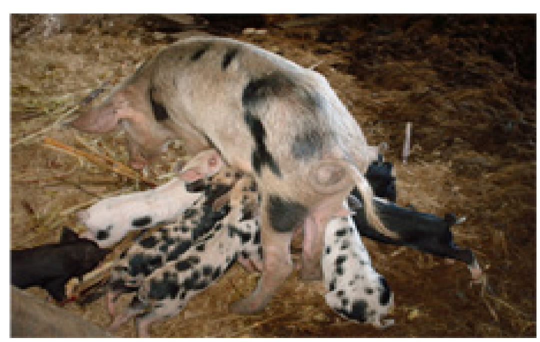
Dr. Harry Archimède

Conference Presenters: Mr. Nigel Dixon [Post Grad UWI], Mr. Alexander Benn, Dr. Reginald Preston, Mr. Cicero Lallo, Mr. Floyd Neckles [at back], Dr. Gary Garcia [at front], Dr Pedro C. Martin Mendez [Instituto de Ciencia Aninmal (ICA), Cuba], Mr. Duniesky Rodriguez Acosta [ICA, Cuba], Dr. Harry Arcimede [at back], Dra. Elaine Valino Cabrera [Director of Research, ICA, Cuba], Snr.Lylian Rodriguez , Dr. Juilo Ly [ICA, Cuba]



Snr. Lylian Rodriguez [Universidade para la Agricultural Tropical:UTA-TOSOLY, Colombia], Dr. T.R. Preston and Dr. Harry Arrchimede

Tropical Hair Sheep on Deep Litter



Sow and Piglets on Sugarcane Litter

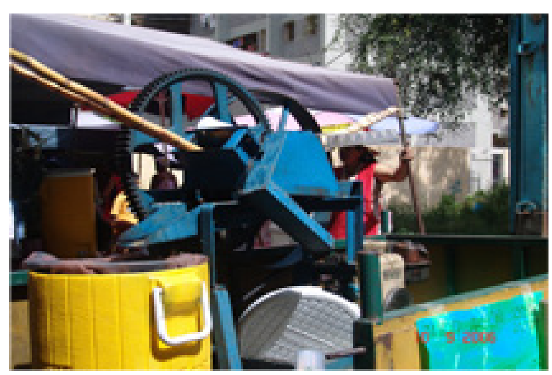
Thomas Reginald Preston

The Team from Trinidad and Tobago (UWI and SFC): Front Row: Dr. William M. Mollineau, Mr. Nigel Dixon [Post Graduate student St Lucia], Mr. Cicero Lallo,
Dr. Gary Garcia, Middle Back: Mr. Floyd Neckles

The Participants: [Left of Picture] Dr. Gisele Alexandre [Small Ruminant Expert, INRA]

Reject Bananas for Animal Feeding: Source of Fibre and Starch

Small Sugarcane Juicer



Small Sugarcane Juicer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