Chapter 7

Technologies for improving the use of renewable natural resources

This chapter describes existing knowledge on methods for improving the use of natural renewable resources in integrated farming systems. The methods that are described extend beyond the use of feed resources. The justification for including them in this manual is that sustainable agriculture requires the close integration of tree and food crops, animals and energy in order to make optimum use of the available biomass.

Thus the success of the "high-offer" system of feeding crop residues depends on alternative use being made of the rejected parts of the feed. The best way of doing this in many situations will be to use these rejected feed components as fuel.

Similarly, where animal manure is an essential feature of the farming system, the capacity to convert feed into manure may have a higher priority than the production of meat or milk.

In order to optimize the use of available resources, researchers should be aware of these complementary activities in which livestock play an important role but are not necessarily the principal actors. In many components of these systems, information is lacking which implies that these are fertile areas for research.

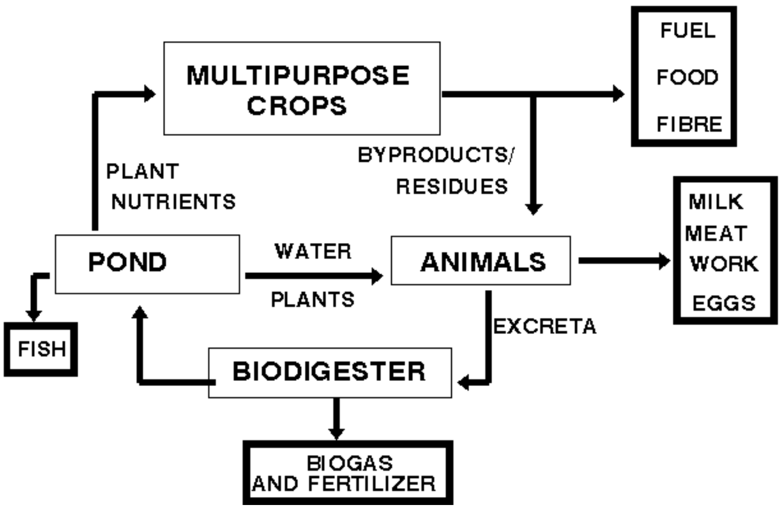
FARMING SYSTEMS AND AGRO-INDUSTRIAL PROCESSING

Feed resources likely to be used by small-scale farmers will be mainly produced on the farm as residues or by-products from other crops. Agro-industry is another source of feed resources, especially when the processing is done at village level.

Integrated farming systems

Sustainable use of natural renewable resources will be facilitated when the feed is grown, the animals are fed and the excreta is recycled on the farm in ways that minimize the use of imported inputs including energy. Integrated farming systems that embody these concepts are seen in many parts of SE Asia and have developed in response to increasing human pressure on land resources. The simple version of this model is shown in Figure 7.1.

Figure 7.1. Flow diagram of the integrated farming system.



It is proposed to describe the methods already in commercial use which will improve the overall productivity and sustainability of the system.

Agro-industrial by-products

Processing of agricultural crops can take place on the farm, in the village - usually by some artisan method - or industrially at factory level. Methods will be described which are likely to be useful at the farm and village level.

MANAGEMENT OF FEED RESOURCES

Two kinds of feed resources are found in practice, depending on the primary crop that is grown. Usually this will be a food or cash crop. In most cases the primary crop will be a cereal grain grown for food security, usually rice in Asia and maize, sorghum or millet in Africa. The residue will then be the stems and leaves which are traditionally left in the field (e.g., in Africa) or carried to the homestead (e.g., in Asia). Examples of cash crops are sugar cane, bananas, cotton, sunflower, groundnuts and various root and tuber crops including cassava and sweet potatoes. Protein crops for home consumption and sale include various types of beans, which frequently are grown in association with cash crops and with maize, sorghum and sunflower. The residues from these crops range from none (the case of jute) to high-protein leaves from cassava and sweet potato and low-protein biomass in the pressed stalk, leaves and the growing point of sugar cane.

From agro-industrial sources, the by-products which will respond to upgrading are: the pulps arising from extraction of juice and slices from pineapple, citrus and tomatoes; the pulp from coffee; cellulosic materials such as sugar cane bagasse; inedible offal from animal and fish processing; organic household and restaurant waste.

Upgrading of crop residues mainly implies the use of technologies to raise digestibility in the case of cereal straws and stover. Other examples of upgrading are methods to neutralize anti-nutritional factors such as hydrocyanic acid in cassava leaves, anti-trypsin factors in soya beans and toxic amino acids and lecithins in *Canavalia* (*Canavalia ensiformis*). In some cases the target will be a monogastric animal (e.g., for cassava leaves) but usually it is the ruminant species that are most appropriate.

Upgrading the feeding value of fibrous crop residues is mostly achieved by interfering with the protective effect of lignin on the availability of substrate to rumen bacteria or to hydrolytic enzymes. While better use of cellulosic roughages can often be achieved by adding a limiting nutrient such as fermentable nitrogen, in the present context, upgrading refers to methods which increase either the rate or the extent of cellulose degradation by rumen micro-organisms. It is important to recognise that upgrading does not necessarily have to result in an increase in digestibility particularly when the roughages in question are given *ad libitum*. An increase in intake can lead to better use of surplus fibrous feed resources and thus increase performance or decrease the need for supplementation. An increase in degradation rate has the effect of removing digesta more rapidly from the rumen which in turn allows the animals to consume more, without necessarily increasing digestibility.

There are many methods for upgrading fibrous residues but only ammoniation (by urea treatment or with anhydrous ammonia) of straw and high-pressure steam treatment of bagasse are used commercially.

Ammoniation

At the present time the only method recommended for practical application involves ammoniation either using gaseous ammonia or through wet treatment of the material with urea. The effect of this treatment is to increase digestibility (often by 5-10% units), to increase the nitrogen content of the straw (to approximately 1% of the dry matter) and to increase acceptability and voluntary intake of the treated straw as compared to untreated straw (usually by 25-50%) when this is made available on a free choice basis. Only a brief outline of the methods is given here and the reader is referred to recent reviews for more complete descriptions of the method (e.g., Sundstol and Owen, 1984).

The principle

Ammonia as gas or generated from urea (by bacterial ureases present in the residue) hydrolyzes the chemical/physical bonds between lignin and the cellulose and hemicellulose in the plant cell walls. The hydrolysis of these bonds makes the cellulose and hemicellulose more accessible to micro-organisms in the rumen and increases total fermentation and usually the rate of fermentation. Some chemical hydrolysis of hemicellulose also takes place resulting in an increase in the portion of soluble carbohydrate in the straw.

Wet treatment with urea

Straw is sprayed with an equal weight of water containing 4-5% urea. This may be done in a pit, in a container such as a basket lined with mud or in the process of building (or re-building) the traditional stack. A garden watering can (or any can with holes punched in the bottom) is convenient for applying the urea solution. If the can contains 20 litres

(800 to 1,000g urea), this will be enough to treat 20 kg of straw. This amount of straw is put into the pit or laid as the base of the stack and the urea solution sprayed on top. The process is repeated until the required amount of straw is treated. In the case of a pit or container, some simple seal such as banana leaves should be put on top. For the stack it is enough to have a final layer of straw arranged in the traditional way for avoiding entry of rain.

For some crop residues (e.g., maize cobs) that have no natural source of urease, it may be advantageous to add a meal containing urease (e.g., from whole soya bean or other legume beans or even livestock excreta which also contains urease). Suggested amounts are 3-5% (dry basis) of the beans or excreta. Additional urease may reduce the reaction time, especially if the fibrous resource appears relatively sterile such as for example, bagasse. The higher the ambient temperature the shorter the time is needed for digestibility to be increased. It is always important to study the reaction time under the local conditions where the straw is to be treated. A minimum of 3 days and a maximum of 14 days is usually required. For a more complete description see Jayasuriya (1984)

Evidence of the reaction taking place is a change in colour of the fibrous material usually to a bright yellow; there is also a strong smell of ammonia when the straw is uncovered. Dark yellow or even brown discoloration of straw may result if the stacks become hot. Treated straw can be fed immediately following ammoniation. It must not be sun-dried as this results in a loss of gaseous ammonia.

The use of animal urine to ammoniate straw

Animal urine, provided that it comes from animals consuming diets adequate in nitrogen, can be used to provide the source of urea for ensiling with straw. The subject has recently been reviewed (Sundstøl, 1994).

Initially in any system where treatment of straw with urine is to be an on-going technology, it is probably advisable to estimate the quantity of urea in urine and to fortify the urine in the first treatment. From then on the urine ought to contain sufficient urea if the animals are fed on the ammoniated straw. Urine is sprayed on the straw in a similar way to that described above for the urea-treatment method.

Ammoniation of straw with gaseous ammonia

Straw stacks are constructed of a size that can be readily covered by the black polythene sheeting available in most countries. On sandy soils a ground sheet is required. Where large stacks are to be ammoniated, the straw should be sampled and the dry matter content determined. Water should be added to the straw to raise the moisture content to at least 15%. The ammonia-gas cylinder is connected to a long perforated metal pipe about 4 cm diameter which is inserted into the stack through a hole in the plastic about the middle of one end and pushed into the stack (the bales are always stacked so as to facilitate its entry).

The plastic sheet is tied around the tube and sealed along the bottom edges of the stack with earth. A weighed amount of ammonia is then added to give 3 kg of ammonia/100kg of straw. It is always better to inject liquid ammonia and not gaseous ammonia and this is done by inverting the cylinder. The ammonia is rapidly absorbed into water and although the plastic sheet billows it is not likely to rupture. As ammonia inhalation is deleterious to health, it is beneficial to force air through the stacks and trap the excess ammonia prior to opening the stack.

Ammoniation with application of heat

Ammoniation of straws with gaseous ammonia is improved by raising the temperature to 90°C. In Europe, ovens have been developed which take several tonnes of straw and enable the treatment time to be reduced to less than 24 hours. The treatment of straw at these temperature can give rise to toxic compounds which cause "bovine hysteria" and since these compounds are transmitted *via* milk, it becomes hazardous (to calf or human health) to give this type of treated straw to dairy cows (see Perdok and Leng, 1985). The method is not recommended for developing countries.

Steam treatment

Steam at high pressure dramatically increases the digestibility of the bagasse produced when sucrose is extracted from sugar cane at industrial level. The effect is mainly due to acid hydrolysis of the hemicellulose fraction since the digestibility of the insoluble fraction is hardly affected.

The method is especially appropriate for sugar factories where excess high pressure steam is usually available. The fresh bagasse (contains 50% moisture) is held in a steel chamber into which high-pressure steam ($17kg/cm^2$) is injected until the temperate rises to 200°C and is kept there for 5 minutes. The pressure is then released abruptly and the material is extracted from the chamber. The treated bagasse takes on a darker colour, has a slightly sweet smell and a pH of less than 4 which enables it to be stored without risk of fermentation. The process also gives rise to toxic phenolic compounds (furfural) if the treatment time is extended much beyond the recommended five minutes.

Multi-nutrient blocks

The formula most frequently used for the preparation of multi-nutritional blocks is (kg/100kg of mixture): "C" (final) molasses (minimum Brix 85) 50, urea 10, calcium oxide (or cement) 10, salt 5, bone meal 5 and wheat bran 20. For those persons making blocks for the first time this is a useful starting point as a good firm block will be produced. Mixing may be done by hand, in a concrete mixer or in a horizontal paddle mixer. Choice of one or other method will depend on the relative costs and availability of labour and machinery.

When using a mechanical mixer it is usually recommended to first add the dry ingredients and finally the molasses. When mixing by hand, it is convenient to mix first the urea in the molasses. It is NOT necessary for the urea crystals dissolve in the molasses - it is enough for them to remain suspended in the viscous liquid. Water should not be added. The dry ingredients are then mixed together in a plastic bowl, metal container or wheelbarrow. The molasses-urea is added last. The mixture is then put into moulds made from wood, plastic (a 4 litre bucket is a convenient size) or metal. The mixture should be consolidated in the mould using a weighted plunger. The pressure moulds used to make clay bricks can also be used. Usually the moulds are removed immediately to accelerate drying and curing of the blocks.

Often "final" molasses is not available (it is only produced in the industrial factory) or is unduly costly. There are several alternatives. In most Asian countries, artisan production of "gur" is a traditional and widespread activity. This is often re-processed into crystalline "A" sugar leaving as a residue "A" molasses. The simple centrifuges used for this purpose require the addition of considerable quantities of water which ends up in the molasses which then will have a final Brix of about 60, and will have lost much of its viscosity. Other replacements for molasses are "vinaza" (distiller's solubles), the scums that are skimmed off boiling cane juice during manufacture of "gur" and "panela" and even fresh cane juice.

The major problem with all these materials is that it is difficult to make blocks of sufficiently hard consistency to limit intake and ensure there will be no risk of urea toxicity which might occur if intake of the block is excessively high.

Experiences in two projects financed by the Technical Cooperation Programme of FAO, first in Cambodia (TCP/CMB/2254; Emergency Plan for Livestock Security [T.R. Preston and C. Kayouli] September 1993, FAO, Phnom Penh), repeated subsequently in Tanzania (TCP/URT/ 2255A, Increasing Livestock Production by making Better Use of Available Feed Resources ([T.R. Preston]. 13 October 1993, Department of Animal Science, Sokoine Agricultural University, Morogoro), have shown that the inclusion of 20% (dry basis) of clay is an effective way of ensuring that a sufficiently hard block will result even when low-brix molasses, vinaza or cane juice are used.

The formula used in Cambodia was: (kg/100 kg mixture) rice bran 35, "A" molasses (Brix 55) 20, urea 7.5, salt 7.5, lime 5, cement 5, clay 20. Twenty kg of clay are mixed with 5 kg of lime and usually water is added in amounts equal to half the weight of the clay. If the clay is wet the amount of water is reduced to one quarter of the weight of clay. As the final activity at the end of the working day, six batches of clay, lime and water are prepared, corresponding to 6 batches each of 100 kg of the final mixture. These are left to soak overnight. The following day the molasses is mixed first with the urea, salt is then added followed by the cement. This mixture is then added to the clay and lime and after thorough mixing is poured onto the rice bran, arranged in the form of a walled circle. The rice bran is then mixed with the liquid component and finally put into individual wooden moulds measuring 20 x 20 x 20 cm, and tightly packed using a weighted plunger.

The mould is then removed and the finished block left to dry in a partially shaded area for a minimum of 4 days. On rainy days, a longer curing time is necessary. The blocks remain under cover for a further 7-10 days before being distributed to the villages.

In Tanzania the formula was: maize bran 35, final molasses 20, urea 10, clay 20, lime 5, cement 5, salt 5. Four kg of clay are mixed with 1 kg of lime and water is added in amounts equal to half the weight of the clay (i.e., 2 litres).

In the Kondoa region of Tanzania, where molasses is difficult to acquire, the scums taken off the surface of the boiling cane juice (during artisan production of syrup) were used instead of molasses. The formula is shown in Table 7.1. In the Amani mountains in Tanzania, fresh sugar cane juice replaced the scums.

Table 7.1: Formula for multi-nutrient blocks containing the scums from boiling sugar cane juice and with addition of clay to improve gelling characteristics (Source: SIDA-MSc, 1994).

Ingredient	% Fresh weight	% Dry weight
Scums*	46	16
Clay (dry)	9	14
Urea	4.5	7
Cement	4.5	7
Salt	2.3	3.5
Maize bran	15	23
Sunflowerseed hulls	18	28

* Juice and flocculated protein and minerals

The urea is first dissolved in the scums or juice. The remaining dry ingredients are mixed separately in a plastic bowl and the scums or juice (containing urea) added last. The final mixture is packed into a mould (a 1 litre can), which is then inverted and the contents ejected carefully to form a cylindrical block, which is then left to dry. The clay acts to adsorb the excess moisture present in the final mixture, thus facilitating the gelling of the block despite its relatively high moisture content (about 40% in the final mixture). When neither molasses nor cane juice is available, blocks can still be made. Examples of formulae without molasses, and descriptions of procedures, used in Tunisia are given by (Hassoun and Ba, 1990).

High-offer level feeding

This system is only feasible when more fibrous feed is available than can be consumed by the available number of animals. Feed resources which lend themselves to this method are cereal straws, especially maize, sorghum and millet stover, and the residual pressed sugar cane stalk after juice extraction in a 2 or 3 roll crusher. For best results the level of offer should be at least twice what the animal is able to consume. Urea-containing multi-nutrient blocks should be a feature of this feeding system to supply the necessary nitrogen and minerals. Depending on the feed resource it may be advantageous to chop it or break it into smaller pieces to facilitate the process of selection. Opinions are divided on this issue. Thus, women farmers in Mauritius collect sugar cane tops after harvest of the stalk and offer it whole to their cattle, claiming that this facilitates selection of the more nutritious growing point (Boodoo *et al.*, 1990b). In contrast, Vargas *et al.* (1994) reported a 60% intake of sugar cane tops when these were offered to African Hair sheep at 2 to 3 times the expected intake. The tops had been chopped before feeding.

NEUTRALIZING ANTI-NUTRITIONAL COMPOUNDS IN FEEDS

Cassava leaves

Recommended procedures for reducing HCN content to non-toxic levels will depend on the species to be fed. For pigs, ensiling is the simplest method and has given good results in Vietnam (Bui van Chinh, 1994, personal communication). The freshly harvested leaves are mixed with 1% (fresh weight) of rice bran and packed into a pit or other suitable receptacle. Covering with banana leaves weighted down by some heavy objects (bricks or stones) appears to be adequate to ensure anaerobic conditions. A period of three weeks is sufficient to reduce HCN to insignificant concentrations. When the cassava leaves are to be included in poultry rations it is more convenient to sun-dry the leaves for 24-48 hours. This process also reduces HCN concentrations to safe levels (Table 4.8).

For ruminants, the leaves can be fed fresh as the rumen micro-organisms appear to be able to detoxify the HCN.

Soya beans

The dry beans contain anti-trypsin factors which interfere with the digestion of the protein in monogastric animals. Industrially, toasting is the standard method for neutralizing these compounds. Toasting can also be done at farm level but it is not always reliable. It is better to boil the beans for 30 minutes following soaking in water the previous 24 hours. Although this method consumes fuel, at least it avoids the need to grind the beans as the soaking and boiling softens them to the point where they are easily digested.

***Canavalia* beans**

Beans from the *Canavalia* plant (*Canavalia ensiformis*) contain toxic amino acids and lecithin. The toxic amino acids can be neutralized by treating the beans with ammonia generated from urea by the action of urease present in the beans. Five kg of urea are dissolved in 50 litres of water and added to 100 kg of beans which are then maintained in a sealed container (e.g., a plastic bag) for 7 days. After this treatment, the beans can be fed safely at levels up to 15% of the diet of` poultry (Udebibie, 1991).

Leaves from multi-purpose trees

The leaves of many species of trees and shrubs contain anti-nutritional compounds such as tannins which, at high levels, can reduce both palatability and digestibility as they form insoluble complexes with the leaf protein. There are three approaches which appear to show promise as a means of improving intake.

High molecular weight compounds such as polyethylene glycol condense with tannins and prevent them reacting with the plant protein. Addition of polyethylene glycol to the drinking water of cattle grazing tanniferous trees in South Africa led to significant increases in growth rate (Leng, R.A., personal communication).

The leaves of *Acacia mangium* have a rumen degradability (*in sacco* method) of only 28-30% in 48hr. Ensiling the leaves with molasses (5kg molasses/100 kg fresh leaves) increased the degradability by 50% (Bui Xuan An *et al.*, 1992). The procedure is similar to that described above for ensiling cassava leaves.

The leaves of *Erythrina fusca*, a leguminous tree used in agro-forestry systems in Colombia (see Chapter 6), is not relished when fed in the fresh state. Wilting the leaves for 24 hours and mixing them with crude palm oil led to threefold increases in intake by crossbred milking cattle. The foliage (leaves, petioles and green stems up to 2cm diameter) are harvested and passed through a forage chopper and left in the shade for 24 hours. Palm oil is added (6 kg oil to 94 kg wilted leaves) and mixed thoroughly with the leaves in a horizontal paddle mixer. The mixture is fed fresh.

It is not known if other tree leaves that are poorly consumed by animals will respond to the same oil treatment. Nor is there an obvious explanation for the effect of the oil in increasing intake. It may act as a "sink" for volatile secondary plant compounds which are responsible for the low palatability. Clearly it is an area worthy of more research.

ENSILING FISH AND ANIMAL WASTES

Fish silage is made from whole fish, of fish offal, that is mechanically ground and liquified by the action of the endogenous enzymes present in the digestive tract of the fish. The addition of acid lowers the pH which inhibits the growth of putrefactive bacteria, enabling long term storage of the silage. There are two approaches: one is to add mineral or organic acids (phosphoric, acetic or formic acid); the other is to add rapidly fermentable carbohydrate (molasses, cassava roots or sweet potato tubers, or a mixture) which ferment anaerobically to acetic acid.

The fish or fish offal is ground as finely as possible, placed in a suitable container and the acid added until the pH falls to 4 or less. The silage is then stored in air-tight conditions until used.

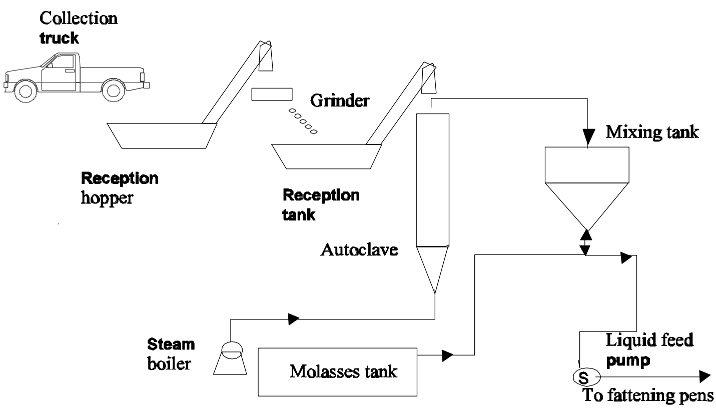
If carbohydrates are used then the amounts are (% by weight): molasses 20, ground fish offal 80 or: roots/tubers 50-30, molasses 10, ground fish offal 40-60. An example of the use of molasses was given by Lien *et al*. (1994) who used a mixture of shrimp heads, blood and molasses in a ratio of 5:3:2 respectively (wet weight).

Molasses can also be used to preserve whole fish or fish or meat offal without grinding (Perez, 1995). In this process, the osmotic pressure of the molasses causes the dehydration of the raw tissue. The fish or offal should be completely covered by the molasses and kept free of air by putting a weighted grid or netting on the surface of the mixture.

ORGANIC WASTES FROM INSTITUTIONS (CANTEENS, RESTAURANTS, HOSPITALS ETC)

The system used in Cuba for collecting, processing and using organic wastes is described as it represents a unique attempt to develop an alternative non-cereal feed for pigs and at the same time avoid the environmental contamination and loss of resources that results when these materials are incinerated or disposed of in land fills.

Figure 7.2. Flow chart of system of processing organic wastes for pig feeding in Cuba (Source: Dominguez, 1991).



The recovery of these materials is done systematically in tanker trucks which follow established routes throughout the country. In 1990 there were 205 such routes and the average amount of organic waste collected on each one was 7.7 tonnes, giving a total of 1,578 tonnes daily, or close on half a million tonnes annually. The wastes are delivered to industrial plants designed specifically for the purpose of processing the wastes (Del Rio *et al.,* 1980), where they are submitted to selection, grinding, steriliz-ation in an autoclave (121°C and 1.0 to 1.5 atmospheres for 30 minutes) and mixing with sugar cane molasses, before being conveyed by pipeline to pig fattening units (usually of some 12,000 head) situated adjacent (within 200m usually) to the processing plant (see Figure 7.2). Initially, the mixtures used were: (% DM basis) processed organic waste 37, "C" molasses 33 and cereal-based concentrate 30. Later "C" molasses was replaced with "B" molasses and the concentrates eliminated. The mixture then was: (% DM basis) 30-40 "B" molasses and 0-60 processed waste.

A related development in Cuba was the design of a "thermal destructor" for the processing of wastes from abattoirs and dead animals. This consists of a horizontal autoclave (130°C and 2 atmospheres pressure) with mechanical agitation which converts the wastes into a paste (Dominguez, 1991). The advantage of this system compared with dehydration is the saving in fuel oil (3.7 tonnes less oil are used in wet processing compared with dehydration) and the lower investment cost of the equipment. The paste is conserved with molasses in the same way as used for fish silage .

WET PULPS FROM FRUIT AND VEGETABLES

Citrus and pineapple pulps

A more sustainable method than dehydration for conserving these materials is to ensile them with poultry litter. The poultry litter has two functions: one is to absorb the excess moisture in the pulps; the other is to supply nitrogen and to act as a "buffer" which slows the rate of fermentation, the final effect being to encourage fermentation by bacteria rather than by yeasts. When ensiled without the litter much of the sugars in the fruit wastes is converted by yeasts to alcohol which is of lower feeding value.

Suitable mixtures are in the range of 20-40% poultry litter and 80-60% fresh pulp. The pulp and litter are added in layers in a pit or bunker silo.

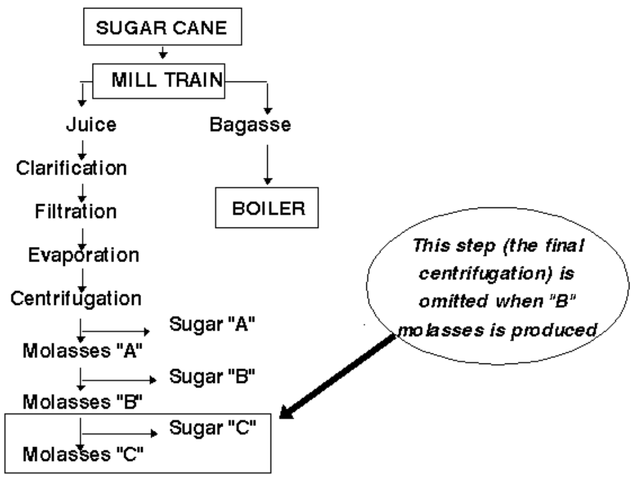
Waste bananas, cassava roots and sweet potato tubers

These can be ensiled effectively without the need for additives. They should first be processed into chips which can be done by hand or mechanically. If the material is to be fed to ruminants, then urea will be needed to provide fermentable nitrogen. In this case, the urea can be added prior to ensiling at a level of 3% (dry basis).

SUGAR CANE
Industrial processing

The flow diagram of the industrial processing of sugar cane to produce crystalline sucrose is shown in Figure 7.3. The modification of this process to produce "B" molasses requires the elimination of the final crystalliz-ation stage such that the "C" sugar remains in the molasses. This "enriched" molasses gives significantly better feed conversion than "C" molasses when the target animals are monogastric species.

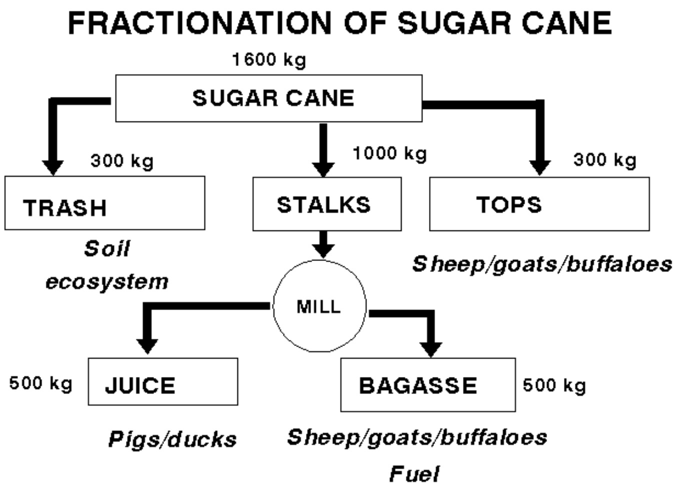
Figure 7.3. The traditional method of sugar cane manufacture can be modified by terminating sucrose extraction at the penultimate centrifugation to produce "B" molasses and no "C" sugar (Source: Figueroa and Ly, 1992).



On-farm fractionation of sugar cane

The flow diagram for the fractionation of sugar cane on-farm to produce: feed for monogastric animals (the juice), ruminants (the tops and residual bagasse) and soil micro-organisms (the trash); and fuel (the residual bagasse) is shown in Figure 7.4. The equipment needed for this process is the same as is used for manufacture of crude brown sugar ("gur" or "panela"). It is easily constructed from scrap metal and gear pinions from broken-down trucks and tractors.

Figure 7.4. Flow diagram of fractionation of sugar cane in a simple 2- or 3-roll crusher.



TECHNOLOGIES TO IMPROVE THE INTEGRATED FARMING SYSTEM

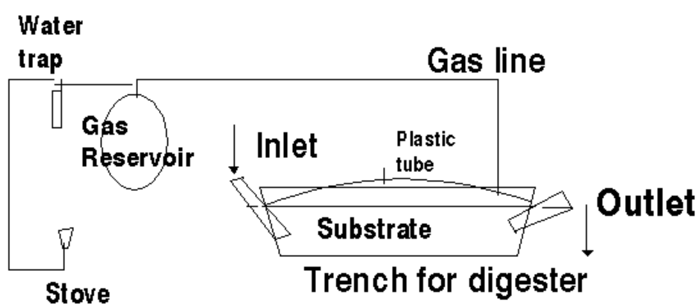
Low-cost biodigesters

Biodigesters should be an essential component of all farming systems involving the integration of crops and livestock (see Figure 7.1). They produce fuel for the household and thus contribute to environmental protection by reducing the demand for firewood which is the traditional fuel source for the majority of rural people in tropical countries. The effluent from the biodigester is also superior to fresh or conserved animal excreta as fertilizer in fish ponds or for crops.

Despite the emphasis given to the promotion of this technology by national and international institutions, the rate of diffusion is slow. The main reason for this has been the relatively high cost (usually exceeding US$500 for a family unit) of conventional biodigesters based on Indian or Chinese designs. Low-cost (less than US$50.00/family unit) plastic film biodigesters, constructed from locally available materials, have recently been introduced in FAO-supported projects in Vietnam, Cambodia and Tanzania (TCP/VIE/2296, TCP/CMB/2254 and TCP/URT/2255). They have been adapted from the "Red Mud PVC" model, first developed in Taiwan, as described by Pound *et al.* (1981). This model was simplified, using cheaper polyethylene tubular film to replace the welded PVC sheet, first in Ethiopia (Preston, 1985, unpublished data) and later in Colombia (Botero and Preston, 1987). The impact at household level has been dramatic especially with the women. The low-cost biodigester also promises to facilitate the adoption of technologies to improve the nutritive value of fibrous feed resources such as urea treatment and use of multi-nutrient blocks, since increased intake of a better balanced fibrous diet leads to greater quantities of manure of superior nutrient content which is reflected in increased gas production and improved fertilizer value of the effluent.

Details of the model (Figure 7.5) presently being installed in Vietnam have been described by Bui Xuan An *et al.* (1994).

Figure 7.5. The essential features of a low-cost polyethylene tubular film biodigester.



Materials

With the aim of minimizing farmers' expenditures and adapting to the local conditions, standard tubular polyethylene film is used as the main component. Factories that produce this material are to be found in principal cities in most developing countries. The choice of supplementary fittings and related materials is limited to those that can be found on farms or in rural markets. The list of materials is given below:

Biodigester

- Transparent polyethylene tubular film of 280cm circumference (89cm diameter; thickness about 0.2mm). The thickness can be estimated by the weight of a given length of tube which should normally be 10 kg for 20m of length.
- 2 ceramic tubes of 100cm length and 15cm internal diameter (id).
- 2 m of 21mm id plastic hosepipe.
- 2 PVC adapters (male and female) of 21mm id.
- 2 rubber washers (from car inner tube) of 10cm diameter and 1mm thickness with a 21mm diameter central hole.
- 2 PVC washers of 10cm diameter and 1mm thickness with 21mm central hole.
- 2 m of PVC pipe of 21mm id.
- 5 to 20m of PVC 21mm id rigid tube or flexible plastic hose-pipe (the length depends on the distance from digester to the kitchen).
- 4 waste inner car tubes cut into 5cm bands.
- 1 transparent plastic bottle.
- 1 PVC elbow of 21mm id.
- 3 PVC "T" pieces of 21mm id.
- 1 tube of PVC cement.

Single stove for cooking:

- 3 steel tubes of 21mm id, each 10cm long.
- 1 tap of 21mm id.
- 1 metal elbow of 21mm id

Methodology

A trench is dug to receive the biodigester. The walls must be firm and the floor must be flat or with only a minimum slope. There must be no sharp stones or protruding roots in the walls or floor.

The cross-section of the trench for a tubular film biodigester of 89 cm diameter has dimensions of 100 cm width at the top, 80 cm width at the bottom and 80 cm depth. The length depends on the amount of manure available. The average is 10 m which requires manure from at least 2 cows or 8 pigs.

Two lengths of the polythene tube are cut, each 11 m long (for 10 m long biodigester), laid on smooth ground, and one inserted into the other.

A small hole is made in the two layers of the plastic tube, approximately 1.5 m from one of the ends. One PVC and one rubber washer are fitted on the flange of the male adapter which is then threaded through the hole from the inside to the outside. A second PVC washer and rubber washer are put on the made adapter from the outside of the tube and secured tightly with the female adapter. The exit of the female adapter is closed temporarily with a small square of plastic film and a rubber band.

A ceramic pipe is inserted to two thirds of its length into one end of the plastic tube. The plastic film is folded around the pipe and secured with 5cm wide rubber bands (made from the used inner tubes). The bands are wrapped in a continuous layer to cover completely the edges of the plastic film, finishing on the ceramic tube. The inlet tube is then closed temporarily with a square of plastic (or a plastic bag) and a rubber band. From the open end, air is forced into the tube in waves formed by flapping the end of the tube. The tube is then tied with a rubber band about 3m from the end so that the air does not escape. The procedure for fitting the outlet tube is the same as for the inlet tube. The complete assembly is then carried carefully to the trench and placed inside. The ceramic tubes are laid at 45° inclination and fixed temporarily.

A safety valve is made from a transparent plastic bottle, a T-piece and 3 PVC tubes (one of 6 and the other two of 30 cm length). Water is poured into the bottle and maintained at 3-5 cm depth (above the mouth of the tube).

The biodigester is filled with water up to two thirds of the depth, moving up and down the outlet (as indicator of the water level inside the tube). The air trapped inside the tube escapes from the safety valve as the volume of water increases.

The gas pipe leading to the kitchen is then attached (it must not be on the ground and the water trap should be at the lowest point in the gas line).

The gas reservoir is made from a length of polyethylene tube (3-4 m) and a PVC "T". It can be located horizontally or vertically but should be shaded from the sun and have a weight (half a brick) suspended from the bottom to increase the pressure. It is fitted into the gas line as close as possible to the kitchen to maximize the rate of gas flow to the burner since the system operates at very low pressure (only 3-5cm water head).