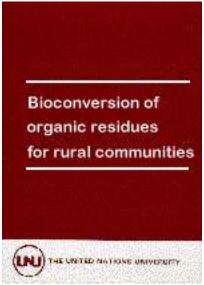
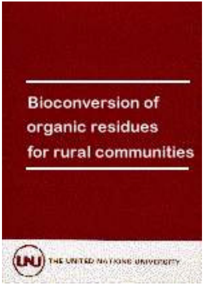


Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)



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countries

- Production of microbial protein foods on edible substrates, food by-products, and ligno-cellulosic wastes
- The role of ruminants in the bioconversion of tropical byproducts and wastes into food and fuel
- Possible applications of enzyme technology in rural areas
- Indian experience with treated straw as feed
- Indian experience with algal ponds
- Organic residues in aquaculture
- Biogas generation: developments. Problems, and tasks - an overview
- Mushroom production technology for rural development
- The combination of algal and anaerobic

waste treatment in a bioregenerative farm system

- A continuous composting system for disposal and utilization of animal wastes at the village level
- Bioconversion of fruit and vegetable wastes
- Integrated research on agricultural waste reclamation
- Solid state fermentation of starchy substrates
- Production of single-cell protein from cellulose
- Analysis of energy cost of integrated systems
- Analysis of bioconversion systems at the village level
- Nutritional evaluation of bioconversion

From the charter of the United Nations University

ARTICLE I Purposes and structure

1. The United Nations University shall be an international community of scholars, engaged in research, postgraduate training and dissemination of knowledge in furtherance of the purposes and principles of the Charter of the United Nations. In achieving its

stated objectives, it shall function under the joint sponsorship of the United Nations and the United Nations Educational, Scientific and Cultural Organization thereinafter referred to as UNESCO), through a central programming and co-ordinating body and a network of research and postgraduate training centres and programmes located in the developed and developing countries.

2. The University shall devote its work to research into the pressing global problems of human survival, development and welfare that are the concern of the United Nations and its agencies, with due attention to the social sciences and the humanities as well as natural sciences, pure and applied.

3. The research programmes of the institutions of the University shall include, among other subjects, coexistence between peoples having different cultures, languages and social systems; peaceful relations between States and the maintenance of peace and security; human rights; economic and social change and development; the environment and the proper use of resources;

basic scientific research and the application of the results of science and technology in the interests of development; and universal human values related to the improvement of the quality of life,

4. The University shall disseminate the knowledge gained in its activities to the United Nations and its agencies, to scholars and to the public, in order to increase dynamic interaction in the world-wide community of learning and research.

5. The University and ail those who work in it shall act in accordance with the spirit of the provisions of the Charter of the United Nations and the Constitution of UNESCO and with the fundamental principles of contemporary international law.

6. The University shall have as a central objective of its research and training centres and programmes the continuing growth of vigorous academic and scientific communities everywhere and particularly in the developing countries, devoted to their vital needs in the fields of learning and research within the framework of the

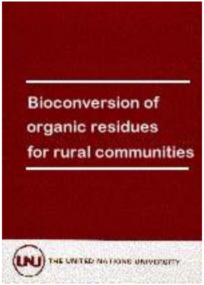
aims assigned to those centres and programmes in the present Charter. It shall endeavour to alleviate the intellectual isolation of persons in such communities in the developing countries which might otherwise become a reason for their moving to developed countries.

7. In its post-graduate training the University shall assist scholars, especially young scholars, to participate in research in order to increase their capability to contribute to the extension, application and diffusion of knowledge. The University may also undertake the training of persons who will serve in international or national technical assistance programmes, particularly in regard to an interdisciplinary approach to the problems with which they will be called upon to deal.

ARTICLE II Academic freedom and autonomy

1. The University shall enjoy autonomy within the framework of the United Nations. It shall also enjoy the academic freedom required

for the achievement of its objectives, with particular reference to the choice of subjects and methods of research and training, the selection of persons and institutions to share in its tasks, and freedom of expression. The University shall decide freely on the use of the financial resources allocated for the execution of its functions....



Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

The role of ruminants in the bioconversion of tropical byproducts and wastes into food and fuel

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Introduction

In many tropical countries, pressure on available land is increasing daily due to the high rate of population increase, bringing, as a consequence, increasing demands for food and the production of export crops to help the balance of payments. As a result, there is a competition for land use between traditional cattle production methods based on grazing, and arable agricultural land dedicated to the production of food crops and export crops.

In the light of these developments, it is becoming increasingly important in the tropics to integrate livestock with agriculture. One of the objectives of this paper is to show how animals, and specifically ruminants, can live and produce on the by-products and wastes of agricultural crops.

The advantages of this approach can be appreciated from a consideration of the potential benefits that can result from integration of livestock and crop production. These are:

- the recycling of animal wastes (manure) to produce biogas by anaerobic fermentation, and later the application of the residual, partially digested slurry as organic fertilizer for crop production;

- the saving in energy that will result from the recycling process, and the reduction in environmental contamination and health hazards;
- the possibility of being able to exploit fully the potential of the tropics for converting solar energy into biomass by means of the production of crops of high biological efficiency with multiple uses.

The possible integration of livestock and crop production encourages decisions to be made and action initiated in the following areas. In the first place, there is the opportunity for better planning in the selection of crops for growing in the tropics, the objective being to select those with double or multiple use characteristics; in other words, crops that have a capacity to produce food for human consumption and large quantities of by-products for animal feeding. On the other hand, the decision to integrate livestock and agriculture makes it imperative to expand, rapidly and widely, research and development into systems of animal production that will encourage the more efficient utilization of these by-products and wastes from crop production and agro-industries.

As an example of crop planning, one can take the existing situation in Central America, where there is a strong tradition of growing maize as a staple for human consumption. However, on the basis of the philosophy of integrating livestock with agriculture, maize is by no means the most appropriate crop, either in its capacity to produce grain and byproducts, or in its mode of growth in the tropics, since maize is susceptible to pests and also encourages land erosion in areas of heavy rainfall. Table 1 shows the considerable advantages that would be obtained by growing bananas instead of maize, with the objective of multiple use for animal and livestock needs. It would appear that the banana plant is capable of producing more energy for human consumption (as starch) and at the same time leaves behind in the form of by-products (the forage, trunk, and leaves) very large quantities of biomass that would be capable of supporting animal stocking rates similar to, or even in excess of, those achieved normally in specialized cattle production systems based on the use of pastures.

TABLE 1. Production of Primary Product (Starch) and By-products from Maize and Banana Crops

	By-products Fresh weight (ton/ha)	Dry weight (ton/ha)	Digestibility (%)	Digestible dry matter	Primary product(starch) (ton/ha)
Maize					
Average yield	2.25	2.0	35	0.7	1.1
Excellent					

yield	12.0	11.0	35	3.8	5.6
Banana					
Average yield	162	13	70	9	3.2
Excellent yield	430	35	70	25	9.0

Nutritional limitations in the use of tropical by-products and waste

It is becoming commonplace to plead for the development of appropriate technology when we talk of the problems of developing countries and the transfer of technology from the advanced countries However, there is a strong argument in favour of this philosophy in the general field of the feeding of ruminant animals on tropical feeds and wastes.

The justification for this approach can be seen in the many results obtained in the feeding of tropical crops and byproducts to ruminant animals, where performance levels have usually fallen short of expectations in comparison with nutritional results obtained in temperate climates.

The majority of by-products and agricultural wastes of tropical origin are characterized by the following factors: a. The carbohydrate component consists of highly soluble elements (sugars) that have a high rate of degradability in the rumen. It also has elements of very low solubility (cell wall components) with low rates of degradation by rumen microorganisms. In particular, most tropical byproducts and wastes do not contain starch, which is an important component of most feeds fed to livestock in temperate zone countries. b. In addition, most tropical by-products and wastes contain low levels of both total nitrogen and true protein. The final effect arising from the combination of these two sets of characteristics is a low voluntary intake by the animal and this, in turn, leads to a low rate of productivity.

The nature of the carbohydrate fraction in tropical feeds, as described above, and the low nitrogen levels that necessitate incorporation of quite high levels of non-protein nitrogen, means that the digestion process in the animal must be principally by the route of fermentation by rumen micro-organisms. This is because the sugars are immediately fermented when they enter the rumen because of their solubility, and because the animal secretes no gastric enzymes capable of hydrolyzing cellulose and associated cell wall components. Obviously, non-protein nitrogen, too, can only be converted into protein by fermentation processes.

One would imagine that such a situation would correspond closely to the environmental niche for which ruminants were evolved. In fact, it has been found that when the nature of the ruminant's diet is such that it is obliged to pass through the rumen fermentation process, and the only "feeds" presented for digestion in the small intestine are the bodies of rumen micro-organisms, the voluntary intake of feed (by the animal) is abnormally low, and as a consequence the level of animal performance rarely exceeds maintenance.

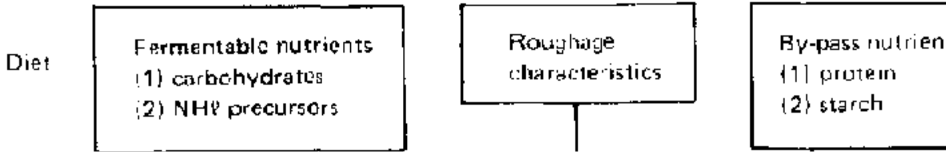
When voluntary intake is low, rumen dilution, or turnover rate, is also low. This, in turn, reduces the rate and efficiency of microbial growth and, therefore, of microbial protein synthesis. Thus, with most tropical feeds and byproducts, we have a poor performance syndrome caused by low voluntary intake and low efficiency of rumen function.

Results of recent research have shown that three factors play determinant roles in such dietary situations. The most important factor is "by-pass" protein. This is protein of dietary origin that is not, or to only a small extent, degraded by the rumen micro-organisms and arrives intact at the duodenum, where it is digested by gastric enzymes to its component amino acids that are then absorbed. The value of such by-pass protein lies less in its role as a direct source of amino acids than in the effect that it has on over all voluntary intake and rumen function. Thus, the higher the amount of by-pass protein, the greater is voluntary intake. Furthermore, both rumen turnover rate and total flow-out of the rumen also increase; ipso facto, efficiency of rumen microbial protein synthesis is increased.

The second factor is the roughage characteristics of the diet. These presumably act through direct effects on rumen motility and rumen contractions, and/or by providing a superior "ecosystem" in the rumen. Evidence for the former is in the increase in intake and rate of animal growth when sugar-cane leaves, employed as the sole roughage in a liquid molasses diet, were chopped into large pieces instead of being ground finely (1). Substantiation for the improved "ecosystem" in the rumen are the observations that both intake and digestibility on a basal sugar-cane diet were improved when a highly digestible, but low-protein, roughage in the form of banana stalk was included in the diet (2).

The third factor is "by-pass" energy. The evidence here is less conclusive; however, there are sufficient observations to justify belief in the basic effect. Starch as a component of the dietary supplement, and glucose infused directly into the duodenum, have been the principal mechanisms used to effect the by-pass. It has been known for some time that some starch sources (e.g., maize) are not rapidly degraded by rumen micro-organisms, and that a considerable portion of the starch passes on to the duodenum (3). These observations were made on temperate zone, cereal-based diets and little practical importance was attached to the findings.

The digestion process in the ruminant, outlining the separate pathways for fermentable and by-pass nutrients, is shown in Figure 1. The quantities of by-pass nutrients required will depend upon the rate of productivity for the particular trait under consideration, whether this is growth of tissue, as in production of meat, or the secretion of milk.



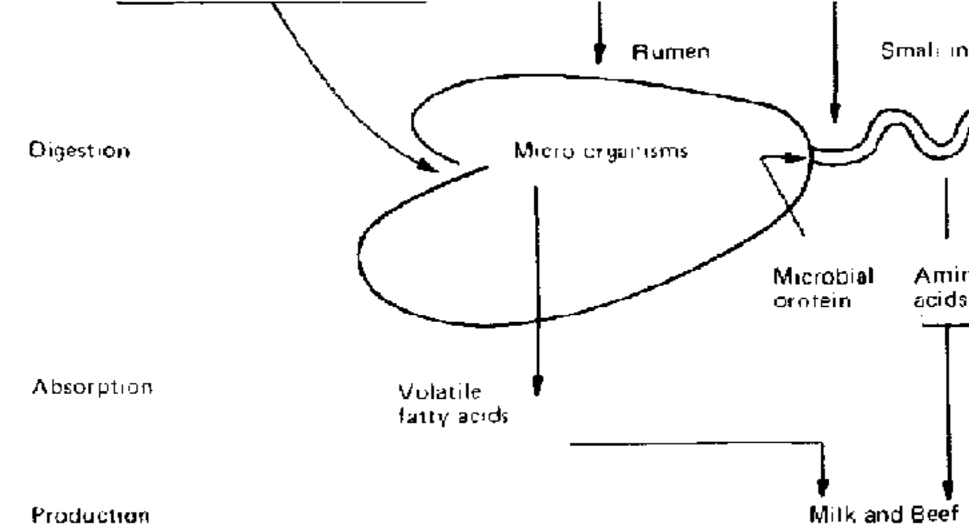
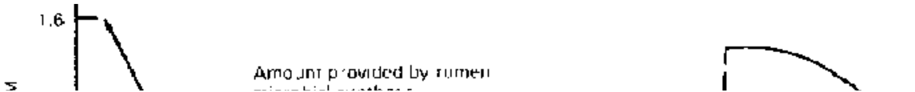
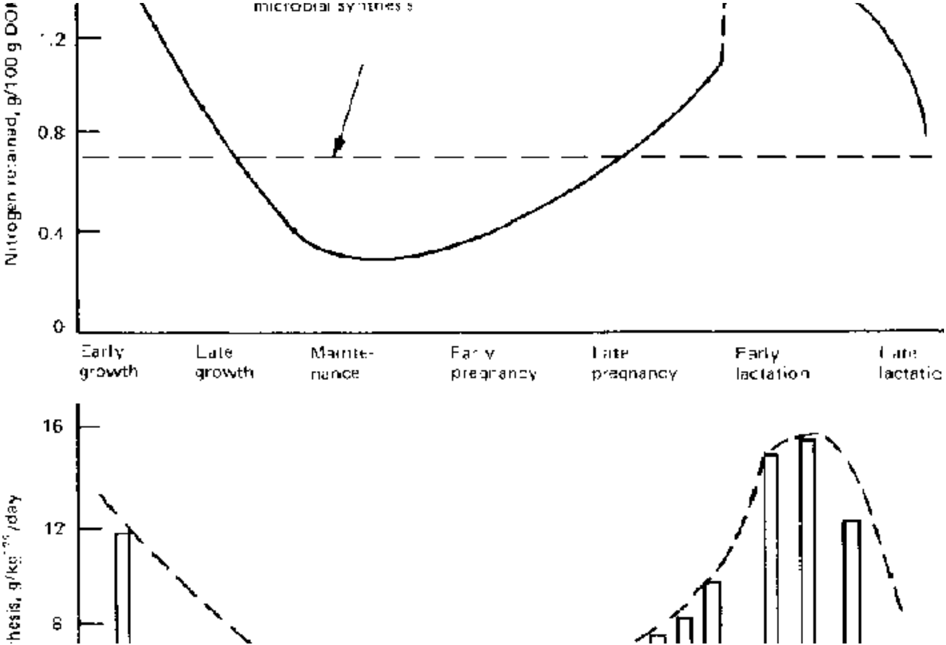


Figure. 1. Simplified Version of Digestion in Ruminants Given Sugar/Cell Wall Carbohydrates and Non-protein N as the Basal Diet, Supplemented with By-pass Nutrients. Voluntary intake of the

fermentable component of the diet is controlled by the amount of by-pass protein and by the roughage characteristics of the diet. By-pass starch appears to improve feed conversion.

Figure 2 shows how these requirements for by-pass nutrients are related to the particular stage of the production cycle of the animal. The neo-natal calf and the high-producing milk cow represent two stages in the production cycle when there is highest demand for by-pass nutrients. Modern systems of cattle production, as developed in the temperate zone countries, emphasize these requirements by the early weaning of the calf and by encouraging very high rates of lactation yield, and have led my colleagues and me to propose that in tropical countries, where by-pass nutrients are expensive, it is desirable to modify the management system so that both early weaning and high individual milk production are discouraged in favour of more moderate, less specialized approaches (e.g., 4, 5).




microbial synthesis
Nitrogen retained, g/100 g DOM
1.2
0.8
0.4
0
Early growth
Late growth
Mainte-nance
Early pregnancy
Late pregnancy
Early lactation
Late lactatio
16
12
8
thesis, g/kg /day

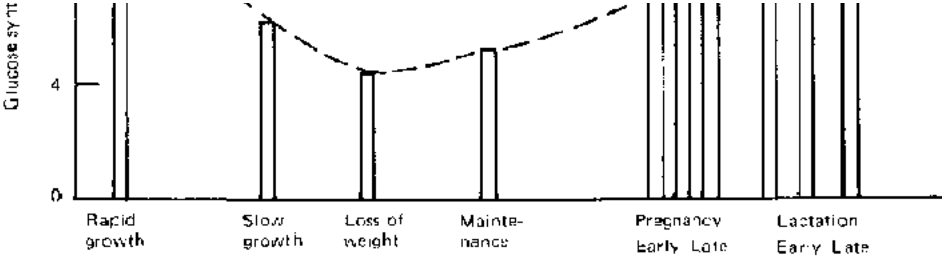


Figure. 2. Relationship between Stage of Production Cycle and Requirements for By-pass Nutrients. The top graph (E.R. Orskov, in H. Swan and D. Lewis, eds., Proceedings, 4th Conference of Nutrition Feed Manufacturers, University of Nottingham, Churchill, London, 1970) shows the requirements for amino acids expressed as total N retained in the body (9) per 100 9 of digestible organic matter consumed; the broken line is an estimate of the contribution from the rumen micro-organisms. The lower graph (from R.A. Leng, "Factors Affecting Net Protein Production by Rumen Microbiota," in T.M. Sutherland and R.A. Leng, eds., Review of Rural Science 11. From Plant to Animal Protein, University of New England: Armidale

NSW, 1975) shows the amounts of glucose synthesized per unit metabolic weight; in many tropical feeds, much of the glucose may come from by-pass starch.

Practical experience with tropical by-products and wastes as feed for ruminants

Research on sugar-cane and its by-products has provided ample confirmation of the role of by-pass nutrients in the feeding of ruminants in the tropics.

The importance of by-pass protein was established in Cuba in the late 1960s, when it was demonstrated that, on a basal diet of molasses consisting principally of sucrose and reducing sugars with small amounts of soluble non-protein nitrogen supplemented with urea and low-quality forage, the rate of animal performance was a curvi-linear function of the amount of true protein fed (Figure 3). Only proteins of low rumen degradability were effective (e.g., fish meal, torula yeast, and soybean meal), indicating that they were acting by by-passing the rumen fermentation (6).

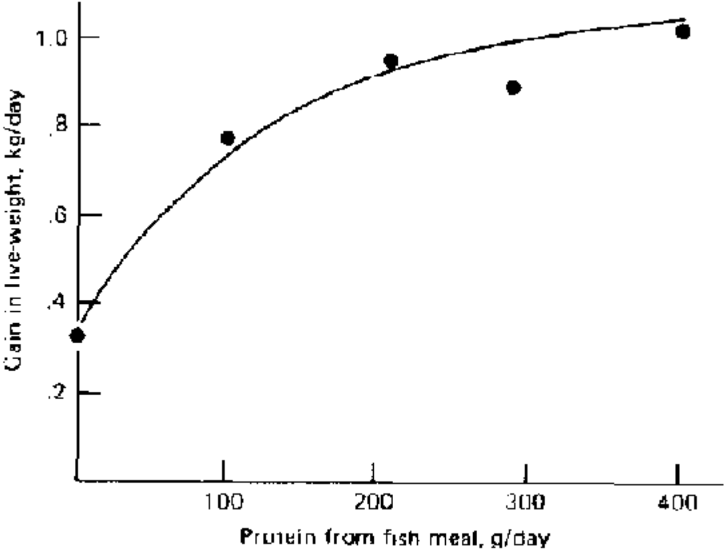


Figure. 3. Effect on Growth Rate of Cattle of Giving Increasing Quantities of Fish Meal. The basic diet was free choice molasses containing 2.5 per cent urea and restricted amounts of elephant grass (3 per cent of body weight, fresh basis).

Work in Mexico (7) showed that similar relationships could be demonstrated with diets based on sugar-cane (which is mainly sucrose and cell wall carbohydrates), and could be ascribed to the by-pass effects of the protein in the supplement (8).

On this diet, the role of by-pass starch also became evident. The data in Table 2 (9) show how feed utilization efficiency was improved by feeding maize containing by-pass starch, but not by molasses when iso-energetic amounts of the two supplements were fed with derinded sugar-cane. It has been shown that when rice polishings containing 15 per cent protein, 13 per cent lipids, and 40 per cent starch were added to a sugar-cane diet, at least half of the starch passed unchanged to the duodenum (10). Furthermore, glucose entry rates on the same diet were directly related to the amount of rice polishings given (11).

TABLE 2. Effect of Adding Maize Grain or Molasses (at 1 per cent of Liveweight) to a Basal Diet of Derinded Sugar-cane and Protein Supplement, in the Three Trials Using Holstein Steers

	Control	Improvement over control (%)	
		Maize	Molasses
Gain in liveweight (kg/day)			
Trial 1	.99	27	9
Trial 2	.95	24	13
Trial 3	1.02	32	3
Feed conversion *			
Trial 1	9 1	8	- 16

Trial 2	10.1	11	0
Trial 3	9.9	15	- 15

Source: James (9).

* Feed dry matter consumed/gain in liveweight.

Further evidence for effects of by-pass starch (maize) on feed conversion rate in sugarcane diets has been obtained. Leng showed that infusing glucose directly into the duodenum of lambs receiving a sugar/straw diet led to better feed conversion, provided that by-pass protein was also given (12).

In summary, therefore, we can conclude that, in order to maximize animal productivity on tropical by-product and waste feeds, small amounts of preformed by-pass nutrients, specifically protein, must also be provided, and attention must be given to the roughage characteristics of the feed.

It is important to stress that these nutrient/dietary characteristics act rather like catalysts, in that they create their effect by enhancing the rate and efficiency of microbial activity within the rumen. A theoretical example of this is given in Table 3.

TABLE 3. Effect of By-pass Protein on Efficiency of Synthesis and Total Daily Production of Rumen Microbial Protein on a Sugar-Cane-Based Diet

	Without by-pass protein	With 150 g/day by-pass protein
Turnover rate, times/day	1.5	2.5
Intake of fermentable CHO, kg/day	1.95	2.63
Microbial synthesis	20	35

rate, g N/kg CHO fermented		
Microbial protein, g/day	243	575

It can be seen in this example that giving 150 g/day of by-pass protein fed to an increased production of 332 g/day of microbial protein arriving at the duodenum.

An integrated system for converting tropical feeds and byproducts into milk, beef, and fuel

Having identified the nutritional constraints associated with the use of tropical byproducts, it becomes possible to plan efficient systems for converting these into animal products such as beef and milk. This task also has been facilitated considerably by the recent findings that both by-pass protein and desired roughage characteristics can be provided by such protein-rich tropical forages as the legume shrub Leucaena leucocephala, the leaves of the banana plant, and the aerial forage part of the sweet potato (2, 13, 14). Cassava forage is also effective with one specific tropical by-product, namely molasses (15).

The likely input-output relationships involved in a rural bioconversion unit using cattle can be appreciated from the data in Table 4. It is assumed that a single family unit has 1.5 ha of land and that it will derive its disposable income from the sale of bananas, milk or cheese, and beef. The cattle population comprises five adult cows, four calves, and four steers/heifers. The cattle are confined throughout the year in an open-side building fitted with a partially slatted floor so that the faeces and urine fall directly into a channel below the floor, which, in turn, connects with the inlet of a biogas digester. After partial digestion, the final effluent is pumped onto the crops as a fertilizer (see Figure 4). The same equipment is used to apply irrigation water. The biogas produced from the unit (about 5.7 m/day) is calculated to be sufficient to provide for cooking in the house and to drive the irrigation/effluent pump and forage chopper.

		Daily ration, kg (fresh basis) per head				
	No. of head	Sugar-cane	Banana forage	Sweet potato forage	Urea	Min-erals
Cows	5	20	20	27	11	.090
Calves	4	5	5	7	027	.020
Steers/heifers	4	15	15	18	083	.060
Feed requirement (ton/yr)		66	66	106	36	.28
Land area (ha)		$\underbrace{.44 \quad .40 \quad .44}_{1.24\ ha}$				

Food production per yr		Biogas production
Milk 5,600 kg	US$ 1,120.00	Cattle excreta = 10,400 kg total solids/yr
Beef (live) 1,600 kg	1,200.00	Biogas yield (40-day retention) 2,080 M³/yr
Banana fruit 10,000 kg	5,000.00	
Total income	US$ 7,320.00	
Cost of inputs		**Fertilizer recycling**
Urea 360 kg	US$ 54.00	Nitrogen 923 kg/yr
Minerals 280 kg	56.00	Phosphorus 112 kg/yr
Total	US$ 110.00	Potassium 146 kg/yr
Final disposable income	US$7,210.00 yr	

TABLE 4. Input-Output Relationships in a Rural Bioconversion Unit Using Cattle

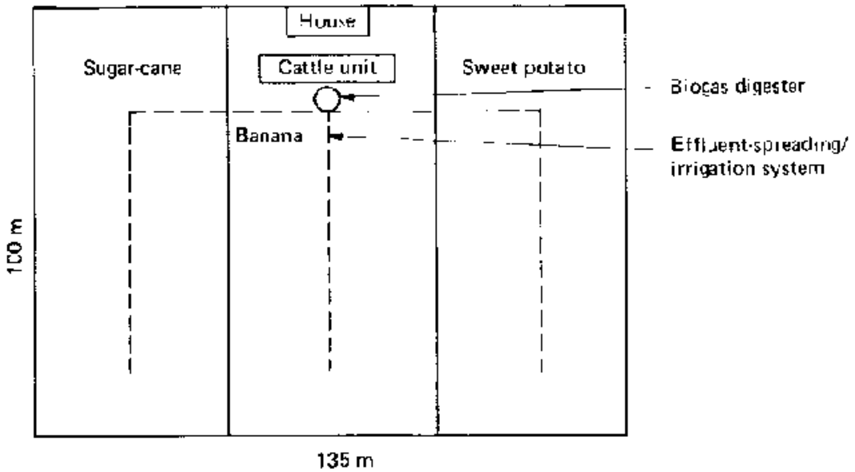


Figure. 4. Layout of Proposed Family Unit Incorporating Direct Food Crop Production and Bioconversion of Wastes through Cattle

The cattle are fed a mixture of sugar-cane (high biomass per unit area), and banana forage - i.e., the residue after harvesting the fruit, as the energy source, and sweet potato forage for by-pass protein. No roots are harvested and the plant is managed as a perennial. Some additional nonprotein nitrogen such as urea, and phosphorus-rich minerals and salt are purchased; these are the only imports into the unit. Both the banana forage and sweet potato forage provide desirable roughage characteristics.

The advantages of this particular system are that it:

a. provides a good level of disposable income for the family;

b. is likely to be in energy balance (except for the energy cost of the urea and minerals);

c. avoids erosion by using perennial forages and by recycling organic matter;

d. relies to a minimum on imported fertilizer, yet represents a high level of plant nutrient application because of recycling;

e. reduces environmental contamination; and

f. uses a minimum of land area (1.5 ha), yet produces both a cash crop and animal products.

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Discussion summary

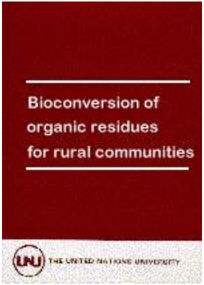
It was generally agreed that the presence of substantial amounts of starch in the ration of ruminants reduces the digestibility of cellulose in the diet, even when straw has been treated with alkali. While this could be significant in the feeds given to cattle in the industrialized, temperate zone countries, animal diets in India are so low in starch and sugars as to make this warning unnecessary.

The question was raised about the mechanism that controls voluntary intake of feed by ruminants. This is not really known, but it is thought to be controlled by hormonal action.

Concerning the advantage of by-pass protein, formaldehyde treatment of fish meal and fish silage have been used for animal feeds. Fish mea) prepared in this manner has been beneficial for ruminants, but fish silage has a better quality if left untreated. As untreated fish silage may have undesirable effects on ruminants, it should be fed only to nonruminants.

Another beneficial by-pass protein for ruminant feed is sewage sludge.

Reports from South Africa indicate that waste water containing algae added to diets high in sugar-cane residues has improved ruminant growth.


Bioconversion of
organic residues
for rural communities
THE UNITED NATIONS UNIVERSITY

Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Possible applications of enzyme technology in rural areas

References
Discussion summary

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Introduction

Enzyme technology, in its broadest sense, involves the problems not only of application of the enzymes themselves, but also their production, isolation, and frequently their modification to achieve stability All of these technology components must be considered in the application of enzyme technology. The rationale for development of enzyme technology is based upon the unique advantages of enzymes as catalysts. These advantages include the highly stereo-specific reactions that are catalyzed with few, if any, side reactions, and the rapid reaction rates that are achieved under mild conditions of pH and temperature. These properties make enzymes particularly desirable for processing natural products for eventual human or animal consumption. For this reason, enzyme technology has had substantial impact on the food industry.

However, enzyme catalysis is not without its disadvantages. Enzymes themselves are sensitive to extremes in pH or temperature. In many applications, enzymes are used only once and then remain, usually denatured, with the final product. As a consequence, the cost of enzyme isolation can be quite high. Lastly, when using enzymes over long periods of time, stability becomes of critical importance If subjected to unfavourable conditions, enzymes rapidly lose their catalytic ability.

Enzyme technology has quickly become a very "high technology," or technologically intensive. Herein lies the major limitation to the application of enzyme technology in rural areas. How is it possible to deliver and routinely use enzymes under variable conditions? The major question becomes: "What have we learned about enzyme technology and the properties of enzymes that can now be directed towards the development of simple technological processes that will better the life of small groups of people in simple, rural environments?" This is the challenge Can we use high technology to develop low-technology processes?

Biocatalytic processes

Biocatalytic processes may be defined quite broadly, as illustrated in Table 1. Such processes include fermentation, enzyme catalysis, and whole cell systems It is interesting to reflect on the historical flow of this technology. Clearly, the earliest form of biocatalytic processes are represented by fermentation itself, both aerobic and anaerobic. In using such processes, the fermentation industry has developed, and continues to create and expand, new technologies related to pharmaceuticals, foods, and chemicals. However, as our understanding of microorganisms, and enzymes in particular, increased, it became possible to develop enzyme catalysis as a process technology in itself. This has taken place in the form of homogeneous catalysis using freely soluble enzymes for a wide range of applications in the food and pharmaceutical industries (1,2).

TABLE 1. Biocatalytic Processes

Fermentation	aerobic
	anaerobic
Enzyme catalysis	homogeneous
	heterogeneous
Whole cell systems	cell suspensions
	packed ceils
	immobilized cells

Primarily as a consequence of the high cost of enzyme isolation and the sensitivity of enzymes to denaturation, technology has been developed for the immobilization of enzymes onto water-insoluble supports (3). This technology has opened the whole field of heterogeneous catalysis to enzyme catalysts. The use of immobilized enzymes has greatly minimized the cost of production by permitting repeated use of the enzymes, and has substantially increased the stability of the enzymes themselves. This technology has had major impact on the food and pharmaceutical industries and will clearly expand its importance in the years to come.

However, an interesting trend is occurring in the development of biocatalytic processes and that is the use of whole cell systems (4). The cells may be in the form of simple cell suspensions, or they may be packed in beds. Building on the development of immobilized enzymes, a technology has been developed to immobilize whole cells to achieve both stability and process control. In a sense, our development of sophisticated technology and our understanding of enzyme processes has allowed us to go full circle. The use of whole cell systems obviates enzyme isolation and immobilization, but presents the challenge of how to develop microbial cell systems with highly focused reactions and, returning to the original question: How can such systems be used to better life in rural areas?

The major class of enzyme reactions offering the most immediate possibilities for application to bioconversion in rural areas are the hydrolytic enzymes. The use of hydrolytic processes makes thermodynamic sense; such processes take advantage of the fact that hydrolysis of natural polymers in a predominantly aqueous environment has a free energy flow in the direction of hydrolysis. Such processes are usually carried out by one or a few enzymes, they do not require biological co-factors, and they permit de-polymerization under very mild conditions, thereby minimizing side-product formation. Furthermore, the substrates are readily available in rural communities. These substrates include cellulose, starch, hemicellulose, proteins, and many heteropolysaccharides that are present in plant materials.

The utilization of hydrolytic processes can be of benefit by improving current processes that are in use in rural communities;

an example is the removal of mucilage from the coffee bean prior to drying (5). Or, it may be possible to use dextranases to eliminate the dextrans that form during prolonged harvesting times or improper storage of sugar-cane before sugar extraction. In a broader sense, it may be possible to use such hydrolytic processes to expand the available raw material base used in food or feed production. For instance, the hydrolysis of starch in products such as cassava, and the hydrolysis of cellulosic materials are possible routes for the production of sugar syrups for immediate use or for further processing.

In the remainder of this paper, I would like to focus on two applications of enzyme technology that might be suitable in rural areas but, more importantly, these two applications illustrate a broad class of possible use. In the first application, emphasis is on the use of enzymes in starch hydrolysis; in the second, it is on the use of whole cell systems in cellulose hydrolysis.

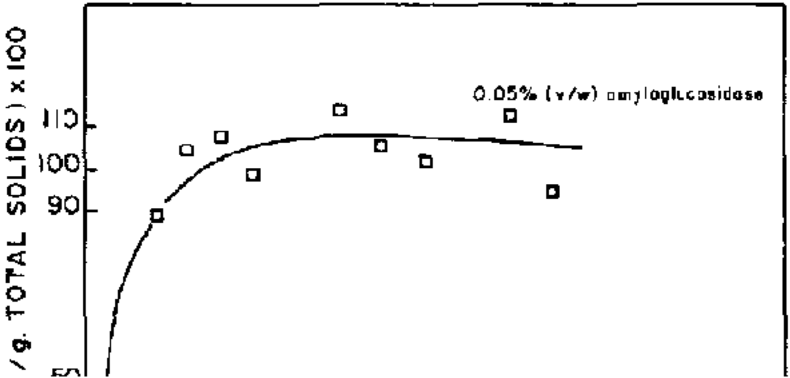
Enzyme hydrolysis of manioc

The manioc plant has become of increasing interest as a consequence of its high starch content in tuberous roots that can be propagated in a wide variety of environments (6). Of the two varieties of manioc, the bitter and the sweet, the bitter varieties are of particular interest for cultivation for industrial use because of their higher starch content The starch content of these roots varies according to soil and climatic conditions, but is generally in the range of 20 - 40 per cent; the remaining 60 - 75 per cent is moisture with about 5 per cent of protein, cellulose, minerals, etc. (7). Manioc can provide a low-cost source of starch for food uses and is important for this reason, and it is of increasing importance to industry for the same reason. In many applications, it is desirable first to hydrolyze the starch to produce soluble sugars for subsequent use.

To this end, Lages and Tannenbaum have recently developed a process for using an extremely thermostable a-amylase for liquefaction of cassava starch followed by a high temperature treatment with amylogiocosidase (8). While starch hydrolysis is itself not new, the utilization of high temperature for hydrolysis has several advantages. These include rapid liquefaction of the starch and pasteurization of the product because of the elevated temperature.

In addition, it has been shown by Lages and Tannenbaum (8) that, following the thermoamylase treatment, the requirements for amyloglucosidase are greatly reduced, as is the time for complete conversion of the starch to sugar. The a-amylase employed was produced from Bacillus licheniformis (Thermamyl Liquid 60; Novo Industrials, Bagsvaerd, Denmark) added to either crude tapioca or cassava meal. Starting solutions of the starches were prepared by adding 33 g of material to enough water to give a total weight of 100 9. After preparation of these slurries, the a-amylase was added and the mixture was heated to 105C for six minutes, after which the temperature was reduced to 95 C for two hours. At the completion of liquefaction, the temperature was reduced to 60 C and amyloglucosidase (AMG 150, liquid; Novo Industrials) was added.

The kinetics and conversion in such a process, in which the authors used an optimal amount of amyloglucosidase (0.5 per cent V/W) to achieve 100 per cent conversion in less than 24 hours, are illustrated in Figure 1. The resulting product from this hydrolysis can be used directly as a sugar syrup, or it can provide the substrate for subsequent fermentations to desired products, including single-cell protein and alcohol for fuel use (9).



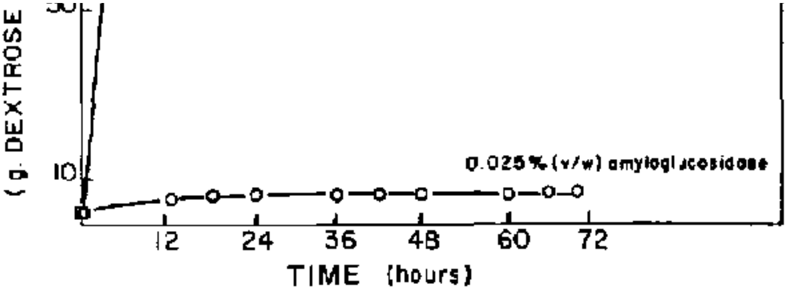


Figure. 1. Kinetics of Tapioca Starch Hydrolysis with Amylo-Glucosidase (0.025 and 0.05 per cent V/W) (From Lages and Tannenbaum [8])

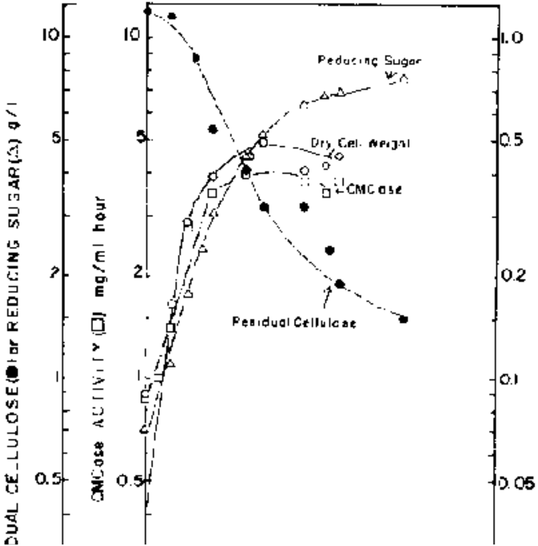
The desirability of carrying out the starch hydrolysis before the production of single-cell protein is based upon the rationale that one can now use widely acceptable food yeasts, e.g., Saccharomyces cerevisiae or Candida utilis, rather than having to develop microbial species with amylolytic activity. These sugar syrups would also be quite suitable for making such products as baker's yeast. However, this approach to enzyme application implies the availability of the enzyme, which may, in fact, be the major limitation in the application of enzyme technology in the rural community.

Whole cell systems

An alternative to the use of purified enzymes is the application of whole cell systems that can be achieved by a variety of means (4). The whole cell represents a "packaged enzyme" or "enzyme system." Most important, by means of the whole cell, it is possible to use sophisticated technology to develop desired cell lines, e.g., through techniques such as genetic engineering, that will carry out highly specific processes under specific conditions. The ability of the cells to grow and reproduce permits the rapid transfer of this technology into the field. The end" user is not concerned with how whole cell systems were developed, but with how they can be used. Desired cell lines carrying out specific functions can be distributed by means of marketing starter cultures, or the technology of cell propagation can be achieved at the local level. An example of one aspect of this approach is the fermentation of cellulose to produce utilizable sugars in a single-step operation.

Cellulose degradation and utilization

In examining the prospects for a simple process for the degradation and utilization of cellulose, we chose to look at the thermophilic anaerobic bacterium, Clostridium thermocellum. This organism grows well at temperatures of 60 C and above. Most important, it has been observed that this organism has the unique capability to accumulate sugars while degrading and growing on cellulose (10). This phenomenon is illustrated in Figure 2. In this example, medium containing 11 g per litre of solka-floc was inoculated with C. thermocellum. During the course of the fermentation, there is a rapid accumulation of reducing sugars approximately in parallel with growth and cellulose (expressed as CMCase) production From the degradation of approximately 10 g/l of cellulose over the course of 60 hours, there is an accumulation of almost 7 g/l of reducing sugars. Thus, one achieves approximately a 65 per cent yield of reducing sugars from the cellulose that is hydrolyzed



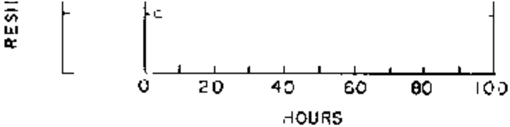
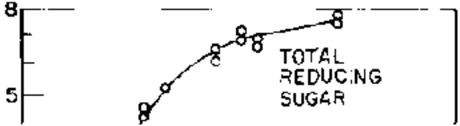
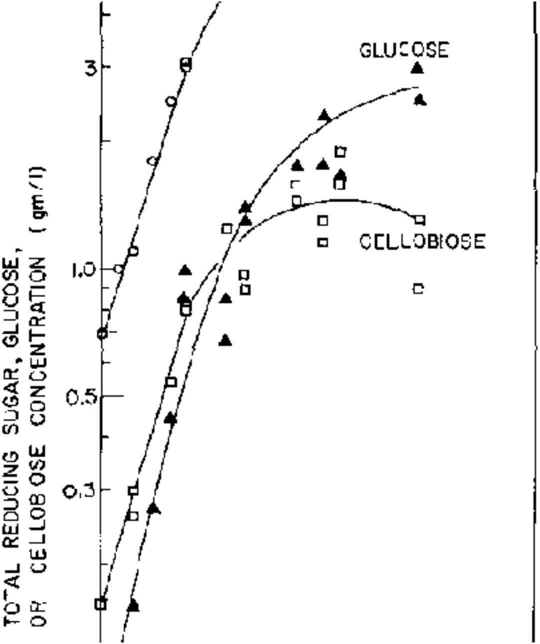


Figure. 2. Fermentation of Cellulose with Accumulation of Reducing Sugar by Clostridium thermocellum at 60 C (From Cooney et al. [13])

When the sugar products are examined by means of high pressure liquid chromatography (HPLC) (Figure 3), the predominant products are glucose and cellobiose. When C. thermocellum is grown on natural cellulosic materials containing hem-cellulose, there is also an accumulation of xylose and possibly xylobiose. This observation is particularly interesting, because C. thermocellum will not use the pentoses for growth.




GLUCOSE
CELLOBIOSE
3
1.0
0.5
0.3
TOTAL REDUCING SUGAR, GLUCOSE, OR CELLOBIOSE CONCENTRATION (gm/l)

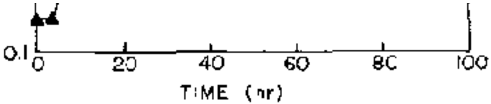


Figure. 3. Accumulation of Glucose and Cellobiose during In Vivo Saccharification of Cellulose by Clostridium thermocellum

We examined both cellulase and xylanase activity in cell-free broths from C. thermocellum grown on a variety of substrates, as shown in Table 2. When C. thermocellum was grown on these substrates, the ratio of xylanase to CMC's activity was consistently one. These results suggest that cellulose activity and xylanase activity are caused by the same enzymes. This observation has been made in other organisms (11), and the dual activity of the cellulase enzymes would account for the simultaneous accumulation of pentoses and hexoses.

TABLE 2. Production of Xylanase and Cellulose Activity by C. thermocellum Grown on Selected Carbon Sources

Substrate	Xylanase* mg/ml/hr	CMCase* mg/ml/hr	Xylanase CMCase
Sorka-floc	7.0	6.75	1.04
Corn stover	1.95	1.9	1.03
Avicel	3.0	3.2	0.94
Cotton	4.8	5.0	0.96

* The variation in the values among the substrates reflects the time when the fermentations were ended, as well as C. thermocellum's ability to grow and produce enzymes on the particular substrate.

In an attempt to improve and optimize the process, we examined the influence of pH control during the course of the fermentation. In the previous experiments, pH was set initially at 6.8 and then left to fall during the course of the fermentation. Results shown in

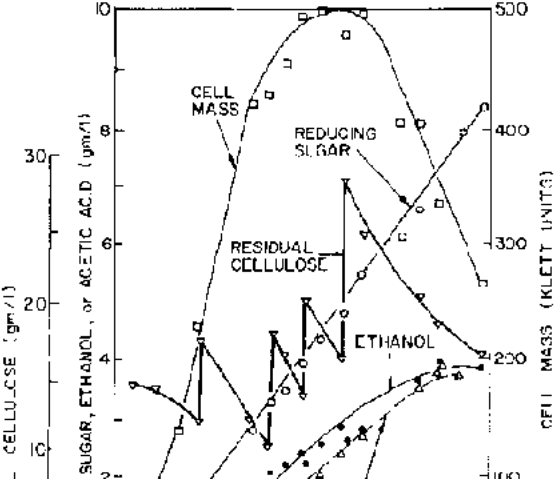
Table 3 illustrate the difference in performance for C.thermocellum with controlled pH (6.8) and uncontrolled pH fermentations on cellulose. As seen by the results in this table, with pH control there is greater degradation of cellulose, increased cell mass formation, increased synthesis of fermentation products, e.g., ethanol and acetic acid, but markedly less accumulation of reducing sugar. These results suggest that the marked sugar accumulation during growth on cellulose results at least in part from a restriction in growth, probably by the decreased pH, in the presence of excess cellulase capacity. Hence, cellulose is hydrolyzed at a rate faster than it can be utilized.

TABLE 3. Comparison of Results from pH-Controlled and Non-pH-Controlled Fermentations of C thermocellum Grown on Solka-Floc

	Non-pH - controlled		pH-controlled	
	Initial	Final	Initial	Final

pH	6.8	5.7	6.8	6.8
Cellulose, g/l	10.1	2.4	10.0	1.8
Dry cell weight, g/l	-	0.5	-	0.8
Reducing sugar, g/l	0.3	6.0	0.1	2.4
Ethanol, g/l	-	0.4	-	1.3
Acetic acid, g/l	-	1.0	-	2.7

The approach illustrated by the above results offers the opportunity for in vivo saccharification of ligno-cellulosic materials to accumulate sugars, as well as the possibility for a direct fermentation for product formation from cellulose. For example, C. thermocellum will produce ethanol, acetic acid, and lactic acid directly from cellulose. Product accumulation is shown in Figure 4, which presents results from C. thermocellum grown on cellulose added intermittently during the course of fermentation. This allowed an increased amount of cellulose to be acided to the broth. A total of 20 9 of cellulose were added, and this resulted in the production of 8.5 g/l of reducing sugars and 4 g/l each of ethanol and acetic acid.



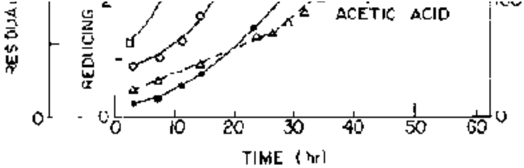


Figure. 4. Kinetics of Cellulose Hydrolysis and Ethanol and Acetic Acid Production in a Fedbatch Fermenter with Clostridium thermocellum (From Cooney et al. 113])

The above example illustrates the direct conversion of cellulose to ethanol. Through genetic manipulation, it is possible to minimize the amount of acetic acid, which is usually produced in molar ratio of 1:1 with ethanol, so that the ethanol-acetic acid ratio becomes 8:1 (12). This is an example of what one can do with high technology to manipulate the ceil in order to generate a cell line with some desired properties, in this case, over-production of ethanol directly from cellulose. One of the bottlenecks in this fermentation is the sensitivity of C. thermocellum to ethanol and aceitic acid. A eel) line that is tolerant to ethanol concentrations of approximately 5V per cent has been developed, and thus we have again modified this cell line to achieve a desired final objective (12).

Transfer of enzyme technology to rural communities

The above examples illustrate the possibilities of using enzyme technology to achieve new or improved use of natural products such as starch and cellulose. In the example of starch hydrolysis, it is possible to produce a fermentable syrup that can be used to cultivate acceptable food and feed yeasts. The major limitation, however, is the lack of the required enzymes in the rural community.

In the second example, a fermentation directly on cellulase that will allow both accumulation of enzymes via saccharification and production of useful products is described. This approach is particularly exciting because it offers a method by which enzyme unavailability can be overcome. The micro-organisms that contain the desired sets of enzyme activity readily reproduce themselves. Therefore, it is possible to develop, via high technology in the laboratory, strains of micro-organisms that have the desired properties and then take these organisms into the field where they can be reproduced repeatedly and used on a local basis. In this manner, the microbial cell becomes the vehicle for transferring high technology to the community.

Examining further the example of cellulose hydrolysis, it is possible to develop a system for saccharification of cellulose for sugar production, or a system for the direct conversion of cellulose to ethanol, acetic acid, or lactic acid. Alternatively, it is possible to add a second microbial culture that would utilize the sugars released by C. thermocellum-mediated cellulose saccharification. The resulting mixed culture could be used to produce lactic acid for use as a food preservative, short-chain fatty acids for animal feeding, or solvents for use in extraction of oilseed meals. Furthermore, via genetic engineering, it should be possible to incorporate traits in these organisms to make them withstand the highly competitive environment encountered in the rural community. The increased ability to compete with indigenous organisms is important so that fermentations can be run with little or no sterilization, under conditions of variable pH and temperature, or in combination with other desired organisms.

The key question raised earlier, of how to transfer and propagate enzyme technology in the field, could be answered by using starter cultures either prepared at a central location or propagated by a serial transfer using techniques similar to those used for traditional food fermentations. An interesting alternative would be to take advantage of the concept of immobilized whole cells. For this purpose, one could use readily available inorganic supports, such as porous rocks. One may choose to use high carbonate rocks to exert some pH control of the fermentation, or simply volcanic rock with a high degree of porosity. The microorganisms present in the system would adsorb to, and become associated with, the solid phase so that after removal of the fermentation liquid the organisms would be left behind. This would serve to help build up a substantial active population of microorganisms, as well as serially transfer the desired population from fermentation to fermentation, even from family to family and village to village.

Conclusions

In conclusion, it is evident from this examination of the possible applications of enzyme technology to rural communities, that any system must employ very simple technology, and that high-technology whole cell systems could be used to develop desired cell lines, while the micro-organisms themselves could provide the mechanism for transfer of this technology to the field. Thus, the application of technologies such as genetic engineering, mixed culture development, and microbial selection could be used to create desired micro-organisms that would then be self-replicating units within the rural community. it is likely that hydrolytic processes would be the first to have immediate impact in world development. This is based on the availability of a wide variety of natural polymers whose hydrolytic degradation would either improve existing technologies or expand the raw material availability to the rural community.

Lastly, the development of starter culture processes for propagation of these cell lines, and/or the implementation of in situ cell recycling by natural immobilization of cells onto porous inorganic materials, offer a possibility for improving and propagating this technology. The use of whole cell systems provides much potential for the application of fermentation and enzyme technology to the improvement of life in the rural community.

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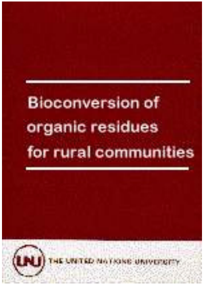
Discussion summary

It was pointed out that the objective of using mixed cultures to degrade cellulose is to accelerate the production of other products such as lactic acid or butanol, not to increase sugar yields.

The question was raised as to whether modifications could be introduced that would make more robust strains of cellulolytic organisms better suited to fermentation processes in rural communities. Although this may be possible, much more research needs to be done.

Professor Cooney was asked whether he had used a mixed culture, taking advantage of sugar-accumulating properties of Clostridium thermocellum combined with a methane-producing bacterium. This kind of methane production has been pursued successfully in Wisconsin, but the MIT work with mixed cultures has concentrated on production of more valuable products. It was noted that there are many ways in which advanced research in industrialized countries can produce results adaptable for use in rural communities.


Bioconversion of
organic residues
for rural communities
UNU

Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Indian experience with treated straw as feed

Discussion summary

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Introduction

Straw is a major by-product of crop production in the world. It is potentially useful as a source of energy, though it also contains worthwhile amounts of plant nutrients. Being bulky, it must, for the most part, be processed on the farm where it is produced. Ploughing it under or composting it are efficient wads of recycling plant nutrients, but these methods waste all of the energy the straw contains. In India virtually all straw is put through a two-stage process that both taps some of its energy and recycles plant nutrients. This process consists of feeding the straw to livestock and then using the dung as fuel. Usually, the dung is dried and burned directly, but this is undesirable because nitrogen is lost. A significant improvement is the introduction of the biogas plant to produce fuel gas from the dung; nitrogen is recovered from the slurry after fermentation (1 - 3). The efficiency of this two-stage, feed-fuel system ranges from 9 to 14 per cent (Annex 1).

Aside from purely energy considerations, the Indian system of processing straw on the farm has much to commend it. The relative simplicity of using an animal to convert straw energy to draught power is perhaps foremost. The same applies to milk production, a process in which straw provides the energy for the bioconversion of low-quality, inedible plant proteins (miscellaneous vegetation, grain-and oilseed-milling offals) into high-quality milk protein; the gain is not simply in proportion to the energy converted. Finally, it may be noted that straw cannot be used as a fuel in villages unless it is first passed through an animal; even present-day biogas plants cannot handle straw directly.

The efficiency of the livestock feed step can be increased by treating the straw before it is fed. The data presented in this paper indicate that the live weight gain in growing animals can be increased substantially if the straw is treated. The overall energy recovery from straw might not increase as a result of straw treatment because the more complete digestion of the treated straw by the animal would leave relatively less dung for use as fuel. Milk is, however, a more valuable form of energy than fuel.

The purpose of this paper is to review the Indian experience with various methods of straw treatment. It will include a discussion of the improvements obtained in animal productivity, the economics of such treatment, as well as the larger considerations of its energy cost and environmental impact. A special point made in this paper is that straw treatment techniques, like any new farming practice, will have to be evaluated on small private farms; satisfactory testing in an experiment station is not possible. A procedure for farm testing is outlined.

Experience with straw treatment

Straw, like all mature plant tissue, is relatively indigestible by the micro-organisms that inhabit the digestive tract of ruminants, This is because straw cell walls are heavily lignified or silicified. The objective of straw treatment is to increase digestibility by disrupting the cell wall. A number of methods have been developed, all of which have been described in detail by Jackson (4). These methods may be classified as chemical, physical, and biological. The chemical methods all involve the use of alkali solutions and are the most widely tested methods at present. Among the physical treatments, only pressure cooking alters the cell wall; simple grinding does not increase digestibility. A promising method of biological treatment is the growing of lignin-digesting fungi on straw. In the Indian village context, the feeding of alkali-treated straw will usually require the simultaneous feeding of additional nitrogen, as it will be the limiting nutrient in straw for both ruminant digestion and growth and production of the animal. As feed nitrogen is extremely scarce, the use of a urea supplement is an essential adjunct to straw treatment.

Alkali Treatment

Sen et al. (5) experimented with the Beckmann method of straw treatment using wheat and paddy during the Second World War. In this method, straw is soaked for about 20 hours in 10 to 201 of a 1.5 per cent NaOH solution per kg straw, and subsequently washed with large volumes (up to 50 I/kg) of clean water to remove residual alkali. The results of the Sen et al. experiments (5) were similar to those from experiments conducted in Europe at the same time (6); the digestibility of the straw was increased by an average of 25 percentage units - from 40 - 50 per cent to 65 - 75 per cent. In spite of its effectiveness, this method of straw treatment did not become widespread in Europe, mainly because costs were too high. Some 8 kg NaOH are needed per 100 kg straw and the yield of treated straw is only 75 per cent.

In India, cost was not a factor (see Table 1, for example), but even so it never came into widespread use. Many state departments of animal husbandry began straw treatment by the Beckmann method on their livestock breeding farms, but it was not continued for long, and it was never really introduced into villages. There are several reasons for this. The units set up on livestock farms were ail small-scale, manual treatment installations that were too small for herds of 100 or more animals. The Beckmann straw treatment method gained ground in Norway only in the 1950s after a mechanized installation was designed (7), a development which did not occur in India. In any case, even if it had, the treatment of straw on a handful of government farms would not have much significance for the bulk of Indian livestock, which is owned by small farmers.

The reason the Beckmann method was never adopted by small farmers in India is primarily that new practices have to be demonstrated on the farm to convince farmers of their usefulness, and in the 1940s and early 1950s there were no organizations that could do this. The very concept of on-farm demonstrations of animal husbandry practices, though introduced two decades ago (8), did not receive any attention until very recently (4). A purely technical problem would probably severely limit the spread of the

Beckmann method of treatment - it requires huge amounts of water. In many villages water is scarce.

In the early 1950s, Kehar (8) demonstrated the value of Beckmann-treated straw for animals maintained in villages by their owners (Table 1). The heifers with which he did his experiment were fed only very limited amounts of supplemental feeds, and even these supplements were given irregularly. The heifers suffered all the vicissitudes of a poor village environment. The simple treatment of the straw in their diet nearly doubled the rate of weight gain.

TABLE 1. Comparative Costs of Feeding Growing Heifers Untreated and Treated Paddy Straw (Beckmann Method) in Rural India

	Untreated	Treated
Straw consumption (kg/day, dry straw basis)	3.00	3.00
Feed cost (Rs/head/day)	0.36	0.56

Liveweight gain (kg/day)	0.10	0.18
Days to gain 100 kg	1,000	555
Feed cost/kg gain (Rs)	3.60	3.11

Source: Kehar (8).

Much more could probably have been achieved if a supplement of urea had been fed along with the treated straw, and if the straw had been fed ad libitum. These results are noteworthy for two reasons. First, they indicate that straw treatment can be profitable under village conditions. Second, it was the first, and probably still the only, example of what has now come to be considered an important technique for testing new animal husbandry practices. The need for on-farm testing of straw treatment techniques is emphasized later.

In the late 1960s, a simple spray method of alkali treatment was developed. Some of this work was done in India (9, 10). This was an improvement over the Beckmann method in that less alkali is used (only about 4 kg/100 kg of straw), no washing is necessary, and recovery is 100 per cent. On the other hand, digestibility increases by only about 10 units on average. Greater increases in digestibility are theoretically possible with higher levels of alkali (up to 8 kg/100 kg of straw), but animals cannot tolerate such large amounts of sodium. Improved rates of weight gain in growing calves of 0.1 - 0.15 kg/head/day have been found by treating straw by this method (see, for example, data in Table 2) (11). The economics are also favourable, as the table shows.

TABLE 2. The Performance of Calves on Untreated and Treated (Spray Method) Straw Diets

	Untreated	Treated*
Straw consumption (kg/day)	4.5	6.0
Groundnut cake consumption (kg/day)	0.8	1.0
Feed cost (Rs/head/day)	0.95	1.39

Liveweight gain (kg/day)	0.25	0.42
Days to gain 100 kg	400	238
Feed cost/kg gain (Rs)	3.80	3.31
NaOH energy input (MJ) additional energy stored as body-weight gain (MJ)		12.1**
NaOH energy input (MJ) total energy stored (MJ)		2.5
NaOH energy input (MJ)total protein energy stored (MJ)		5.0***

Source: Singh et al. (1 1).

* Straw was treated with 3.3 kg NaOH/100 kg straw.

** For the method of calculating this value, see Annex 2.

*** Protein energy content of the gains made by the calves is assumed to be half the total energy stored.

On the basis of this limited information, a set of recommendations for farmers has been prepared (Annex 3). A few progressive farmers here and there are treating their straw with this method. Demonstrations of straw treatment (alkali and urea) have also been done on animals in one dairy development project, and some experience has been gained. On the whole, however, there is a need for further testing under village conditions. A proposal for doing this has recently been made and is described in a later section. The exercise presented in Annex 4 indicates the type of evaluation of straw treatment that should be made, and the information that needs to be generated.

Two newer methods, more effective than the spray treatment, are potentially applicable under Indian village conditions, and experimentation has already begun on these. One is the modified Beckmann, also known as the Torgrimsby method. Straw is soaked as in the original Beckmann method, but washed in a fixed amount of water, which is then recycled. Straw is effectively treated as in the original method, but residual sodium is less completely removed. Recovery is 100 percent. Two digestibility trials to date have yielded increased digestibility values of 15 and 18 units. Further work is in progress in India (D.V. Rangnekar, personal communication, 1978) as well as in Europe (F. Sundstol, personal communication, 1978).

The second method is spray treatment and stacking. If the amount of NaOH solution applied to the straw is kept low (not more than 10 - 151/100 kg of straw), and the straw is stacked (minimum size of stack 3 tons), the heat generated in the chemical reaction between the alkali and the straw causes a temperature rise in the stack. This temperature rise increases the efficiency of treatment (units increase in digestibility/kg of NaOH used). To apply such small amounts of solution uniformly, specially designed treater-mixers must be used. Such treater-mixers have been designed for use in factories and for on-farm use in Europe. Capacity is 2 - 6 tons/hour.

A small machine, operated by a 5 hp electric motor and giving an output of 0.3 tons/day, has been developed in India (12). Farmers always stack their straw after threshing; it is envisaged that they could put it through this machine at the time of stacking. Many farmers already have an electric motor on their pump or wheat thresher that could be used on a straw treater. Manufacturing cost without the motor is about Rs 3,000. Evaluation of straw treated in this way is in progress.

Supplementation of Straw with Nitrogen and Minerals

It has been conclusively demonstrated that treated straw will not be digested to its full potential digestibility if the nitrogen content of the diet is below 1.2 per cent (E.R. Orskov, personal communication, 1977) (13). This corresponds to rates of supplementation of 1.5 per cent for urea or 10 - 15 per cent for oilcake. These levels of supplementation must be ensured if straw is to be treated. From the point of view of the ability of the animal to utilize the energy available from treated straw, these levels of supplementation must be considered a bare minimum. Under average village conditions, animals, particularly growing animals, do not receive even this level of 1.2 per cent nitrogen in the diet from the meagre supplements of grass/forage and milling offals they are fed. Thus, a urea supplement is an essential adjunct to straw treatment. Further experimental work on this subject is proposed in a later section.

In many parts of India, animals suffer from deficiency diseases such as rickets and anaemia. Some progress has been made in mapping these areas. General purpose mineral mixtures are now widely available, although still not as widely used as they might be. Obviously, where a mineral is the first limiting factor for productivity, increasing energy intake by straw treatment will be futile.

Field testing and demonstration of straw treatment

Among crop scientists it is now widely recognized that the on-farm testing of new varieties and production techniques can lead to greater success in developing usable new technology and also save time. On-farm tests also have a potential demonstration value. Experience with on-farm testing of maize in Pakistan has been described by Palmer (14). The need for onfarm testing of new animal husbandry techniques is even more essential, because it is impossible to simulate village conditions in which livestock are reared on an experiment station. At the same time, it is as essential to demonstrate new techniques on a farmer's animals as it is to demonstrate new cropping practices on his fields. For these reasons, I have suggested a field testing and demonstration project for straw treatment (4).

In this project, the preferred method of straw treatment on a suitable scale (i.e., individual farm or village co-operative society) would be used to treat straw fed to village animals. The treatment and supplementation of straw will be super-imposed on the feeding and general management regime normally followed by each farmer. A standard experimental design will be used. The "herd" or statistical population from which the experimental animals will be selected will comprise all the heifers in the age group of six to nine months in a cluster of four to six villages. These animals will be divided into groups of three on the basis of age and similarity of management conditions.

Each one of these three animals will be randomly allotted to one of three dietary treatments. The results can then be analyzed statistically in the manner appropriate to a randomized block design. Because management practices will be a long-term one, about 60 animals should probably be taken at the outset in order to obtain statistically significant results. The heifers will continue on the experiment from the age of 6 months until they complete their first lactation.

For each village, or for each two villages, one man will be employed to guide farmers in the feeding of the selected animals according to the experimental plan. He will weigh feeds offered and refused on one day per month, measure the animal to estimate weight, weigh milk produced by animals when they come into lactation, and record the dates of first oestrus, service, and calving. Caustic soda, urea, minerals, and any other supplement to be used will be supplied free of cost to the participating farmers.

The three experimental diets will be:

A	B	C
Existing farmer feeding practices.	Existing farmer feeding practices, except that urea is sprayed on straw and a mineral supplement is fed.	Existing farmer feeding practices, except that straw is alkali treated, urea is Sprayed on straw, and a mineral supplement is fed

If the protein supply from grass or cultivated legume forage in some seasons is adequate, the use of urea would be discontinued at such times.

The project has been proposed as a co-operative one among institutions in several countries where straw is traditionally fed to livestock. As far as possible, these institutions would be those which have successful livestock development programmes based upon co-operative societies so that a regular supply of materials (caustic soda, urea, mineral mixture) can be guaranteed and, after the project is over, the farmer can pay for these conveniently (e.g., by adjusting their costs against income from milk sales).

General considerations

While experimental data are limited, we may nevertheless attempt to evaluate straw treatment in a wider context. Indeed, it is essential that we make the attempt at this stage when we are contemplating a rapid expansion in our research and extension programmes on straw treatment.

A major concern in India should be the high support-energy cost of alkali treatment. Support-energy is obtained by burning fossil fuels, from falling water, and nuclear fission as opposed to the energy of the sun that is trapped on the farm. In the systems of farming that have come into existence in Europe and North America during the era of cheap fossil fuels, support-energy costs have been found to be very high and are, in the present changed circumstances, a cause for concern. Krummel and Dritschilo (15) have calculated the support-energy cost of producing one MJ animal protein in the United States. These figures are 6 MJ for milk and 32 MJ for beef. The corresponding support-energy costs for feed alone are 4 and 20 MJ, respectively. The values for beef include, however, the maintenance of cow herds as well as the rearing of animals for slaughter. In India, support-energy costs for animal protein production are near zero, as by-products are fed and few chemicals or machines are used. The introduction of alkali treatment would, at one stroke, raise support-energy costs to as much as 5 MJ/MJ animal protein (Table 2, Annex 4).

If all 200 million tons of straw produced in India every year were to be treated, some 10 million tons of NaOH would have to be manufactured at an energy cost of 510 x 109 MJ. This is three times the amount of energy currently expended in manufacturing nitrogenous fertilizers in one year (1,774,000 tons N x 84,000 MJ/ton). Not only is the support-energy of this magnitude not available, it can also be argued that even if it were, it would best be used to manufacture more nitrogen fertilizer, which would provide more additional feed energy than the NaOH would, and at the same time solve many other problems. One example will serve to indicate the strength of this argument.

One kg of urea applied to crops in India, under favourable conditions, can return 10 kg of grain, or 100 kg of green forage. In the example given in Annex 4, a buffalo cow would consume 883 kg of NaOH in her lifetime. This is equivalent to 1,272 kg of urea which, if applied to crops, would produce enough additional grain to feed the buffalo 3 kg per day for life, much more - probably three times more - than would be needed to produce the increment of milk resulting from the treatment of straw. If this urea were applied to non-leguminous forage crops, the additional yield would be enough to feed the buffalo 30 kg of forage per day, again much more than would be needed to produce the increment of milk produced by straw treatment.

Aside from energy considerations, NaOH treatment may prove unacceptable in the long run because of the sodium pollution it would cause. Newer methods of NaOH treatment avoid river pollution at the treatment stage, but each 100 kg of treated straw fed contains 3 - 5 kg of sodium that will find its way into soil and rivers. In the humid countries of Northern Europe this may not be a cause for concern, but in an arid country like India, with vast areas already afflicted with soil salinity, it could be. In the German Democratic Republic, KOH is being used extensively in place of NaOH (A. Hennig, personal communication, 1978), but soils in that country must be fertilized with potassium; Indian soils need not be. Indian soils also do not need calcium, which makes Ca (OH)2 less attractive than it might otherwise be. In any case, these alkalis are also expensive to manufacture in terms of support-energy.

What, then, are the alternatives? There are several possibilities, and each of them is discussed briefly in the following paragraphs. Unfortunately, considerable research and development effort would be needed to develop these alternatives to alkali treatment. By drawing attention to these alternatives now, however, the necessary effort may be stimulated more quickly.

The biological fungal treatment of straws needs no support-energy, but the fungi derive some of the energy they need from carbohydrates in the straw that the ruminant could use itself. Thus, overall energy efficiency (milk energy output/straw energy input) might not be improved. However, there are inadequate data (4). More information should be obtained quickly in order to evaluate this method of treatment critically. There would be no pollution with this method.

Ammonia treatment offers the advantage that it can help meet the protein needs of the animal consuming the straw, and later on the same nitrogen in dung and urine can help to meet the nitrogen needs of crops. It does not cause pollution. However, the methods developed thus far for farm use employ NH_3 gas and would, therefore, be difficult or impossible to use in Indian villages.

One interesting possibility is that suggested by Oji and Mowat (16). They sprayed straw with a urea solution and packed it in a silo so as to exclude air. The urea was broken down to NH_3, thus subjecting the straw to an alkaline treatment and, at the same time, increasing its nitrogen content. This method deserves further testing. A disadvantage is the capital cost of constructing silos; only the more affluent farmers in India could afford to do so.

A final alternative is the breeding of varieties of cereal crops that have highly digestible straw. The extent to which this is possible is not known at present. The genetic variability that may exist would have to be ascertained. Next, the compatibility of highly digestible straw with high grain yields would also have to be determined. Some varietal differences do exist (17). Growing cereal varieties that produce straw of high intrinsic digestibility could be combined with urea treatment in a silo.

Summary

Indian experience with alkali treatment of straw is reviewed. Earlier experiments with the Beckmann treatment of wheat and paddy straws confirmed European work with respect to the effectiveness of the method. It was also found to be profitable to treat straw under village conditions, but because suitable extension machinery and concepts were lacking, it was not popularized. Scarcity of water was another limiting factor. There have been recent experiments with newer methods, but it must be determined whether they will be economical under village conditions. A method of on-farm testing and demonstration is suggested to accomplish this, and at the same time popularize straw treatment.

An analysis of the energy cost of straw treatment with alkali under Indian conditions suggests that it may be unacceptably high. Alkali treatment also poses a distinct pillution problem in India. The rapid

development of alternative methods is therefore urged. The use of wood rotting fungi or ammonia (straw treated in silos with urea) is suggested, as well as an effort to breed cereal varieties with highly digestible straw.

Annex 1. The energy efficiency of the two-stage, feed-fuel processing of straw in indian villages

Table 3 shows the calculation of energy efficiency for different methods of using dung as fuel. The following factors are taken into consideration.

TABLE 3

	Traditional open fire-place	**Closed fireplace with chimney**	**Biogas production**
Energy content (MJ) of:			

Original straw	100	100	100
Resulting animal products and services	4.6	4.6	4.6
Resulting dung	55	55	55
Gas produced from dung			15.4
Useful energy obtained from dung (MJ)	5.5	11.0	9.2
Deduction for energy equivalent of nitrogen lost (MJ)	- 1.5	- 1.5	
Total useful energy recovered from straw	8	14.1	13.8
Efficiency of processing (%)	8.6	14.1	13.8

1. 6.9 kg straw containing 90 per cent dry matter and having a rate of combustion of 16 MJ/kg dry matter contains 100 MJ combustible

energy. This amount of straw is approximately the daily consumption by an adult bovine.

2. The efficiency of animal production on a typical straw diet is calculated (see Annex 4) to be 4.6 per cent. This value is for the diet as a whole, the value of the straw component is probably slightly less.

3. 18.3 kg of dung containing 20 per cent dry matter and having a rate of combustion of 15 MJ/kg dry matter (the digestibility of straw energy averages 45 per cent) = 55 MJ.

4. 18.3 kg wet dung x 37 I biogas/kg wet dung x 0.61 CH_4/l biogas x 0.038 MJ/l CH_4 = 15.4 MJ.

5. The efficiency of burning dung in an open fireplace is estimated to be 10 per cent, in a close fireplace with chimney, 20 per cent, and in a gas burner, 60 per cent (2).

6. Assuming that 50 per cent of the nitrogen contained in straw is

recovered in dung, the manufacturing energy value of this nitrogen is:

$$6.9 \text{ kg straw} \times \frac{0.5}{100} N \times 0.5 \times 84 \text{ MJ/kg N} - 1.5 \text{ MJ (18).}$$

7. Total useful energy = energy contained in animal products and services + useful heat energy - deduction for energy equivalent of nitrogen lost.

8. Efficiency of processing = (total useful energy obtained x 100) / (energy content of original straw)

Annex 2. Method of calculating the value presented in table 2 for the efficiency of naoh energy usage

The MJ of NaOH energy input per MJ additional energy stored as body-weight gain was calculated as follows.

1,000 kg untreated straw provided for

$$\frac{1{,}000}{4.5} - 222 \text{ calf days of feeding}$$

1,000 kg treated straw provided for

$$\frac{1{,}000}{6.0} - 167 \text{ calf days of feeding}$$

In 222 days a calf fed untreated straw also consumed

222 x 0.8 = 178 kg oilcake

In 167 days a calf fed treated straw also consumed

167 x 1.0 = 167 kg oilcake

In 222 days a calf fed untreated straw gained

222 x 0.25 = 55.5 kg

In 167 days a calf fed treated straw gained

167 x 0.42 = 70.0 kg

Therefore, the treatment of straw increased weight gain by 70.0 - 55.5 = 14.5 kg/1,000 kg straw. (This figure is conservative, because a calf fed treated straw consumed slightly less oilcake/1,000 kg straw than the one fed untreated straw.) The energy value of this bodyweight gain is taken as 9.6 MJ/kg (calves about 1-year-old gaining at a rate of 0.40 kg/day[19]), or 139.2 MJ for 14.5 kg. The manufacturing energy cost of NaOH is estimated to be 51 MJ/kg;

1,000 kg straw x 3.3 kg NaOH/100 kg x 51 = 1,683.

$$Hence: \frac{NaOH \text{ energy input (MJ)}}{\text{additional energy stored as body weight gain, MJ}} = \frac{1,683}{139.2} = 12.1$$

Annex 3. Recommendations to farmers on the treatment of straw

A simple method of treating straw with alkali has recently been developed that can boost the rate of gain of growing animals and the output of adult stock substantially and cheaply. The digestibility of straw is low - only 40 - 50 per cent - and thus it does not give much energy to the animals that eat it. The alkali treatment of straw increases digestibility to 50 - 60 per cent. Animals also eat 10 - 20 per cent more of the treated straw. As a result they get much more energy (up to 50 per cent more) when straw is treated.

The method of treatment is simple and requires nothing more than a garden sprinkling can, a hay fork, a pair of rubber gloves, and a pair of goggles. The latter two are for safety, as caustic soda can burn the skin and eyes if it splashes. Care must, therefore, be taken in handling it. In case of accident, the affected area should be immediately washed with large amounts of clean water Once the alkali is sprinkled on the straw it is no longer harmful. The straw must be broken or chaffed in order to be treated uniformly and easily. The straw to be treated is piled onto a pucca floor. One man sprinkles the caustic soda solution over the straw and another man turns the pile simultaneously with the hay fork. It is important to achieve uniform wetting of the straw.

The caustic soda solution can be made from solid flakes or from a lye solution. The latter contains 50 - 60 per cent caustic soda and is less difficult to handle when making up the solution for treatment, but must be stored and transported in drums, which is not as convenient as handling caustic soda flakes in bags. Usually the cost of caustic soda (dry flakes equivalent) is less, often only half the cost, in the form of lye than in the form of flakes, and for this reason is preferred. If flakes must be used, it is advisable to make up a 50 per cent stock solution in a drum; this makes the daily preparation of the dilute solution used in treatment more convenient. For treating the straw, make up a 2 per cent (2 kg/100 I) solution of flakes, or a 4 per cent (4 kg/100 I) solution of lye. Two litres of solution are needed for each kilogramme of straw. The sprayed straw will be moist, dark yellow in colour, and have a slight smell of caustic soda. A fresh batch should be prepared every day, though it should not be fed until 24 hours after it is treated. This is because the caustic soda continues to react slowly with the straw for 24 hours. Other feeds should be mixed with the treated straw only at the time of feeding it.

In order to obtain the maximum benefit from treated straw, it should further be treated with urea. The urea should be made into a solution (1 kg/10 1) and sprinkled on the straw at the rate of 1 1/10 kg of straw just before feeding. A complete mineral mixture should also be added to the diet.

Experiments have shown that a combination of alkali and urea treatment of straw can boost the daily rate of gain in growing stock by at least 0.2 kg/day. This will be equivalent to doubling the rate of weight gain or more, which means a much earlier first calving for heifers and start of working life for bullocks.

These recommendations are for average animals. Those fed large amounts of concentrates and/or green forage may not respond to straw treatment unless the amount of alkali is increased. If straw constitutes only about half of the diet (on a dry-feed equivalent basis), it should be treated with a 4 per cent solution of caustic soda flakes or an 8 per cent solution of lye. All additional feeds should be mixed at the time of feeding. Urea treatment may be dispensed with. A mineral supplement will, however, still be desirable.

Animals given treated straw will need to drink more water than usual, and provision should be made for this.

Annex 4. Calculated efficiency of milk production by straw-fed village buffaloes

Table 4 shows the calculation of milk-production efficiency. The data for the consumption of various feeds on untreated straw diet represent average village feeding rates and are taken from Amble et al. (20). Lactation milk yield for the untreated straw diet is estimated as the national average, as is the frequency of calving, namely, once every two years (21). Urea energy is not included in the total for energy input, on the grounds that much of it can be recovered and used as a fertilizer on crops. This procedure results in crediting the NaOH with all the improvements in productivity; thus the last three figures in the table, relating to the MJ NaOH energy per MJ milk or milk protein energy, are underestimated.

TABLE 4

	Untreated straw diet	Treated straw diet
Mature weight (kg)	400	400
Life span (years)	11	11
Age at first calving	5	35
Number of lactations/lifetime	3	4
Lactation yield (kg)	900	1,200
Lifetime milk production (kg)	2,700	4,800
Daily feed consumption (average	4.5	55

over lifetime; kg)straw		
grass/forage	6	6
concentrates	0.250	0.250
urea, 1% straw	0.055	
NaOH, 4% of straw	0.220	
Lifetime milk consumption (kg)	100	100
Lifetime energy intake (MJ)		
from feeds only	372,902	430,703
from feeds + NaOH	475,751	
Lifetime energy output (MJ)		
milk	12,420	22,084
calves	600	800
carcass	4,000	4,000
Total	17,020	26,884

Efficiency

$$\frac{\text{energy output} \times 100}{\text{feed energy input}}$$

4.6 6.2

$$\frac{\text{energy output} \times 100}{\text{feed} + \text{NaOH energy input}}$$

5.7

$$\frac{\text{NaOH energy input (MJ)}}{\text{additional energy output (MJ)}}$$

7.3

$$\frac{\text{NaOH energy input (MJ)}}{\text{total energy output (MJ)}}$$

1.7

$$\frac{\text{NaOH energy input (MJ)}}{\text{total protein energy output (MJ)}}$$

5.4

For the method of calculating the ratio MJ NaOH energy/MJ output, see Annex 2. The increased production due to alkali treatment is a very rough estimate. Growth rate can be doubled, leading to a reduction in age at first calving of about 1.5 years, making it possible for an animal to have one extra lactation in its lifetime. Data from a substitution trial with milk cows (22) indicate that treated straw fed ad libitum to cows is equal to at least 0.5 kg concentrate mixture/day. This, in turn, should be equal to 1 litre of milk/day in village buffaloes on the plane of nutrition indicated in the table (23). Energy values (MJ/kg) used in calculations are as follows, assuming straw and concentrates contain 90 per cent dry matter and grass/forage contains 25 per cent.

Straw	14.4
Grass/forage	3.6
Concentrates	16.2
Milk	4.6
Protein in milk	1.0

NaOH (manufacturing cost)	51.0 (24)

Assumed energy contents of carcasses (MJ) are:

Calf	200
Buffalo	4,000
Protein in calf	150
Protein in buffalo	3,000

The efficiency of a bullock with similar feed intake will be only slightly less than the buffalo in this example (untreated straw) if it works 1,200 hr/yr over a 6-year working life and has an 11-year total life span; i.e., 0.5 hp x 0.7455 kw x 1,200 hour x 6 x 3.6 MJ/kwh = 9,662 MJ energy output (2).

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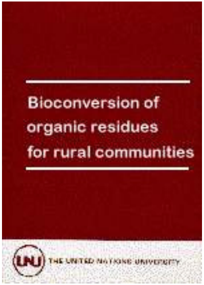
Discussion summary

Straw is more effectively treated with sodium hydroxide than with ammonia for increasing digestibility. However, urea would have the advantage of introducing the elements of nitrogen for protein synthesis.

It was questioned whether the financial incentive would suffice to encourage farmers to adopt straw treatment, as it takes two or three seasons for the beneficial effects of treated straw to be of evident significance. For this reason, it was recommended that straw treatment projects be run in conjunction with milk production ones, because increased milk production is a convincing indicator of improved nutrition in cows fed treated straw.

Straw treatment projects are suitable at both the village and individual farm level. It was queried whether money might not be better spent on buying groundnut meal rather than on straw treatment; it was pointed out that straw is far more plentiful than groundnut.



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Acknowledgements
Discussion summary

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Introduction

As early as 1949, Spoehr and Milner (1) suggested that mass culture of algae would help to overcome global protein shortages. The basis for their optimism was that algae had a crude protein content in excess of 50 per cent and a biomass productivity of the order of 25 tons/ha/year. Ironically, in spite of the lamentably low per capita protein supplies in many parts of the world, mass cultivation of algae has received only casual interest. The United Nations Environmental Programme (UNEP) is emphasizing nitrogen fixation and nutrient recycling through a programme that will establish microbiological centres (MIRCENS), and it is hoped that this will stimulate interest in micro-algae technology as a component of an integrated recycling system for rural communities.

There are a number of relatively large production systems for micro-algae, using completely synthetic nutrients. These systems are expensive, not only because of the high cost of land and the technology required but also in terms of water use and the price of inorganic nutrients. Even an optimistic cost extrapolation indicates that production expenses will be US$2 - 3 per pound of crude algae, or US$4 - 6 per pound of crude protein. For reasons of economy alone, it is therefore necessary to use organic wastes for industrialized production of algal protein feed.

In India, we are developing an integrated waste recycling system, in which algal production forms an integral part (2). This is significant from both the biological and the environmental point of view. This system can provide, simultaneously, fuel (methane), feed algae (for fish, livestock), fish, manure for crops, and water for irrigation. The two main objectives of the All India Co-ordinated

Project on Algae are: a. to develop rural-based recycling systems involving agriculture-aquaculture-pisciculture, and b. to develop viable, economical, rural-oriented systems for algal biofertilizers for rice that will help to relieve the pressure on chemical nitrogen supplies without impairing crop productivity. This will provide a cyclic instead of a linear system of nutrient supply.

Cultivation of algae in wastes for feed

While Spirulina platensis is grown at Delhi (Indian Agricultural Research Institute) and Nagpur (National Environmental Engineering Research Institute), Chlorella is being grown at Pondicherry (Auroville Centre for Environmental Studies). Spirulina, besides its rapid growth rate, high protein content, and lack of a thick cell wall (3), is amenable to simple filtration, giving it an economic advantage over such algae as Scenedesmus and Chlorella.

At Delhi, the algal production unit is a 30 m cement tank with a partition in the middle to facilitate circulation of the algal suspension by means of a hand-operated paddle wheel turned for 30 minutes twice a day (Figure 1). For harvesting, the algal suspension is pumped out by a hand-pump onto a series of cloth filters fitted to wire mesh baskets suspended in a frame. The filtered algal slurry is scooped out of the cloth and sun-dried. The filtrate is then recycled into the production unit. The average yield of algae amounts to about 15 - 20 g/day/m.

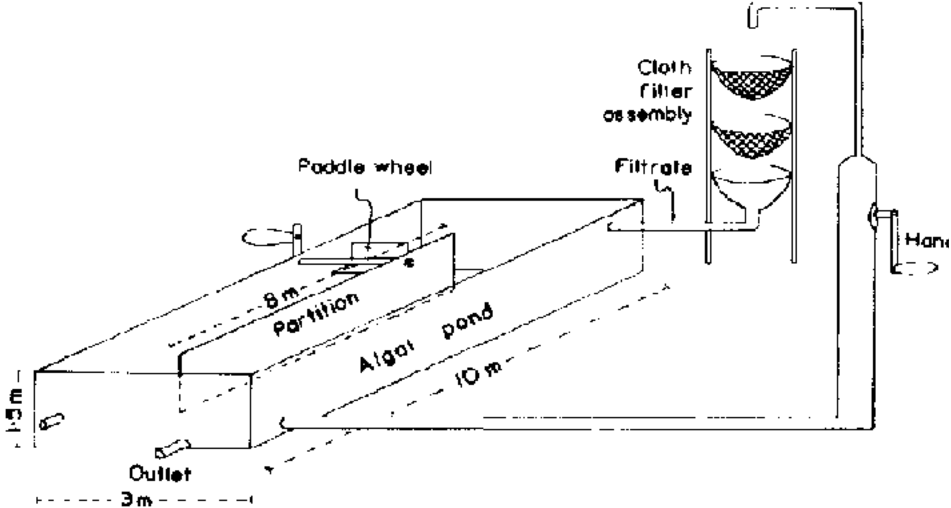

Figure. 1. Schematic Diagram of the Spirulina Production Unit at the Indian Agricultural Research Institute, New Delhi

Tables 1 and 2 show the growth potential of Spirulina in the digested slurry effluent from the cow dung gas plant and in cattle urine, respectively, with and without bicarbonate fortification. The slurry effluent supported algal growth at all dilutions even in the absence of added bicarbonate, although addition of bicarbonate (18 9 $NaHCO_3$/l) stimulated algal growth to the level of algae grown in synthetic inorganic nutrient medium. In contrast, pure cattle urine failed to support algal growth in the absence of bicarbonate, presumably because the urine lacks an available carbon source. Supplementation of cattle urine with bicarbonate supported the growth of the algae up to a level of 3 per cent urine, beyond which the urine per se seemed to inhibit algal growth even with addition of bicarbonate.

TABLE 1. Growth Potential of Spirulina platensis in Digested Cow Dung Slurry Effluent, with and without Added Bicarbonate (18 9 $NaHCO_3$/l)

concentration of	pH	Solids	Nitrogen	Dry wt.

slurry effluent		(g/l)	(mg/l)	alga (g/l)
1%	8.7			0.23
		0.0684	25	
1% + bicarbonate	9.2			0.63
2%	8.7			0.27
		0 1368	50	
2% + bicarbonate	9.3			0.74
3%	8.7			0.33
		0.2052	75	
3% + bicarbonate	9.1			0.87
5%	8.7			0.32
		0.3420	125	
5% + bicarbonate	9.1			1.08

7%	8.7			0.38
		0.4788	175	
7% + bicarbonate	9.2			0.84
10%	8.7			0.37
		0.684	250	
10% + bicarbonate	9.1			0.94
Control (synthetic medium)	9.2	-	400	0.9

Source: Rao and Venkataraman, unpublished data.

TABLE 2. Growth Potential of Spirulina platensis in Cattle Urine with and without Added Bicarbonate (18 9 NaHCO3/l)

Concentration of urine	pH	Dry wt. Alga(g/l)
1%	7.9	-

1% + bicarbonate	8.8	1.33
3%	8.6	-
3% + bicarbonate	8.8	0.8
5%	8.7	-
5% + bicarbonate	8.8	-
7%	8.7	-
7% + bicarbonate	8.8	-
Control (synthetic medium)	9.2	0.91

Source: Rao and Venkataraman, unpublished data.

Spirulina has a 50 - 60 per cent protein content with a well balanced amino acid pattern except for a deficiency of sulphur amino acids. The PER is higher than that in Chlorella and Scenedesmus (4) (Table 3). The BV, TD*, and NPU values are 68, 75.5, and 52.7, respectively. Cereals like rice, wheat, and ragi fortified with the alga were used in our experimental diet. Because lysine content is higher in the alga (4.34 9/16 9 N) than in the cereals, an increasing proportion of algal protein in the supplemented diets progressively improved the PER. The best growth pattern was obtained in diets containing alga and rice, each of which contributed 50 per cent of the protein.

TABLE 3. PER, NPU, and BV Values of Different Micro-algae.

	PER	NPU	BV
Spirulina maxim*	2.30	45.6 - 49.8	60 - 65
Spirulina platensis	2.07	52 7	68
Scenedesmus acutus**	1.27	52	72.1
Chlorella ellipsoidea	0.94	-	-

* Clement and Van Landeghem (3)
** Becker et al. (4)

Two types of integrated recycling systems are being developed at the Nagpur centre. In one, domestic sewage is utilized to produce an alga which is then used for fish culture. To adapt Spirulina to raw and settled sewage, a system has been developed in which the alga is initially grown in a synthetic medium that is progressively diluted at regular intervals with raw-plus-settled sewage, and finally with raw sewage alone. By this means, a population of alga that grow profusely in raw sewage has been selected. As sufficient phosphate is present in sewage, no phosphate fortification has been found necessary. However, 2 - 3 g NO_3/l are required under such conditions for optimum growth of the alga. In contrast to a high requirement for bicarbonate (18 9 $NaHCO_3$/l) by the alga growing in the synthetic nutrient medium, only a little bicarbonate (2 - 4 9 $NaHCO_3$/l) is required in the sewage medium.

The other approach involves an integrated system of a night soil gas plant, algal culture, and pisciculture. The digesters have a capacity of about 18 m and yield about 25 m gas per day. The volatile solids loading is kept at about 2.5 kg/m3 /day. Destruction of volatile solids varies from 40 to 50 per cent. The oxidation pond (36' x 18'x 4') is made of earthen embankments with inlet and outlet structures and normally holds about 25 m (825 cubic fee feet) of effluent. After digestion, the sludge filtrate is added to the pond. The biological oxygen demand (BOD), chemical oxygen demand (COD), suspended solids, pH, and alkalinity are being studied to arrive at the optimum load for a pond of this size. The efficiency with which this system kills helminths and other parasites will also be determined. The sludge is dried on special drying beds and carted off as manure.

At Pondicherry, the major emphasis is on Chlorella production and harvesting. This requires aeration and rain water collection, the latter achieved by pumping and water delivery systems. The circular algal production unit of about 200 m illuminated surface directs the circulating culture alternatively in a thin moving sheet and in cool, deeper sections to optimize utilization of light and CO2 as well as to control temperature. Three pre-existing concrete slopes have been joined to the pond to give a total of more than 100 m to be used for the moving sheet illumination and aeration.

Four venturi devices have been installed in one compartment of the underground reservoir to increase aeration in the circulation pattern. The suction produced evacuates the CO2enriched air from a system of three inter-connected fermentation tanks of 25,0001 total capacity as well as from two composting chambers (each 5 m x 0.75 m x 1 m). The fermentation tanks are heated by the composting chambers as well as by the solar collectors that form the top of the tanks. The complete circuit for the circulation of the culture thus includes an aeration chamber drawing warm, CO2-enriched air from the fermentation tanks, a dark retention period in the underground reservoir, passing through the pump into a thin, rapidly moving sheet over the sloping roof, a distribution channel jetting into a cool, growing ring of 20,0001 capacity that overflows into a thin sheet and collects in the cool central growing basin before again passing into the venturi aerators by gravity.

This circulation can be timed at various speeds up to 30,000 I/sec. The average yield of the alga in this system, which uses 3 per cent cattle urine, amounts to 10 - 15 9/ m /day. Infusion of small quantities of animal blood from a slaughter house has been found to stimulate algal growth considerably.

The alga is harvested from the sedimentation tanks and sundried.

Problems of contamination

Simple production is not the main problem in algal technology. The shallow, open-air ponds are vulnerable to contamination. Not only are methods required to maintain conditions favouring the chosen algal species to the exclusion of other organisms, but also monitoring programmes must be developed to insure a non-toxic, hygienically safe algal product. Serious problems of contamination have not been encountered, although occasional infestation of the culture with Brachionus and Chironomus larvae were observed during certain seasons. In waste stabilization ponds, contamination with other algae was frequently seen, but this could be overcome by a gradual population build-up of the desired organism.

Cultivation of algae for biofertilizer

The ability of certain forms of blue-green algae to carry out both photosynthesis and nitrogen fixation confers on them an ecological and agricultural advantage as a renewable natural resource of biological nitrogen. Nitrogen is one of the most important crop nutrients, and the great demand for nitrogenous fertilizers is apparent from the more than 580 chemical fertilizer plants now in operation or under construction throughout the world, representing an investment of over US$10,000 million.

It is estimated that the total energy required for the production of global ammonium fertilizers is equivalent to 2 million barrels of oil per day - a non-renewable resource. The energy crisis has driven fertilizer prices unrealistically high, dramatically illustrating the dependence of the world's food crops on petroleum-based fertilizers. Hardest hit by the chemical scarcity are the densely populated and land-scarce nations of Asia, where more than half of the earth's people live. Most depend on rice as their staple food. The millions of small-scale rural farmers in this region who have reaped the benefits of the new rice technology often lack the capital for chemical fertilizers. Any saving in the consumption of this fertilizer without affecting productivity, and the introduction of a cyclic nutrient supply system through biological sources, will be ecologically and economically advantageous.

Recent research has clearly shown that one of the most effective nitrogen-fixing biological systems in the rice fields are certain blue-green algae that, expressed on a per ha basis, contribute about 25 - 30 kg N/ha/season. A rural-oriented device to exploit these algae has been developed at the Indian Agricultural Research Institute at New Delhi. The merit of this process lies in its adaptability by the individual farmer without any appreciable capital investment or technical complications. Many farmers are now using this method to produce their own algal inocula for field application.

The basic principle is to grow algae using natural sunlight under conditions simulating the rice field. A thin, one-inch layer of soil is spread in rectangular trays or shallow dugout areas lined with polyethylene and flooded with two inches of water. After the soil settles down, the desired strains of blue-green algae are inoculated into these with a little superphosphate. The entire unit is kept exposed to the sun, and within a week, the entire water surface is covered by a copious growth of the inoculated species of algae. The standing water and its algae crop are allowed to dry in the sun, and the dried algal flakes are collected for field use. During bright summer, a continuous production of about 100 kg algal material is possible every fifteen days from an area of about 25 m The cost of production is about 12 cents/kg, and the farmer needs only about 10 kg/ha to give him about 25 - 30 kg N/ha. The inherent capacity of these algae to stand extreme dessication has made it possible to preserve the product in a sun-dried form without any impairment of its viability (5, 6).

In India, a significant portion of algae production appears to have great potential as a highprotein feed supplement for livestock, particularly for poultry, and also will make an excellent biofertilizer for rice. This, coupled with the emphasis on waste recovery and efficient land utilization, will encourage the integration of algae-feed-fertilizer production with livestock raising in the nitrogen recycling systems. The major merit of algae as animal feed is that low-quality algal protein can be converted by the animals into higher quality protein in the form of meat or meat byproducts without the necessity for extensive pre-processing of the algal product. The use of algae as biofertilizer provides a cyclic nutrient-supply system with inherent ecological advantages.

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Discussion summary

Spirulina is about 90 per cent stable with sewage, and could be even more so with other substrates. There is a 30 per cent saving of inorganic fertilizer when blue green algae are used in its place to fertilize rice, and crop response is evident within one year.

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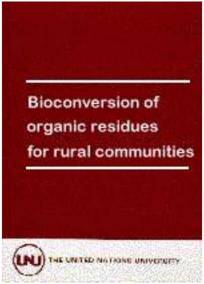

Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Organic residues in aquaculture

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Introduction

The use of organic residues in aquaculture is best discussed with awareness of the following facts about aquatic biology: (i) Limitations to biological production in fresh, brackish, or ocean waters are predominantly dissolved nutrients and/or food as well as shelter or substrate. Seasonality and intensity of the input of solar energy are also important. Iii) In aquaculture (and incidentally in fisheries), what is eventually to be harvested has to be contained or concentrated.

Among these inputs, nutrients and/or food can be supplied, at least in part, by organic materials or residues. As aquacultural practices increase in magnitude and hasten the flow of materials and energy through the systems, compared to natural conditions, it stands to reason that fertilization wastes can, under certain conditions, save both monetary and caloric inputs. Likewise, judicious use of agricultural or organic industrial wastes as feed materials can lower the cost of growing aquatic animals. it is the purpose of this paper to describe the use of such practices and to discuss certain ecological, economic, and managerial conditions that determine or limit them.

The range of production in aquaculture

Organic waste utilization in aquaculture can either be extensive, with wastes occurring naturally or being added, with little or no further management of production (1), or it can be highly intensive under conditions where extraneous feeding and fertilization with inorganic plant nutrients play a major role in augmenting animal protein yield from the system. Aquatic animal husbandry is pursued in embayments, ponds, rivers, lakes, raceways, in brackish water, fresh water, and full-salinity ocean water. Many variants of extensive and intensive fish culture rely importantly on the growing together of a few compatible species (polyculture) to make fullest use of the various types of food present (plankton, bottom fauna) in a body of natural or managed water (Figure 1). Feeds and/or inorganic or organic fertilizers may also be added. Shellfish - molluscs and prawns or shrimp - can also be grown in polyculture, but managerial practices involving several species of fish exclusively are more advanced than those that combine the husbandry of invertebrates and fishes.

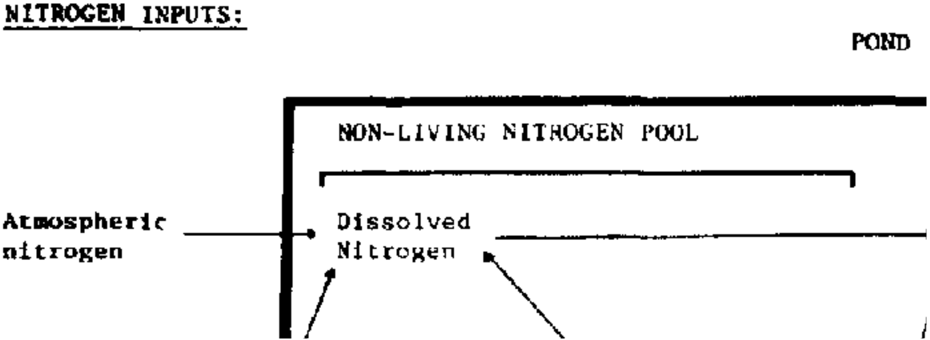

1
2
3
4
5
6

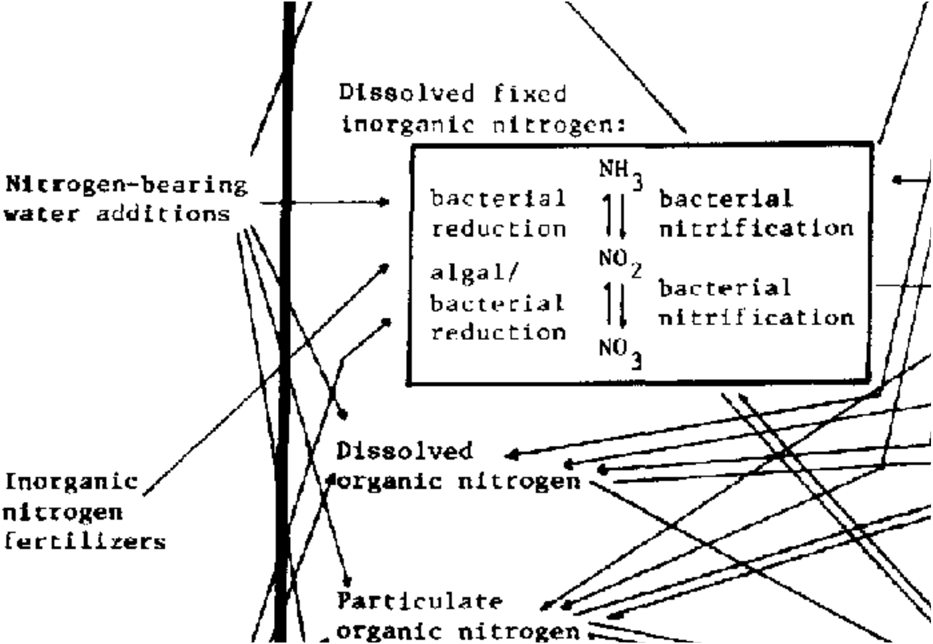
Figure. 1. Feeding Niches of Chinese Carp Species: 1, grass carp (Stenopharyngodon idellus) eating vegetable leaves; 2, bighead carp (Anistichtys nobilis) eating zooplankton; 3, silver carp (Hypophthalmichtys molitrix) eating phytoplankton; 4, mud carp (Cirrhinus molitorella) eating benthic animals, detritus, fish faeces; 5, common carp (Cyprinus carpio) on diet similar to that of mud carp; 6, black carp (Mylopharyngdon picous) eating molluscs. (From Bardach et al. [1])

The rationale of polyculture is obviously to divert as much as possible of the attainable biomass into channels that are useful to man, compared to those that prevail in a wholly natural food web. It should be pointed out that stocking fish in a lake does not necessarily increase the productivity of the lake, only the productivity of harvestable (i.e., desirable) organisms. In a lake supporting a complex food web ending in only a few harvestable fishes, and many other non-desirable organisms (for human consumption), stocking with desirable fish fingerlings, as well as control of undesirable species, especially predators, diverts the biomass of the "non-suitable" species into production of desirable fish biomass. It should be added, though, that monoculture, especially of molluscs in brackish water and of predatory fish such as trout, salmon, or groupers, can furnish high annual yields that are commercially attractive in spite of substantial inputs: for these species, the food is extraneously supplied.

A brief comparison of materials flow in ponds versus cage culture seems appropriate here. The food webs of manured, fed, and fertilized polyculture ponds are exceedingly complex in comparison with cage monoculture systems.

The principal pathways of nitrogen in ponds are illustrated in Figure 2. Possible nitrogen inputs to intensively managed polyculture ponds may be many and varied: atmospheric nitrogen, and nitrogenous substances present in in-flowing water, in inorganic fertilizers, in organic wastes, and in feeds. Similar diversity is also present in losses of nitrogen from ponds. Measurement of nitrogen flow between the various nitrogen pools (e.g., dissolved nitrogen pool, bacterial nitrogen pool, etc.) is a difficult task, requiring sophisticated techniques. For the present, aquaculturists are utilizing information on a few such inputs, pathways, and pools, and are only very slowly evolving models allowing prediction of harvests of fish from a pond given a specified set of conditions.




Dissolved fixed
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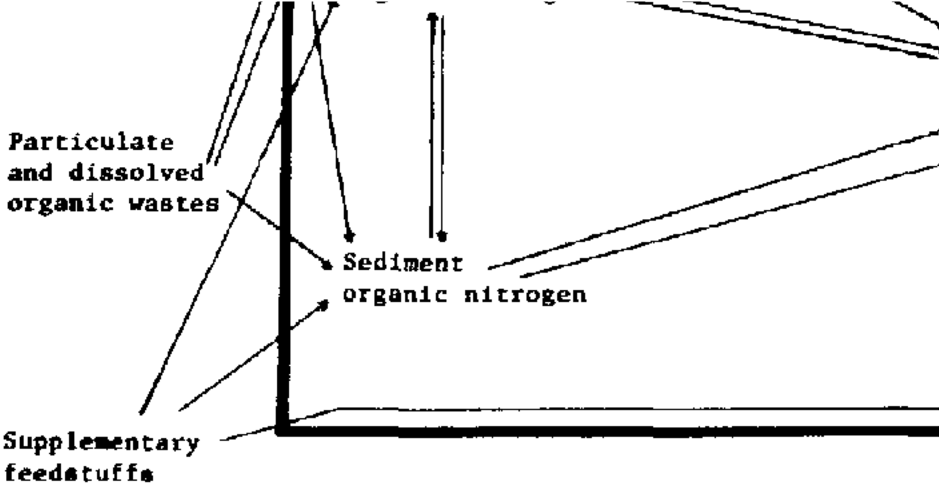


Figure. 2. Principal Pathways of Nitrogen in a Fish Pond Receiving Organic Wastes, Fertilizer, and Supplementary Feed. The various

tropic levels and relationships for animal biomass are not shown.

In contrast, cage culture represents a simplified ecosystem, at least within the confines of the cage itself (Figure 3). Cages are the aquatic counterpart to high-density terrestrial husbandry systems, including cattle feedlots, chicken batteries, and so forth. Such production systems are fashioned to provide all of the environmental needs of the animal and maximize production per unit surface area. The cage system is quite simple, with feed or food supplied to the fish (usually monoculture, but with polyculture cage culture becoming more common), and faeces, uneaten food, and waste metabolites being swept away from the cage by the continuous flow of fresh water. Cage culture, however, is generally more capital-intensive than pond culture, and requires a considerably higher degree of knowledge of the nutritional needs of the fish, as the aquaculturist often supplies the fish with their sole source of food or feed.

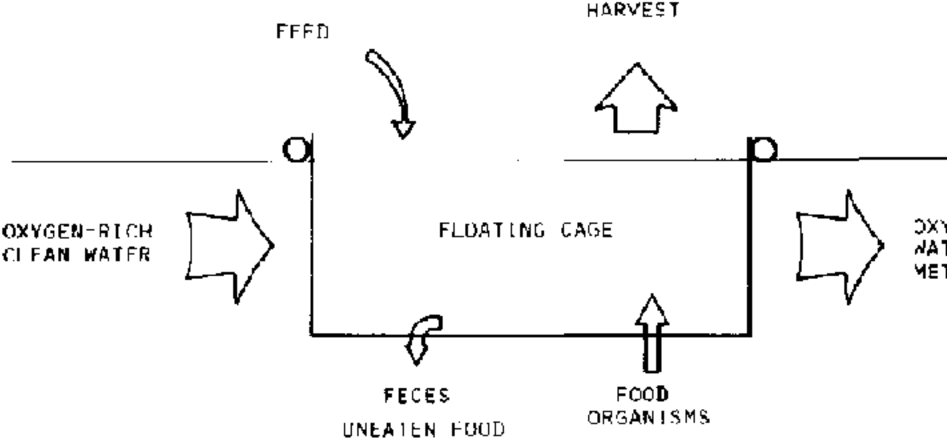


Figure. 3. Generalized Flow of Materials important in Cage Culture of Aquacultural Animals

The denser the stocking rate in fish culture, the more difficult the management, largely because of the accumulation of waste substances, depletion of dissolved oxygen, and other problems of sanitation. Yet it is known from the interaction of sewage with rivers that fertilization does not necessarily lead to oxygen depletion when the river flow is reasonably swift, causing diffusion of atmospheric oxygen into the water. Thus, it is not surprising that higher aquatic production is more often registered in flowing than in still waters, and that estuarine waters with their river-borne nutrients and continuous water circulation (via river flow and tides) represent the world's most fertile and productive aquatic environments. A comparison of annual productivity for several aquatic ecosystems is provided in Table 1, based on Crisp (2).

TABLE 1. Examples of the Productivity of Various Aquatic or Marine Ecosystems

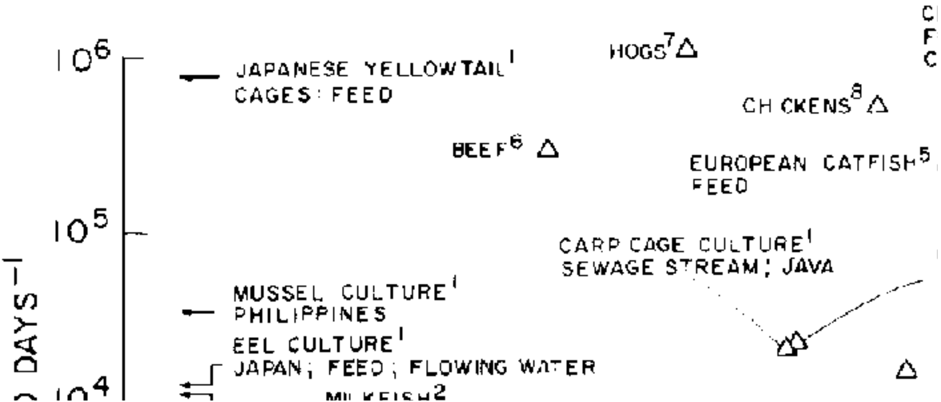
	Production kcal/m /year
Sargasso sea (oligotrophic)	1,340
Peru current (eutrophic)	36,500

Estuarine and brackish water marsh	16,000
Lake (oligotrophic)	70 - 250
Lake (eutrophic)	750 - 2,500

After crisp (2).

Several compilations in the literature 11, 3 - 6) permit quantitative comparisons of these various conditions under more or less intensive management regimes. The time base of a hundred days rather than a year is chosen, on the advice of Ohla of the Hungarian Aquaculture Research Institute, so that summer production in the temperate zone can be compared with the average in the tropics.

The animal protein yield to man in natural waters of the temperate zone ranges from less than 20 to several hundred kg/ha (Figure 4). There are specific sites, often with inadvertent fertilization by run-off, where yields are much higher: a dead river arm in Hungary with a slow flow that also serves a duck farm produces 1.3 tons/ha/100 days, and a portion of the lake Laguna del Bay in the Philippines, the shallow recipient of much agriculture) and domestic drainage where the wind also concentrates the plankton, is capable of producing 3 tons or more of milkfish per ha/100 days; however, the site is now plagued with pollution from highly populated shores.



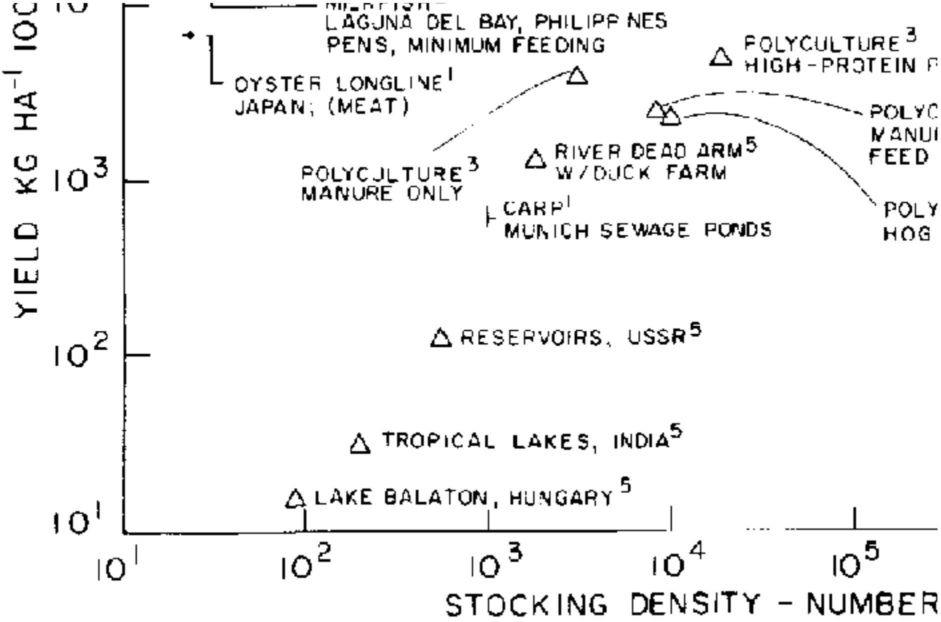

LAGUNA DEL BAY, PHILIPPINES
PENS, MINIMUM FEEDING
OYSTER LONGLINE 1
JAPAN; (MEAT)
POLYCULTURE 3
HIGH-PROTEIN
POLYCULTURE 3
MANURE ONLY
RIVER DEAD ARM 5
W/DUCK FARM
CARP 1
MUNICH SEWAGE PONDS
RESERVOIRS, USSR 5
TROPICAL LAKES, INDIA 5
LAKE BALATON, HUNGARY 5
YIELD KG HA-1
STOCKING DENSITY - NUMBER
10^1
10^2
10^3
10^4
10^5

Figure. 4. Comparison of Yields of Animal Production Systems (Kg/ha/100 days) and Their Corresponding Grow-out Densities (in numbers of animals per hectare): 1, from Bardach et al., (1); 2, from Delmendo (27); 3, from Moav et al., (28);4, from Buck et al. (17); 5, from Ohla and Sinda (3); 6 - 8, from personal communications with various experts in the field. (Yields are for single horizontal, i.e., not multi-level, surface only.)

A comparable level of fish productivity prevails in the more typical fish ponds of Israel or India, albeit with more material inputs. Animal wastes are applied and often there is extraneous feeding; there also, the 100-day yield reaches 3 to 4 tons/ha. Sewage oxidation ponds that are stocked with polyculture species able to make the best use of the rapid production of algae and invertebrate biota yield between 2.4 and 4 tons of fish per ha/100 days.

Still higher yields are reached in flowing waters: Indonesian carp cages in sewage-fed streams produce 8 kg/m/100 days (cage surface area only), amounting to a practical harvest of at least 20 tons/ha in the same period. The apparent discrepancy is due to the fact that only a portion of the flowage can be obstructed with cages lest inundation become severe. Intensive feeding of the carp is not practiced because blood-worms thrive in the sediments of these streams, feeding on the bacteria-rich silt and ooze, and these worms are grazed upon by the carp. The peculiar aspect of the situation, however, is that the worms regenerate fast and easily after the fish nibble off a portion of them. The worms, incidentally, contain growth stimulators, probably hemoglobin-related compounds (7).

The relationship between fish stocking, density, and water flow rate is illustrated in Figure 5. Although these values are species-specific, the benefits of increased oxygenation and removal of toxic body metabolites by rapid water exchange hold true for most species.

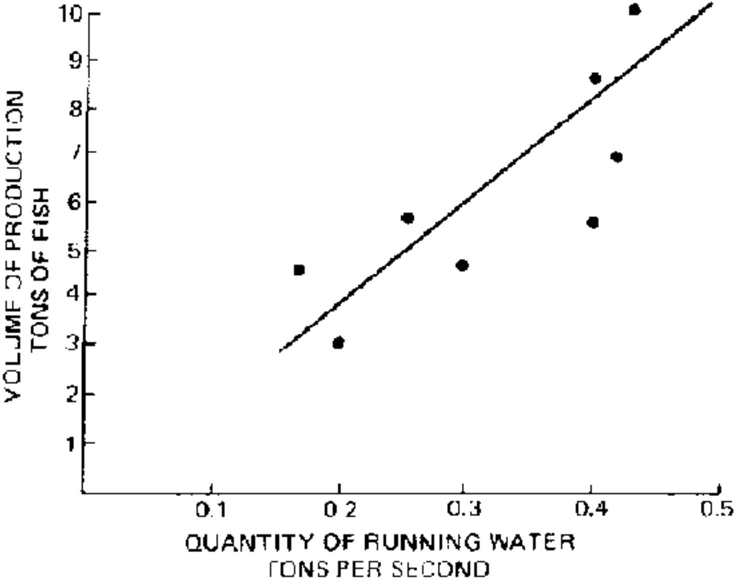


Figure. 5. Relationship between Fish Production and Quantity of

Water in a Carp Aquacultural System (From Brown and Nishimura [29])

Sewage oxidation ponds are also good bases for aquaculture. J. Ohla (personal communication, 1978) established that 2.5 tons/ha/100 days of severe) species of carp, mainly silver carp, can be grown if 200 m/ha/day of primary sewage effluent is added to the water (after settling of the solids).

The stocking of fish in sewage oxidation ponds is beneficial not only to fish culture, but to the waste treatment processes within the oxidation pond itself. Tilapia and silver carp were stocked in an oxidation pond and compared to an oxidation pond not containing fish (8). Bacteria levels were lower in the pond containing fish (Table 2), perhaps due to the disinfection potential of waters with high pH and oxygen. The high pH probably results in a greater loss rate of ammonia to the atmosphere, considered to be beneficial from the waste-treatment viewpoints, and also from the viewpoint of fish health management (ammonia is toxic to fish). However, it represents a loss of valuable fixed nitrogen fertilizer, and hence can be a somewhat negative trade-off.

TABLE 2. Measured Chemical and Biological Parameters in Waste Treatment Ponds with (+) or without (-) Liquid Cow Manure, and with (+) or without (-) Polyculture Fish (Tilapia, Carp)

	Pond type + Manure - Fish	+ Manure + Fish	- Manure + Fish	- Manure Fish
Dissolved oxygen (0900 h)	0.7 9.5	9.0 - 15.9	10.0 - 13.8	
pH	7.9 - 8.3	8.3 - 8.9	8.6 - 8.7	-

Bacteria (103/ml)	17 - 27	1.6 - 6.7	0.7 - 4.3	
Phytoplankton (principally) (g dry/m)	0.2 - 4.3	0.3 - 1.4	< 0.06 - 0.2	< 0.06
Zooplankton (principally) (g dry/m)	0.3 - 42.4	0.1	- 1 0 < 0.06	< 0.06
Chironomides (10/m)	79 - 215	1 - 4	0 - 2	1 - 7

Source: Schroeder (8).

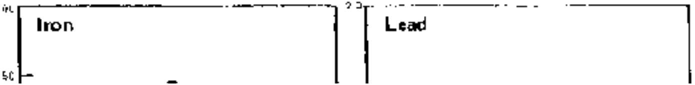
The use of raw or primary treated sewage has been questioned for health reasons. It should be noted here that intestinal parasites and flora of man and other warm-blooded animals are anaerobic, or nearly so, and that the high oxygenation of fast flowages, of balanced sewage ponds, or of balanced fish ponds receiving organic wastes, does not permit the survival of most such pathogens (5). Finally, thorough cooking provides an additional safeguard.

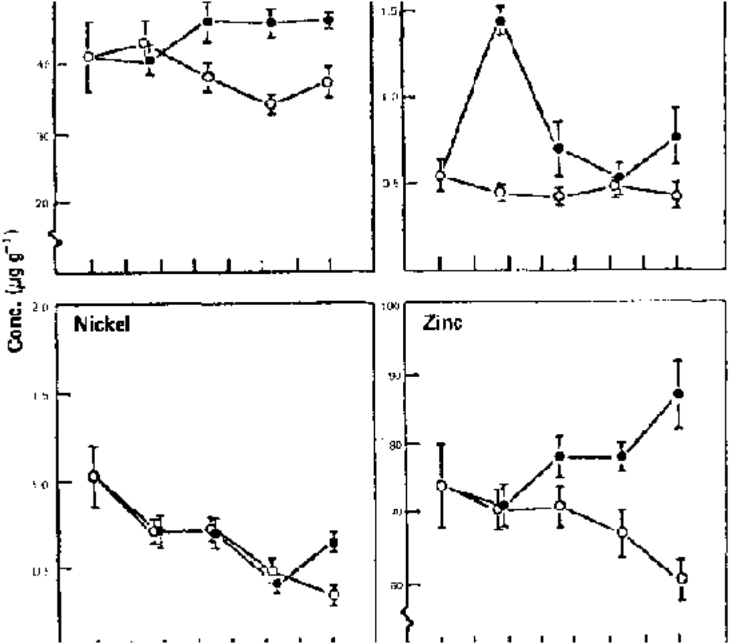
The addition of sewage to pond or river water, and the use of fertilization by means of animal wastes in aquaculture, are well established and economically sound practices. Higher yields per unit surface area are reached with other extraneous inputs, mainly by supplementary feeding and/or by forced water circulation or even filtering. The main secret of success in achieving up to several hundred tons/ha annual fish production (often extrapolated from smaller surface areas) lies in the use of natural or artificial flowages in which many thousands of fish can be stocked and fed. Similarly, cage-reared fish in strong tidal flows can achieve phenomenal rates of growth and production. They are fed with compounded feed (however expensive), with trash fish, with household wastes, or with cereals, cereal wastes, or other agricultural residues. Attractive economic returns conditioned by cultural food tastes invite these practices (1; see chapter 1).

Yet another high-yield aquatic production system ought to be mentioned, this time in the sea. In certain bays near Vigo, Spain, where tidal exchange as well as fertile run-off from the land are high, mussels are grown on containment/ attachment devices suspended from rafts. Three hundred tons of mussel flesh per year have been reported (9). Under roughly comparable conditions, similar planktonfiltering bivalves (Mytilussmaraydinus) also reach such high yields (10). Tidal movement-based mollusc culture, however, is more advanced in Europe and Japan than it is in tropical Asia; nonetheless, in all locations it is threatened by pollution.

Having noted the beneficial effects of dissolved organic wastes on aquacultural systems, one must hasten to add that most fish farmers use chemical fertilizers, predominantly or entirely. Manure is just not sufficiently ubiquitous, and the use of domestic sewage, even while more widely available, has strong cultural and economic barriers against its use. While the cultural component of this barrier is perhaps understandable, though ill-advised, the economic one invites further comment.

Where sanitation is advanced, investments in rendering sewage effluents innocuous and infertile are so great that sewage aquaculture can only be envisaged when cost of invested capita) need not be considered. That is, in the temperate zone and in technologically advanced countries, one may think of planning sewage aquaculture for small to medium-sized towns with readily available cheap land or a nearby lake. Installations will be necessary to separate domestic sewage from all other liquid effluents such as industrial wastes and nonsewage domestic and stream run off components. Even then, big-accumulation of toxic substances may occur (11). The actual levels of trace metal accumulation will be species- and site-specific. For example, rainbow trout fed a diet containing activated sludge selectively accumulate certain metals, but not others (Figure 6).

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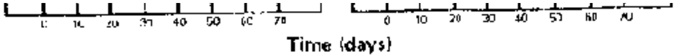

Figure. 6. Changes in Heavy Metal Concentration for Rainbow Trout Fed a Diet Containing Activated 30 Per Cent Sewage Sludge (solid circles) and a Control Diet Composed of Standard Feed Ingredients (open circles) (From Slingh and Ferns [11])

In the tropics, as already indicated with reference to the cage culture for carp in Indonesia, the situation may be more favourable to the direct use of domestic sewage because there is, as yet, less admixture with the effluents of industrial or hydrocarbon chemicals. Aquaculture and agriculture in mainland China utilize both animal and human wastes. Reports suggest that, while animal wastes are normally either applied untreated, or composted and applied, anaerobic treatment and composting are the preferred methods for human wastes (12). This process greatly reduces parasites and pathogens, rendering the manure safer to use (13).

The value of organic wastes

On a polyculture fish farm in Israel, for instance, where yields are reasonably high (4,150 kg/ha/yr.), nitrogen and phosphorus fertilizers, applied as liquid ammonia and superphosphate, amount to 18 per cent and feed to 31 per cent of the annual calorie inputs (14). Obviously, savings could accrue when manure is used instead of inorganic fertilizer, depending, of course, on nearby production and low-cost handling of manure. Just how economical - albeit site- and condition-specific - sewage-fed aquaculture can be, is exemplified by a comparison of the energy inputs of the above-mentioned Israeli operation with that in the Indonesian cage culture for carp in sewage-fed streams, and pond-grown carp near Munich that derive their sustenance from a mixture of the sewage of Munich and the water of the Isar River. In Israeli pond polyculture, 65 keels (representing fixed and variable production inputs, excluding labour) produce 1 9 of protein; this could be reduced to about 50 kcals/g if the industrial fertilizer were replaced with manure. In contrast, the sewagebased carp culture in flowing water in Indonesia, as wed) as in Bavaria, requires only 4 - 10 kcals/g of protein. Channel catfish and chickens are less efficient, requiring approximately two times the calorie input per gram of protein required for Israeli poly culture, and fourteen to thirty-seven times that of pure sewage-based carp culture (15). Another advantage in polyculture is that nutrients are re-used as they pass through the digestive tracts of the various component species.

The use of manure and domestic sewage, however, represents a saving for the fish farmer only when these materials are available, and because of their inherent bulk, need not be transported even over medium distances.

Their use prevails in many parts of tropical Asia, in India, in communes of China, and in kibbutzes of Israel, where land animal husbandry and aquaculture are practiced conjointly (5, 12, 16). Examples of this are provided by a hog-cum-fish polyculture experiment (17), and a study comparing biomass harvest of an oyster-only culture system, and an oyster-cumdetritus feeder system (18).

In the hog-cum-fish system (Figure 7), overall productivity of biomass was increased by 67 per cent - with no additional feeding or fertilizer - by providing swine wastes (uneaten food, faeces, urine) to a polyculture pond. Food conversion efficiency increased from 3.8:1 in the hog-only system to 2.2:1 in the hog-cum-fish system. Conversion of feed nitrogen (our extrapolation) was 58 per cent in the hog-only system versus 70 per cent in the hog-cumfish system.

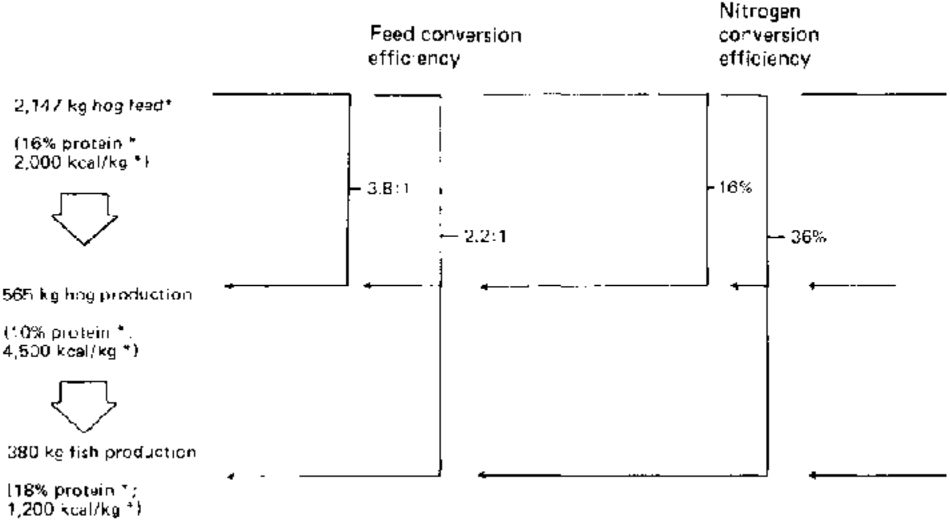

Figure. 7. Efficiencies of Conversion of Feed, Feed Nitrogen (extrapolated), and Feed Calories (extrapolation) of a Hog-Only System and a Hog-cum-Fish Polyculture System (After Buck, Baur,

and Rose [17], plus our calculations). * Assumed or extrapolated value.

The addition of a detritus feeder (a polychaete worm) to an algae-oyster culture system (Figure 8) increased biomass conversion efficiency from 9.8 per cent (oysters only) to an overall 11.2 per cent efficiency for an oyster-cum-worm polyculture system (18).

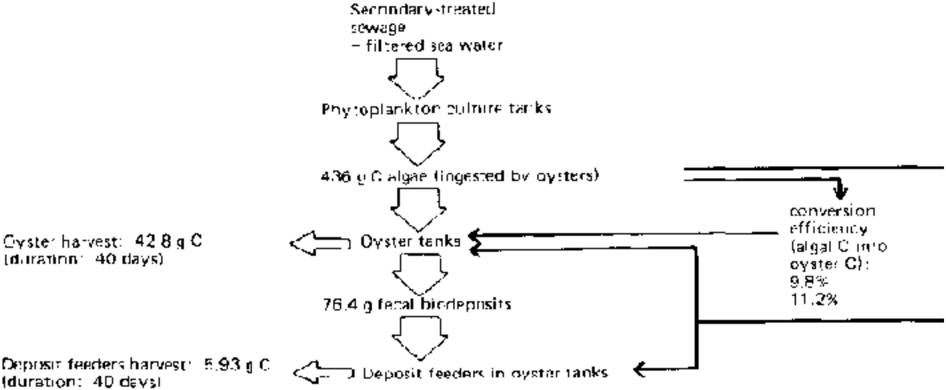

Figure. 8. Materials Flow, Harvest Levels, and Conversion Efficiencies of an Experimental Sewage Aquaculture System (After Tenore, Browne, and Chesney [18], plus our calculations)

The use of domestic sewage, as practiced in certain sites in Asia, is also favoured by site as well as ecological conditions, and, above all, by the availability of abundant water. Here, as in the case of animal manure, the aquacultural planner may have to weigh the advantage of biogas via anaerobic digestion of organic wastes and sludge production against direct use of sewage. The former practice generally has benefits applicable to other portions of agricultural production systems, including cooking, heating, and lighting, and production of fertilizer and soil conditioner (19).

Anaerobic digestion has been reported to increase the manure's ammonia content, a preferred species of agricultural nitrogen fertilizer, from 26 per cent in raw, unprocessed manure, to 50 per cent following treatment (19). However, the extent to which anaerobically-treated manure sludge and supernatant can be substituted for untreated manure in a fish pond while maintaining high yields of fish has not been demonstrated. This is a very important consideration, because organic substances added to a pond can be consumed directly by heterotrophic organisms and bypass the photosynthetic production level. Thus, production of fish using organic manures can greatly exceed levels predicted for a pond based entirely on an ecosystem starting with light-limited plants utilizing inorganic nutrients.

Certain special conditions of combined aquaculture and land animal husbandry have been devised that reduce to a minimum the difficulties and costs of handling organic manures, and that benefit both husbandry components. Ducks are natural manure carriers, as it were, and in duckcum-fish culture in Hungary, ducks are stocked in ponds after the fish have reached fingerling size. The presence of ducks leads to an increase in fish biomass of 0.3 to 0.4 tons/ha over conventional ponds without ducks (F. Mueller, personal communication, 1978). The ducks in this case are selectively bred to reach their market size of 2.5 kg in 45 days on copious feeding with a special pellet diet; sheds and runways for ducks are necessary, as is the skill of poultry-keeping in addition to that of aquaculture. However, intensive use of the fish ponds by ducks can threaten the pond walls. Care must also be exercised not to overload the aquatic ecosystem with excrete and bring about highly anaerobic conditions in the bottom mud, which is the nursery ground of many invertebrates that serve as important food components for the fish.

Despite these possible problems, mutual benefits to fish and bird-rearing are many, including: lower capital investment than for intensive chicken culture; shortened growing time for ducks; better utilization of feeds; ducks eat organisms not ordinarily eaten by fish (e.g. aquatic weeds, frogs, etc.); ducks distribute manure evenly throughout the pond; and fish pond ducks are healthier, leaner, and have cleaner feathers than do ducks raised in other conventional production systems (20).

Another pattern for land and water animal-rearing presents itself through the placing of pigsties partially over the ponds, in such fashion that wastes from the pig platform can be sloshed down into the ponds. The ecological basis for this practice was discussed earlier. The technique has been pioneered in Malaysia, with water hyacinths grown on part of the pond surfaces being incorporated into the pigfeed, and with the fertile pond water also being used to water market garden crops (Figure 9) (21). Such integrated farming systems that can amortize themselves and bear profit after three years depend, of course, on year-round availability of water and on having a suitably sloped terrain.

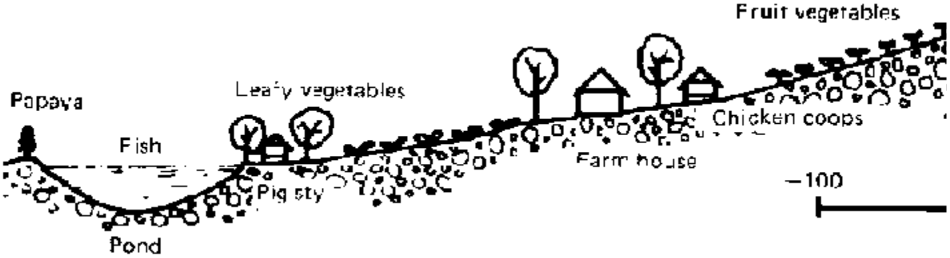

Figure. 9. Integrated Aqua-Agricultural System Used in Singapore

(After Ho [21])

Direct feeding

Feeding types among fishes range from predatory gulpers to sifters of organic materials in mud, to zooplankton feeders, and to herbivores that eat algae or even leafy plants. As already intimated, the rationale of polyculture is the selection of compatible species with different feeding patterns. In addition, because fish learn to feed on almost anything, it is relatively easy to develop pelleted food for fish culture, dietary quality considerations aside. At the same time, such catholic feeding habits permit the use of plant materials, especially cheap or nearly valueless crop residues such as bran, etc. Table 3 (22) illustrates this, as does the practice of building very wide pond margins to the fish ponds in China for cultivating grasses where leafy plant-feeding grass carp (Ctenophryngodon idella) comprise about 20 per cent of the stock in the pond (12).

TABLE 3. Proximate Composition of Feedstuffs Used in Fish Culture

	% Carbohydrates	% Fats	Total protein	% Fibre
Baobab press cake	76.7	0.8	2.2	6.8
Beer waste	46.4	7.8	22.8	18.8
Cabbage leaves	4.8	0.1	1.7	1.2
Cassava flour, dry	83.2	0.5	1.6	1.7
Cassava leaves	14.3	1.0	7.0	4.0
Cassava tubers	34.6	0.2	1.2	1.1
Cocoa hulls	57.5	0.8	8.7	23.7
Coffee hulls	33.5	7.2	12.2	39.0
Corn, cooked	79.2	4.8	8.0	1.9
Corn bran	64.4	8.6	12.2	2.8
Corn flour	71.5	3.8	9.3	1.9

Corn grain	81.3	4.6	10.3	2.3
Corn leaves and stalks, dry	46.6	1.6	5.9	30.9
Cotton seed cake	38.5	7.4	47.3	9.6
Cotton seed	29.6	18.8	22.8	24.1
Cow stomach, dried	37.6	1.9	16.7	28.2
Cow stomach, fresh	36.2	1.0	11.6	37.8
Kale	6.1	0.8	3.5	1.6
Lettuce	3.7	0.2	1.2	0.6
Millet	81.0	2.8	9.0	3.0
Mill sweepings	58.0	14.0	12.5	7.5
Napier grass	1.0	0.2	2.6	1.1
Palm nut press cake	53.0	8.9	19.9	14.0
Peanut press cake	27.3	7.6	53.5	6.2
Peanut shells,	46.3	1.0	4.0	46.7

ground				
Plantain banana, whole	79.2	1.8	6.5	5.3
Potatoes	19.7	0.1	2.1	0.9
Pumpkin	4.7	0.1	1.0	0.8
Rice	77.7	2.2	7.4	0.4
Rice bran	56.9	3.8	0.7	22.6
Sorghum	81.0	2.8	9.0	3.0
Soybeans, ground	31.4	15.7	33.7	5.5
Spinach	4.5	0.2	2.1	0.8
Sugar-cane fibre	55.4	0.6	1.3	40.0
Sweet potatoes	27.5	0.2	1.6	1.0
Wheat bran	59.7	3.8	4.5	14.5
Yam	25.6	0.1	1.5	0.9
Blood, fresh	36.2	1.0	11.6	0.0

Blood meal	-	1.0	76.6	0.0
Smoked, salted fish waste (local)	-	-	35.8	-

Source: Bardach 122).

All sorts of other wastes, even sludge, are fed to fish (23 - 25) with very low conversion efficiencies, to be sure, but presumably favouring cheap production costs just the same (Table 4).

TABLE 4. Yields of Fish for Various Residues Used in China

Residue or feed	Residue or feed quantity	Fish yield	Estimated conversion efficiency (kg yield/kg

			feed x 100)
Grass or vegetable tops	60 - 70 kg	1 kg grass carp	1.4 - 1.7%
Snails and clams	50 kg	1 kg black carp	2.0%
"Fertile water": 77% bean curd residue; 23% residue of fermented products	100 kg	1 kg silver carp	1,0%
Animal manure bighead carp	25 kg	0.5 kg silver carp	2.0%

Based on information given to mission members; after Tapiador (12); conversion efficiencies are our estimates

Carnivores make up a certain portion of the polyculture components; in fact, various traditional aquaculture schemes incorporate a few voracious predators, albeit under intensively supervised management conditions, for example, pike in common carp ponds and catfish (Silurus glands) in polyculture carp ponds (1) and (A. Ruttkay, persona) communication, 1978). Sometimes pure carnivore culture is practiced depending on the availability of the so-called trash fish; that is, species that are too small to be eaten directly or not acceptable as table fare. The culture of groupers in various parts of the Pacific and of yellow tail in the Inland Sea of Japan are based on the availability of this kind of high-protein feed; it is mentioned here because one sometimes hears the argument that such practices are ecologically unsound. They may appear so at first glance, but these comments usually do not take into consideration that aquaculture is pursued to gain a livelihood, providing its practitioner with income first and foremost. It usually also supplies fish for the table, but hardly as its prime purpose. The rearing of carnivores relying on "waste" species, or for that matter on slaughterhouse wastes and/or blood meal, can be a sound practice, even from the ecological vantage point.

Concluding remarks

Fertilization is so widely practiced in aquaculture that it seems almost superfluous to point out the economic advantages that can accrue through judicious use of the inexpensive nutrients present in manure or sewage. These substances, together with other agricultural or organic industrial processing residues, can also provide substitutes for expensive feed ingredients. Obviously, there are regions where few agricultural residues are available, and the aquaculturist must resort to chemical fertilization. But where these residues are available, and where ecological and sociological factors permit the use of such wastes, handling and transportation of the wastes to the ponds are important cost factors that may limit the use of waste residues. The closer the animal pens are to the water, the more economical the fertilization task is and a premium can be placed on planning and modifying new or existing farms to promote optimal operational logistics of joint animal husbandry, market gardening, and aquaculture. We are not aware of any studies concerning the distances between residue sources and ponds, or comparisons of various farm lay-out schematics for this joint agriculture-aquaculture production system, under various edaphic, climatic, and socio-economic conditions.

Manures from pigs and birds are more frequently used than cattle manure, and even in some areas where cattle exist their droppings are often unavailable to aquafarms (e.g., India, Afghanistan) because the dung is dried and used as fuel. In many cases, animal wastes are anaerobically digested in order to allow for multiple benefits, specifically biogas for cooking, and supernatant and sludge for agricultural or aquacultural use. Although the latter two products are largely used for fertilization, their potential use as feed ingredients is high and is currently receiving considerable research attention.

It should be mentioned that plant residues until now have had little use as fertilizers for aquaculture, in contrast to their application in agriculture. This is because of the fundamental physico-chemical differences between water and soil as cultivation media. However, some fish ponds are occasionally or regularly fallowed. Then crops or crop residues are ploughed into the pond as a sort of "green manure." Rice paddies are good examples, where fish can be stocked (ecologically sound pest management permitting), and the rice straw and stubble are ploughed into the paddy soil as soil conditioners.

The use of organic residues in aquaculture is, to a certain extent, dependent on competition for these residues by agricultural production systems. Although detailed studies comparing agricultural and aquacultural use of organic residues from an energy or material-accounting viewpoint are not available, it is quite possible that manure recycling is more efficient in aquacultural animal production (including integrated land animal-cum-fish systems) than in agricultural animal husbandry. Manures produced by fish in a polyculture pond immediately enter a detritus food chain. A portion of this detritus is recycled into higher trophic levels, in this case, table fish. The system, while bearing some resemblance to terrestrial grazing systems (i.e., cattle produce manure, which fertilizes plants, which are eaten by cattle, etc.), is considerably more efficient than that found in intensive agricultural animal production systems. In the latter, manure must be collected and distributed with an attached expenditure of energy and human labour.

Sewage utilization in aquaculture is conditioned by cultural, sanitary, and economic constraints. The simplest use is the establishment of family or village privies over Asian fish ponds, and/or the use of domestic effluents from rural settlements into flowages for cage culture. In these situations, the presence of toxic substances (e.g., trace metals, carcinogens) in the wastes are minimal, and there is less chance for excessive accumulation of harmful substances in the flesh of the fish. Disease and parasite transmission, while still a consideration, is often over-rated. Adequate pond management, as discussed earlier, and careful cooking can overcome most of these potential problems. When the sewage of small or large towns is used for aquaculture (e.g., Calcutta), the presence of materials such as industrial wastes may be potentially dangerous from the standpoint of toxic substances that accumulate in the flesh of the fish. The use of the wastes of such localities for the production of food for man is entirely contingent on segregation of these substances from the normal domestic sewage. The costs of such separation systems will ultimately decide the possibility of their use in food production.

Socio-cultural objections to the use of sewage for fish culture seem to be decreasing in several societies as ecological information becomes disseminated and as fertilizer costs increase. There is, for this reason, urgent need for intensified engineering, economic, and management studies of sewage use under various conditions of light to dense urban development.

The direct use of organic residues as fish feed is highly opportunistic; as intimated in Table 3, it depends on the local availability of anything from various by-products of grain milling to cheap but otherwise unusable animal proteins. Here, as with manure, the location of the feed source in relation to the location of the animals to be fed is a prime economic consideration. Widening the pond berms in China to supply feed for grass carp, as well as locating grouper cage culture near fishing ports, are cases in point. There is urgent need, however, regardless of the nature of the feeds, to have far better characterization of their nutrient values and to incorporate such data in computerized international feed data banks.

The future prospects for the increased use of organic wastes in aquaculture (especially as fertilizers) are clearly influenced by the cost of chemical fertilizers. As the price of fertilizer increases because of increased fossil fuel costs, one can anticipate greatly increased use of organic wastes in aquaculture even without vigorous promotion. Certain key research needs to be undertaken to make such use as beneficial as possible. These investigations should relate to the big-economics of combined agri-aquacultural systems. They should place emphasis on system-wide total and energy accounting with the goal of establishing trade-off values between the use of manure in aquaculture against other agricultural/domestic purposes. The organic value of various wastes, and the cost of handling and treating them under various levels of intensity of operation and development, need to be established. Health problems related to the use of sewage also need attention, especially as they relate to cost trade-offs and permissible risks under various treatment and handling conditions. Questions of the environment need to be addressed vigorously; as the pressure on water supplies increases, fish ponds may be used increasingly to supply water for people. Multiple-use oxidation ponds supplying animal protein and furnishing domestic water will also increase, and problems of eutrophication and contamination of ground and surface waters need to be addressed. The need for interdisciplinary research is obvious if one wishes to aim for optimization in the trade-offs among the several possible goals of fish pond use stated here.

One more caveat seems necessary about aquaculture in general, but more specifically about the seemingly simple, but really complex, subject matter of the use of organic residues in aquatic animal husbandry. This warning is also a challenge embodied in the quotation from Matsuda (26) to follow, which stresses, by implication, the need for multiple-level research, with strong emphasis on pilot installations and culture-oriented extension:

"Aquaculture is not solely a matter of growing a product; it is also a part of rural development, including marketing, distribution of food and income, employment, and living conditions. Thus aquaculture should not be recommended indiscriminately to people who are not ready for it."

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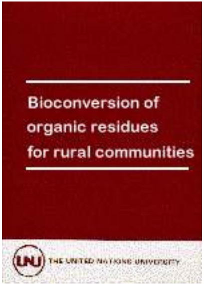
Discussion summary

A question was posed regarding the possible advantages of aquaculture in the sea rather than in inland ponds. It was pointed out that control of seed fish, breed, and feed is more difficult in the sea, although under controlled circumstances, molluscs do well in certain bays. There are great possibilities for future aquaculture in the sea, but this will depend on the genetic modification of existing marine species.


Bioconversion of
organic residues
for rural communities
THE UNITED NATIONS UNIVERSITY

Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Biogas generation: developments. Problems, and tasks - an overview

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Introduction

In recent years, biogas systems have attracted considerable attention as a promising approach to decentralized rural development. Developed and developing countries and several international organizations have shown interest in biogas systems with respect to various objectives: a renewable source of energy, biofertilizer, waste recycling, rural development, public health and hygiene, pollution control, environmental management, appropriate technology, and technical cooperation. Within the context of the UNEP/Unesco/ICRO microbiology programme, which is sponsored jointly by the United Nations Environment Programme, Unesco, and the International Cell Research Organization, several workshops have already been held in Yogyakarta, Manila, Mexico City, Singapore, and Bangkok, in an attempt to catalyze the applications of this acknowledged low-cost, nonwaste-producing technology that is increasingly being deployed to manage the environment and to ameliorate the search for substitute sources of fuel, food, and fertilizer (1 - 4). Early in 1979, in joint co" operation with IFIAS and ESCAP/UNIDO, a workshop will be held at Bandung to deal specifically with village micro" biology and the integrated biogas farming system. In this context, it is hoped that this activity on "The State of the Art of Bioconversion of Organic Residues for Rural Communities," a UN University joint World Hunger-Natural Resources activity receiving Unesco and UNEP/Unesco/ ICRO Panel support, will be making a significant contribution to the application of bioconversion processes for rural communities.

The utilization of microbial activity to treat agricultural, industrial, and domestic wastes has been common practice for a half century. Treatment includes the aerobic, activated sludge process and the anaerobic or methane fermentation method; the latter is simple, does not require imported know-how or components, is suited to small family or village-scale digestion, and is the only process utilizing waste as a valuable resource. Of great importance to the developing countries, the use of methane has, until recently, been restricted because of public antipathy or because other, cheaper energy sources were available. But, as can be seen from Tables 1 and 2, biogas technology today is a sufficiently significant producer of energy to command the attention of a fair number of countries (5) and agencies.

TABLE 1. Promotion of Research and Development Related to Use of Biogas

Place	Sponsors of biogas research and development	Number of plants	Use of residual material and genera remarks
Bangladesh	Central government; Bangladesh	20 (under	Meet fertilizer need develop co- operati or family-size bioga

	Academy for Rural Development	construction)	plants in rural area
China	Local authorities	200,000(Szechuan)	Family-size plants
Cook Islands	Central government	1 (Roratonga)	Integrated cattle farm with piggery pens; promote growth of algae and fish for production of protein
Ecuador	Family co-operative effort in Iluman		Development of a biogas reactor to provide fuel for individual homes and a community bakery

Fiji	Private enterprise	10	Rural development
India	Government of India: All-India Co-ordinated Project	36,000	Target 100,000 uni by 1978
Delhi	Delhi Development Authority Delhi Dairy Corporation Indian Agricultural Research Institute		Research on biogas reactor: design, construction, and capacity Pioneer in biogas research and development Research on

	Indian Institute of Technology (B.E.R.G.)		biodegradable cellulosic substrates
Haryana	National Dairy Research Institute, Karnal Mutuka Farm, Hatari village	12	12 plants (100 to 200 cu.ft.) operatin in Sonepat and Gurgaon districts
Uttar Pradesh	Gobar Gas Research Station, Ajitmal		Pioneer in biogas research and development Research on bagass

	National Sugon Institute, Kanpur National Livestock Development Research and Extension Institute		as substrate 10 plants (60 to 50 cu.ft.) operating in the Deviapur and Kashipur districts Kashipur
Gajarat	Tulsi Shyam Temple, Una		3,000 cu.ft. plant in use for supply of electricity only
Maharashtra	National Environmental Engineering Institute,		Research on insulator materials minimize heat losse in winter months

	Nagpur Khadi and Village Industries Commission Gandhi Samarak Nidhi, Pune National Dairy Research Institute, Bombay (Regional Station)		Pioneer in biogas research and development 55 plants in operation using nig soil Has successfully experimented on "integrated farming system" that yields cattle fodder, fruits and vegetables Deployment of biog for diesel

	Indian Institute of Technology, Bombay (see also under Tamil Nadu)		engines
Andhra Pradesh	Rural Electrification Corporation, Karimnagar		4,500 cu.ft plant fo community development with technical assistance from Council of Scientific and Industrial Research
Orissa	Central Rice Research		Biogas production from Azolla crops

	Institute, Cuttack		
Tamil Nadu	Indian Institute of Technology, Madras (in collaboration with I.I.T., Bombay and Indian Oil Research Centre, Faridabad) Shri A.M.M. Murugappa Chettiar		Research in the use of biogas in petrol kerosene and diese engines Development of low cost materials for biogas reactors

	Research Centre		
Pondicherry	Auroville Ashram		Work in progress or inclusion of algae in biogas system
Indonesia	Dian Desa Indonesian Board of Voluntary Services, Development Technology Centre, I.T.B., Bandung	12	Intensification of preliminary programme;regiona network proposed for training and operation of biogas plant processes

Japan	Ministry of International Trade and Industry (MITI); National Institute of Animal Husbandry; Bioconversion Committee of the Agency of Industrial Science and		Pollution control biogas digestion processes involve th use of thermophilic micro-organisms

	Technology; M/S Hitachi Plant Construction Fermentation Research Institute, Inage		
Korea (Republic of)	Organization of Rural Development; Institute of Agricultural Engineering and Utilization, Suweon;	29,400	Production of food and fertilizer; 55,000 units planne by 1985

	Korea-U.K. Farm Machinery Training Project		
Nepal	Development and Consultancy Services, Butwal Technical Institute; Energy Research and Development Group;	10	200 units planned

	Tribhuvan University		
Philippines	National Institute of Science and Technology; National Institute of Animal Husbandry, Maya Farms, Angono	100	Supports algal growth in photosynthetic oxidation ponds; irrigation of vegetable gardens
Thailand	Agricultural Economic Dept., Sanitation	225	50 digesters planne for every year since 1975 for cooking and lighting

	Division, Health Dept., Ministry of Public Health; Mahidol University; Kasetsart University; Applied Scientific Research Corporation of Thailand (MIRCEN - Microbiological Resources		purposes

	Centre)		
Upper Volta	Services de Recherche et Applications Techniques, Socit Africaine d'Etudes et de Dveloppement	Research on development of biogas	technology initiated
United Kingdom	National Centre for Alternative Technology, Wales		Working demonstrations on methane generation
United States	Biogas of Colorado, Inc.,		Development of a mobile

	Denver		demonstration unit to generate biogas for use in rural area of Colorado. Completed unit in corporates solar temperature contro system for use in winter Emphasis is on simplicity of technology.

Sri Lanka	Industrial Development Board of the Ministry of Industries		100 regional centre planned; Rural Energy Centre planned with UNEP to meet the basic energy needs of a village community (50 - 200 families)

Sources: S.K. Subramanian, Bio-Gas Systems in Asia, Management Development Institute, New Delhi, 1977; U.N. Agency documents.

TABLE 2. International Agencies Engaged in Biogas Research, Training, and Development Programmes

Agency	Area	Remarks
Economic and Social Commission for Asia and the Pacific (ESCAP)	Examination of technological and economic aspects (ESCAP projects on biogas technology and utilization supported by United Nations Development Programme)	Workshops - Manila, Ne Delhi, Bangkok, and (with Government of Netherlands assistance) Fiji
FAO	Agro-industrial residue utilization	UNEP/FAO Seminar, "Residue Utilization - Manageme of

		Agricultural and Agro-Industrial Wastes," Rome, 1977; information available in FAO bulletins, compendium of technologies, and world directory of institutions
International Cell Research Organization (ICRO)	Promotion of research and development See under Unesco and UNEP/	Unesco/ICRO Panel on Microbiology

	of trained manpower	
International Development Research Centre (IDRC)	Supports research designed to adapt science and technology to the specific needs of developing countries	IDRC Project Identification Meeting c "Social and Economic Evaluation of Biogas Technology," Sri Lanka, 1976
International Federation of Institutes for Advanced Studies (IFIAS)	Identification and promotion of research through commissioned studies	See under Unesco and UNEP/Unesco /ICRO Panel on Microbiology
Unesco	Promotion of basic	In collaboration with

	microbiological research and development of trained manpower	ICRO training course on "Waste Recovery by Micro-organisms" Kuala Lumpur, 1972, and with IFIAS, a commissioned study on "Energy Self- Sufficiency - A Feasible Prerequisite for Self-Reliance"
UNEP/Unesco/ICRO Panel on	Promotion of research in low-cost non-	Training courses in Indonesia;

Microbiology in close co- operation with UNEP, Unesco, ICRO, and IFIAS	waste- producing microbial technologies and development of trained manpower at established microbiological resources centres (MIRCENs) at Bangkok, Cairo, Nairobi, Porto Aiegre, and Stockholm. Dissemination of information on micro- organisms through	Thailand, The Philippines, Republic of Korea, Kenya, Egypt, Mexico, Guatemala, Singapore, Kuwait, New Delhi, etc., on waste conversion and environmental management using microbes

	the World Data Centre at Brisbane	
United Nations Environment Programme (UNEP)	Environmental management and counteraction of pollution	UNEP Rural Energy Programme - pilot projects in collaboration with (i) Brace Research Institute, McGill University, Canada: African Rural Energy Centre at Senegal (ii) Oklahoma State University, USA;

		Asian Rural Energy Research Project, Sri Lanka (iii) Dissemination of information through UNEP International Referral System (IRS)
UNICEF	Provision of basic services to children	Studies on contribution of biogas systems to village technology and rural

		development
UNIDO	Dissemination of information on biogas	Proposed project: Bioga Plants - assistance for the mobilization of existing technology anc its transfer and integrated development
UNITAR	Provision of specialized training	Seminar on "Microbial Energy Conversion," Gottingen 1976

United Nations University (UNU)	Counteraction of World Hunger (WHP) Management of Natural Resources (NRP)	Conference at INCAP with ICAITI on "Bio-conversion of Organic Residues for Rural Communities, November 1978, Guatemala
WHO	Waste disposal and possible health hazards	Preparation of monographs on composting and on biogas utilizing night soil

Sources: S.K. Subramanian, Bio-Gas Systems in Asia, Management Development Institute, New Delhi, 1977; U.N. Agency documents.

What is biogas?

Methane is the main constituent of what is popularly known as biogas. A colourless, odourless, inflammable gas, it has been referred to as sewerage gas, klar gas, marsh gas, refuse-derived fuel (RDF), sludge gas, will-o'-the-wisp of marsh lands, fool's fire, gobar gas (cow dung gas), bioenergy, and "fuel of the future." The gas mixture produced is composed roughly of 65 per cent CH_4, 30 per cent CO_2, and 1 per cent H_2S. A thousand cubic feet of processed biogas is equivalent to 600 cubic feet of natural gas, 6.4 gallons of butane, 5.2 gallons of gasoline, or 4.6 gallons of diesel oil. For cooking and lighting, a family of four would consume 150 cubic feet of biogas per day, an amount that is easily generated from the family's night soil and the dung of three cows. In addition, rural housewives using the biofuel are spared the irritating smoke resulting from the combustion of firewood, cattle dung cakes, and the detritus of raw vegetables (Figure 1).

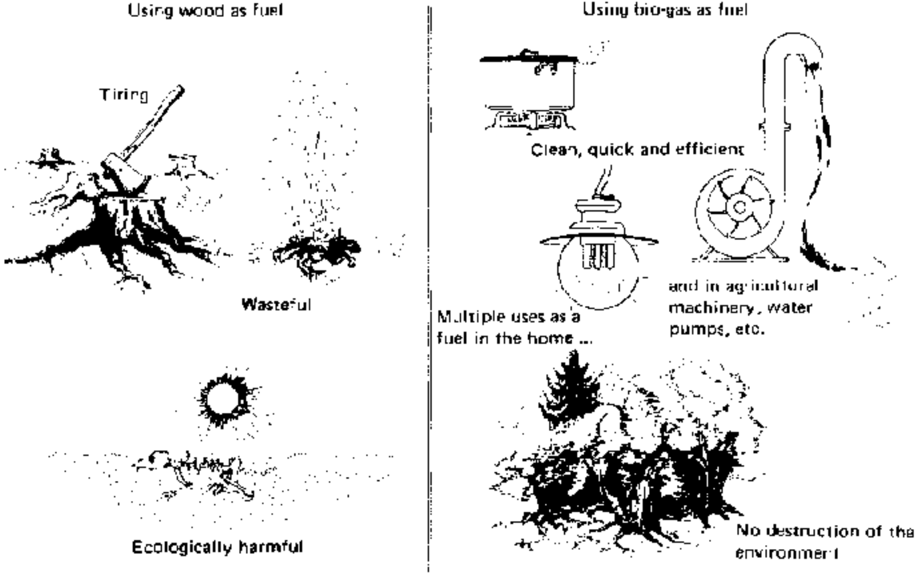


Figure. 1. The Attributes of Biogas as a Fuel vs. the Disadvantages

of Wood (Source: Bio-Gas Newsletter, August 1976)

Microbiology of CH_4, or bio-methanogenesis

Anaerobic digestion technology or the methane-generating bioconversion yields both fuel (biogas) and organic fertilizer (sludge), products that are the final result of microbial action on cellulosic and other non-chemically processed organic residues. These substrates are obtained through a series of degradative steps that involve a variety of bacteria (6 11). In the first step, complex polymeric organic substrates - proteins, carbohydrates, and fats - are transformed by non-methanogenic bacteria into essentially non-methanogenic substrates like butyrate, propionate, lactate, and alcohol. Through a second step that involves the acetogenic bacteria, the composition and identity of which still remain to be determined, these compounds are transformed into methanogenic substrates, i.e., acetate, H_2 and C1 compounds that are converted into CH_4 and CO_2 by the methane bacteria, obligate anaerobes that multiply in a neutral or slightly alkaline environment.

That the smooth cooperation of the three groups of bacteria has to be well regulated is exemplified by Bryant's discovery (12) of two mutually inter-dependent species existing in a symbiotic association that was formerly considered a pure culture under the name of Methanobacillus omelianskii. The association is comprised of two symbionts: an acetogenic organism and a methanogenic organism. The acetogen produces acetate and H2 and CO2, thereby disrupting the process of auto-inhibition with the acetogen, which succumbs to the H2 it produces.

Again, it is necessary that both aspects of the anaerobic digestion process - liquefaction and gasification - be well balanced. If the methane bacteria are absent, the digestion process may only succeed in liquefying the material and may render it more offensive than the original material. On the other hand, if liquefaction occurs at a faster rate than gasification, the resultant accumulation of acids may inhibit the methane bacteria and the bioconversion process as well.

The biogas plant-some technical considerations

The biogas plant consists of two components: a digester (or fermentation tank) and a gas holder. The digester is a cube-shaped or cylindrical waterproof container with an inlet into which the fermentable mixture is introduced in the form of a liquid slurry. The gas holder is normally an airproof steel container that, by floating like a ball on the fermentation mix, cuts off air to the digester (anaerobiosis) and collects the gas generated. In one of the most widely used designs (Figure 2), the gas holder is equipped with a gas outlet, while the digester is provided with an overflow pipe to lead the sludge out into a drainage pit.

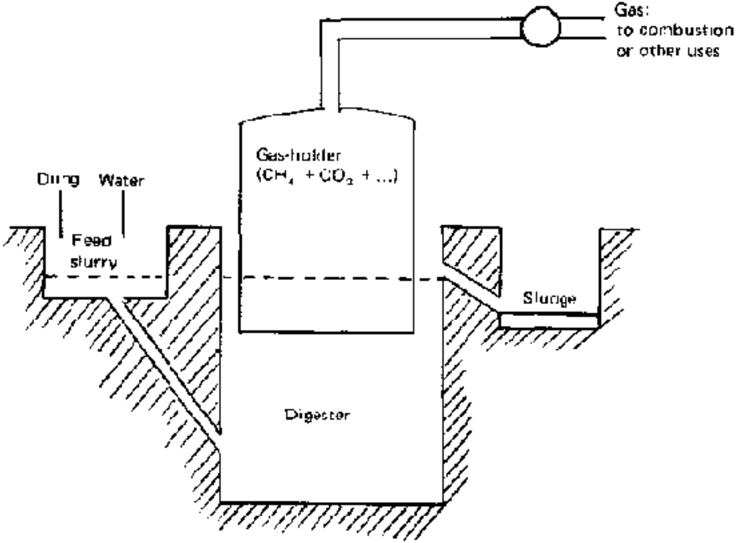


Figure. 2. Diagram of Gobar-Gas Plant Used to Obtain Methane from Dung by Anaerobic Fermentation (After Prasad et al. [20]1

The construction, design, and economics of biogas plants have been dealt with in the literature (13 - 21). For biogas plant construction, important criteria are: (a) the amount of gas required for a specific use or uses, and lb) the amount of waste material available for processing. Fry (17)

Singh (21), and others (1, 3) have documented several guidelines for consideration in the designing of batch (periodic feeding) and continuous (daily feeding) compartmentalized and non-compartmentalized biogas plants that are of either the vertical or horizontal type. In addition, Loll (18) has recently dealt with the scientific principles, process engineering, and shapes of digestion reactors, and with the economics of the technology.

Digester reactors are constucted from brick, cement, concrete, and steel. In Indonesia, where rural skills in brick making, brick laying, plastering, and bamboo craft are well established, clay bricks have successfully replaced cement blocks and concrete. In areas where the cost is high, the "sausage" or bag digester (14) appears to be ideal (Figure 3). The digester is constructed of 0.55 mm thick Hypalon laminated with Neoprene and reinforced with nylon. The bag is fitted with an inlet and an outlet made from PVC. Even if imported from the United States, the cost of the digester and the gas holder (both combined in one bag) is only 10 per cent of that for a concrete-steel digester. Another advantage is that it can be mass produced and is easily mailed. In rural areas, the whole installation is completed in a matter of minutes. A hole in the ground accommodates the bag, which is filled two-thirds full with waste water. Gas production fully inflates the bag, which is weighted down and fitted with a compressor to increase gas pressure.

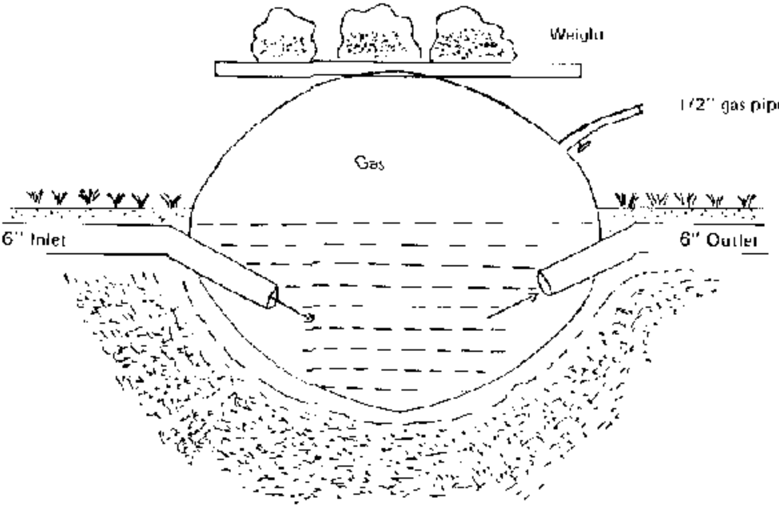


Figure. 3. Diagrammatic Sketch of the "Sausage" Bag Digester Made of Hypalon Laminated with Neoprene

Environmental and operational considerations

Raw Materials (19)

Raw materials may be obtained from a variety of sources - livestock and poultry wastes, night soil, crop residues, food-processing and paper wastes, and materials such as aquatic weeds, water hyacinth, filamentous algae, and seaweed. Different problems are encountered with each of these wastes with regard to collection, transportation, processing, storage, residue utilization, and ultimate use. Residues from the agricultural sector such as spent straw, hay, cane trash, corn and plant stubble, and bagasse need to be shredded in order to facilitate their flow into the digester reactor as well as to increase the efficiency of bacterial action. Succulent plant material yields more gas than dried matter does, and hence materials like brush and weeds need semi-drying. The storage of raw materials in a damp, confined space for over ten days initiates anaerobic bacterial action that, though causing some gas loss, reduces the time for the digester to become operational.

Influent Solids Content (16, 19, 21)

Production of biogas is inefficient if fermentation materials are too dilute or too concentrated, resulting in, low biogas production and insufficient fermentation activity, respectively. Experience has shown that the raw-material (domestic and poultry wastes and manure) ratio to water should be 1:1, i.e., 100 kg of excrete to 100 kg of water. In the slurry, this corresponds to a total solids concentration of 8 - 11 per cent by weight.

Loading (14, 19)

The size of the digester depends upon the loading, which is determined by the influent solids content, retention time, and the digester temperature. Optimum loading rates vary with different digesters and their sites of location. Higher loading rates have been used when the ambient temperature is high. In general, the literature is filled with a variety of conflicting loading rates. In practice, the loading rate should be an expression of either (a) the weight of total volatile solids (TVS) added per day per unit volume of the digester, or (b) the weight of TVS added per day per unit weight of TVS in the digester. The latter principle is normally used for smooth operation of the digester.

Seeding (14, 19)

Common practice involves seeding with an adequate population of both the acid-forming and methanogenic bacteria. Actively digesting sludge from a sewage plant constitutes ideal "seed" material. As a general guideline, the seed material should be twice the volume of the fresh manure slurry during the start-up phase, with a gradual decrease in amount added over a three-week period. If the digester accumulates volatile acids as a result of overloading, the situation can be remedied by reseeding, or by the addition of lime or other alkali.

pH (14, 19)

Low pH inhibits the growth of the methanogenic bacteria and gas generation and is often the result of overloading. A successful pH range for anaerobic digestion is 6.0 - 8.0; efficient digestion occurs at a pH near neutrality. A slightly alkaline state is an indication that pH fluctuations are not too drastic. Low pH may be remedied by dilution or by the addition of lime.

Temperature (13,14,19, 21)

With a mesophilic flora, digestion proceeds best at 30 - 40 C; with thermophiles, the optimum range is 50 - 60 C. The choice of the temperature to be used is influenced by climatic considerations In general, there is no rule of thumb, but for optimum process stability, the temperature should be carefully regulated within a narrow range of the operating temperature. In warm climates, with no freezing temperatures, digesters may be operated without added heat. As a safety measure, it is common practice either to bury the digesters in the ground on account of the advantageous insulating properties of the soil, or to use a greenhouse covering. Heating requirements and, consequently, costs, can be minimized through the use of natural materials such as leaves, sawdust, straw, etc., which are composted in batches in a separate compartment around the digester,

Nutrients (13,17,19, 21)

The maintenance of optimum microbiological activity in the digester is crucial to gas generation and consequently is related to nutrient availability. Two of the most important nutrients are carbon and nitrogen and a critical factor for raw material choice is the overall C/N ratio.

Domestic sewage and animal and poultry wastes are examples of N-rich materials that provide nutrients for the growth and multiplication of the anaerobic organisms. On the other hand, N-poor materials like green grass, corn stubble, etc., are rich in carbohydrate substances that are essential for gas production. Excess availability of nitrogen leads to the formation of NH_3, the concentration of which inhibits further growth. Ammonia toxicity can be remedied by low loading or by dilution. In practice, it is important to maintain, by weight, a C/N ratio close to 30:1 for achieving an optimum rate of digestion. The C/N ratio can be judiciously manipulated by combining materials low in carbon with those that are high in nitrogen, and vice versa.

Toxic Materials (13,14,19)

Wastes and biodegradable residue are often accompanied by a variety of pollutants that could inhibit anaerobic digestion. Potential toxicity due to ammonia can be corrected by remedying the C/N ratio of manure through the addition of shredded bagasse or straw, or by dilution. Common toxic substances are the soluble salts of copper, zinc, nickel, mercury, and chromium. On the other hand, salts of sodium, potassium, calcium, and magnesium may be stimulatory or toxic in action, both manifestations being associated with the cation rather than the anionic portion of the salt. Pesticides and synthetic detergents may also be troublesome to the process.

Stirring (13,14,17 - 19, 21)

When solid materials not well shredded are present in the digester, gas generation may be impeded by the formation of a scum that is comprised of these low-density solids that are enmeshed in a filamentous matrix. In time the scum hardens, disrupting the digestion process and causing stratification. Agitation can be done either mechanically with a plunger or by means of rotational spraying of fresh influent. Agitation, normally required for bath digesters, ensures exposure of new surfaces to bacterial action, prevents viscid stratification and slow-down of bacterial activity, and promotes uniform dispersion of the influent materials throughout the fermentation liquor, thereby accelerating digestion.

Retention Time (19, 21)

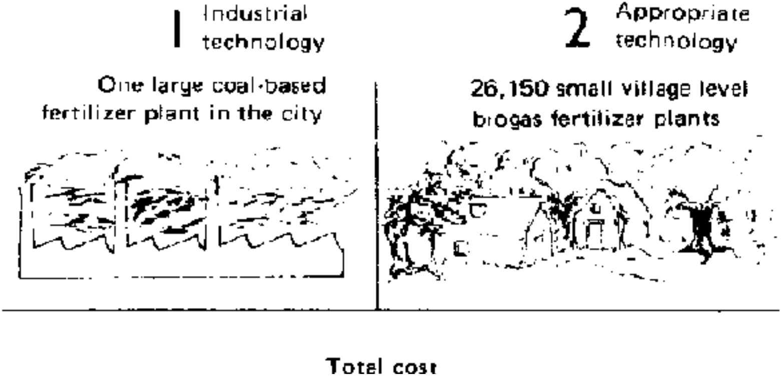
Other factors such as temperature, dilution, loading rate, etc., influence retention time. At high temperature bio-digestion occurs faster, reducing the time requirement. A normal period for the digestion of dung would be two to four weeks.

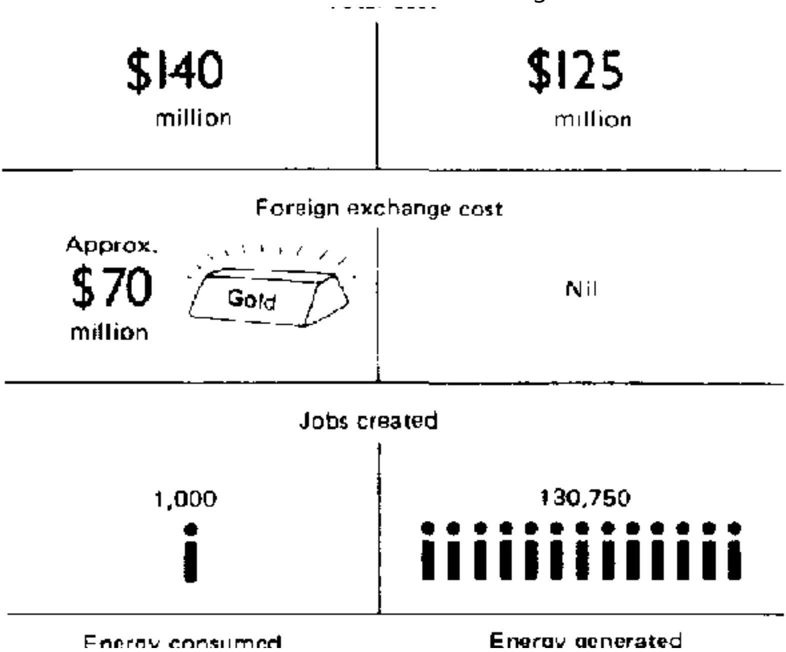
Developments and processes for rural areas

Two years ago, the Economic and Social Council of the United Nations adopted a survey, presented in 1978 to the Committee on Science and Technology for Development, listing the on-going research and development in unconventional sources of energy. From the point of view of the developing countries, it is heartening to note that the "use of farm wastes to produce methane" has also been identified in the United Nations World Plan of Action for the Application of Science and Technology to Development.

The Economic and Social Council for Asia and the Pacific, moreover, adopted the Colombo Declaration at its thirtieth session, which determined that the most urgent priorities for action are in the fields of food, energy, raw materials, and fertilizers, and that these priorities would be best met by the integrated biogas system (IBS).

An integrated system aims at the facile generation of fertilizer and acquisition of energy, production of protein via the growth of algae and fish in oxidation ponds, hygienic disposal of sewage and other refuse, and is a tangible effort to counteract environmental pollution. The heart of the system is the biogas process; it has the potential to "seed" self-reliance in relatively primitive economies (14, 22, 23). Allied benefits include the development of rural industry, the provision of local job opportunities, and the progressive eradication of hunger and poverty (Figures 4 - 7).




$140
million
$125
million
Foreign exchange cost
Approx.
$70
million
Gold
Nil
Jobs created
1,000
130,750
Energy consumed
Energy generated

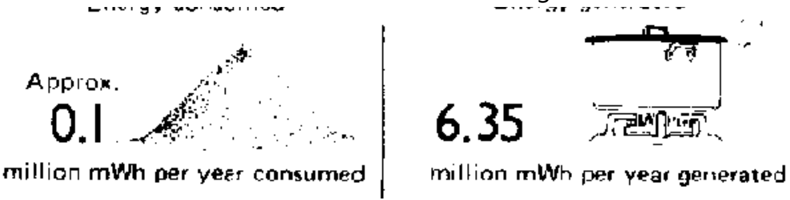
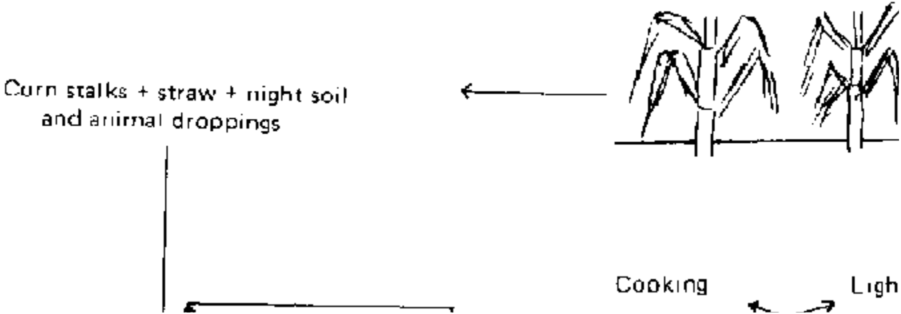
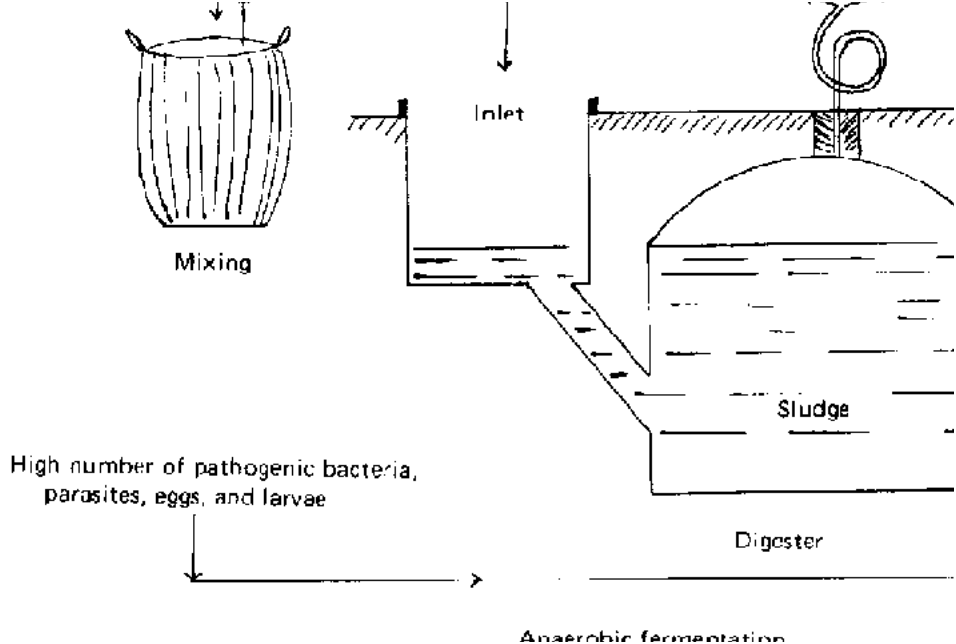


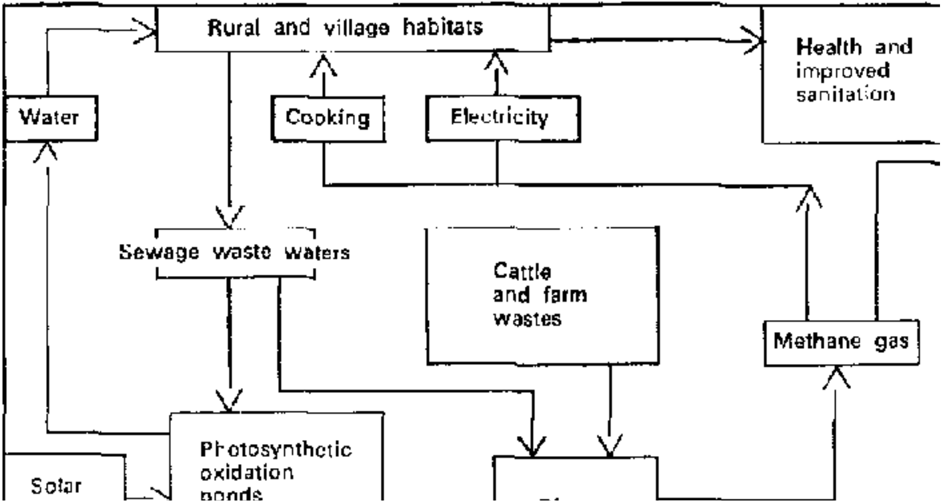
Figure. 4. Two Ways of Increasing Fertilizer Production Target: 230,000 tons of nitrogen fertilizer per year. (Adapted from A.K.N. Reddy, Uniterra, Vol. 1, 1976)




Mixing
Inlet
Sludge
High number of pathogenic bacteria, parasites, eggs, and larvae
Digester
Anaerobic fermentation

$$C_6H_{10}O_5 + 2H_2O \longrightarrow 3CH_4 + 3$$

Figure. 5. Biogas Cycle in China (Source: FAO Soils Bulletin 40, Rome, 1977)



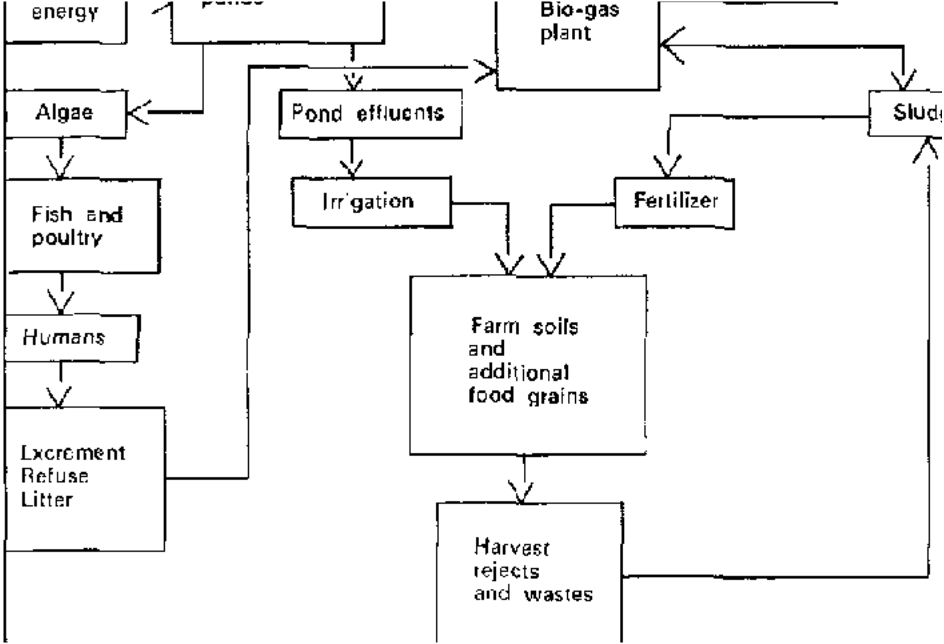
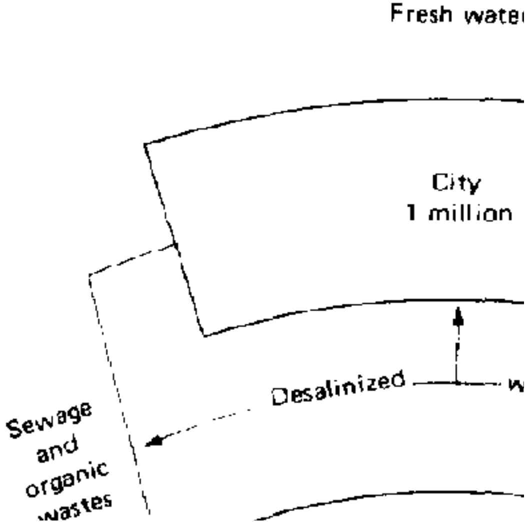
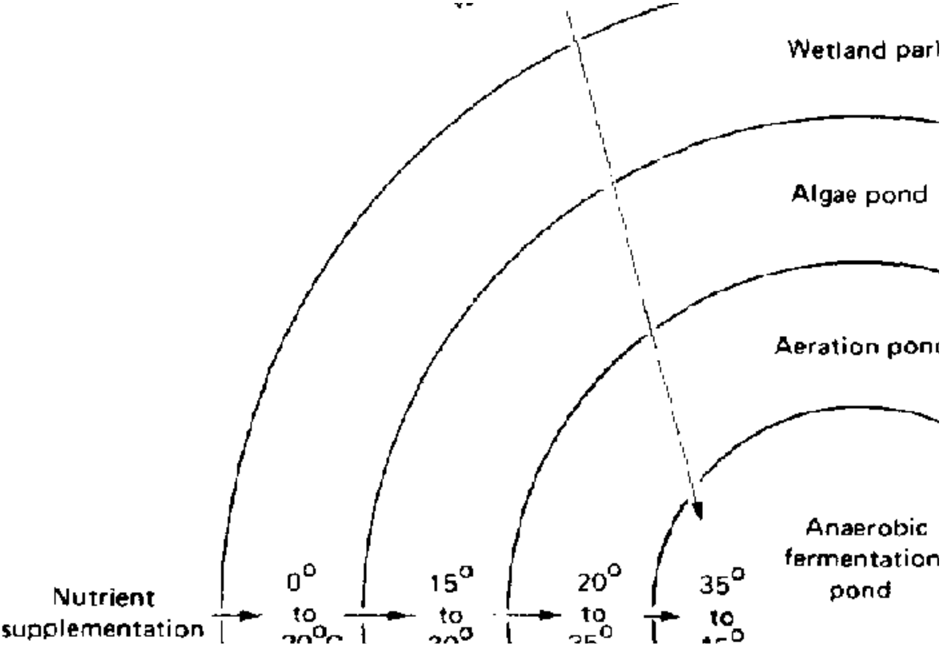
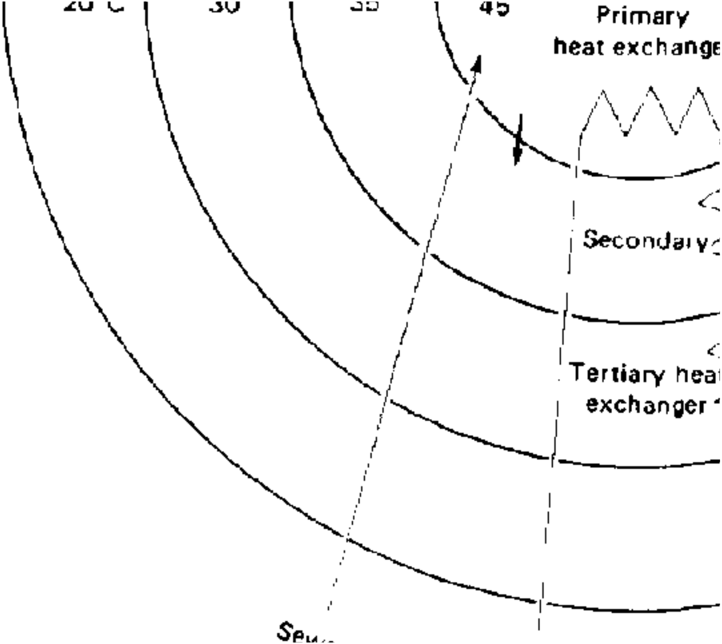

energy
Bio-gas
plant
Algae
Pond effluents
Sludg
Irrigation
Fertilizer
Fish and
poultry
Farm soils
and
additional
food grains
Humans
Excrement
Refuse
Litter
Harvest
rejects
and wastes

Figure. 6. Interactive Loop of Rural or Village Farming System Based on Biogas or Methane Economy




Algae pond
Anaerobic fermentation pond
Nutrient supplementation
0^o to
15^o to
20^o to
35^o to


45
Primary
heat exchange
Secondary
Tertiary heat
exchanger

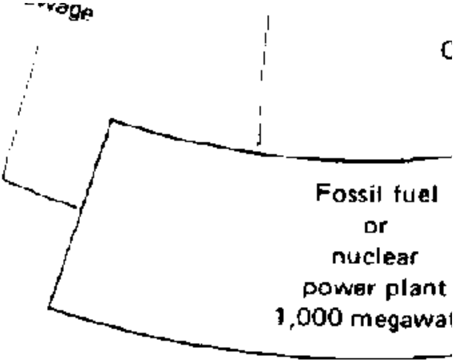


Figure. 7. A Proposed Integrated Nuclear Cooling and Organic Waste Disposal System (After W. Oswald, University of California)

The coupling of a photosynthetic step (24 - 26) with digestion provides for the transformation of the minerals left by digestion directly into algae that can then be used as fodder, as feed for fish, as fertilizer, or for increased energy production by returning them to the digester process (Figure 8).

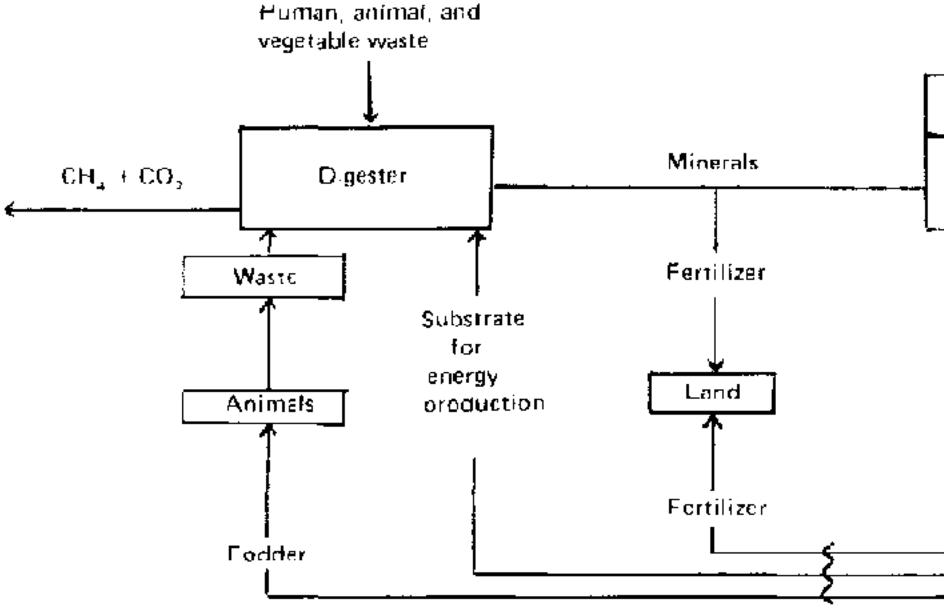
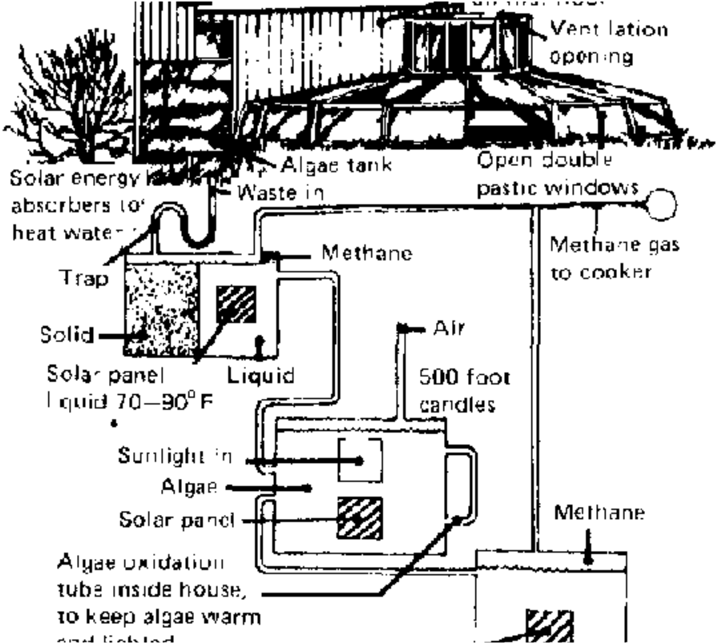
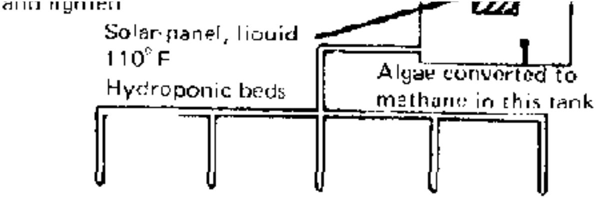

Human, animal, and vegetable waste
Digester
CH_4 + CO_2
Minerals
Waste
Fertilizer
Substrate for energy production
Animals
Land
Fertilizer
Fodder

Figure. 8. Simplified Scheme Indicating Various Combinations of Digestion and Photosynthesis for Fodder, Fertilizer, and Fuel Production (After J.W.M. LaRivire, J. Sci. Soc., Thailand, 1977)

The IBS aims at putting back into soil and water what has been taken from them, and increasing the amounts of nutrients by fixing CO_2 and N_2 from the atmosphere into the soil and water through photosynthesis by algae. Involving low cash investments on a decentralized basis, the implementation of IBS provides employment to the whole work force without disruption of the rural structure. Furthermore, it is an apt example of soft technology that does not pollute or destroy the physical environment. At the College of Agriculture of the University of the Philippines, preliminary work on a small scale has begun. In England, an Eco-house (Figure 9) has been built by Graham Caine on the Thames Polytechnical Playing Fields at Eltham, southeast of London. Results on the project, however, are not yet available.


Vent lation opening
Algae tank
Solar energy
absorbers to
heat water
Waste in
Open double pastic windows
Methane
Trap
Methane gas to cooker
Solid
Air
Solar panel
Liquid 70—90° F
Liquid
500 foot candles
Sunlight in
Algae
Solar panel
Methane
Algae oxidation tube inside house, to keep algae warm


Solar panel, liquid
110° F
Hydroponic beds
Algae converted to
methane in this tank

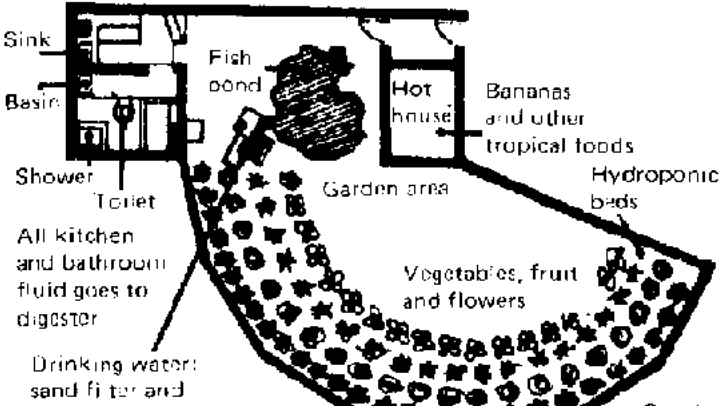

Sink
Basin
Shower
Toilet
All kitchen
and bathroom
fluid goes to
digester
Drinking water:
sand filter and
Fish
pond
Hot
house
Bananas
and other
tropical foods
Hydroponic
beds
Garden area
Vegetables, fruit
and flowers

Figure. 9. Graham Caine Eco-House (Reprinted with permission from Mother Earth News, No. 20 [March 1973], p. 62)

Cost-benefit analyses

There is no general answer to the economic feasibility of biogas production. National economic considerations play an important role. In Korea, wood is in short supply (27) and domestic fuel substitutes like rice and barley straw, and coal and oil could be conserved; wood could be a foreign-exchange earner in the field of handicrafts. In India, transportation costs of coal and oil to the rural areas is high and an extra burden on an already poor farmer.

The consumption of commercial and non-commercial energy for the whole of India, as determined for the period 1960 - 1971 by the Fuel Policy Committee Report, is provided in Table 3.

TABLE 3. Consumption of Commercial and Non-Commercial Energy in India

Year	Coal (Million Tons)	Oil (Million Tons)	Electricity (Billion kwh)	Firewood (Million Tons)	Cow dung (Million Tons)	Vegetable waste (Million Tons
1960 - 61	47.1	6.75	16.9	101.04	55.38	31.08
1965 - 66	64.2	9 94	30.6	111.82	61.28	34.41
1970 - 71	71 1	14 95	48.7	122.75	67.28	37.77

Sources: Report of the Fuel Policy Committee,1974; S.N. Ghosh, Invention Intelligence 12:63 (1977).

The rural share in the energy consumption of electricity and coal is not considerable because, as the Report of the Panel of the National Committee of Science and Technology on Fuel and Power indicates, the large towns and cities with populations of 500,000 and more accommodate only 6 per cent of India's total population but consume about 50 per cent of the total commercial energy produced in the country.

In the villages, however, kerosene is used for lighting, but it is clear that with increasing population, biogas generation seems to offer solutions in the areas of fuel availability, electricity, fertilizer for cash crops, and would provide other socio-economic benefits.

On the other hand, cost-benefit analyses of methane generation vary widely, depending upon the uses and actual benefits of biogas production, public and private costs associated with the development and utilization of methane, and on the technology used to generate methane. Several factors have been listed in the economics of biogas generation (14, 17 - 19, 28). An appropriate example is the fact that a village-model gas plant, which cost Rs 500 some years ago, cost Rs 1,500 in 1974 and Rs 2,000 in 1977. Hence, a significant problem is whether rural people who cannot spend Rs 2,000 can cope with increasing inflationary and digester construction material costs.

The Khadi and Village Industries Commission has helped to tackle the problem through rural community co-operation and a scheme of subsidies and loans to encourage individual families, groups of families, institutions, and communities to construct biogas plants. An analysis of cost and income for a plant producing 3m/day is given in Table 4. The net annual income of approximately US$60 shows that the capital investment of US$340 can be recouped in about six years. There are also incidental advantages of hygienic improvement, the absence of smoke and soot in gas burning, convenience in burning, and the increased richness of manure.

TABLE 4. Cost-Benefit Analysis of Khadi and Village Industries Commission Plant (in US dollars)

a. Capital cost	
Gas holder and frame	$ 93.5
Piping and stove	$ 34 7
Civil engineering construction (tank, inlet and outlet, etc.)	$210.1
Total	$338.3
b. Annual expenditure	
The interest on investment at 9%	$ 30.4
Depreciation on gas holder and frame at 10%	$ 9.3
Depreciation on piping and stove at 5%	$ 2.0
Depreciation on structure at 3%	$ 6.3
Cost of painting, once a Year	$ 6.7
Total	$ 54,7
c. Annual income	

Gas 3m per day at $1.5 per 29m (1,000 cu.ft.)	$ 50.3
Manure (7 tons, composted) with refuse 16 tons at $4 per ton	$ 64.0
Total	$114.3
d. Net annual income (b - c)	$ 59.6

Source: ESCAP Document NR/EGNBD/4, 20 - 26 June 1978

Health hazards

Health hazards are associated with the handling of night soil and with the use of sludge from untreated human excrete as fertilizer.

In general, published data indicate that a digestion time of 14 days at 35 C is effective in killing (99.9 per cent die-off rate) the enteric bacterial pathogens and the enteric group of viruses. However, the die-off rate for roundworm (Ascaris lumbricoides) and hookworm (Ancylostoma) is only 90 per cent, which is still high. In this context, biogas production would provide a public health benefit beyond that of any other treatment in managing the rural health environment of developing countries.

Bottlenecks, considerations, and research and development

Bioconversion of organic domestic and farm residues has become attractive as its technology has been successfully tested through experience on both small- and large-scale projects. Feeding upon renewable resources and non-polluting in process technology, biogas generation serves a triple function: waste removal, management of the environment, and energy production. Nevertheless, there are still several problems (14, 19, 20) that impede the efficient working of biogas generating systems (Table 5).

TABLE 5. Considerations Relating to Bottlenecks in Biogas Generation

Aspect	Bottlenecks	Remarks
Planning	Availability and ease of transportation of raw materials and processed residual products	Use of algae and hydroponic plants offsets high transportation costs of materia not readily at hand. Easily dried residual products facilitate transportation.
	Site selection	Nature of subsoil, water table, and availability of solar radiation, prevailing climatic conditions, and strength of village population need to be

		considered.
	Financial contraints: Digester design; high Transportation costs of digester materials; installation and maintenance costs; increasing labour costs in distribution of biogas products for domestic purposes	Use of cheap construction materials, emphasizing low capital and maintenance costs and simplicity of operation; provision of subsidi and loans that are not burdensome.
	Necessity to own or have access to relatively large number of cattle	Well-planned rural community development, ownership and biogas distribution schemes

		necessary.
	Social contraints and psychological prejudice against the use of raw materials	Development of publicity programmes to counteract contraints compounded by illiteracy; provision of incentives for development of small- scale integrated biogas system
Technical	Improper preparation of influent solids leading to blockage and scum formation	Proper milling and other treatment measures (pre- soaking, adjustment of C/N ratio); removal of inert particles: sand and rocks.
	Temperature	Careful regulation of

	fluctuations	temperature through use of low-cost insulating materials (sawdust, bagasse, grass, cotton waste, wheat straw); incorporation of auxiliary solar heating system.
	Maintenance of pH for optimal growth of Methanogenic bacteria C/N ratio	Appropriate choice of raw material, regulation of C/N ratio and dilution rate. Appropriate mixing of N-rich and N-poor substrates with cellulosic substrates.
	Dilution ratio of influent solids content	Appropriate treatment of raw materials to avoid

		stratification and scum formation.
	Retention time of slurry	Dependent upon dilution ratio, loading rate, digestion temperature.
	Loading rate	Dependent upon digester size, dilution ratio, digestion temperature.
	Seeding of an appropriate bacterial Population for biogas generation	Development of specific and potent cultures.
	Corrosion of gas holder	Construction from cheap materials (glass fibre,

		clay, jute-fibre reinforced plastic) and/or regular cleaning and layering with protective materials (e.g., lubricating oil).
	Pin-hole leakages (digester tank, holder, inlet, outlet)	Establishment of "no leak" conditions, use of external protective coating materials (PVC, creosotes
	Occurrence of CO_2 reducing calorific value of biogas	Reduction in CO_2 content through passage in lime-water

	Occurrence of water condensate in gas supply system (blockage, rusting)	Appropriate drainage system using condensate traps
	Occurrence of H2S leading to corrosion	On a village scale, H2S remove by passing over ferric oxide or iron filings
	Improper combustion	Designing of air-gas mixing appliances necessary
	Maintenance of gas supply at constant pressure	Regulation of uniform distribution and use of gas; removal of water condensate from piping systems; appropriate choice of gas holde in terms of weight

		and capacity
Residue utilization	Risks to health and plant crops resulting from residual accumulation of toxic materials and encysted pathogens	Avoid use of chemical industry effluents; more research on type, nature, and die-off rates of persisting organisms; minimize long transportation period of un-dried effluent
Health	Hazards to human health in transporting night soil and other wastes (gray-water)	Linkage of latrine run-offs into biogas reactors promotes non-manual operations and general aesthetics
Safety	Improper handling and	Appropriate measures necessa

	storage of methane	for plant operation, handling, and storag of biogas through provision of extension and servicing facilities

Rural communities using the integrated system are appropriate examples of recycled societies that benefit from low-capital investments on a decentralized basis and such communities are attuned to the environment. The technology thus seeded and spawned is, in essence, a populist technology based on "Nature's income and not on Nature's capital."

Biogas generated from locally available waste material seems to be one of the answers to the energy problem in most rural areas of developing countries. Gas generation consumes about one-fourth of the dung, but the available heat of the gas is about 20 per cent more than that obtained by burning the entire amount of dung directly. This is mainly due to the very high efficiency (60 per cent) of utilization compared to the poor efficiency (11 per cent) of burning dung cakes directly.

Several thousand biogas plants have been constructed in developing countries. A screening of the literature indicates that the experience of pioneering individuals and organizations has been the guiding principle rather than a defined scientific approach. Several basic chemical, microbiological, engineering, and social problems have to be tackled to ensure the large-scale adoption of biogas plants, with the concomitant assurances of economic success and cultural acceptance. Various experiences suggest that efficiency in operation needs to be developed, and some important factors are: reduction in the use of steel in current gas plant designs; optimum design of plants, efficient burners, heating of digesters with solar radiation, coupling of biogas systems with other non-conventional energy sources, design of large-scale community plants, optimum utilization of digested slurry, microbiological conversion of CO2 to CH4, improvement of the efficiency of digestion of dung and other cellulosic material through enzyme action and other pre-digestion methods, and anaerobic di gestion of urban wastes

We may summarize some of the research and development tasks that need to be undertaken as follows.

In basic research:

a. Studies on the choice, culture, and management of the micro-organisms involved in the generation of methane.

b. Studies on bacterial behaviour and growth in the simulated environment of a digester (fermentation components: rate, yield of gas, composition of gas as a function of variables - pH, temperature, agitation - with relation to substrates - manure, algae, water hyacinths).

In applied research:

a. Studies on improving biogas reactor design and economics focusing on: alternative construction materials in stead of steel and cement; seeding devices; gas purification methods; auxiliary heating systems; insulator materials; development of appropriate appliances for efficient biogas utilization (e.g. burners, lamps, mini tractors, etc.).

b. Studies for determining and increasing the traditionally acknowledged fertilizer value of sludge.

c. Studies on quicker de-watering of sludge.

d. Studies on deployment of methane to strengthening small-scale industries, e.g., brick-making, welding, etc.

In social research:

a. Effective deployment of the written, spoken, and printed word in overcoming the social constraints to the use of biogas by rural populations.

b. Programmes designed to illustrate the benefits accruing to rural household and community hygiene and health.

c. Programmes designed to illustrate the need for proper management of rural natural resources and for boosting rural crop yields in counteracting food and feed unavailability and insufficiency.

d. On-site training of extension and technical personnel for field-work geared to the construction, operation, maintenance, and servicing of biogas generating systems.

e. Involvement and training of rural administrative and technical personnel in regional, national, and international activities focusing on the potentials and benefits of integrated biogas systems.

Table 6 shows a number of the benefits of biogas utilization, set against the related drawbacks of presently used alternatives.

Present problems	Benefits of Biogas
Depletion of forests for firewood and causation of ecological imbalance and climatic changes	Positive impact on deforestation; relieves a portion of the labour force from having to collect wood and transport coal; helps conserve local energy resources
Burning of dung cakes: source of environmental pollution; decreases inorganic nutrients; night soil transportation a hazard to health	Inexpensive solution to problem of rural fuel shortage; improvements in the living and health standards of rural and village communities; provides employment opportunities in spin-off small-scale

	industries
Untreated manure, organic wastes, and residues lost as valuable fertilizer	Residual sludge is applied as top-dressing; good soil conditioner; inorganic residue usef for land reclamation
Untreated refuse and organic wastes a direct threat to health	Effective destruction of intestinal pathogens and parasites; end-products non-polluting, cheap; odours non-offensive
Initial high cost resulting from installation, maintenance, storage, and distribution costs of end-products	System pays for itself
Social constraints and psychological prejudice to use	Income-generator and apt example of self-reliance and self-

of human waste materials	sufficiency

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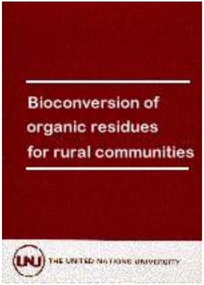
Discussion summary

The question arose as to whether retention time in the biogas fermentation could be reduced by mixing. There seems to be very little in the literature on the subject, and, although information is now becoming available from the United States National Academy of Sciences and the Economic and Social Commission for Asia and the Pacific (ESCAPI, much more is needed. There is a great deal of information on domestic sludge, and it is now possible to treat dissolved residues, e.g., potato, in continuous anaerobic processes.


Bioconversion of
organic residues
for rural communities

Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Mushroom production technology for rural development

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One of the low-cost, appropriate technologies being offered by the National Institute of Science and Technology, National Science Development Board (NIST-NSDB) for rural development is the production of the tropical mushroom Volvariella volvacea (Bull ex Fr.) Singer. This variety of mushroom usually grows on piles of decaying rice straw, sawdust, coffee pulp, sugar-cane bagasse, oil palm extraction wastes, etc. The mycelium grows outward towards the sunlight, which stimulates the growth of small nodules called pin-heads. These small white bodies are approximately the size of the pins Filipino women wear in their hair, hence the name. Great numbers of them develop almost simultaneously all along the sides of the growth substrate. Within two to three days the clour changes from white to black, then to brown, and gradually fades as the mushrooms grow larger. There are, however, some strains that are dark brown or black. They may be chestnut- or egg-shaped.

The young mushroom is covered initially with a thin membrane called the volva As the mushroom develops, the stem or stipe elongates, gradually pushing the cap upwards, which causes the volva to rupture and remain at the base of the stem. The still unopened mushroom cap is further pushed up to a height of about 6 to 10 cm. Once the stem reaches its maximum height, the cap starts to expand. Initially, the gills are white, but they turn brown once mature basidiospores are produced in the gills. The opened mushroom has a stronger odour and taste attributable to the mature basidiospores.

Figure 1 illustrates the stages of growth of this variety of mushroom. Growth to maturity usually takes five to seven days, depending on the prevailing environmental conditions. Low temperatures (25 - 27C) slow down development and high temperatures (28 - 35 C) hasten the rate of growth.

The recent expansion of the commercial production of this tropical mushroom in the Philippines is the result of several complementary factors: (1) there is technology available and the climate is favourable to good mushroom production throughout the year; (2) there is plenty of manpower available, ample space, and abundant bedding material; (3) there is high demand for the product both locally and abroad; and (4) financial assistance can be extended by government and private lending institutions.

Given these available resources, field demonstrations were conducted to show farmers simple methods of mushroom culture in different regions of the country. This was done through the 17 regional offices of the NSDB. To hasten the dissemination of the technology, all the Science Field Officers of NSDB were given one month of intensive training in mushroom production. Each regional office was provided with facilities for making mushroom spawn as well as space for mushroom demonstrations, including the construction of a single unit mushroom house.

Seminars were conducted in different barrios to make the people aware of available technology for home mushroom production. There are also technicians in the Tropical Mushroom Research Laboratory at NIST who can extend technical assistance in spawn and mushroom production in different regions.

Materials and methods for growing mushrooms under natural or field conditions

The Mushroom Bed Foundation The foundation for bedding material can be soil, concrete, or a wooden bench. A soil foundation is made by raising the soil in the same manner used to build a garden plot to a height of about 12 cm above ground level. It is surrounded by a canal 30 cm wide and 15 cm deep. The earth excavated from the canal is used to elevate the foundation The width of the foundation should be 45 cm, and the length 1 m or more. Sandy soil will not make a strong enough foundation, but this can be remedied by cementing the sides or by constructing a wooden bench 30 cm high with the rest of the dimensions the same.

Rice Straw as Bedding Material

Thoroughly dried, long rice straw is preferable. Properly prepared straw produces a better yield of mushrooms compared to the yield when care is not taken to provide a strong base.

The straws are bundled to a size of about 8 cm in diameter, tied at the middle with abaca twine or any good substitute, cut to a uniform length of 45 cm and soaked in water for three hours. The soaked straw bundles are laid crosswise side by side on top of the bed foundation until the whole length of it is covered. All the butt ends are placed on one side in a layer, alternating between layers. If the butt ends of the first layer are on the left side, the butt ends of the second layer must be on the right side. This manner of arrangement is continued until four to six layers are made. About 240 bundles are needed for a six-layer, 4-metre-long bed. Each layer must be pressed firmly to make the surface level, and should be watered.

Simultaneously with the bed preparation, several crumpled newspapers are soaked in a container with 3 9 of urea per gallon of water. This "fertilized" paper is planted along with the mushroom spawn or seed. The mushroom spawn and soaked paper are first distributed on top of the layer in thumb-sized pieces. The plantings are 5 - 8 cm from the edge of the straw and 5 cm apart. For every six-layer bed 4 m long, three bottles (16 fl. oz.) of spawn are used. One-half bottle of spawn is apportioned to plant one layer. The spawn is buried with the paper 4 cm deep in the layer. The same procedure is repeated on the remaining layers. Any left-over straw is mounded on top to a thickness of about 10 cm at the centre.

The straw bed is protected by an elevated, transparent plastic sheet immediately after the planting. The cover is attached to a bamboo frame to prevent the moisture that accumulates on the plastic from spilling onto the straw.

During the dry season, a four-layer bed is recommended because of lower relatively humidity. Beds of six or more layers are possible in the wet season.

Banana Leaves as Bedding Material

Dried banana leaves, still hanging on the plant, are gathered and cut to a uniform length of 45 cm, bundled to a diameter of 8 cm, and soaked in water for three or four hours

The leaf bed is made in a manner much the same as that used for straw; i.e., the bundles are laid side by side crosswise on the bed foundation, watered, pressed, and planted. Four or sixlayer beds are constructed, depending on the season. The leaf bed also requires the elevated plastic sheet on a bamboo frame immediately after planting.

Care of the Bed

For both rice-straw and banana-leaf beds, no water should be given for the first five days after the bed preparation. During the dry season, the bed may be watered gently but generously on the sixth or seventh day after planting, and this should be repeated once a day until the mushroom pin-heads have developed. During the rainy season, the bed may not need further watering, or at least not as much as during the dry months. Water is applied more along the sides of the bed in the rainy season.

When the mushrooms are at the pin-head stage, the bed should not be watered. Water should be applied only when the mushrooms reach the size of corn seeds and the bed has become somewhat dry.

Harvesting

Under normal conditions, the first harvest of mushrooms is taken 10 to 14 days after planting. The harvest usually lasts for three consecutive days. This is the so-called first flush. The average daily production is 1.2 kg. The bed rests for five to seven days, and another crop is harvested over another two- to three-day period. The average production for the second harvest is 0.42 kg. This manner of production may continue for a month or even longer.

During harvest, the mushrooms must be carefully pulled out whole from the bed. Any portion left behind will decay and permit bacterial soft-rot to spread in the succeeding crops, causing a drastic reduction in yield.

Yield

For a standard 4-metre, six-layer bed, a harvest of 7 kg of buttons or 12.6 kg of fully mature mushrooms can be obtained. This quantity represents the total from the entire productive life of the bed.

Advantages and Disadvantages of These Methods

Both rice-straw and banana-leaf beds are highly adaptable and inexpensive for growing mushrooms as a family project in the rural areas, where labour and materials can be obtained free. Sudden changes in weather conditions do not materially affect production.

Both types of bed require a large quantity of bedding material Yields depend on the volume of bedding material used. Either kind of bed may be hard to manage. Because of side exposure, they easily become infested with pests and diseases.

Growing mushrooms under semicontrolled conditions

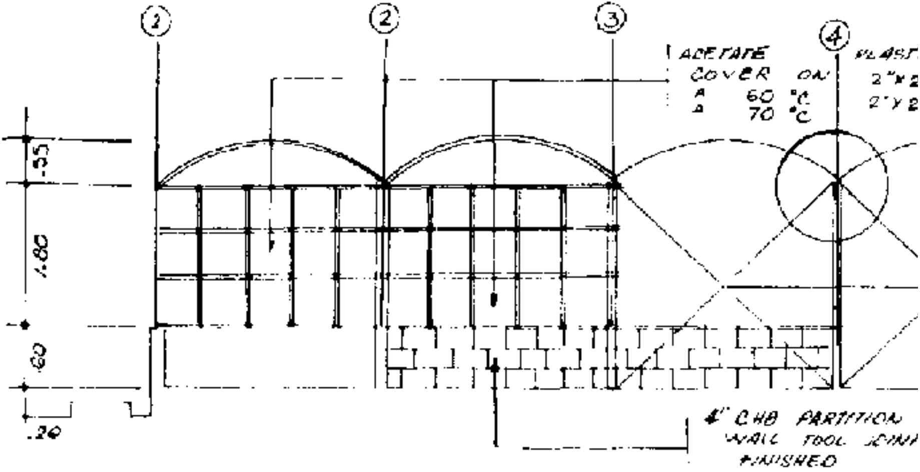
One possible approach towards establishing a mushroom industry in the countryside is the so-called community level scheme of production. This involves most of the people from all strata in the rural areas, thereby providing an additional source of income to a greater number of persons.

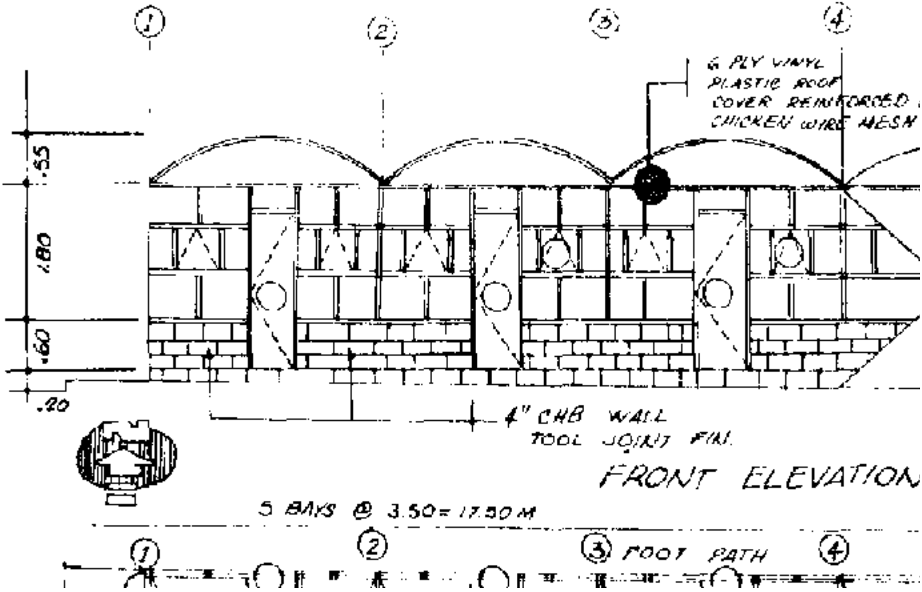
Recently, it has been shown that it is feasible in the Philippines to grow Volvariella mushrooms on a commercial scale in boxes placed in special growing houses. Compared with the ordinary open-bed method, the percentage of yield conversion of box-grown mushrooms was improved from 10.5 to 25 per cent based on the weight of dry straw. There is greater assurance of consistent production because pests and diseases are more easily controlled under these more protected growing conditions. The only possible drawback is the higher initial cost of constructing the growing houses and boxes.

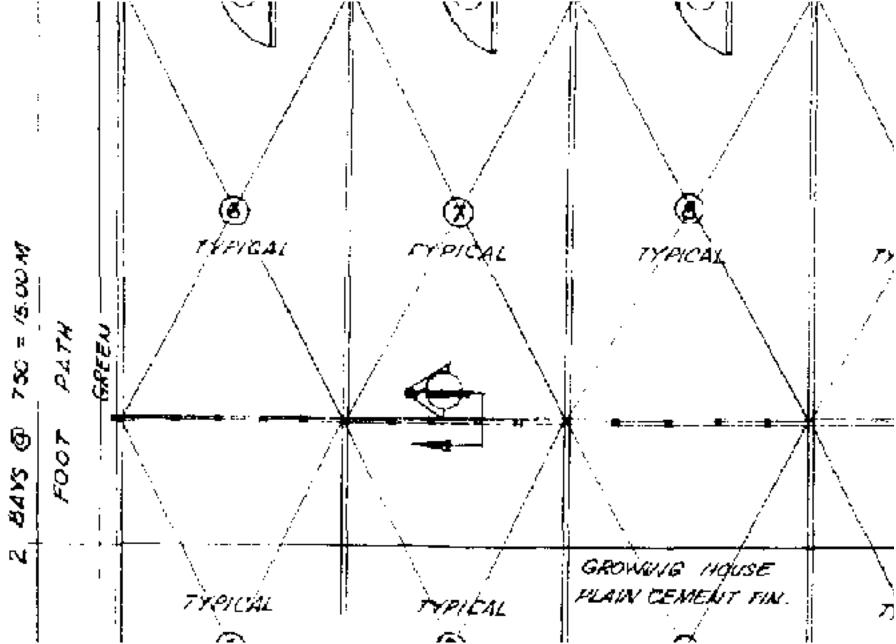
Materials and Methods

Growing houses

The growing houses consist of a concrete floor set on a gravel base, four layers of hollow blocks set on the floor, wooden frames, plastic walls (gauge 6), plain galvanized sheets for roofing, and a plastic screen for ventilators (Figure 2).




1
2
3
4
6 PLY VINYL PLASTIC ROOF COVER REINFORCED CHICKEN WIRE MESH
.55
1.80
.60
.20
4" CHB WALL TOOL JOINT FIN.
FRONT ELEVATION
5 BAYS @ 3.50 = 17.50 M
FOOT PATH



TYPICAL
TYPICAL
TYPICAL
2 BAYS @ 750 = 15.00 M
FOOT PATH
GREEN
GROWING HOUSE
PLAIN CEMENT FIN.
TYPICAL
TYPICAL

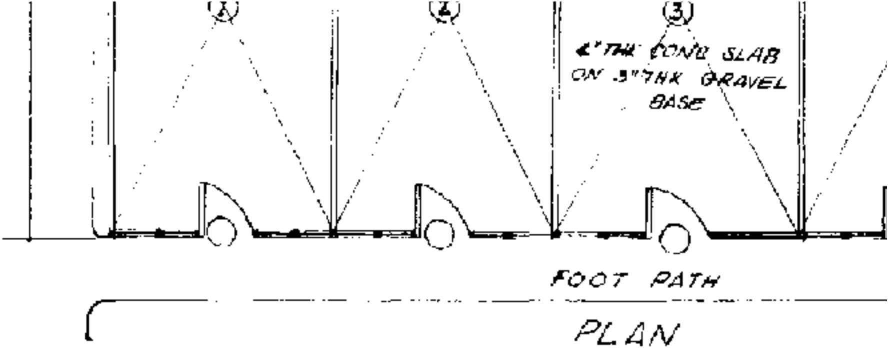
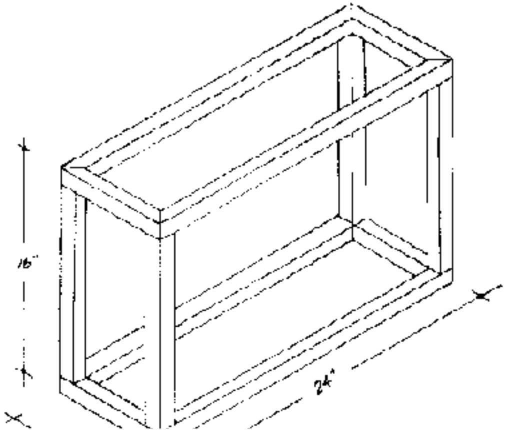


Figure. 2 Mushroom-Growing House Plan in Series

The roof is convex for better air circulation - about 2.4 m high from the floor to the rafter. There are two ventilators with hinged covers, properly screened to keep out insects. The length of the house is 7.5 m and it is 4.5 m wide. There are five rows of one-foot high cement blocks spaced 60 cm apart where 150 mushroom boxes can be accommodated. This type of growing house can be constructed singly or in a series of five or more units.

Making and filling the box

The box is made of 2.5 cm x 5 cm wood, The wooden frame is 60 cm long, 45 cm wide, and 20 cm thick (Figure 3).



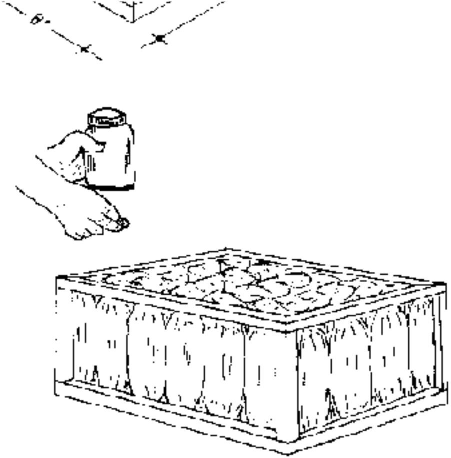


Figure. 3. Mushroom Box, and Planting of Tropical Mushrooms

The bedding materials (rice straw or dried banana leaves) are cut to a uniform length of 20 cm. The box is tightly filled to the brim in anticipation of loosening when the pack is soaked in water, Any protruding or dangling bedding materials are trimmed to avoid obstruction during watering. The bedding materials in the boxes are soaked for at least three hours in water, or until the straw becomes dark-brown or the banana leaves exhibit a certain degree of transparency. The boxes are then removed from the soaking tank and drained of excess water immediately prior to planting of the spawn.

Planting the spawn

Young (10-14-day-old) spawn are used Thumb-sized pieces are removed from the bottle and distributed on the surface of the bedding material. Starting on one side of the box, four pieces are equally distributed along the width, and five pieces are placed along the length at a distance of 5 cm from the side of the box. The spawn are then buried 5 cm deep in the bedding material, after which the surface is massaged to close the open spaces resulting from spawn insertion. The same procedure is carried out on the other side of the box.

Incubation of the boxes

The boxes are placed in a specially built incubation room (similar to the growing house, only smaller and without ventilation), where the temperature is maintained at 35 - 38 C, with high relative humidity (85 C +). In lieu of an incubation room, the boxes can be covered with plastic sheets. The boxes are removed from the incubation room after three days, or once a good spawn run has been obtained. When the box is merely covered with plastic, it takes five days to attain good mycelial growth.

Care of the boxes

Incubated boxes should be exposed to conditions not too different from those in the growing house to minimize serious stress on mushroom mycelial growth. Twenty-four hours after removing the boxes from the incubation room, the temperature should be lowered gradually by opening the ventilator(s) or by allowing fresh air to circulate in the growing room The temperature should be maintained at 26 - 28 C with a relative humidity of 75 85 per cent.

Aerial spraying with superfine mist will maintain the desired relative humidity, and the proper temperature can be assured by manipulating the ambient air through aeration or closing the ventilators, whichever is called for. The bedding material must be watered with fine mist to avoid destroying the delicate mycelial threads of growing mushroom molds.

Results and discussion

Harvesting of Mushrooms

The first crop of mushrooms can usually be harvested ten days after planting. This first growth normally supplies enough of a crop to require three successive days of harvesting, and 65 - 75 per cent of the expected yield is obtained. During the ensuing rest period of three to five days watering of boxes may be resumed; proper conditions in the growing room must be carefully maintained.

The second crop also takes two to three days to harvest, but the yield will be much less, supplying 25 to 35 per cent balance of the total 1 kg per box produced over a period of 18 to 22 days.

It should be noted that box-cultivated mushrooms are less likely to grow in clusters than are spawn planted in beds.

Because of the semi-controlled conditions in the growing houses, pests and diseases are more easily controlled. Boxes showing contamination can be removed right after the incubation period to prevent spreading of contamination in the growing house

A target production of 1 kg per box per growing cycle can be attained with a high degree of certainty through better management of the mushroom farm. Some boxes have produced only about 350 9 per cycle, but a production of more than 2,000 9 through the end of the second-stage harvest is possible under optimum conditions.

The Nutritional Value of Volvariella Mushrooms

Fresh local mushrooms, according to The Food and Nutrition Research Centre, are good sources of phosphorus, and when dried to a moisture content of 15 per cent, the percentage content of this nutrient is doubled. There are only trace amounts of iron and calcium in the fresh mushroom, and the low levels of thiamine and vitamin C contained in the fresh form are lost when the mushrooms are dried. Dried tropical mushrooms are an excellent source of riboflavin and niacin. The protein content of 100 9 of dried mushrooms (16 to 25 per cent of the dry matter) is comparable to that in some protein-rich legumes (Table 1).

TABLE 1. Composition of Tropical Mushrooms

Nutrient per 100 g Edible Portion	Fresh	Dried*
Moisture (%)	87.7	14,9
Food energy (calories)	39.0	274.0

Protein (g)	3.8	16.0
Fat (g)	0.6	0.9
Total carbohydrate (g)	6.9	64.6
Fibre (g)	1.2	4.0
Ash (g)	1.0	3.6
Calcium (mg)	3.0	51.0
Phosphorus (mg)	94.0	223.0
Iron (mg)	1.7	6.7
Thiamine (mg)	0.11	0.09
Riboflavin (mg)	0.17	1.06
Niacin (mg)	8.3	19.7
Ascorbic acid (mg)	5.0	-

Source: "Food Composition Table Recommended for Use in the Philippines," FNRC Handbook 1, 3rd rev. (1964), Item Nos. 148 and 149, p. 18.

* Analyses of dried mushrooms were done on different samples.

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Discussion summary

Regarding mushroom production, what impact does it have on use of village residues, and what happens to the spent straw? One community exhausted its straw supply in three months. The spent straw was decomposed to the extent of about 40 per cent, and it was recommended that it be composed. Its possible use for biogas production is now being studied.

Spent straw has not been used as feed for ruminants, but residual mycelium can be extracted with coconut water and used as a food. In India, preliminary results on using spent straw as a ruminant feed are promising

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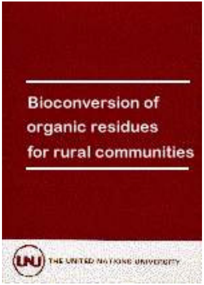

Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

The combination of algal and anaerobic waste treatment in a bioregenerative farm system

Discussion summary

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Introduction

The concept of the bioregenerative farm has been introduced to describe a model farm in developing countries (that can easily be applied in developed countries as well) where domestic and farm wastes are recycled and recovered to a maximum level through a chain of biological processes and farming practices, thus reducing input of cash-intensive items such as proteinaceous animal feed, irrigation water, fertilizers, and fuel, while increasing cash-intensive outputs such as animal products, fish, and cash crops (1). Enhancing sanitary and health conditions by proper waste management is an important fringe benefit of the bioregenerative farm concept, though not always fully appreciated. Once the concept of self-reliance in the farming community has been accepted, other non-biological resource recovery techniques, such as utilization of solar and wind energy, can be introduced as well.

The principal bioregenerative process discussed in this paper involves the intensive growth of algae on wastes, with an emphasis on its combination with anaerobic bacterial processes. Pond fish production can be tied to the bioregenerative scheme, as can other, though less well established, biological systems, such as nitrogen fixation by the blue-green alga Anabaena azolla, which is symbiotically associated with the Azolla fern in rice paddies, replacing commercial nitrogenous fertilizers (2).

All biological processes involved in the bioregenerative concept are well established in nature's cycles of organic matter degradation and primary productivity, and in the food chain. Within the bioregenerative farm they are, however, intensified many-fold and are designed to increase their biomass growth rate, and hence their activity, by optimizing the physical conditions and the growth-limiting factors such as substrate and nutrient concentrations, light intensities (in the case of algae), retention time, etc.

Some of the components of the bioregenerative farm considered for application in rural regions of developing countries stem from results and experiences accomplished by using sophisticated techniques, such as algal systems for life-support space applications (3), for food production (4), for treatment of municipal wastes (5), etc. The development of the Gobar anaerobic fermenter for rural areas in India benefited from decades of development of heated, mechanically mixed, continuous anaerobic digesters of municipal waste-waterborne sludges

Some famous racing-car manufacturers who later turned to the production of less complex, popular, inexpensive cars have learned that simple technologies can benefit greatly from experience with complicated ones. Or, as illustrated by an advertising slogan of a large US corporation that was involved in the space programme, but has now turned to manufacturing consumer products as well:

"... it took putting a man on the moon to produce a reliable coffee-maker ...."

Indeed, a significant part of the information that is being used now to develop the bioregenerative farm concept comes from two major comprehensive projects carried out at the Technion Environmental Engineering Laboratories in Haifa, planned for communities in industrialized countries using more sophisticated techniques and methodology The first is the joint Israeli-German project on Combined Algal Municipal Waste Water Treatment, Water Reclamation, and Animal Protein Production (6), and the second is the project on Utilization of Agricultural Wastes for the Anaerobic Production of Biogas, which has been sponsored by the Kibbutz Industry Association of Israel since 1975, and whose goal is to accomplish a maximum degree of self-reliance in energy through biogas production and utilization in the kibbutz-type communal, highly modernized farming system (7, 8). The relevant information from both projects, together with results of experiments directly related to the bioregenerative farm in developing countries, are discussed in this paper.

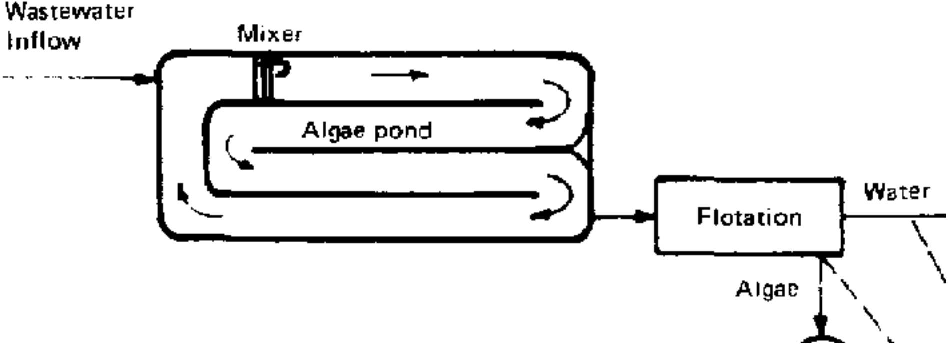
Algae production on organic wastes

High-Rate Algal Systems for Municipal Waste-Water Treatment

The treatment of municipal waste water in shallow (less than 50 cm deep), mechanically mixed, meandering (folded) channels was first proposed and demonstrated by Oswald and Golueke (9) in California. It was later studied by McGarry et al. (10) in Thailand, by Goldman and Ryther (11) in Woods Hole, Massachusetts, and by Benemann et al. (12) in California, and has been further developed by Shelef et al. (13, 14) in Israel.

Experiments at the Technion Environmental Engineering Research Center ranged from laboratory and pilot plant studies to field-scale studies in ponds of 1,000 m each, one of which at Haifa Bay is illustrated in Figure 1.

The flow scheme of this system is shown in Figure 2, where raw municipal sewage is continuously introduced to the photosynthetic pond with an average retention time of three days, depending on climatic conditions. The effluent of this pond, which contains between 300 to 500 mg/l suspended matter, mostly algal biomass (approximately 60 per cent) and bacterial biomass (approximately 35 per cent), is treated physico-chemically, using aluminum sulphate (alum) flocculation and dissolved air flotation.



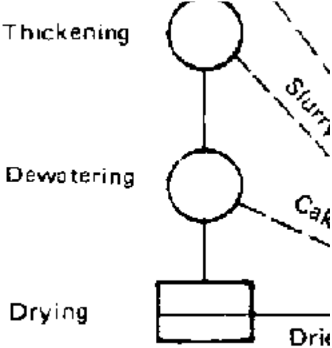
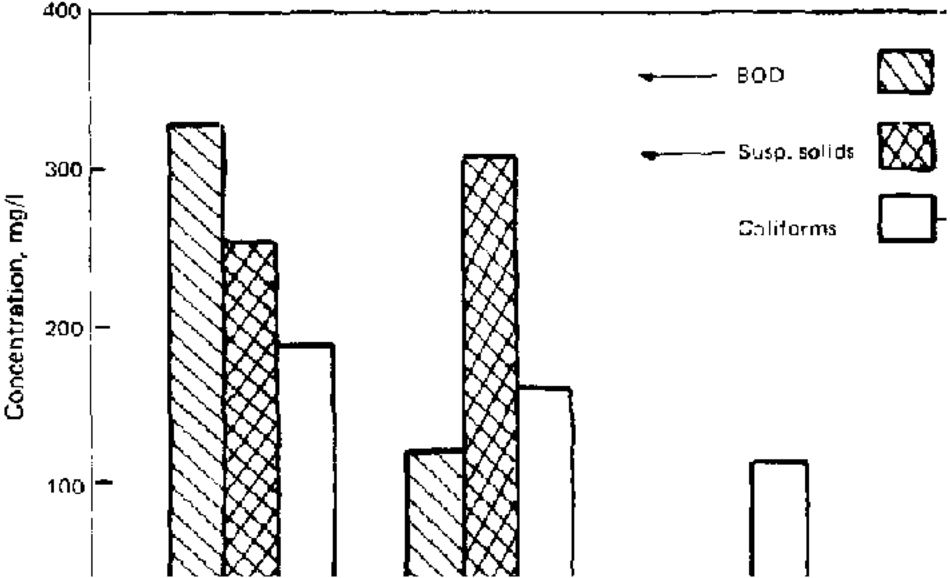


Figure. 2. Flow Scheme of the Accelerated Photosynthetic Process for Waste-Water Treatment and Algal Protein Production

The flotation unit, with a surface flow-through rate of between 4 and 6 m hr(-1), separates the algal bacterial biomass, yielding a treated effluent with average quality characteristics summarized in Table 1 and illustrated in Figure 3. This effluent has a quality adequate for use as irrigation water for most agricultural crops, or for discharge into most receiving bodies of water.



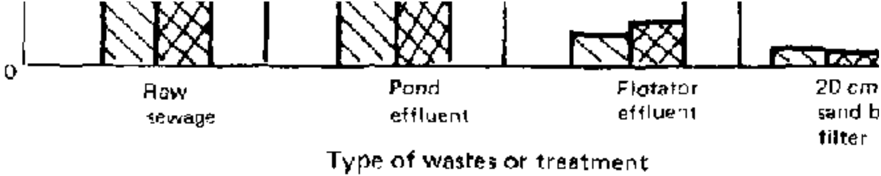


Figure. 3. Enhancement of Effluent Quality in Various Treatment Steps of the Accelerated (High Rate) Algal Process

TABLE 1. Effluent Quality from Various Stages of the Accelerated Photosynthetic WasteWater Treatment Process (under Favourable Operational Conditions)

Effluent characteristic	Raw sewage	Pond effluent	Flotator clarified effluent	30 cm sand filtrate
BOD total, mg/l	330	120	<25	<10

BOD dissolved, mg/l	-	-	<10	<10
COD total, mg/l	750	450	140	110
COD dissolved, mg/l	-	120	90	85
Suspended solids, mg/l	260	300	<25	<10
Ntotal, mg/l	80	45	25	20
Ndissolved (NH3) mg/l	-	20	18	18
Ptotal, mg/l	15	12	<2	<1
Coliforms/100 ml	108	106	104	<10

By additional slow sand filtration through a 30 cm-deep sand bed, followed by disinfection by chlorination, the effluent is adequate for irrigation of all agricultural crops, including/hose edible in raw form, for discharge into virtually all surface receiving bodies of water, and for ground-water recharge.

The separated algal-bacterial biomass, in the form of "froth" containing between 4 and 5.5 per cent solids, is skimmed off, thickened by inverted decantation to a slurry of between 7 and 9 per cent solids, further dewatered to a light cake of between 14 and 18 per cent solids, and then steam drum-dried to form dry flakes or powder that can be pelletized with other feed ingredients.

The biomass production, as well as other characteristics of the system, serving, for example, a city of 100,000 inhabitants living in climatic conditions simian to those near Haifa Bay, are given in Table 2.

TABLE 2. Summary of Algae Production Data Based on Technion Pilot Plant and Field-Scale Pond Operation

Total net biomass yield (dry)	155 tons/ha-year
Average daily total biomass production (dry)	42.59/m-day
Per cent algae in biomass	57

Algal biomass yield (dry)	88 tons/ha-year
Average daily algal biomass production (dry)	24.29/m day
Pond area requirement for city of 100,000 inhabitants under Eastern Mediterranean climatic conditions (assuming waste- water flow of 200 litres per capita per day)	13.3 ha
Total yield (dry) per city	2,060 tons/year
Total protein yield (43% dry matter)	886 tons/year
Average daily incident irradiance (total)	450 cal/cm-day
Average daily incident photosynthetically	202 cal/cm

available irradiance	day
Photosynthetic light conversion efficiency (based on total irradiance)	2.96%
Photosynthetic light conversion efficiency (based on photo- synthetically available irradiance)	6.59%
Maximum possible light conversion efficiency (based on photosynthetic available irradiance)	- 12%
Percentage of light conversion attained vs. potential	55%

The effluent, containing algal-bacterial biomass suspension, can be used directly to feed fish ponds, and yields of Tilapia galilea (St.

Peter's fish) of over 7 tons per hectare were achieved in field experiments by Hepher and Sandbank (15). The flotator concentrate, after further thermal dewatering, can be mixed directly with other ingredients and used for semi-wet feeding of cattle and poultry (16). Sun-drying of the dewatered material is practical, preferably when dried over beds containing ground corn, soymeal, and wheat, which are components of the animal feed ration. Because preservation of the wet biomass for more than 48 hours is problematic, wet feeding is possible only when the farm animals are in close proximity to the photo synthetic waste water treatment plant. That is why most of the nutritional and feeding tests were performed with pelletized, drum-dried algal biomass. Extensive feeding experiments with broiler chicks and laying hens (17, 18) showed conclusively that between 25 and 50 per cent of the soymeal portion in the feed rations could be replaced with dried algal biomass, with no change in growth characteristics, weight gain, egg production, or the general welfare of the animals compared to animals fed feedmeal based on soymeal as the principal source of protein. An added benefit of the carotenoid-rich algae feeding was the "healthy" colour of the egg yolk.

Large-scale feeding experiments in intensive, mechanically aerated fish ponds stocked with carp (Cyprinus carpio) and St. Peter's fish (Tilapia galilea) were performed by Hepher and Sandbank 115) using pelletized feed containing approximately 22 per cent of drum-dried algal biomass, replacing on an equal protein basis all the fish meal in the ration (usually 15 per cent of the commercial ration). Fish growth rate, weight gain, and general welfare have been found conclusively to be equal to, and in most cases significantly better than, in fish fed fishmeal-based ration, with yields of between 15 and 20 tons per hectare per year of fish.

Extensive organoleptic and toxicological tests were performed on this material by Yannai et al. (19), using alum flocculated algae. The algae, although containing aluminum and wastewater-borne heavy metals, showed no adverse effects when fed to chickens or to rats fed on the chicken's meat, and no accumulation of these metals was noticed in the animal's meat or other organs. No abnormal taste or odour was noticed in organoleptic tests of algae-fed chicken or fish.

The economics of the combined waste-water treatment, water reclamation, and protein production photosynthetic system is extremely favourable (14), based on the various benefits simultaneously gained by the system - namely: (a) waste-water treatment with lower energy requirements for mechanical aeration, (b) the value of the high quality effluent for irrigation, and (c) the value of the proteins for animal feeding.

Conservatively, subtracting the benefits of waste-water treatment and reclamation results in a net cost for dried algae of less than US$140 per ton, compared to more than US$200 per ton for soymeal and more than US$380 per ton for fishmeal.

The Growth of Algae on Animal Wastes

Animal wastes constitute an excellent medium for growing algae when diluted with water, and they provide a carbon source (through bacterial aerobic degradation that produces CO2), nitrogen, phosphorus, and trace elements to sustain rich algae production.

On small farms in developing countries, where algae separation and processing are too complicated and costly, the growth of the blue-green Spirulina algae is preferred over green algae for the following reasons: (a) mechanical separation by straining or filtration is possible; (b) protein content is high (55 - 70 per cent); and (c) protein digestibility and availability are high.

Under conditions in small rural communities in developing countries, these advantages surpass the disadvantages of Spirulina compared with green algae (Chlorophytee). The disadvantages include: reduced rate of growth, need for higher temperature, need for relatively high concentrations of bicarbonates or carbonates, and sensitivity to high irradiance levels. Growing Spirulina on animal wastes has been studied experimentally under the conditions prevailing in developing countries by Seshadri (20) in

India, Soong (21) in Taiwan, and others Two sets of experiments testing Spirulina growth potential on animal wastes are described herein, one on raw (fresh) cow manure and the other on anaerobically digested cow manure.

Growth potential of Spirulina on raw cow manure

Experiments on the growth potential of Spirulina maxima under outdoor conditions in shallow (20 cm) multiple batch-type 200-litre "mini-ponds" have been performed at the Technion Institute in Haifa.

Five kg of wet, raw (fresh) dairy cow manure from Kibbutz Yagur with a total solids content of 16 per cent were added to each 200-litre mini-pond in order to reach initial solids concentration of 0.4 per cent (25 9/l) based only on the added manure and excluding the initial algae concentration of approximately 200 mg/l.

The composition of the raw manure and the concentration of its various components after the manure was added to the 200-litre mini-ponds are given in Table 3. It should be noted that the composition of the manure in Table 3 includes both the suspended and the dissolved matter of the wet manure fed into the mini-ponds.

TABLE 3. Composition of Raw Cow Manure Used for Growth of Spirulina maxima

Component	Raw cow manure (wet basis) g/kg	Concentration at 1:40 dilution in mini-pond' (mg/l)
Total solids	166	4,150
Total volatile solids	135	3,380
COD total	155	3,880
Total Kjeldahl nitrogen	5.3	130
Ammonia nitrogen	1.6	40

Total phosphate as PO4	4.1	100
Volatile acids	10.2	260
pH	7.2**	9 - 11**

* Components of stock algae culture are excluded.
** Dimensionless

Two weeks before the addition of the manure, the mini-ponds were inoculated with Spirulina maxima that had been isolated from domestic waste-water treatment ponds (the latter ponds were inoculated with Spirulina a few years ago). The initial medium was a synthetic one enriched with 16 g/l of sodium bicarbonate. The temperature of the mini-ponds was maintained at 30 C, and the ponds were continuously stirred by a long-winged rotor (6). The concentration of Spirulina before the addition of the manure was approximately 200 mg/l, and the chlorophyll-a concentration was approximately 3.5 mg/l. The changes in suspended solids concentration and in chlorophyll-a are given in Figure 4.

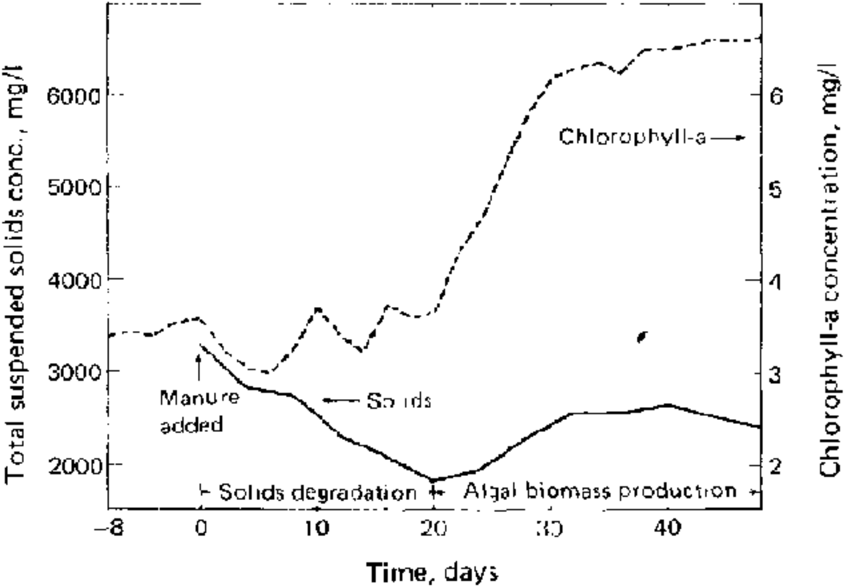


Figure. 4. Chlorophyll-a and Suspended Solids Concentrations in

Batch-Type 200-litre Spirulina maxima Outdoor Mini ponds Fed with Raw Cow Manure

Following the addition of the manure, chlorophyll-a concentration was reduced by 20 per cent, and for approximately 20 days algal growth was almost negligible. It should be noted that the addition of 5 kg wet, raw manure to the 200-litre mini-ponds created highly stressed conditions as far as organic loading and turbidity were concerned, and the ponds became turbid and brown. During the initial 20 days, intensive degradation of the manureborne organic matter and solids occurred, evident in the reduction of solids concentration.

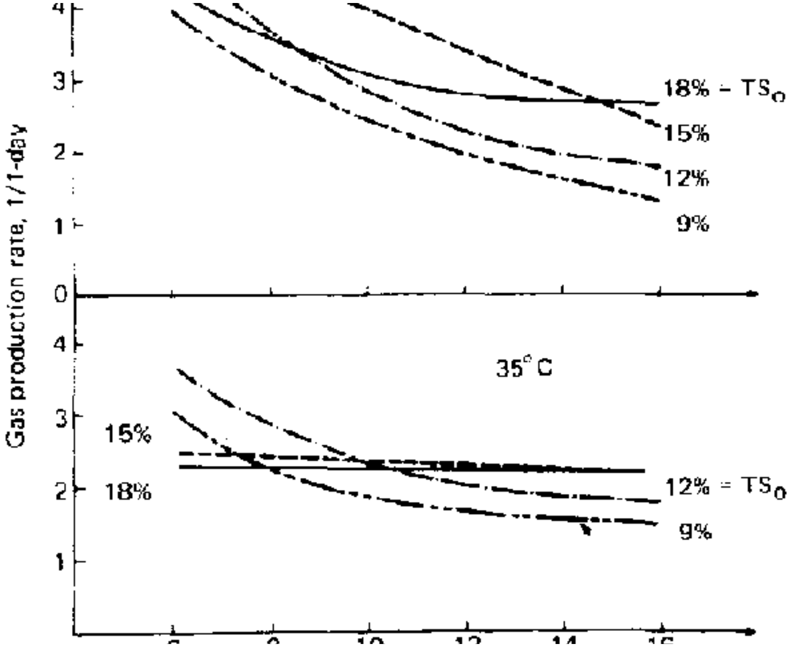
Spirulina grew rapidly between the twentieth and thirtieth days, as revealed by rises both in chlorophyll-a and suspended solids concentration. After 30 days, algal concentration stabilized and a small reduction in suspended solids was observed after 40 days; this reduction was not followed by a reduction in chlorophyll concentration, which might have been due to the continuing increase in chlorophyll-a content of the alga.

No direct measurement of Spirulina biomass production was possible because of the presence of manure-borne suspended matter and the bacterial biomass developed during the degradation of the manure. Algal growth was therefore estimated by the increase in concentration of chlorophyll-a, which is a rather poor indicator of algal biomass because the chlorophyll content varies according to growth conditions, light availability, etc. Depending on conditions, chlorophyll-a content can range between 0.5 and 2.5 per cent in blue-green algae (22), and between 1 and 2.5 per cent in Spirulina grown in outdoor mass cultures (23). The chlorophyll-a content of the Spirulina maxima prior to the addition of the cow manure was approximately 1.75 per cent, and assuming that its percentage remained the same, Spirulina concentration reached 370 mg/l at the end of the experiment.

The growth of Spirulina following the addition of cow manure was therefore quite slow, but this can be explained by the high initial dose of raw manure. During the manure degradation period, algal growth was minimal, indicating the advantage of using treated manure (composted or digested) as an algae growth medium.

Growth potential of Spirulina on digested manure

Following the experiments described above, anaerobically digested cow manure from mesophilic (35C) and from thermophilic (55C) mixed, semi-continuously fed digesters with a retention time of eight days was used as a medium in batch, continuously illuminated, 500 ml laboratory algae growth units. The production of biogas (approximately 65 per cent methane) during the thermophilic and mesophilic anaerobic digestion of the cow manure (24) as a function of retention time and at various concentrations of total solids is given in Figure 5.


Gas production rate, 1/1-day
4
3
2
1
0
18% - TS_o
15%
12%
9%
35° C
15%
18%
12% = TS_o
9%

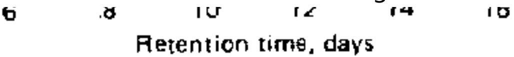


Figure. 5. Biogas Production Rate from Thermophilic (55C) and Mesophilic (35C) Digestion as a Function of Retention Time and Feed Total Solids (TSo) Concentration (24)

The digested matter, with approximately 16 per cent total solids, of which approximately 30 per cent of volatile solids had been destroyed during the anaerobic digestion, was mixed with the sodium bicarbonate-enriched medium at dosages of 10 and 25 g of wet, digested manure per litre of medium. The medium was inoculated with 5 ml of Spirulina maxima concentrated suspension.

Enrichments with 0.5, 1.0, and 1.5 per cent NaHCO3 in the medium were compared to growth units with no enrichment. The concentration of chlorophyll-a after ten days of algal growth, fed with 10 9/l of both mesophilically and thermophilically digested manures, is given in Figure 6.

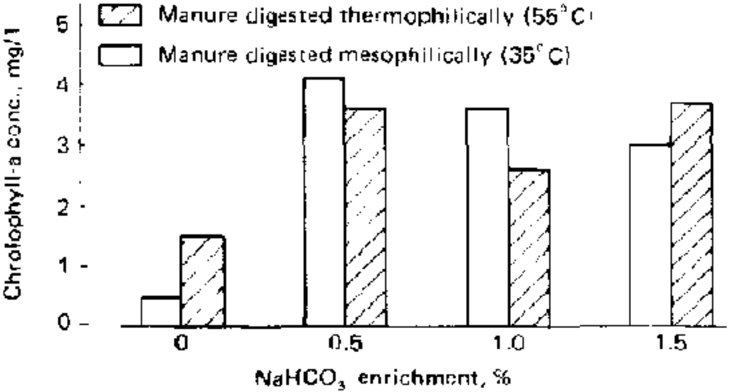
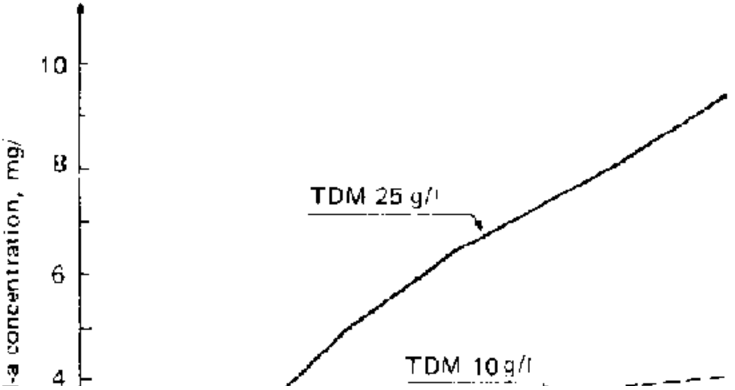


Figure. 6. Chlorophyll-a Concentration Following Ten Days, Growth of Spirulina maxima in Batch Continuously Illuminated Laboratory Growth Units, Fed 10 Grams (Wet) per Litre of Anaerobically Digested Manure

No marked effect on Spirulina growth was observed by increasing NaHCO3 enrichment above 0.5 per cent, nor have the temperatures of the anaerobic digestion (55 C vs. 35 C) of the feed had a significant effect on Spirulina growth, as evident from the concentration of chlorophyll-a.

The effect of the dosage of digested manure is given in Figure 7, where dosages of 10 and 25 9 of wet, digested manure per litre of alga culture were compared.



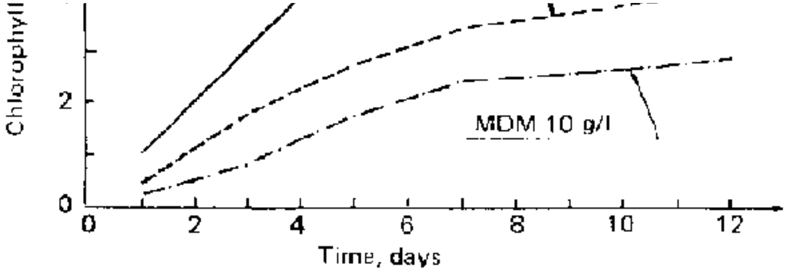


Figure. 7. The Effect of Digested Manure Dosage on Chlorophyll-a Concentration in Batch Laboratory Culture of Spirulina maxima (TDM denotes thermophilically digested manure, and MDM-mesophilically digested manure.) Concentrations of digested manure are in grams (wet) per litre of growth unit.

The higher digested manure dosage, which was similar to the raw manure dosage described earlier, gave the highest increase (up to 9.3 mg/l after 12 days) in chlorophyll-a concentration. Assuming average concentrations of 1.75 per cent of chlorophyll-a in Spirulina (dry basis), an algal concentration of over 510 mg/l was achieved in 12 days. The limitations of chlorophyll-a as a reliable quantitative measurement of algal biomass production have been discussed previously.

No appreciable lag time was observed in these experiments, and no time requirement for organic matter degradation (which was particularly evident in the experiments with raw manure) was found. Obviously, the production of biogas during anaerobic digestion is an important added benefit to the production of Spirulina Combined System for Algae Production and Anaerobic Digestion.

Following the previously discussed experiments showing the potential of algal growth on anaerobically digested manure, a combined "sandwich" system was developed whereby anaerobic digestion of farm organic residues takes place at the bottom part (gas is collected by a bell-shaped dome), while the digester's supernatant directly feeds the algal pond at the upper part of the system. A small pilot plant outdoor system with a 100-litre digester and a 2.7 m algal pond (35 cm deep) was recently set up at the Technion Institute and is now under study. Preliminary results show a production of 50 litres of biogas (STP) per day and a total biomass production (approximately 67 per cent algae) of 130 g/day (dry basis). A solar panel has recently been installed to heat the digester part of the system to approximately 37C (mesophilic) to increase gas production rates.

A small windmill is under design to provide driving force for digester and pond mixing and for the outflow pump.

The bioregenerative farm

Following the experiments described above, a conceptual design of a bioregenerative farm based on the utilization of wastes from 5 adult humans, 12 cows, 30 pigs, and 2,000 hens was developed. The quantities of wastes, volatile matter, expected biogas production, gross energy output, and nitrogen and phosphorus content are given in Table 4. It should be noted that the human wastes contain both liquid (sewage) and solids (garbage). Conditions in both developing countries (a) and developed countries (b) were assumed regarding the quantities and composition of wastes as well as the degree of volatile solids destruction (25 per cent and 30 per cent, respectively). Mesophilic digestion with 12 days average retention time was assumed for developing countries, yielding a digester with a net liquid volume of 17.5 m, while a thermophilic digester with 8 days retention and 28 m (liquid) volume is assunied for developed countries. Waste matter mixture fed into the digesters contains 6.6 per cent volatile solids in the developing countries, and 4 per cent in the developed, with gross energy outputs of 0.1 and 0.2 million kcal per day in the developing and developed countries, respectively.

TABLE 4. Material and Energy Balances of the Anaerobic Digestion Part of a Model Bioregenerative Farm under Conditions of Developing Countries (a) and Developed Countries (b)

Source	Volume	Volatile	Biogas	Energy	Nitrogen	Pho

of wastes	per day*		solids kg (dry) per day		production m (STP) per day**		production (gross) 10 kcal/day***		kg-N/day range	cont P/da rang
	a	b	a	b	a	b	a	b		
5 humans (liquid and solid waste)	0.56	1.00	2.8	5.6	0.58	1.40	3.3	7.9	0.1 - 0.3	0.0 0.0
12 cows	0.10	0.50	19.2	60.0	3.95	14.80	22.5	84.4	0.5 - 2.7	0.0
30 pigs (75 kg each)	0.71	1.84	35.4	35.4	7.28	8.74	41 5	49.8	1.9 - 3.2	0.2
2,000 hens (2	0.08	0.12	38.0	38.0	7.82	9.38	44.6	53.5	1.4 - 2.9	0.4

kg each)										
TOTAL	1.45	3.46	95.4	139.0	19.63	34.32	111.9	195.6	3.9 - 9.1	0.70

* Average data for developing countries la) and developed countries (b).
** Assuming 25 per cent of volatile solids converted to biogas in developing countries and 30 per cent conversion in developed countries with 0.823 litres (STP) of gas produced per gram of volatile solids destroyed.
*** Assuming 60 per cent methane in biogas with an energy content of 5700 kcal per m (STP) of biogas.

Not only will this energy production enable the farm household to become self-sufficient in energy, but surplus energy is provided for such purposes as water pumping, algal thermal treatment, digester heating, crop drying, small agro-industry, etc. Solar heating of the digester and wind-driven mixing and pumping can further reduce energy requirements and increase net energy surplus.

The digester's supernatant is diluted to provide an effluent with a concentration of 750 mg/l volatile solids to be fed to algal photosynthetic ponds. This diluted liquid medium contains the bulk of the nutrients (primarily nitrogen and phosphorus) as well as an ample carbon source in the form of organic carbon, dissolved CO2, and bicarbonates.

Table 5 summarizes the data of an algal pond model under conditions of both developing and developed countries under proper climatic conditions. It can be seen that the area for the ponds is 1,200 m in developing countries and 1,620 m in developed countries, yielding 45.4 and 61.6 kg per day of dry biomass, respectively, with an average protein content of 42 per cent. This yield of biomass can provide the major source of the farm animals' protein requirements through recycling. The pond effluent, following algal biomass separation, can be used for fish ponds, crop irrigation, or diluting the digester's supernatant.

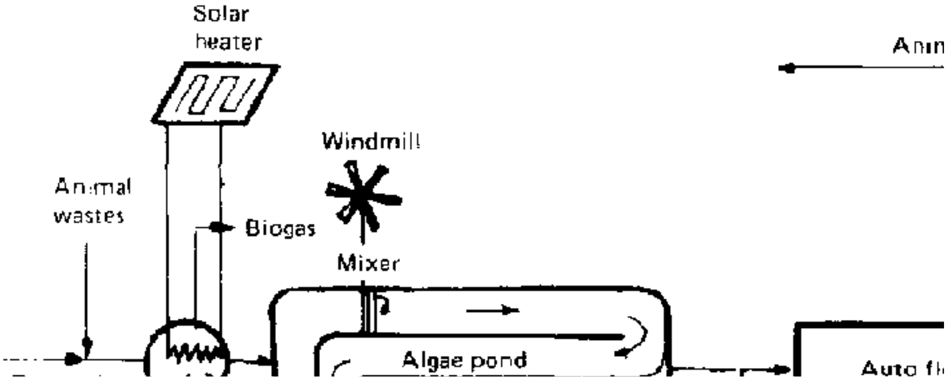
TABLE 5. Summary of Parameters for the Biomass Production Part of the Model Bioregenerative Farm

	Developing country	Developed country
Daily quantity of digested volatile solids	71.5 kg	97 kg
Daily volume of digested material	1 45 m	3.46 m
Dilution factor	65	37.4
Volume of wastes diluted to 750 mg/l volatile solids	95 m/day	130 m/day
Photosynthetic (algal) pond retention time	5 days	5 days
Pond's depth	0.4 m	0.4 m
Pond's area	1,200 m	1,620 m
Algal biomass production (net)	22 g/m/day	22 g/m/day

Total daily net algal biomass production (dry)	26.4 kg/day	35.6 kg/day
Daily production of non-algal biomass (200 mg/l)	19.0 kg	26.0 kg
Total daily biomass production (dry) (algal and non-algal)	45.4 kg	61.6 kg
Total daily protein production(dry) (assuming 42% in biomass)	19 kg	36 kg

Separation of the algal-bacterial biomass can be done by auto-flocculation (increasing pH by intensive exposure to sun-light in a shallow pond) or by alum flocculation-flotation. Thermal treatment of the algae slurry is recommended to provide pasteurization and partial dewatering.

Figure 8 illustrates schematically a conceptual bioregenerative farm where animal and domestic wastes are treated in a solar-heated, windmill-driven mixed biogas digester. The digester's supernatant feeds an algal photosynthetic pond from which proteinaceous biomass is produced for animal feeding and treated effluent is reclaimed for irrigation. A cycle combining the algal pond with a fish and duck pond is proposed as well. The scheme of Figure 8 shows a physical separation between the anaerobic digester and the photosynthetic pond; however, the combination of the two as in the "sandwich" design is possible and even advantageous.



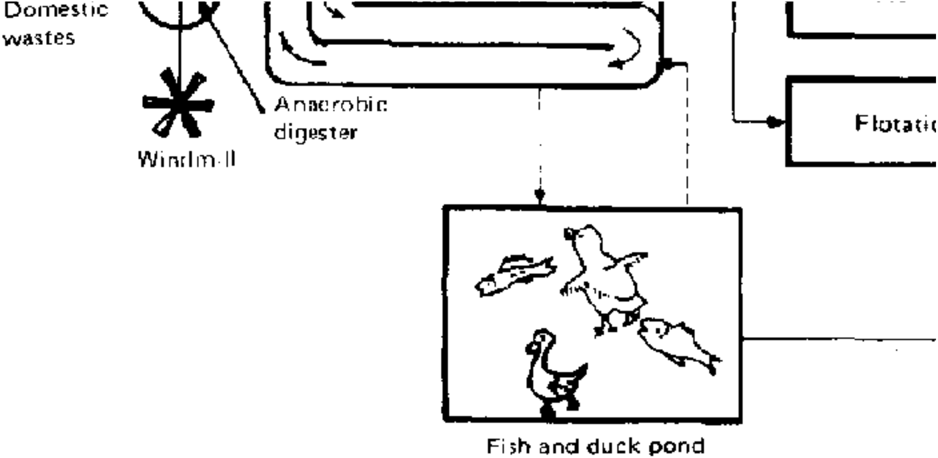


Figure. 8. Schematic Layout of the Bioregenerative Farm Concept

Past experience with both anaerobic digestion and algal biomass production can provide the necessary design criteria and the data for material and energy balances of such a combined system.

Nevertheless, actual demonstrations in various climates, using different farming practices and in various socio-economic settings in both developing and developed countries, under full-scale farm unit conditions, are required and recommended in order to prove and establish the complete design criteria for such a bioregenerative system, thus bringing about maximum self-reliance and self-sufficiency of the farming communities in the developed and developing countries.

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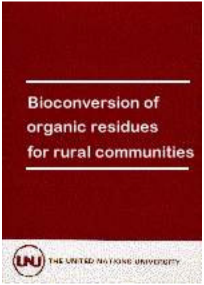
Discussion summary

It was asked whether any attempt had been made to concentrate algal slurry by winddriven centrifuges. This method would be too expensive in Israel. Others wondered about seasonal variations in the toxicological and nutritional characteristics of the algae, and were assured that these could be controlled by causing a single species of known toxicological and nutritional characteristics to become dominant. This may be done by selecting the appropriate conditions of loading and retention times in the ponds.

There was the suggestion that membrane separation might well be feasible at the present time. In reply to a question on the stability and reproducibility of the process, it was stated that the system had worked satisfactorily in both summer and winter over a period of three years.


Bioconversion of
organic residues
for rural communities

Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

A continuous composting system for disposal and utilization of animal wastes at the village level

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Status of land utilization and disposal of animal wastes

Never in the history of agriculture has soil fertility been considered as much as today. However, there is almost no literature on the subject, and no definite conclusions about how organic matter such as manure compost affects the fertility of soil. Nevertheless, a tremendous amount of manure is used on farm land.

The reason for the recent interest in soil fertility was the observation that crops grew abnormally and yields were highly variable when the amount of organic substances used for farming decreased and began to be replaced by chemical fertilizer. Why this is so is not clear. However, in one intensive vegetable cultivation area, farmers improved both quantity and quality of their crops when they applied organic matter to the soil.

The rapid economic expansion during the 1960s in Japan turned conventional agriculture into an enterprise, with the result that farmers were forced into raising either vegetable crops or cattle.

This caused a shortage of organic fertilizer for vegetable farmers on the one hand, and created a serious problem of manure disposal for cattlemen. Subsequently it was found that application of cattle manure to soil improved its fertility significantly, even though it was originally considered as a source of nutrients for plants rather than as a component for maintaining soil texture. Thus, it appears likely that an agricultural system that depends on the heavy use of chemical fertilizer has a deleterious effect on soil fertility. The present paper summarizes the results from 13 years of studies beginning in 1964, to establish a system for using cattle manure as a valuable organic fertilizer for farm land.

The study was begun without any prior assessment of the impact of large-scale cattle raising, which it was thought would be common in the future. Furthermore, animal waste management was the main interest, and only scant attention was paid to the use of this valuable resource. For management purposes, it is mechanically easier to handle waste if large quantitites of excretions are mixed without separating solids from liquid. However, this method causes severe problems both from the standpoint of handling waste and using it. For one thing, only 50 per cent of solid waste was obtained when solids and liquids were mixed. Accordingly, the need was to develop an efficient system to separate solid matter from liquid waste, and this was accomplished by means of a screw press. Moreover, water-soluble organic matter, which has a high biological oxygen demand (BOD), remained in the liquid. The result of this study clearly indicated that the problem was due to the presence of soluble solids and the BOD of the raw faeces, and that the samples used for screw press treatment would have a high content of solids and a high BOD.

We have tested other systems, such as the centrifuge and rotary screen, for comparison with the screw press method, and found that solid matter isolated by the screw press is best for rapid manure composting. The conclusion is that the screw press method should be used on large-scale hog farms having several thousand animals. The best results are obtained when raw faeces are removed separately from the hog pen and the remaining, mixed excrete are partitioned by the screw press. It is not as efficient to separate total excretions by the screw press without any prior separation. The amount of faeces that can be preseparated from the hog pen is about 80 - 90 per cent of the total, and subsequent treatment of the remaining mixture of 10 - 20 per cent of faeces and urine by the screw press ensures that all solid wastes are preserved for composting. This method is ideal for large-scale hog raising, because it reduces costs of both waste management and pollution control.

Although most farmers still have a water pollution problem because they do not preseparate faeces, the screw press is becoming popular in Japan. About 400 such presses are now in use. One possible explanation for the wide farmer support of the screw press is that it provides fertilizer for the fields and improves soil fertility and crop production.

The main problem associated with the screw press system is handling of the raw faeces removed directly from the hog pen. Bad odour and high water content, together with psychological aversion, prevents some farmers from pre-separating faeces from liquid wastes.

In order to ameliorate this problem, we have tried heat-drying of raw faeces. Because cow and hog manures contain more water than found in chicken manure, more fuel is consumed if a conventional chicken faeces dryer is used. In addition, the quality of cow or hog manure in terms of soil fertility is inferior to that of chicken manure, so that in the long run, costs increased disproportionately.

Another approach is semi-drying of manure. This process was first developed mainly to reduce fuel consumption, but an additional advantage is that manure so treated can be composted fairly rapidly. Usually, high water content in the raw faeces and solid fractions remaining after mechanical separation of excrete precluded rapid composting. It is now understood that reducing the water content of faeces from 80 - 85 per cent to 60 - 65 per cent is the key process in making good compost. Rice straws and leaves can be used to absorb water during composting.

The continuous process of composting animal faeces, i.e., semi-drying by heat, composting, mixing with raw faeces, and re-composting, was tested on a small scale for evaluation of the process. Although no large-scale study was done, the process was considered to be quite promising, and use of the method began to spread in the country beginning in 1970.

Unfortunately, mixing the compost with raw faeces was thought to be too labour-consuming, so widespread use of the continuous composting system did not take place until Tsuneo Jimbo developed a loading system in 1973. This success stimulated Shuichi Anzai to develop a so-called "pile-up system," which consisted of loading raw faeces on top of the compost so that mixing is required only on the top portion.

This development not only means that the middle-sized farmer can continuously make compost from manure but also allows centralized composting at the village level. The process is now popular all over the country.

The carbon ratio of raw cow manure is about 15:25, that of hog manure 10:13, and of chicken manure, less than 10. The carbon ratio of solid fractions after mechanical separation of excrete is 30 in cow dung and 17 for hog manure. These values are quite different from those in rice straw, which has a ratio of 70:80 due to the high content of lignin. Raw faeces have an equal or lower carbon ratio compared to well-matured compost or manure compost. If one judges the maturity of compost by its carbon ratio, raw faeces have a value close to that of fully matured manure compost, and thus is satisfactory.

However, when the water content of raw faeces or solid isolate was reduced to 60-65 per cent, rapid fermentation was usually observed. One possible explanation of such active fermentation is that manure usually contains many biodegradable substances, such as shortcarbon-chain fatty acids. In addition, manure is also high in nitrogen, thus making a good substrate for microorganisms. The temperature profile increased significantly at the beginning of fermentation and fell after the first few days during composting, supporting the idea that the time required for composting raw faeces is much shorter than that observed during conventional manure composting. The reason is believed to be that raw faeces are much more susceptible to attack by micro-organisms.

Compost from either raw faeces or solid isolate is generally rich not only in organic materials but also in various minerals that help to enrich soil. In particular, the compost made by fermentation at high temperature did not decompose rapidly in the soil, which lessens the hazard of gas production that has been observed when immature compost is applied.

Raw faeces could become an ideal organic resource if a system is developed to remove water content economically without just mixing in rice straws, etc. Compost from raw faeces has been proved, not only by small-scale tests, but also by practical use, to be a good fertilizer as well as a soil conditioner. Although it is difficult to detect a significant change in the physico-chemical properties of soil by adding compost at a level of 1 - 2 tons per year per 10 acres (it is generally said that 5 tons per year are essential to change soil conditions), a significant improvement in crop growth has been observed when compost was used compared with results from application of chemical fertilizer. For example, in vegetable production, manure compost used alone led to a good yield of high-quality vegetables and met more than 60 - 70 per cent of total nutrient requirements of the crops.

It is particularly interesting to note that unlike chemical fertilizer even a small amount of organic matter improved acid soil in a vegetable field.

Cattle manure is particularly beneficial in volcanic ash soil. On the other hand, application of organic matter to a paddy field is valuable under the right soil conditions. In certain instances, reduced rice yields were observed, implying that the method used for adding raw faeces is very important. They should be applied to the paddy field as early as possible to allow enough time for decomposition before the rice is planted, to prevent any drop in pH value of the soil. If this is done, the effect of organic matter has a detectable benefit, even in a rice paddy with peat in its lower layer.

Raw cow, hog, and chicken manures have been tested in direct application to the field using 200 tons per 10 acres of each kind of manure. Micro-organism activity peaked four to seven days after application, and then dropped quickly. This phenomenon correlates with the process of composting raw faeces. The increase in micro-organism activity at the initial phase is due to the higher BOD of the faeces, and the BOD and CO2 gas production have shown a good correlation.

An unusual increase in microbial activity in soil will affect the crops adversely, particularly right after planting. Care should be taken to avoid these undesirable effects when raw faeces are going to be used. A large quantity of raw faeces applied to soils maintained good productivity of vegetables without further addition of fertilizer for four years, which means that raw manure is slow-acting and effective for long periods. Chicken manure, which showed a very high microbial activity at the initial phase, became less effective much faster than either cow or hog manure in terms of crop productivity. This result indicates that chicken manure has less residual activity and soil-conditioning power than the other manures.

Mixing raw faeces with soil will heighten the rate of faecal decomposition because good aeration is permitted by increased surface contact between faeces and soil.

The problem with the present method is that the amount applied to the field is far beyond the quantity required by the plants. Such large-quantity application of raw manure will certainly have an undesirable effect, particularly with regard to pollution of the environment. For example, part of the nitrogen in raw faeces may diffuse into the soil during decomposition. It is interesting to note that denitrification has been observed when raw faeces, rich in organic nitrogen, have been applied, while with application of inorganic nitrogen, no denitrification has been detected. This phenomenon indicates that, when organic nitrogen is applied in large quantities, part of the nitrogen is denitrified by the activity of micro-organisms. I believe that this sort of microbial regulation, such as conversion of excess organic nitrogen to an inert form, is very important and further study of the interrelationships between organisms and their environment is essential.

A more detailed description of the foregoing discussion can be found in my article in the Bulletin of the Agricultural Research Institute of Kanagawa Prefecture, No. 1 18, "Studies on the Utilization of Animal Wastes in Agriculture," 1977.

A continuous composting system for land utilization of animal wastes at the village level

Use of This Method on Small-Scale Animal Farms

Since the early 1960s, concern has been expressed about disposing of bulky animal wastes from the large-scale livestock production units in suburban areas of Japan. The disposal problem, however, is not merely one of environmental protection. Vegetable growing, another type of agricultural practice dominant in suburban areas, is suffering from declining soil fertility resulting from heavy dependency on chemical fertilizers to the neglect of organic manuring. Therefore, an efficient use of animal wastes as compost for vegetable growing could solve these two problems at the same time.

From the livestock railers' point of view, washing out all animal excrement with water is the easiest way to maintain good sanitary conditions in barns and pens. Therefore, in our early studies we began with a mixture of excrete and water as a source material and then became concerned with how to separate solid matter from waste water efficiently (1 - 3).

Various mechanical methods were tested, but all proved to be unsatisfactory. The reasons were:

a. although fresh manure contains about ten times more soluble solids and has a higher BOD than urine (Table 1), the recovery rate of solid matter from mixed excretions was found to be only 50 per cent by any mechanical methods; and

TABLE 1. BOD Content of Animal Wastes (ppm)

	Faeces	Urine
Cow	22,000 - 26,000	2,500 - 3,000
Hog	55,000 - 60,000	4,500 - 5,000
Chicken	65,000 - 70,000	-

b. water-soluble organic matter, with a high BOD, remains in the liquid portion after separation.

Therefore, by mechanical separation methods, not only does the liquid portion, which has to be disposed of, impose a heavy burden on sewerage facilities, but also a large portion of organic matter that could otherwise be used as farm manure, is lost.

Based on the experience of the early studies, a different approach was sought to solve the problem of disposal and use of animal wastes. The idea of using the excrete mixture as a source material was abandoned; instead, an efficient composting system using fresh faeces collected separately from urine was conceived, developed, and tested. A brief description of the system and some examples are presented here.

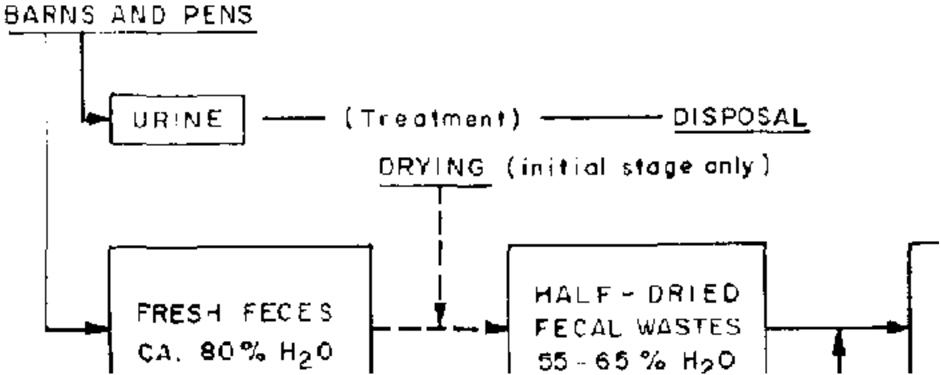
The basic procedure

Fresh animal faeces contain about 80 per cent moisture (Table 2). To begin with, the moisture content must be reduced to 55 - 65 per cent by drying either naturally (air drying) or artificially with the help of fuel. The product is called "half-dried faecal waste." Second, this material is piled into a heap and turned over every three or four days. Highly active aerobic fermentation takes place following a self-generating rise in temperature, and a well-matured manure compost of 40 - 50 per cent moisture content is obtained after two weeks. The product of this second stage is called "seed compost." The procedures up to this stage are preparatory.

TABLE 2. Composition of Animal Faecal Wastes 1% dry basis)

Animal	Moisture (% Wet basis)	T.C.	T.N.	C/N	Ash	P_2O_5	K_2O	CaO	MgO
Cow	84.3	41.4	1.8	23	27.5	2.7	0.7	3.7	1.5
Hog	81.1	41.5	3.9	11	19.1	4.8	0.4	4.9	1.6
Chicken	75.0	42.2	4.6	9	27.3	8.6	2.3	10.9	1 6

Third, to this seed compost, a fresh volume of faeces is added so that the moisture content of the mixture does not exceed 55 - 65 per cent, the level equivalent to the half-dried waste described above. The mixture is piled up and subjected to aerobic fermentation for two weeks. Part of the mature compost thus obtained is used as farmyard manure and the rest as seed compost for the next cycle of composting (Figure 1).



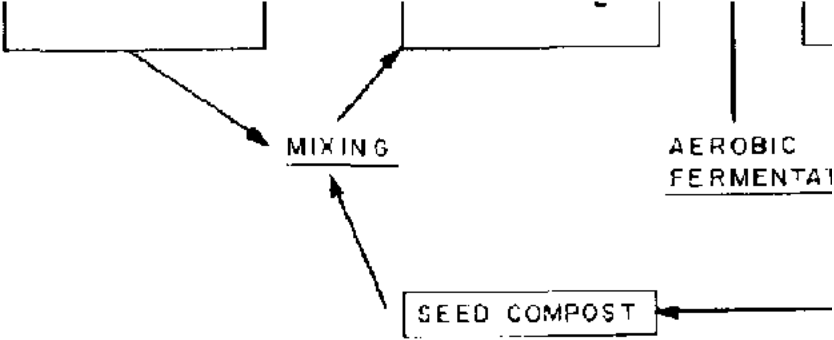


Figure. 1. The Basic Procedure of Continuous Composting System

As described above, drying is required only at the initial stage. Once the seed compost is obtained and recycling begins, quality farmyard manure can be obtained every two weeks without being influenced by weather conditions and without the help of supplementary energy.

Practical system A: The whole-mixing method

This method is one of the practical applications of the basic procedure at the local farm level. It was developed by T. Jimbo, who raises dairy cattle near Yokohama. A detailed survey of his farm was made in July - August 1974 (4). Below are some salient features of the survey results.

Thirty head of cattle at his farm produce about 750 kg of faeces and 3001 of urine per day. The latter is anaerobically treated and discharged to the river. The faeces are manually collected from the barn and carried to the composting ground. For preparation of the initial seed compost, fresh faeces were spread on either the open field or the greenhouse floor. When the moisture content dropped to 55 - 60 per cent, the half-dried faeces were piled into a heap of about 2 - 3 m Within two to three days the temperature rose to 60 - 70 C. Every two or three days the heap was turned with a manure fork attached to the front loader of a small tractor. Matured manure with a 40 - 50 per cent moisture content was obtained after 10 - 15 days.

Fifteen-hundred kg (about 1.5 m) of fresh faeces, the amount produced at the Jimbo farm during a two-day period, was added to about 1.5 m of the seed compost and mixed thoroughly with the manure fork. The mixture was piled and stirred every two or three days. After about ten days, 2.5 m of mature manure was obtained, of which 1 m was applied to the field and 1.5 used again as seed compost.

When the ratio of the seed compost to fresh faeces was 1: 1, 10 - 1 5 days seemed to be sufficient time for obtaining mature manure. However, the ratio should be reduced to 1:0.7 during the winter season. For easy operation of the manure fork, the height of the heap should be 1 m and its volume at least 3 m. A maximum temperature of 74 C in the heap was attained four to seven days after mixing. The composition of the mixture underwent drastic changes. Among them, the rapid decrease in moisture content and in the C/N ratio was particularly noticeable (Table 3).

TABLE 3. Changes in the Composition of Animal Faecal Wastes

during Composting

Animal cow			Moisture (% Wet basis)	Ash	T.C.	T.N.	C/N
	new faeces		81 8	16.5	32.9	2.03	16.2
		2	55.1	62.4	16.3	1.49	10.9
	Days after mixing with seed						
		7	48.5	63.2	15.0	1.54	9.7

	compost	15	41.6	73.4	12.7	1.33	9.6
		32	40.4	69.3	14.1	1.48	9.5
	Raw faeces		73.9	16.4	44.8	5.32	8.4
		3	62.5	27.0	44.8	4.34	10.
	Days after						
	. . .	7	55 2	27.3	39.1	3.96	9.9
	mixing with	15	33.2	30.0	37.7	3.56	10.
	seed						
	compost	30	9.1	24.6	38.2	4.10	9.3

Practical system B.: The partial-mixing method

This is a simplified version of the basic procedure, and was developed by S. Anzai who raises 500 pigs in Kanagawa Prefecture. His farm was carefully studied during October 1975 - February 1976 (5).

At this farm, the amount of faeces treated was about 1.2 tons per day. The usual procedure for preparing the seed compost was similar to that described above. In addition, almost completely air-dried faeces also proved effective as seed compost. The seed compost, which was left in a heap for more than 20 - 30 days, proved to be ineffective because the temperature did not usually rise rapidly when fresh faeces were mixed with such aged seed compost.

The seed compost was laid on the ground in a rectangle of 1.0 - 1.5 m, and fresh faeces were spread on it. The seed compost was about 20 cm thick, and the fresh manure layer was about 10 cm. These double layers were manually turned with a scoop to improve air penetration. Thorough mixing was unnecessary, and sometimes could adversely affect subsequent fermentation. During fermentation, the heap was manually turned every two to three days. Mature manure was obtained after 15 - 20 days. Unlike the whole-mixing method, fresh faeces were spread on the whole matured manure rectangle without separating part of it out for application on the field. The thickness of newly added faeces was also about 10 cm. Only the upper 20 cm part of the heap was turned at the same intervals mentioned above.

By repeating the operations described earlier, the height of the heap increased, and turning became difficult when the height reached 70 - 80 cm. The greater part of the heap was used as farmyard manure, while the surface layer in which the greatest microbial activity was found was used as the seed compost for the next cycle.

Because the height of the heap was initially only 25 - 30 cm, the rate of temperature rise was slower than in system A. Yet, it reached 50 - 60 C within four to five days when the heap grew to 50 cm high or higher, and the maximum temperature reached 60 -

70C, as high as in the whole-mixing method. The highest temperature was recorded in the upper portion of the heap where fermentation was most actively taking place. In the lower portion, the temperature was found to be constant at a relatively high level throughout the composting process.

The composition of the hog faeces changed significantly during the composting process, as shown in Table 3. In spite of drastic changes in the other components, the C/N ratio was found to be constant, in contrast to the decreased ratio in cow dung.

Discussion

Generally speaking, the ratio of carbon to nitrogen, or- the C/N ratio, decreases when organic matter is decomposing. The rate of decomposition is initially rapid and becomes slower at the C/N ratio approaches that of the micro-organisms themselves, i.e., about 5:6. In the case of rice straw compost, the initial C/N ratio is about 70, and decomposition almost ceases after three to six months, when it falls to 20, which means that well-matured rice straw compost has a C/N ratio of about 20.

The initial C/N ratios of animal faeces are much lower: 20:25 for cows, 10:15 for hogs, and 8:10 for chickens. These figures are as low as, or lower than, the C/N ratio of matured rice straw compost. Yet, as demonstrated by the systems discussed above, the faecal wastes undergo drastic decomposition during a surprisingly short period (only two weeks) if certain conditions are met. Therefore, the C/N ratio alone is not necessarily an index for maturity of animal waste composts.

The easy decomposition of animal wastes, in spite of the low C/N ratio, can be explained by the abundance of easily decomposable organic matter, such as lower fatty acids and sugars, the main sources of BOD, as well as the high nitrogen content. The former is the energy source and the latter the nutrient source for rapid microbial activity. To realize this potentially high susceptibility to decomposition, there must be an ample supply of oxygen. Lowering of the moisture content by either drying or mixing in fresh faeces with the seed compost is effective for improving aeration within the heap. Heat generated by active aerobic fermentation also effects evaporation.

The key to success in the continuous composting system is maintenance of a highly active aerobic fermentation. Once the microbial flora are contaminated with anaerobes, recycling does not operate smoothly. In this sense, the system is similar to sewer water treatment, in which the maintenance of favourable bacterial activity of activated sludge must be managed with the greatest care In the case of sewer water treatment, BOD proceeds from one phase to another. The first phase is said to take 14 days, which coincides with the period required for the aerobic fermentation in the system described.

A Large-Scale Composting Centre in an Agricultural Co-operative

A large-scale composting centre started operating in 1975 with financial support of the Ministry of Agriculture and Forestry, Kanagawa Prefectural Government, Ayase Town Office and Ayase Town Agricultural Co-operative. The main installations and expenses are shown in Table 4.

TABLE 4. Main Installations and Expenses in Large-Scale Composting Centre (1977)

Items	Scale	Expenses
Building	560 m	Y 15,626,000 (US$58,966)
Shovel loader	1.0 ton load	Y 2,515,000 (US$ 9,491)
Dump lorry	2 0 ton load	Y 1,894,000 (US$ 7,147)
Automatic scale and shed	9.7 m, 5.0 ton max.	Y 3,020,000 (US$1 1,396)

Total		Y23,055,000 (US$87,000)

Management and operations of the agriculture/ co-operative

An operations committee is organized by the representatives of the Livestock Raising Association, the Horticultural Farmers' Association, and the Tractor Operators Group. Their function is to collect jointly animal faecal waste, process it, and then redistribute it among members of the co-operative when desired.

Composting faecal waste

Wastes that arrive at the centre are weighed automatically and unloaded onto sawdust. Fresh faecal waste is mixed with about 10 per cent sawdust, and the same quantity of mature compost previously processed for 15 to 20 days is piled to a height of 1 m by bucket loader. Every three or four days mixing and piling are repeated for a period of 15 to 20 days. Analytical data on processed compost are given in Table 5.

TABLE 5. Chemical Constituents of Processed Compost (% on wet basis)

Moisture	pH	Ash	SiO_2	T.C	T.N.	C/N	P_2O_5	K_2O	Na_2O
52	7.7	19.0	5.9	39.8	2.1	19	3.0	1.1	0.7

The price of fresh faecal waste and processed compost

When the moisture contents of cattle and hog faeces carried to the centre are more than 85 per cent, US$2 per ton are paid to the livestock-raising farmers, and they receive US$2.50 when the moisture content is less than 85 per cent. Well-matured compost thus produced is sold and delivered for US$14 per ton, including a US$1.50 charge for delivery.

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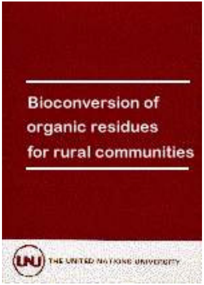
Bioconversion of
organic residues
for rural communities
THE UNITED NATIONS UNIVERSITY

Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Bioconversion of fruit and vegetable wastes

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Evidence is accumulating that people have developed ingenious methods of fermentation to overcome inherent indigestibility, or toxicity, of the protective (fruit-coat constituents) and not-to-be-eaten components of plants by a combination of physical (to destroy the antimicrobial factors) and microbial methods, with or without leaching or throwing away the cooking wastes. These combined treatments act to dispose of alkaloids, glycosides (CN- and S-compound-containing), phenolics (bitterness principles) and their glycosides, saponins, sterols, toxic peptides, and anti-enzymatic factors, to name some of the commonly found compounds inhibiting consumption

Within limits, a useful method of ascertaining the causes of consumption inhibition is to bite into the normally uneaten portion, though it is advisable to be aware of the general content of secondary compounds in the plant family before doing so. The message will be clear to the human predator of acute astringency (e.g., capsule of the mangosteen, Garcinia mangostona) or acute bitterness (e.g., seed and rind of the papaya, Carica papaya). Other fruits are simply tough and full of aromatic compounds, though they are used by indigenous people. Examples include Mangifera spp. and Baccaurea spp. - the species B. griffithii is deliberately used as a flavouring and fermentation control agent. The pericarp of the nutmeg, Myristica fragans, is boiled and sweetened as a sweetmeat, but it is doubtful whether it is wise to consume it in large quantity.

Anaerobic fermentation is frequently employed concomitantly with purification by washing and decanting. The classical example of this is the treatment, before eating, of yams (Dioscorea spp.) and keladis, taros, cocoyams (aroid yams of the genera Colocasia, Xanthosoma, Amorphophallus), tapioca, cassava (Manihot esculenta Cranz), and the so-called cabbages of palms. Monkeys are fond of this last-named delicacy, but some species of cultivated palms are avoided because nature adds to the normal inhibitor - bundles of needlelike crystals of oxalic acid - a coating of highly toxic protein The needles serve to inject the protein into the mucous membrane of the mouth For many of the above examples, pectinolytic and mild cellulolytic bacterial action separates and weakens the starchcontaining parenchyma cells. Beta-glucosidases split the glucosides (the bacteria use the sugar), and the nitrites and sulphur compounds and degraded; other molecules may be eluted. The CN radical is capable of being used as both a nitrogen and carbon source by certain yeasts, but is normally disposed of. The main cause of a high incidence of CN toxicity is due to absorption of the acid through the skin by women preparing the food by grating the raw material for fermentation. Neuropathy symptoms (optical, peripheral) are linked with a low sulphur-amino acid diet where the body is incapable of detoxifying CN by the thiocyanate pathway.

Digestive disturbance due to sulphur compounds - thioglycosides, thioalkaloids, and thioethers - is widespread, and tolerance seems to vary greatly among individuals. The function of these compounds in plants is commonly bacteriostatic, though they also function as repellents and attackers. Addiction to durians (Durio zibethinus Murray) may be due to these compounds, and the so-called aphrodisiac effect is, I suspect, via a mild irritant action on vascular and mucous tissue. The sulphur compounds are dispersed in pickling, though their microbiostatic properties appear to have been unwittingly employed in pickle fermentations (e.g., the Korean kimchi). This is pickled Brassica sinensis cabbage with added chili peppers (Capsicum frutescens), pepper, ginger, and garlic, all containing bacterially active compounds.

In the fermentation of wastes from fruit and vegetables, fats, waxes, and longer-chain fatty acids may also play a role in inhibiting the fermentation. The situation is confused if the material is cooked prior to fermentation because without critical experimentation it may be difficult to distinguish between the effects of heat, or removal of the wax or fat, and the presence of microbial inhibitors in the original living plant cells.

State of the art of bioconversion

Regarding bioconversion, from the examples in the above review, it may be observed that:

a. by-product processing of fruit and vegetable wastes is biochemically strongly species-dependent;

b. the species may be ecosystem specific, though many have been subjected in recent years to inter-regional transfer;

c. substantial processing skill has been developed at the place of origin, but may not have been transferred with the original plant transfer. Thus, the apparent social reasons for nonuse may be lack of transfer of the appropriate technique.

Technical transfer

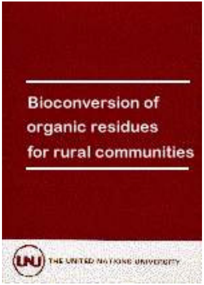
Inter-regional technical transfer has lagged behind crop transfer, and removal of biochemical contraints to use of residues may be effected by following the crop transfer with appropriate technical transfer.

The sophistication of the indigenous fermentation technology, although a process may appear simple, must not be under-rated, and technical transfer may be easiest among established communities having homologous crops. Because it is only a homology, the transfer may not be automatic and a block to full harvest utilization may occur. That is, the two plants of the agronomically homologous pair may occupy similar agro-ecological niches, but the plants' biochemistry, enabling them to occupy the respective homologous biological niches, may differ.

By contrast, the robustness of yeast fermentation has resulted in successful new developments in village technology in safe alcohol distillations in places as far apart as Nigeria and the Philippines. Even in Europe the itinerant technician (the distiller) takes his apparatus to the substrate, producing the schnapps for the individual farmer from his own brew.

At present this trend in domestic technology is most highly developed in Japan, and the Japanese experience is worth studying in this context. If you bake your own bread, it does not matter if the commercial bakers go on strike. Bringing the process to the raw material may be a good energy budgeting and waste elimination practice

In my view, the marriage of industrial technology in microbiology, enzymology, small-scale equipment, and the village or domestic processer has only just begun, and one may foresee a continued development of the concept of industrially produced starters and processing aids for the wide range of village-level processes.


Bioconversion of
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processing of organic residues
- Production of feed as an objective for bioconversion systems
- Environmental goals for microbial bioconversion in rural communities
- Strategies for developing small-scale fermentation processes in developing countries
- Production of microbial protein foods on edible substrates, food by-products, and ligno-cellulosic wastes
- The role of ruminants in the bioconversion of tropical byproducts and wastes into food and fuel
- Possible applications of enzyme technology in rural areas
- Indian experience with treated straw as feed

substrates

- Production of single-cell protein from cellulose
- Analysis of energy cost of integrated systems
- Analysis of bioconversion systems at the village level
- Nutritional evaluation of bioconversion products for farm animals
- Bioconversion products: toxicology - problems and potential
- Nutritional evaluation in humans
- Biomass from organic residues for animal and human feeding
- Appropriate biotechnology - summary remarks
- Other UNU Publications

Foreword

We are pleased to share these Proceedings of the first joint workshop of the World Hunger Programme (WHP) and the Programme on the Use and Management of Natural Resources (NRP) of the United Nations University (UNU). The conference was financed by the United Nations University with the supplementary assistance of Unesco and UNEP, and was hosted jointly by the Institute of Nutrition of Central America and Panama (INCAP) and the Central American Research Institute for Industry (ICAITI).

The United Nations University was founded in 1975 and its World Hunger Programme was established in the same year. Its priorities include the post-harvest conservation of food, and food and nutrition policies and programmes that will reduce human hunger. The UNU Programme on the Use and Management of Natural Resources started in 1976. One of the priority areas of this programme is the development of appropriate methodologies for the production of biomass from organic residues, especially in rural areas. Hence, these two UNU components were well suited to a joint effort to encourage research and development of the bioconversion of organic residues for animal and human feeding and the testing of the safety and nutritional value of the end-products of such processing.

To explore the feasibility of a joint UNU WHP-NRP project, a small meeting was convened in Athens (4-5 March 1978). On the recommendation of this group the UN University established, in April 1978, a Task Force on Bioconversion of Organic Residues for Rural Development. This task force was composed of specialists in the fields of nutrition, the testing of non-conventional feed products, bioconversion and biomass production at the farm level, and socio-economic developments in rural communities, as well as experts from FAO, Unesco, and the International Cell Research Organization (ICRO) in their private capacities.

At its first meeting, in June 1978 at the Institute for Animal Nutrition Research (ILOB) in Wageningen, Netherlands, the task force formulated the plan and an outline for this conference on the State of the Art of Bioconversion of Organic Residues for Rural Communities, which was held in Guatemala City, Guatemala, 13 - 15 November 1978. The goal of the conference was an inventory of recent developments in selected fields of biomass production through bioconversion of organic residues specifically aimed at improving the socio-economic, nutritional, and health conditions of low-income communities in rural areas.

The enormous potential of the smallest among living organisms - yeasts, bacteria, fungi, and algae - to upgrade organic wastes into valuable feed and fodder through simple fermentation processes has become increasingly recognized. This awareness is timely, for more efficient utilization of the world's resources and their recycling have become essential.

The fact that huge quantities of organic residues are discarded and pollute the environment, while in fact they form an enormous potential for feed and food production, is being realized more and more. For instance, the amount of cellulosic wastes, in the form of rice straw, in Southeast Asia amounts to 300 million tons a year.

Also, the quantity of residues from the production of fruit, cassava, rubber, coffee, sugar, and sisal, to mention a few of the world's major commodities, is staggering. In addition, animal and human wastes are excellent starting material for bioconversion, and are found in large quantities wherever human and animal populations are concentrated. Upgrading of these residues through microbiological processes can make an important contribution to self-sufficiency in rural regions and to human welfare in general.

Nutritional and toxicological evaluation of the various forms of biomass derived by microbiological conversion of organic residues and wastes is, in most cases, non-existent. Consequently, the task force, following the trend set by the Protein-Calorie Advisory Group of the UN system, is paying great attention to this aspect of bioconversion processes.

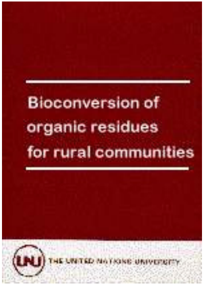
Fermentation is a simple, low-cost process, which, in its various forms, has been practiced traditionally for food processing at farm and village levels in many regions of the world over hundreds of years. Bioconversion of organic wastes into valuable fodder is, in principle, no different from food fermentation processes and can be carried out efficiently in rural areas where organic wastes are abundantly available and often pose environmental and health hazards.

The workshop proposed that the product of microorganisms plus substrate resulting from the micro-biological processing of organic residues be referred to as "microbial biomass product," or MBP. The papers presented in this publication draw attention to the high potential of MBP, and it is hoped that they will stimulate research and feasibility studies for application at the village level.

Dr. Cyril A. Shacklady, of ILOB, served as the technical editor of these Proceedings, which were prepared for publication by Miss Jane Dittrich. Dr. Anton Burgers, Senior Programme Officer,

represented the Programme on the Use and Management of Natural Resources at the conference.

Nevin S. Scrimshaw
Senior Adviser
World Hunger Programme
Walter Manshard
Vice-Rector
Programme on the Use and Management of Natural Resources



Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Integrated research on agricultural waste reclamation

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Introduction

A stable supply of feedstuffs is an absolute necessity for the sound development of the animal and fishery industries in Japan.

However, the recent trend, particularly in 1972 - 73, towards world-wide constraints on foodstuff supplies has caused sharp rises in animal feed market prices. In order to cope with this, research efforts have been accelerated to improve forage production. However, our domestic feed supply is limited because most of the arable land is already cultivated, and because climatic conditions control how much can be grown. The forage supply in Japan is sufficient to meet the requirements of dairy cows and beef cattle, but hogs and poultry require a much higher concentration of protein in their feed than cattle do.

Constant supplies of soybean meal and fish meal, major sources of feed protein, will not always be ensured in view of the drastically changing patterns of crop marketing and reduced availability of fish in the world. These circumstances justify the development of alternative feed proteins, among which single-cell protein (SCP) is of prime importance. Although there are many possible substrates on which to grow SCP, production technology based on the exploitation of agricultural, forestry, and fishery waste materials is of the greatest significance, both from the standpoint of resources and environmental preservation.

In 1975, a national project to develop novel microbial protein foodstuffs from agro-waste was begun by several research institutes in the Ministry of Agriculture, Forestry, and Fisheries. These efforts are to last until 1980.

Table 1 lists the investigations being undertaken on SCP production by the National Food Research Institute, the National Forest Research Institute, and the Tokai Regional Fisheries Research Laboratory, with the assistance of the associated prefectural institutes. In addition, investigations on methods to assess the safety, feed value, and acceptability of SCP products, as well as the means to pelletize and store them, are being developed by the National Institute of Animal Health and the National Institute of Animal Industry. The most promising current potential wastes for SCP production in Japan are also listed in Table 1. These materials are available in bulk at nominal price, or even at a negative price from the food industries and forest industries.

TABLE 1. Potential Agricultural and Fishery Wastes and Institutes Where Their Utilization Is Being Studied in the Ministry of Agriculture, Forestry and Fisheries

Agro-waste	Amount and property	Micro organisms for SCP	Institutes
Soybean cooking waste	380,000 570,000 tons COD 30,000 ppm	A. oryzae	NFRI*
Citrus waste	350,000 tons	Saccharomyces sp. Candida sp. A. oryzae	NFRI and Ehime Prefectura Inst.

			Chemical Industry
Cellulosic residue	Saw mill waste 22,000,000 tons Rice straw 13,000,000 tons Rice husks 2,400,000 tons	Tricoderma sp. Candida sp.	Natl. Forest Res. Institute NFRI
Fish processing waste	2,700,000 tons, including 160,000 tons of solids	A. tamaril	Tokai Regiona Fishery Res. Lab KFRL**

* National Food Research Institute
** Kushiro Fishery Research Laboratory

Cooking waste results from the processing of miso, typical fermented soybean food in Japan. The treatment to reduce the chemical oxygen demand (COD) before discharging the waste into a river is very difficult because the COD level is so high, and because it is extremely foamy. Consequently, much research has been conducted in this area (1). The subject will be treated in more detail in a later portion of this paper.

Citrus waste is discharged mainly from the juice and canning processing of Citrus unshiu, a popular fruit in Japan. The waste, estimated to amount to approximately 350,000 tons per year, is pressed again after liming to obtain the secondary juice; this juice accounts for 50 per cent of the initial waste (2). The secondary juice, containing about ten per cent sugar, can be used as an SCP substrate. This secondary waste, which is currently dehydrated in rotating dryers for making compound feed, can also serve as a solid medium for fungus cultivation in order to raise its protein level.

A large amount of cellulosic residue is also available in Japan. The key to its use for SCP production is in developing methods to treat the materials in order to produce fermentable carbohydrate economically. Possible treatments of agro-waste materials through mechanical, chemical, and biological degradation are being intensively investigated. For example, using a cryomill, one can obtain, in a short time, a fine rice husk powder of 250 mesh or even smaller particles. The cellulosic powder, which lacks the normal fine-structure crystallinity of cellulose, is easily degrated by enzyme treatment, particularly after delignification with 1 per cent NaOH solution. Cryomill processing is promising because energy for cooling is available as a by-product from the evaporation of liquid natural gas in Japan.

The large amount of waste from the fisheries industry is an urgent problem because of water pollution. Each year, 2,700,000 tons of fish processing waste containing 6 per cent dry matter are discharged from fish meal factories. The dry matter amounts to 160,000 tons, of which 50,000 tons are utilized as feed after condensing and dehydration. The other 110,000 tons have yet to be utilized. An investigation is being undertaken to utilize this waste, which contains protein and oil, as an SCP substrate, employing a fish oil-assimilating fungus, Aspergiflus tamarii, isolated from tamari-miso, which in itself contains a comparatively high level of oil.

Special considerations are paid to the safety of both the ingredients and the microorganisms selected for processing. In screening tests, suitable micro-organisms have been isolated from the traditional fermented foods such as miso, shoyu, and sake in Japan. For example, as shown in Table 2. Aspergillus oryzae, A. sojae, and A. tamarii are widely employed in the fermented food industries. The total amount of koji, the fermented products of these fungi, is approximately 900,000 tons per year. The mycelium content of koli, as determined by Arima (3), differs widely depending upon the ingredients and culture conditions, including duration, temperature, relative humidity, level of oxygen and carbon dioxide in the fermenting facility, and mechanical agitation of the materials. The total amount of mycelium in koji is calculated to be approximately 73,000 tons, which have been traditionally eaten as part of miso, shoyu, sake, and other fermented foods made with koji. This fact is very important for the acceptance of novel microbial protein either as a food or feed prepared with Aspergillus oryzae or its related strains.

TABLE 2. Amount of Mycelium in Aspergillus for Several Kinds of Koji Food Processing in Japan

	Ingredients in koji	Amount (Tons)	Koji (Tons)	Mycelium in koji (%)	Amount (Tons)
Food					
Sake	Rice	120,000	132,000	1.2	1,585

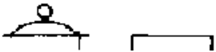
Mirin	Rice	3,000	3,300	2.6	85
Miso	Rice	100,000	106,000	5.0	5,300
	Barley	30,000	31,800	5.0	1,590
	Soybeans	26,000	24,310	16.6	3.560
Shoyu	Soybeans	190,000	350 000	16.6	58,930
	Wheat	190,000			
Miscellaneous	Rice	30,000	31,800	5.0	1,590
Total		689,000	679,210		72,640

Production of yeast from soybean cooking waste at miso factories

Because soybean cooking waste has such a high COD value, it is one of the most difficult of all food industry wastes to treat in Japan. Consequently, there are many devices to treat soybean cooking waste via mechanical, chemical, or biological methods.

In 1970, an industrial co-operative was formed to treat this waste. It was established by nine members from a miso factory at Maruko, Nagano Prefecture (4). This is the sole factory in Japan where SCP is being made from agro-industrial waste, except for factories that make torula yeast from spent sulphite liquor.

As shown in Figure 1, soybean cooking waste is sent to the factory by tank trucks or pipelines directly from the miso factory cookers. After the pH value is adjusted to 4.0 in a serving tank, the waste is transferred into a Waldhof continuous fermenter of 15 kl capacity. In the fermenter, Torulopsis xylinus is cultivated, with an anti-foaming agent, at 30Cat a dilution rate of 0.3 - 0.4 hr(-1) without any other nutrient supplements. Maximum production of dehydrated yeast is 800 kg when 80 tons of waste are supplied and COD is reduced by 70 - 75 per cent. For purpose of lowering production costs, the yeast milk, after washing and heating at 80C for 30 min., is often delivered to neighborhood farms.



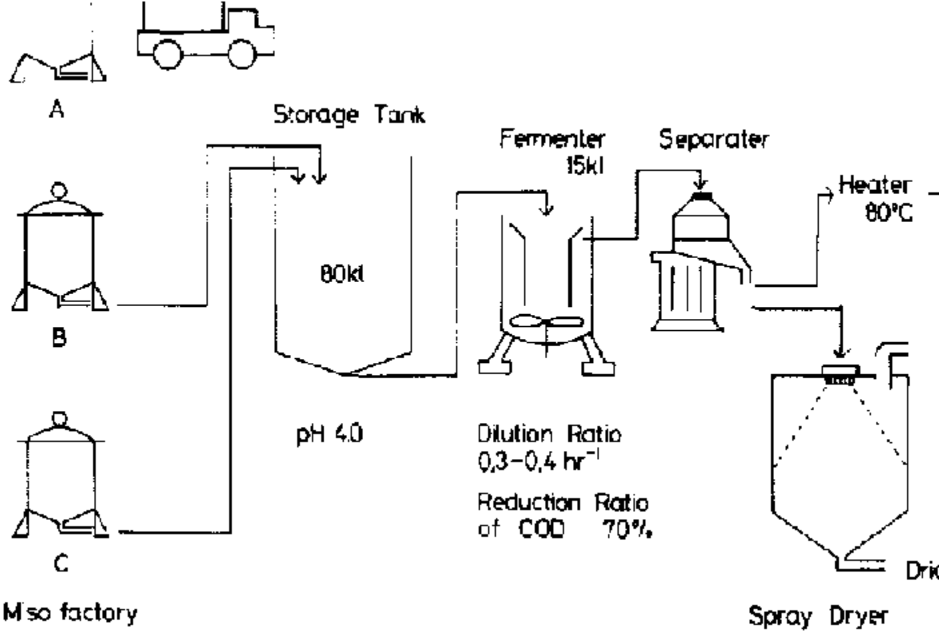

A
Storage Tank
Fermenter
15kl
Separater
Heater
80°C
80kl
B
pH 4.0
Dilution Ratio
0,3-0,4 hr⁻¹
Reduction Ratio
of COD 70%
C
Dri
M'so factory
Spray Dryer

Figure. 1. Flow Diagram of Production of Fodder Yeast from Soybean Cooking Waste

At present, this method has problems that must be solved: (i) the 70 - 75 per cent COD reduction rate should be raised still further; (ii) microbial contamination, originating mainly during transportation of the waste in tank trucks, must be eliminated; and (iii) the process, although small in scale, requires trained technologists to conduct it properly, resulting in higher costs to the consumer.

Application of soy waste as koji substrate for rice miso manufacturing (5, 6)

Milled rice is used for making rice koji, which supplies the necessary enzymes for the fermentation of rice miso. However, during the 48-hour period of koji preparation, approximately 10 per cent of the solids are consumed by the fungi. Soybeans also lose approximately 10 per cent of their solids, though the rate varies widely, depending on soaking and cooking methods. This investigation, there fore, was designed not only to determine the best way to manufacture rice miso, but also to explore the utilization of soybean cooking waste as a substrate for cultivating the fungus, Aspergillus. Soybean waste contains all the nutrients required by Aspergillus and also promotes the fermentation of miso (7). If successful, the results should yield the following advantages:

1) reduction of the COD value of soybean cooking waste by 80 per cent or more;

2) an up-grading of the biomass to food level, and

3) lowering the amount of rice koji needed, thereby eliminating the necessity of using so much expensive rice as an ingredient.

After screening tests employing 28 strains of fungi, including Aspergillus sp., Rhizopus sp., Penicillium sp., and Paecilomyces sp., we selected Aspergillus oryzae FRI-23 for the experiment. It was isolated from commercial tanekoji (fermented brown rice) and proved to be free of mycotoxins.

Soybean cooking waste with a COD of 20,000 ppm gave the highest rate of growth and the best reduction of COD, as shown in Figure 2. Cultivation was conducted at 30C under conditions of 1 vvm at a stirring rate of 400 rpm for 24 hours. At that time, the proteolytic enzyme activity attained a peak. At this stage, except for amylase, most of the proteolytic enzymes, particularly polypeptidases, were found to remain in the cells. As shown in Table 3, except for acid proteinase and amylase, the activity of essential enzyme produced in the cooking waste from 1,000 kg soy beans was higher than that in rice koji made from 700 kg of rice. This fact suggests the possibility of replacing the koji from rice with the mycelium grown in the waste when miso is made from 1,000 kg of soybeans, 700 kg of rice, and 430 kg of salt, or the same ratio of these ingredients.

TABLE 3. Enzyme Activity of Mycelium Made from Soybean Cooking Waste and Rice Koji

Enzyme		Enzyme activity Mycelium (x 1,000)	Rice koji (x 1,000)
Proteinase	(pH 3)	23,200	42,000
	(pH 6)	36,000	35,280
	(pH 7.5)	17,200	15,960
Acid carboxypeptidase		144	84
Leucine aminopeptidase		188	59
Amylase		1.2	1,176

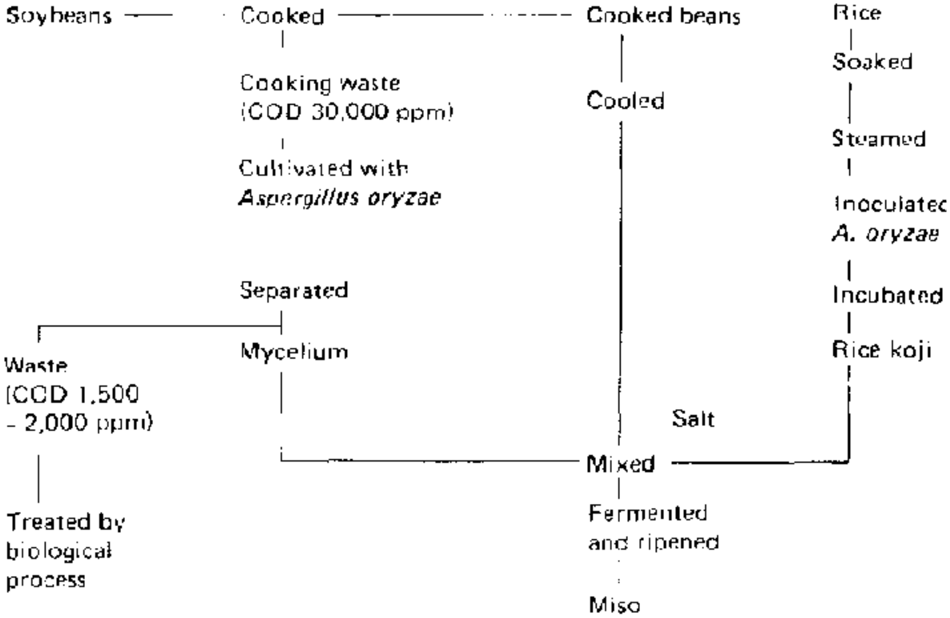

Soybeans
Cooked
Cooked beans
Rice
Soaked
Cooking waste
(COD 30,000 ppm)
Cooled
Steamed
Cultivated with
Aspergillus oryzae
Inoculated
A. oryzae
Separated
Incubated
Rice koji
Mycelium
Waste
(COD 1,500
- 2,000 ppm)
Salt
Mixed
Treated by
biological
process
Fermented
and ripened
Miso

Figure. 2. Flow Diagram of Miso Fermentation with Supplementation of Mycelium Grown in Cooking Waste

The mycelium was forced through a filter cloth and pressed to an 80.5 per cent moisture level. After chopping and grinding, the mycelium was mixed with green miso, prepared by mixing cooked soybeans and salted rice koji with an inoculum that included salt-resistant lactic acid bacteria and yeast. After fermentation, this new type of miso, containing two to five per cent of wet, living mycelium, showed a more advanced fermentation and degree of ripening than did the conventional miso

As illustrated in Table 4, the amounts of amino acids liberated from the protein of the mycelium-containing miso

TABLE 4. Effect of Mycelia on the Liberation of Free Amino Acids and Amides of Miso (mg/100 g)

	Control	67 Days	2%	5%

	0 Days*		Mycelia 67 Days	Mycelia 67 Days
Asp-NH	60	104	176	229
Glu-NH2	103	271	360	428
Lysine	73	188	220	248
Histidine	17	36	42	61
Arginine	133	277	244	221
Asparagine	27	130	154	170
Threonine	30	119	132	188
Serine	41	157	186	232
Glutamine	62	249	311	381
Proline	23	101	109	115
Glycine	12	58	73	92
Alanine	34	125	155	188
Cystine	28	78	71	70

Valine	25	124	149	167
Methionine	17	42	63	70
Isoleucine	18	110	132	153
Leucine	40	223	260	289
Tyrosine	23	143	144	174
Phenylalanine	38	197	189	228

* Immediately after mixing rice koji, soy cooking waste, salt, and water for fermentation.

Mycelium enzyme represents the total amount of enzyme in the mycelium grown in the cooking waste from 1,000 kg of soybeans. Rice koji enzyme represents the total amount of enzyme in the rice koji made from 700 kg of rice were greater than those found in conventional miso. The soy waste mycelium also accelerated the growth and fermentation of the micro-organisms added as starters, thus playing a very important role in the formation of the attractive flavours found in ripened miso.

The amino acid patterns of the mycelium were similar to those in biomass grown on acetate. It is of interest that the content of nucleic acids, including RNA and DNA in mycelium, was 4 per cent on a dry weight basis (Table 5).

TABLE 5. Amino Acid, RNA and DNA Composition of Soybean

Cooking Waste and Mycelia of A. oryzae FRI-23

	Medium* (g 100/ml, 100 g dry mycelia)	Mycelia**
Amino acids		
Asparagine	0.071	3.3
Threonine	0.019	1.6
Serine	0.019	1.7

Glutamine	0.151	4.7
Proline	0.032	1.3
Glycine	0.024	1.5
Alanine	0.020	2.0
Cystine	-	-
Valine	0.018	1.9
Methionine	(0.007)	(0.6)
Isoleucine	0.014	1.4
Leucine	0.022	2.3
Tyrosine	0.014	1.2
Phenylalanine	0.019	5.5
Lysine	0.039	3.0
Histidine	0.016	1.0
Arginine	0.058	1.9

Tryptophan	-	-
RNA	-	3.5
DNA	-	0.5
Crude protein***	0. 11	40. 0

* Soybean cooking waste (COD 20,000 ppm)
** Shaking culture at 30C for 72 hours
*** T.N. x6.25

Conclusion

The utilization of the wastes from the food industries is beset with many problems, among which economic feasibility is of prime importance, particularly for comparatively smallscale factories. As an example of one solution for coping with these problems, the use of soybean cooking waste as a substrate for koji-mould cultivation was investigated. The biomass obtained contributed not only protein and other nutrients, but also enhanced enzyme activity for the fermentation of miso, thus providing an apparent economic advantage.

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Discussion summary

Questions concerning the extent to which SCP production on secondary juice from citrus peel is applied in Japan, and about the economics thereof, cannot be adequately answered until the project is completed in 1980.

is a 3rd World Development private-sector initiative, mastered by Software Developer Alex Weir and hosted by GNUveau_Networks (From globally distributed organizations, to supercomputers, to a small home server, if it's Linux, we know it.)ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

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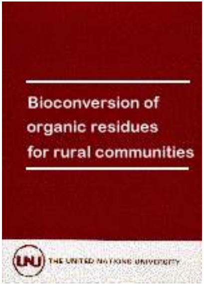

Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Solid state fermentation of starchy substrates

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Introduction

In spite of a combination of currently unattractive economics and political opposition in some quarters, large-scale production of single-cell protein (SCP) will undoubtedly develop soon in industrialized countries in Western Europe and in Japan and the USSR, where the development of new protein sources is becoming an absolute, urgent necessity. A priori, it could also be expected that the SCP industry would provide a contribution to the problem of hunger in the Third World. In this regard, however, there are several major obstacles.

To be economically viable, an SCP production unit should have a minimal capacity of at least 100,000 tons per year, corresponding to a capital cost of US$50 - 70 million. On the other hand, a plant producing 100,000 tons of SCP from paraffins would require an equal supply of substrate and should thus be associated with an oil refinery having a minimal capacity of about 3 to 5 million tons of crude oil per year. Similar considerations apply to the production of SCP from natural gas or from methanol. Such facilities are obviously absent in most non-oil producing countries of Asia, Africa, and Latin America. Moreover, these countries may have neither a potential market nor a transportation and distribution network for the commercialization of 100,000 tons of SCP per year.

Clearly, those countries that cannot currently import food or feeds because of currency shortages will also be unable to import industrial SCPs. Consequently, it is of utmost importance for them to develop their own protein resources. In addition to hydrocarbons and methanol, a wide variety of raw materials potentially utilizable for SCP production might be considered. However, most of them are available at too high a cost to be economically competitive, or exist in quantities too low for protein production on a significant scale. Among the substrates suitable in cost and supply, special emphasis is usually put on cellulosic materials, but, at the moment, the many attempts made in this direction have had little success, the main difficulty being the lack of cellulolytic organisms with an adequate growth rate.

In contrast, starchy materials, more specifically cassava in the tropical regions or potatoes in temperate climates, are of obvious interest because of both high productivity per hectare and excellent rate of conversion to biomass by a great number of fast-growing micro-organisms.

In order to be economically competitive, the production of protein from starch should not be undertaken by classical fermentation in liquid medium, under aseptic conditions, followed by biomass separation and drying. As in the case of SCP production from paraffins or methanol, the optimization of such sophisticated technology would require a minimal production of well over the potential market of most developing countries, and would result in high investment and operation costs. Moreover, in the developing countries, the collection, transportation, and storage of large quantities of raw materials would result in major difficulties. Considering these factors, a more practical approach would be to enrich starchy materials with protein by means of a simplified technology that can be applied at the farm or village level, and that would allow the combination of cultivation of raw material, its conversion into protein, and its direct utilization for animal feeds.

Economically, a great and decisive advantage of such an integrated procedure is to prevent intermediary profits and speculation that would inevitably take place if either the raw material or the final product were commercialized.

To be workable at the farm level, a protein enrichment process should not require aseptic conditions, and should be performed in a single operation. Additionally, the product must be sufficiently rich in protein to be utilizable as such, without a secondary fortification step. This last requisite creates a biotechnological difficulty that has been responsible for the failure of many previous attempts to achieve direct protein enrichment of starchy materials. In a mash of raw material dense enough to be directly utilized for animal feeding, the major problem is to maintain aerobic conditions and oxygen transfer efficiency so as to prevent anaerobic contamination of the culture.

A new procedure of solid state fermentation (1) fulfilling the above specifications was developed in collaboration with Drs. M. Raimbault and F. Deschamps at the French Office de la Recherche Scientifique et Technique d'Outre Mer (ORSTOM), and the Institut de Recherche en Chimie Applique (IRCHA), respectively. A preliminary report on this procedure has already been presented (2) at the 5th International Conference on the Global Impacts of Applied Microbiology, held in Bangkok in November 1977.

Materials and methods

Tempeh and many other food preparations obtained by solid state fermentation of soybeans or other materials with filamentous fungi (3 - 5) are traditionally used in various parts of Asia and Africa. On the other hand, procedures for direct protein enrichment of cassava by liquid (6, 7) or solid state fermentation have been described. However, protein enrichment by these methods does not exceed 3 - 4 per cent, and therefore is insufficient for use as a complete feedstuff. The principle of the new procedure devised by ORSTOM and IRCHA for protein enrichment of cassava and other starchy materials is summarized in Table 1.

TABLE 1. Protein Enrichment of Cassava by Solid State Fermentation

Initial substrate (g)	
Cassava flour*	100
SO4 (NH4)2	9
Urea	2.7
PO4 KH2	5
water	100 - 120
Optimal growth conditions	
T: 35 - 40C; initial pH: 3.5	
Inoculum: 2 x 107 spores/g flour	
Incubation time: 30 hours	
Composition of the product	
Protein**	18 - 20% in dry matter

Residual sugar***	25 - 30% in dry matter
Water	63%

* Carbohydrates: so per cent; protein: 1 per cent; water: 30 - 35 per cent.
** Determined by the Lowry method.
*** Determined by enzymatic hydrolysis (amyloglucosidase) and Somogyi-Nelson titration

All of the operations are conducted in a commercial dough mixer of ten kg capacity, modified for that purpose. The coarsely ground raw material, with 30 - 35 per cent moisture content, is gently steamed for 15 - 20 minutes to break the starch granules. After cooling to 40C, the preparation is mixed with water containing the inoculum (spores), the nitrogen sources (ammonium sulphate and urea), and mineral salts, to 55 per cent final moisture content. After mechanical stirring, the inoculated substrate spontaneously takes the form of well separated and uniform granules of about 1 mm diameter.

Aeration is performed by passing humidified air through the perforated bottom of the tank. Conventional probes are used to monitor, after mixing and water spraying, the temperature, pH, and moisture content. To date, all experiments have been performed with a selected strain of Aspergillus niger having high amylolytic activity and suitable amino acid composition However, other filamentous fungi could be utilized as well.

With the organism currently utilized, the optimal temperature is +40 C, but growth still takes place at temperatures from +30 to +45 C without significant changes in the final protein yield. The initial moisture content is critical, with an optimum of 55 per cent. In the course of fermentation, the water content is progressively increased to a final value of 70 75 per cent.

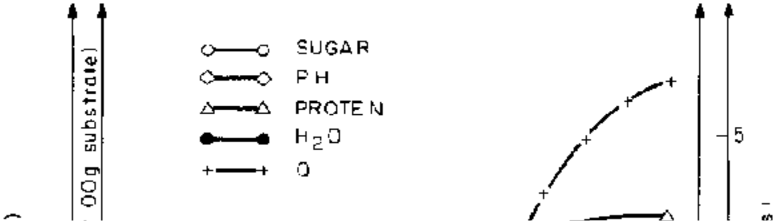
This method of protein enrichment has already been worked out with a variety of starchy materials, namely cassava, whole potatoes, potato waste from industrial starch works, and banana refuse. The results are summarized in Table 2, showing that, after

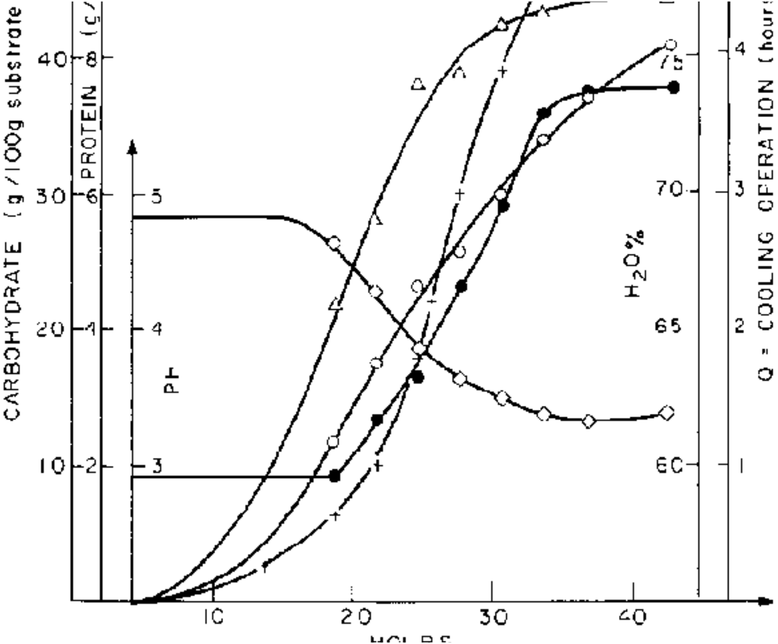
30 hours of incubation, a product is obtained that contains, on average, 20 per cent true proteins, measured by the Lowry method, and 25 per cent residual reducing sugars. The rate of conversion of carbohydrates to protein is 20 to 25 per cent, corresponding to 40 to 50 per cent conversion into dry weight biomass.

TABLE 2. Protein Enrichment of Various Raw Materials

	Initial composition		Final product	
	Protein %	Carbohydrate %	Protein %	Carbohydrate %
Cassava	2.5	90	18	30
Banana	6.4	50	20	25
Banana waste	6.5	72	17	33
Potato	5.0	90	20	35
Potato waste	5.0	65	18	28

The kinetics of a fermentation on potato waste are shown in Figure 1, illustrating the production of protein, reducing sugars, water content, and the pH of the preparation. The curve, marked by crosses, is of special interest. It shows that, during a total incubation time of 30 hours, the monitoring devices for mechanical stirring and water spraying had to operate for only five hours, thus demonstrating the excellent efficiency of the cooling device. Additionally, it requires a remarkably low expenditure of power, a fact of obvious importance in regard to the production cost of solid state fermentation and to its economic feasibility at the farm level in tropical regions.




CARBOHYDRATE (g /100g substrate
PROTEIN
pH
$H_2O\%$
Q = COOLING OPERATION (hours
10
20
30
40
2
4
6
8
3
4
5
60
65
70
75
1
2
3
4

HOURS

Figure.1. Solid State Fermentation of Potato Waste

It has been pointed out that, owing to perfectly aerobic and highly selective conditions, no aseptic precautions have to be taken, and sporulation of the mould is totally inhibited. Nutritional and toxicological tests on rats and chickens are in progress, and the preliminary results are quite satisfactory, showing a nutritional value similar to that of soybean meal.

Currently, the studies on solid state fermentation are being actively developed in France by ORSTOM and IRCHA in close collaboration with the Applied Scientific Research Corporation of Thailand. The scaling-up of the process to a fermenter unit of 1 m has been undertaken and is in progress. This equipment, which is expected to be operative in the coming months, will be utilized for large-scale nutritional and toxicological testing on target animals (pigs and poultry), for further optimization of substrate preparation and growth conditions, and for determination of the actual investment and operation costs. It is intended that the experimentation will be extended to the setting up of experimental production units in tropical Asia and Africa, in order to adapt the procedure to local climatic and agro-economic conditions.

Agro-economic perspectives

As already pointed out, the two main sources of starch potentially available for protein enrichment are cassava in tropical regions and potatoes in temperate climates. Protein enrichment of cassava is of special interest in those semi-arid regions of Latin America and Africa where climatic conditions are not suitable for the cultivation of soybeans or other protein-rich feeds.

The productivity of cassava per hectare varies widely from one region to another, depending on climatic and agro-technological conditions. From about 16 tons (harvested weight) per hectare in northeastern Brazil, the yield can be easily increased by the use of fertilizers and by improved cultural practice to 40 and even 60 tons per hectare. Other advantages of cassava are low production costs, easy storage in the soil for several months, and the fact that cassava is also an excellent source of calories.

On the basis of a productivity of 40 tons per hectare and 20 per cent protein enrichment via solid state fermentation, cassava or potatoes may provide 2.4 tons of protein per hectare, i.e., the supply required for the feeding of 65 pigs (Table 3). This is about four times the quantity of protein per hectare provided by soybean cultivation in the United States. The crop yield and protein productivity per hectare of other protein sources conventionally utilized for animal feeding are reported in Table 4.

TABLE 3. Agro-Economic Prospects of Cassava Enrichment

A. Productivity of raw material and of protein	Cassava	Soybeans*
Raw material (tons/ha)	40	1.8**
Moisture content (%)	70	-
Protein (tons/ha)	2.4***	

	0.6	

B. Conversion into animal product (pork)****

Alimentary conversion rate (units of feed per unit liveweight gain)	3:1
Protein consumption:	
birth to weaning†	11.3 kg
- weaning to slaughtered††	25.5 kg
- total†††	36.8 kg

C. Overall agro-economic prospect

(1) Protein productivity per hectare: protein-enriched cassava versus soybeans:

c.a. 4:1

(2) One hectare of cassava can produce, via solid state fermentation, enough protein for feeding:

c.a. 65 pigs

* 34 per cent protein.
** data from U.S. Department of Agriculture.
*** for 20 per cent protein enrichment.
**** From: C.A. Shacklady, in G. de Pontanel (ed.), Proteins from Hydrocarbons, pp. 115 - 128, Academic Press, New York, 1972.

† Birth to weaning: 70 days; + 25 kg; diet with 15 per cent protein.

†† Weaning to slaughter: 130 days; + 85 kg; diet with 10 per cent protein.

††† Total: 200 days; 110 kg.

TABLE 4. Optimal Productivity of Protein-Rich Feeds

	Total yield (tons/ha)	Protein Content %	Tons/ha
Soybeans	1.8	34	0.6
Rapeseed	3.0	23.3	0.7
Sunflower	2.5	22	0.6
Horse bean	3.2	28	0.9
Peas	3.0	25	0.75
Protein-enriched cassava	12.0*	20	2.4

* 40 tons per hectare of cassava with 70 per cent moisture content.

Based on prices in October 1978 and on the average yields of agricultural products, a comparison can be made of the gross product per hectare of corn, wheat, soybeans, and protein-enriched cassava. The figures in Table 5 strikingly demonstrate the economic advantage of protein enrichment by solid state fermentation. In the case of cassava, the value of the residual sugars (25 per cent dry weight) should increase the gross product figure by about 10 per cent. On the other hand, for a rural community combining the production of raw material with protein enrichment and direct utilization for animal feeding, the actual gross product should be estimated, not from the commercial value of protein, but from the value of the feedstock produced. Moreover, as already pointed out, one of the major agro-economic advantages of proteinenriched cassava is the possibility of feedstock production in regions where no other suitable source of conventional feed protein is available.

It is obvious that the economic competitiveness of protein enrichment by solid state fermentation depends ultimately on the investment and production costs of the process. It would be premature to propose a really accurate estimate in this regard, and information must be obtained from pilot operations at the farm level. However, based on its present state of technological development, and on the data reported in Table 5, the conclusion is that the process will prove valuable.

TABLE 5. Comparison of Productivity and Gross Product per Hectare

	Average yield (tons/ha)	price* (US$/ton)	Gross product (US$/ha)	Comparative gross product
Corn	6	82.9	497.4	114
Wheat	5	127.7	638.5	147
Soybeans	1.8	241.8	435.2	100
Protein-enriched				
cassava	12**	485.4***	1165.0	268

* On 29 September 1978.

** Cassava: 40 tons per hectare, with 70 per cent moisture, dry product containing 20 per cent protein.
*** Estimated from current price (US$213.6, Rotterdam, cif) of soybean meal with 44 per cent protein.

Summary

Protein enrichment of starchy materials was achieved by a simple, inexpensive process of solid state fermentation not requiring aseptic conditions and workable at the farm or village level for direct animal feeding. From cassava, banana refuse, potatoes, and other substrates potentially available in tropical or temperate climates, the process provides foodstuffs containing up to 20 per cent protein and 35 per cent residual sugars. On the basis of 40 tons productivity (harvest weight) per hectare, cassava and potatoes could thus provide four times more protein per hectare than is obtained by soybean cultivation. Hence, its agro-economic prospects compete favourably with the cultivation of corn, wheat, and soybeans.

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Discussion summary

Regarding the yield of biomass from fungal treatment of cassava, approximately 50 per cent of the starch is converted, in the course of which the percentage of protein content in the starting material is increased between ten- and twenty -fold.

CD3WD (680 Megabytes) and distribute it to the 3rd World. CD3WD is a 3rd World Development private-sector initiative, mastered by Software Developer Alex Weir and hosted by GNUveau_Networks (From globally distributed organizations, to supercomputers, to a small home server, if it's Linux, we know it.)ar.cn.de.en.es.fr.id.it.ph.po.ru.sw

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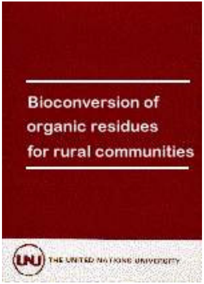

Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Production of single-cell protein from cellulose

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Introduction

Production of food, fuel, and chemicals is one of the primary requirements for the development and welfare of a society. During the past decade, the pattern of agricultural production has shifted in the world in such a manner that most of the countries around the world are not self-sufficient in their food production. The present shortage and impending depletion of fossil fuels place certain constraints on increasing agricultural productivity even in industrially developed countries. Further constraints are placed on the developing countries in meeting their food needs because of low productivity in agriculture and a steady increase in population. The race to catch up with the need for food by modernization of agriculture is steadily being lost to the burgeoning populations in several areas of the world. Thus, the necessity for exploring unconventional, non-agricultural means of food production, especially of proteins, cannot be over-emphasized. Production of microbial proteins or bioproteins by fermentation of agricultural waste products is one of the most promising approaches for increasing the availability of proteins in the world.

During the past several years, we have concentrated our efforts in developing fermentation of cellulose by micro-organisms. Cellulose is the major constituent of all agricultural wastes. Also, as a renewable resource, it is plentifully available for utilization as a substrate for fermentation of non-wood plant fibrous raw materials. The potential availability of such natural raw material is presented in Table 1 (1).

TABLE 1. Estimated Availability of Specific Non-Wood Plant Fibrous Raw Materials

Raw materials	1,000 metric tons
Sugar-cane bagasse	55,000
Different straws (wheat, rice, oat, etc.)	88,500
(Bast fibres kute, kenaf, etc)	6,099

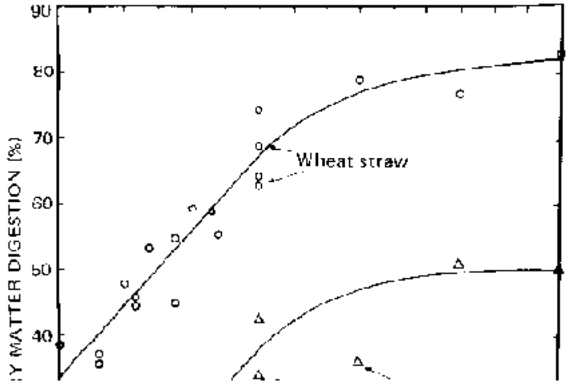
Leaf fibres (sisal, abaca)	904
Reeds	30,000
Bamboo	30,000
Papyrus	5.000
Esparto grass	500
Sabai grass	200
Cotton fibre	13,500
Total	229,703

Source: Virkola (1).

Cellulose, however, does not occur in pure form. It is always associated with lignin and hemicelluloses. Thus, naturally occurring cellulose is not readily susceptible to microbial attack. Hence, it is essential that the cellulose be previously treated, by either physical or chemical methods, to facilitate the growth of micro-organisms (2).

Reduction of particle size of ligno-cellulosics leads to an increase in their susceptibility to microbial fermentation. This has been accomplished with both wet and dry raw materials. Either very fine grinding or ball milling has been the usual procedure. These methods require a high amount of energy, and hence add considerable cost to the overall production of biomass. Other physical methods for particle size reduction make use of sonic energy, cryogenic grinding, or extremely rapid depressurization with steam to cause multiple fractures within the cell walls of natural fibres, thereby increasing the total surface area. Some of the possible chemical methods of treatment include: (i) treatment with gaseous sulphur dioxide; (ii) alcoholysis of lignin with methanol or ethanol containing small amounts of hydrochloric or sulphuric acids; (iii) degradation of lignin under mild acid conditions; (iv) extraction of lignin by organic solvents such as acetone, dioxane, or others in the presence of mild acids, and (v) treatment with sodium hydroxide or ammonia to swell the cellulose fibres and solubilize lignin and hemicelluloses.

Alkali treatment has been the method of choice in all our investigations of cellulose fermentation. In this process, cellulose is steeped in 5 - 10 vol of 1 N sodium hydroxide and heated for 15 - 30 minutes at 100 - 120 C. In order to illustrate the efficacy of alkali treatment, some of the results obtained by Wilson and Pigden (3) on the in vitro digestion of wheat straw and poplar wood are presented in Figure 1.



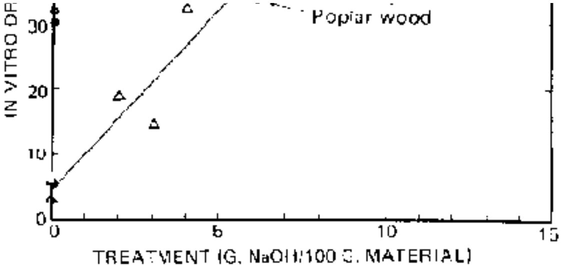


Figure. 1. Effect of Sodium Hydroxide Pre-Treatment on the In Vitro Digestion of Wheat Straw and Poplar Wood

There are only a few organisms that can attack "native" cellulose. However, when cellulose is treated or modified before micro-organisms are introduced, the choice of available organisms increases greatly. Table 2 presents a few selected organisms that have been investigated in the biodegradation of ligno-cellulosics (4 8).

Peitersen (4).** Chahal and Wang (5).*** Eriksson and Larsson

(6).+ Daugulis and Bone (7).++ Humphrey et al. (8).

This paper describes the "state of the art" in our laboratory investigations on the biodegradation of cellulose by microorganisms, leading to the production of single-cell protein.

Experimental results

The investigations carried out to date are as follows:

a. studies on bacterial fermentation of cellulose using Cellulomonas as the main organism;

b. Aspergillus terreus as SCP from cellulose;

c. growth of yeast on cellulosic substrates.

Studies on Bacterial Degradation of Cellulose

The primary objective in all earlier investigations was to optimize the growth environments of Cellulomonas in such a manner as to increase the rate of degradation of alkalis treated cellulose, and thereby increase the productivity (biomass produced per unit volume per unit time). The problem was investigated in three different sets of experiments: (i) symbiotic growth of Cellulomonas with organisms having the ability to grow on cellobiose as the sole carbon source; (ii) mutation of the parent strain of Cellulomonas by chemical mutagens, and isolation of strains with less fastidious requirements for growth, and (iii) studies on the physiology of the organism in continuous culture with a view towards making the best use of the constituents in the nutrient medium to promote maximum growth. Based upon observations from studies of continuous culture, a simple technique known as gradient feed was developed for growing cells at high densities in batch cultures in laboratory fermenters (9). The experimental results obtained so far from batch fermentations of Cellulomonas are summarized in Table 3.

All cellulose substrates were treated with NaOH** Fermentations were carried out at controlled pH at 6.8 in New Brunswick 7-litre fermenter at 35 C.

Investigations on continuous cultivation of Cellulomonas were conducted with glucose as the carbon source. Although our main interest is in growth of the organism on cellulose, glucose was initially chosen as the substrate in order to understand the basic physiology of the organism, which is more easily observed using glucose. During these experiments, we noted that trace elements in the medium play an important role in regulating the growth rate of the organism. The minimum concentration of Zn(++) ion required for maintenance of steady states at different dilution rates was examined. Moreover, the macromolecular composition of the organism at different dilution rates was determined (Figures 2, 3). As seen in Figure 3, RNA content in the cell is lower in Zn(++). This is indeed an interesting observation, for this may provide a method of decreasing the total nucleic acid content of the cell.

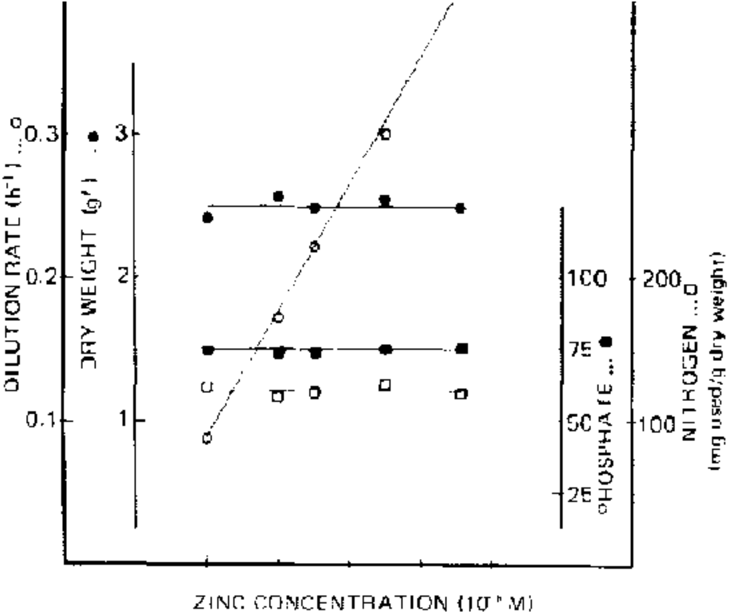

DILUTION RATE (h⁻¹) ...o
0.3
0.2
0.1
DRY WEIGHT (g⁻¹) ...
3
2
1
100
75
50
25
PHOSPHATE ...
200
100
NITROGEN ...□
(mg used/g dry weight)
ZINC CONCENTRATION (10⁻⁸ M)

Figure. 2. Variation of the Dilution Rates Dependent upon the Minimum Concentrations of Zn(++) in the Influent for the Maintenance of Constant Biomass at Steady State during Cultivation of Cellulomonas in a Chemostat Dilution Rate

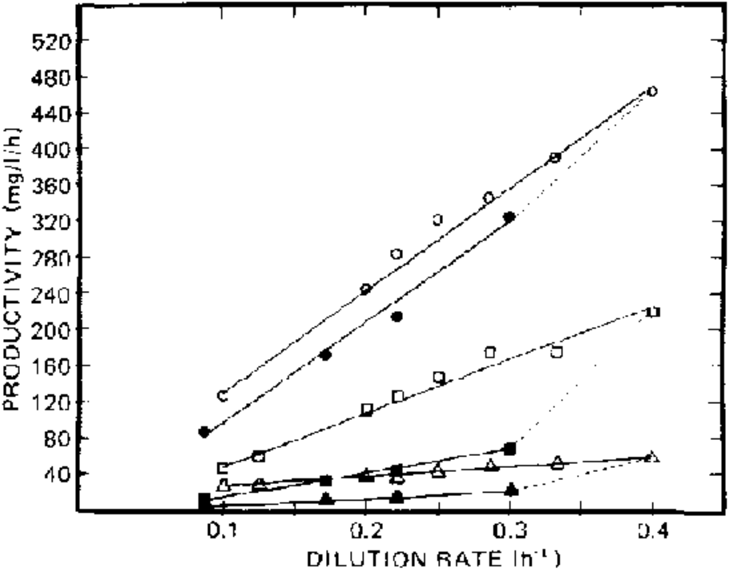


Figure. 3. Macromolecular Composition of Cells of Cellulomonas in a

Chemostat under Conditions of Minimum and Excess Amounts of Zn(++) in the Nutrient Feed

Studies of Cellulose Degradation by Asporgillus terreus

Microfungi have attracted but little attention as single-cell proteins for two reasons: (i) fungi are supposedly slow-growing, and (ii) they may produce mycotoxins during cultivation. However, they have several advantages. They can be grown at low pHs and thereby minimize the problem of contamination. Because of the size of the organisms, they may be more economically harvested out of the fermentation menstruum. A number of fungi have growth rates exceeding 0.20 hr(-1) sufficiently fast enough for consideration for the production of SCP (10). Gray has shown that filamentous fungi have been used widely by man either directly or indirectly for food (11). Mycotoxins are produced only by a few organisms in stationary phase as secondary metabolites, and they are synthesized only at a particular stage in the life cycle of the organism. Hence, even in fermentations with such organisms, it may be possible to inhibit the production of toxins by growing the organism at fast growth rates. We have, therefore, attempted to develop a fungal fermentation on cellulose.

We have screened for several fungi and isolated a cellulolytic strain of Aspergillus terreus for further study. Preliminary experiments showed that the organism has the potential to grow on a variety of carbon substrates such as glucose, lactose, cellobiose, and starch as well as on cellulose. Although the germination of the spores required additional growth factors from yeast extract, mycelial growth occurred on carbon substrates in a simple minerals medium. The organism exhibited growth over a wide range of pHs (3.5 to 7.0) and temperatures (30 to 45C).

A typical experiment on the growth of Aspergillus terreus on different cellulosics is presented in Table 4. The fermentations were conducted in New Brunswick equipment fitted with 7-litre vessels with a working volume of 5 i. The temperature was maintained at 35 C, and pH was kept constant at 3.5 with an automatic pH controller. No undue precautions were taken with regard to conditions of sterility. The mass doubling time at the initial phase of fermentation was approximately 5.5 - 6 hours. The final product of fermentation consisted of filamentous fungi and undigested cellulose. Very few contaminating organisms, predominantly yeast, were detectable in the product. Attempts were made to grow the organism on treated bagasse (2 per cent) in a 100-litre fermenter under non-sterile conditions as batch fermentations. The final product contained between 20 - 22 per cent protein. All our efforts to run the fermentation as a semi-continuous operation proved futile because of contamination.

TABLE 4. Growth of Aspergillus terreus on Cellulose

Expt.	Carbon source	Inoculum size g/l	Biomass (after 20 hr)g/l
1	Solka-floc	1.5	9,0
2	Bagasse	1.2	8.0

3	Bagasse pith	0.8	5.2

The experiments were conducted in 5-litre volume with a substrate loading of 3% at a temperature of 35 C. The pH was kept constant at 3.5. The fermentation was carried out under non-aseptic conditions.

A series of experiments on the continuous cultivation of Aspergillus terreus were conducted using treated solka-floc as the carbon source. A 5-litre working volume was used in these experiments, which were carried out under aseptic conditions. Because of the difficulty of pumping a slurry of cellulose continuously, a substrate level of only 0.15 per cent was used. The experiments were run at different temperatures and pHs. Steady state values were maintained for at least eight residence times before samples were taken for analyses. The results obtained from a few such experiments are summarized in Table 5.

TABLE 5. Continuous Cultivation of Aspergillus terreus on Alkali-Treated Solka-Floc

Expt.	Dilution rate hr(-1)	Temper-ature C	Dry wt. of biomass mg/l	True protein content mg/l	Residual cellulose mg/l	Percent utilization of cellulose
1	0.1	35	868	214	330	78
2	0.11	35	870	196	250	83
3	0.14	40	780	191	270	82
4	0.14	44	737	180	200	87

The experiments were run with a substrate concentration of 0. 15% cellulose The pH was maintained at 3.8 with an automatic pH controller, working volume 51.

As seen in the table, 80 - 85 per cent of the cellulose substrate was assimilated on a continuous basis with a productivity of 103 mg/l/hr when the substrate loading was kept constant at 0.15 per cent. On a commercial scale, substrates may be introduced into the fermenter at a level of 5 per cent. If we allow the luxury of extrapolating, at the present state of the art, a productivity of 3.4 g/l/hr might be achieved. An economic estimate of the process has been made with the following assumptions: 300 days operation of a plant volume of 40,000-litre capacity producing 800 metric tons of product per year containing 25 - 30 per cent crude protein from bagasse. The unit cost of production is approximated at US$180/ton.

The next phase in the development of the project requires pilot studies in an industrial site to solve the problems of scaling up and testing the product for its usefulness as animal feed.

Experiments on the Degradation of Cellulose by Yeast

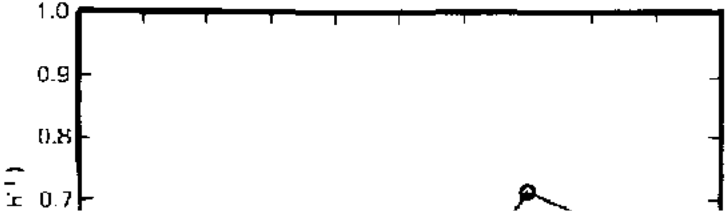
There are only a few investigations on the degradation of cellulose by yeasts reported in the literature (12, 13). After having successfully completed the experiments on Aspergillus, it was of interest to study the growth of yeasts on cellulose, based upon the knowledge gained during the investigations on the growth of Cellulomonas as well as Aspergillus. A cellulolytic yeast was isolated from piles of sugar-cane bagasse and tentatively identified as a strain of Trichosporon cutaneum. The organism had the ability to grow on several carbon sources, and Table 6 presents the specific growth rates of the organism on different substrates. An 0.5 per cent carbon source was used in all of these experiments. The pH was initially adjusted to 7.0 and the temperature was kept constant at 35 C. Turbidity was measured at intervals with a Klett-Summerson photo-electric calorimeter, and the maximum specific growth rates were calculated from the kinetics of growth.

TABLE 6. Specific Growth Rates of Trichosporon cutaneum on Different Carbon Sources

Expt.	Carbon source	Sp. growth rate

	(0.5% w/v)	
1	Glucose	1.06
2	Cellobiose	1.00
3	Lactose	1.03
4	Maltose	0.81
5	Carboxymethyl cellulose	0.76

Similar experiments were carried out to determine the characteristics of growth of the organism on carboxymethyl cellolose at different temperatures and pHs. In the experiments on the effect of pHs on the growth of yeast, only the initial pH was established and no attempts were made to control the pH during the course of the experiments, because they were only short term and the measurements were completed over a period of six to eight hours. The organism grows well at a temperature between 30 - 40 C, and optimally at about 35C. Figure 4 presents the specific growth rates at different pHs. Growth of Trichosporon cutaneum on treated cellulose was fairly rapid. However, during the period of growth, cellulase was bound to the cells during the rapid growth phase, and no detectable amount of the enzyme was found in the supernatant fluid after harvesting the cells from the culture. Figure 5 illustrates the growth of, and cellulose production by, the organism grown on 0.5 per cent treated cellulase in batch culture at 35C. Cellulase activity was determined by measuring the reducing sugar released from 0.5 per cent CMC incubated with 10 ml of the supernatant fluid or cells from 10 ml of the culture. During the incubation of the cells for measurement of cellulase activity, 10 g/ml of cyclohexamide was used to inhibit further enzyme synthesis.



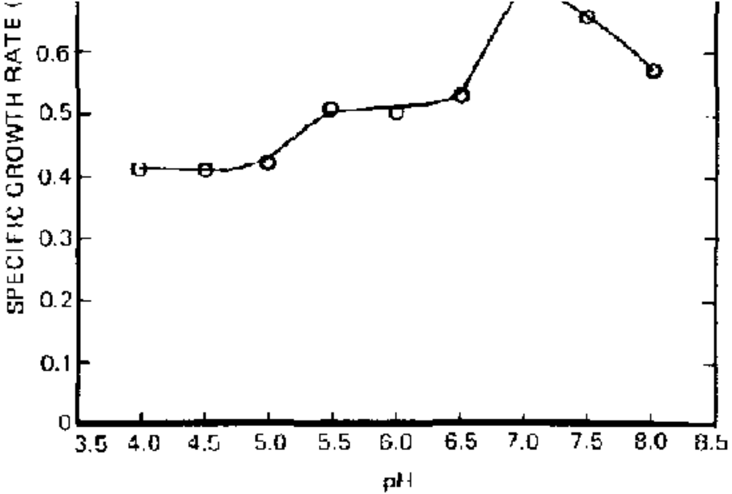
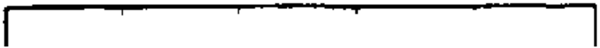
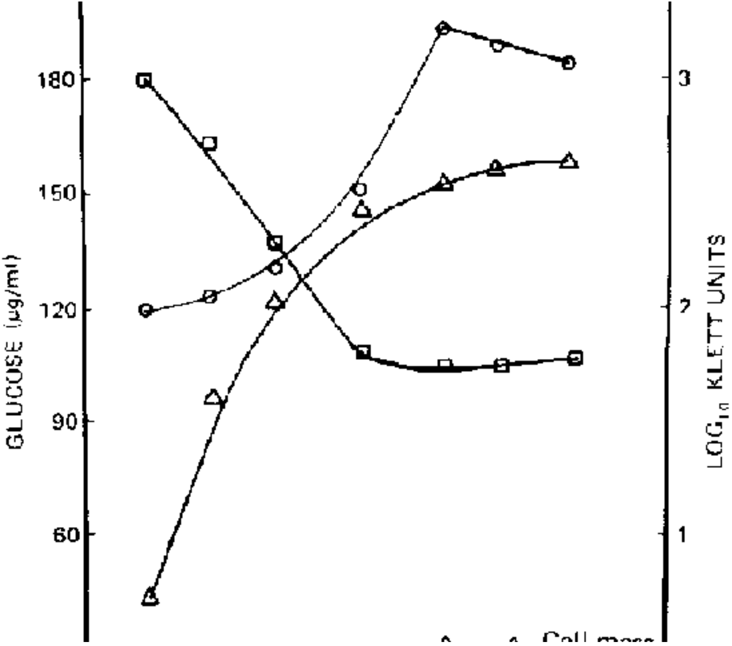


Figure. 4. Effect of pH on the Specific Growth Rate of Trichosporon cutaneum Grown on Carboxymethyl Cellulose as the Carbon Source




GLUCOSE (µg/ml)
180
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2
1

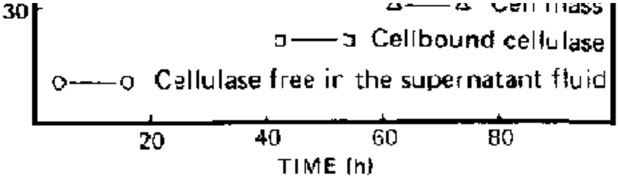

Figure. 5. Growth of Trichosporon cutaneum and Secretion of Cellulase by the Organism Grown on Treated Solka-Floc

TABLE 7. Solubilization of Different Cellulose Substrates by Trichosporon cutaneum

	Percent solubilization after 72 hrs	
Carbon substrates	Alkali-treated	Non-treated
Solka-floc	64.3	28.6
Rice husk	44.4	22.2
Newsprint	33.3	6.6

Sisal fibres	44.4	40.7
Bagasse pith	38.5	30.7
Bagasse fibres	50.0	32.5

The medium contained 0.5% of cellulose at the time of inoculation. The organisms were cultivated in 250 ml flasks containing 50 ml of medium. The cultures were aerated on a gyrotary shaker kept at a constant temperature of 35C.

Table 7 shows the ability of the organism to solubilize cellulosic substrates. After 72 hours of growth of the organism on different substrates, the residual cellulose was determined by the method of Updegraff (14). Per-cent utilization was calculated by the formula

$$\frac{C_I - C_F}{C_I} \times 100$$

where CI = initial amount of cellulose in the medium, and

CF = residual cellulose left after 72 hours of growth.

Studies on the continuous cultivation of the organism on CMC are in progress to determine the kinds and amounts of nutrients required for maximum productivity.

Discussion

The experiments described in this paper clearly show that there are several approaches to the development of a successful technology for fermentation of cellulose. As mentioned earlier, cellulose occurs complexed with hemicelluloses and lignin in nature. Thus, if fermentation is to be developed on native ligno-cellulosics, we have to deal with at least three different types of carbon compounds as substrafes, namely, short-chain pentose polymers, complex aromatic polymers built from phenyl-propane units, and insoluble, large molecular linear polymer cellulose. In general, microbial growth on more than one substrate tends to lower the overall growth rate. Hence, the productivity of the fermentation may, in all probability, be lower on mixed substrates with a single organism (6) than on the different components of the mixture if used singly.

However, the productivity on mixed substrates may be increased with a system of several microbes whose populations can coexist commensally or neutrally (15). With the latter approach it may be difficult to obtain, from fermentation, final products of uniform composition. In order to ensure the reproducibility of composition of the product, our efforts have been directed to examine microbial growth on treated cellulose with a single organism under aseptic conditions.

Of all the three systems of micro-organisms discussed, the technology for SCP production with Aspergillus has advanced farthest. Although our initial intention was to develop a lowlevel technology for producing fungal protein under non-sterile conditions, it became apparent that, with the present knowledge on cultivation of Aspergillus, it may be much more economical to produce SCP by continuous cultivation under aseptic environments. To date, this is the first report on continuous cultivation of a micro-organism for the production of SCP with 80 - 85 per cent assimilation of cellulose. It is almost tempting to speculate that, with further development of the process on the pilot fermenters, the problems of scaling up can easily be overcome and that the production of SCP from cellulose is on the verge of becoming a reality.

Summary

Three different systems (bacterial, fungal, and yeast) of microbial degradation of cellulose have been described. At the present state of the art, the most promising technology is singlecell protein production by Aspergillus terreus. Continuous cultivation of Aspergillus terreus on treated solka-floc with more than 80 per cent utilization of cellulose indicates that SCP production from cellulose is economically feasible on a commercial scale. The importance of basic studies on the physiology of the organism under conditions of continuous cultivation in a chemostat was discussed.

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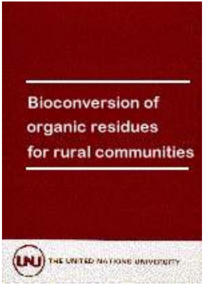
Discussion summary

The comment was made that high conversion rates are readily obtained on low concentrations of substrate.

What would be the effect of high substrate concentrations? Srinivasan's reply was that the arheology of concentrated substrates makes them difficult to handle in continuous fermentation systems. He felt that batch fermentations, though not subject to this limitation, have other disadvantages that reduce their attractiveness in the processing of cellulosic residues.


Bioconversion of
organic residues
for rural communities
UNU

Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Analysis of energy cost of integrated systems

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In recent years, there has been a burgeoning interest in what is sometimes called the "energy cost" of goods and services. The purpose of this paper is to explain what is meant by "energy cost" and how such numbers can usefully be employed to evaluate systems, such as the conversion of organic residues. In doing so, I must touch on the methodology used to obtain the numbers, but this does not represent a major part of the paper, for it is liberally described in the literature (1, 2).

Energy cost and energy requirement

The words "energy cost" are no longer used among professional energy analysts. Cost is a word reserved for money, and the term now used is "energy requirement", and the process of analysis, energy analysis. Energy cost is relegated to its old meaning, that is to say, the cost (in money terms) of energy used. Money cost is what must be paid in the marketplace to buy a product or have a service rendered. By the time it reaches the market, that cost reflects all the inputs that have gone into making the product or providing the possibility of the service, including raw materials, energy, labour, profit, rent, royalty, interest, and so on. Only experience with the market allows judgement on whether the price is fair or exorbitant.

It is important to note that money cost can be judged by experience - an empirical process. If I am suddenly transported to a country with whose currency I am unfamiliar and seek to buy a shirt, I am at a loss to know whether I am getting a bargain or being cheated. I need much experience with that currency before I can make sensible economic decisions. This is because money is a value judgement, an abstraction. It has neither weight nor volume nor intensity. It is not a vector. It is a singularly clever invention, and because we all grow up with money as an everyday part of our lives, we have a feeling for it, but, as many learned works have demonstrated, no one quite under stands it, and as a device for estimating future costs it becomes steadily less reliable as we move into the future. Economists try to circumvent this by carrying out their accounting in constant money units, such as the current dollar, but even this invention fails eventually, because in due course what represents the average basket of goods changes, so like is no longer being compared with like. Nevertheless, money, as a basis for making an economic decision today about today, has no equal. Only as the future approaches does money fail us.

It was in this environment of uncertainty about money that energy as a numeraire of "cost" entered the picture. it was, of course, stimulated by the 1973 oil crisis, which for a time gave many people the feeling that the world was about to run short of energy. Unfortunately, as a result, energy analysis came to be associated with a pessimistic view of resources, and was thus instinctively rejected by anyone of a more optimistic turn of mind. It was also rejected by the economics profession (3). Energy analysis, with its methodological procedure for finding the energy requirement to provide a given good or service, is now an accepted activity, with reasonably well defined conventions. It is the job of energy analysts to use the numbers derived to interpret situations in the same way as economists use the computations of accountants or statisticians as the starting point for their broad analyses. Very rarely does an economist do an accountant's work, however. Some energy analysts do both the accounting and the analysis. Such is the nature of a young discipline.

To return to the words "energy requirement", they were chosen so that they would not be ambiguous. For example, if I wear a nylon shirt, the "gross energy requirement" (GER) of that shirt refers to the amount of the earth's energy stock that had to be sequestered in order to deliver it to me. Clearly, such a definition embraces all the energy that went to acquire the hydrocarbons that were subsequently changed into nylon, the energy to drive the process, the capital equipment, the transport, the life support system of the workers, and so on - even the operation of the store that sold it to me.

This definition can best be understood through the concept of system boundary. When carrying out an accounting procedure, one draws an envelope around the activity whose cost is to be accounted, e.g., a shirt factory. Perhaps the shirt factory buys in nylon thread. What it pays for that thread reflects many costs upstream. In an integrated system the thread may be made by the same company, but the company's accountants may wish to know the costs and profits of each section of the enterprise, so they divide the system into two or more envelopes, and work within two-system boundaries and thus compare added costs with added value.

In energy analysis there is the same choice, but it means less. In order that all energy requirement numbers be comparable to each other, and with money, it is necessary every time to go back to the same system boundary as money; that is to say, the point where the energy resource was as yet unexploited, i.e., as energy in the ground, and down-stream, the point of sale. The value so derived is the gross energy requirement mentioned earlier. Figure 1 depicts the analytical process illustrated by the simple example of crude oil from an offshore well. In the ground, crude oil has an energy content (as heat, burned in air) of about 45 MJ/kg, but to get it out of the ground requires some energy and much capital investment, which itself has an energy requirement.

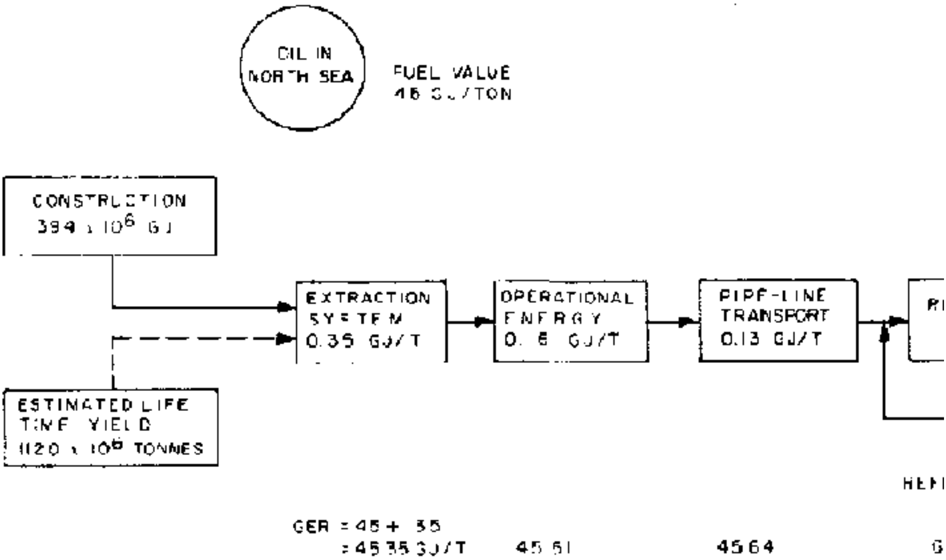

Figure. 1. Energy Requirement of Scottish Off-shore Oil (Source: R. Peckham and K. Klitz, EUR 6062 EN, JRC Ispra, 1978)

In the North Sea this sum, in energy per kilogram of oil, is not large, yet by the time it reaches a pipeline in Scotland the value has risen to about 45.7 MJ/kg, and when refined and delivered through the refinery gates, may be something of the order of 49.8 MG/kg. That is to say, for every kilogram of refined oil that is delivered, some 49.8 MJ of energy resource has been irrevocably consumed. We can say that 49.8 - 46 = 4.8 MJ energy were needed to deliver 1 kg of oil. This kilogram of oil may be used in manufacturing a tractor, fertilizer, or even a nylon shirt.

When an energy analyst wishes to consider the energy used in only a part of the process, e.g., the step from natural gas to fertilizer, the number so derived is called the "process energy requirement" (PER), It is important to note that, whereas properly derived values of GER can always be compared, PER values can only be compared where the system boundaries are clearly described and identical.

Personally, I never use PER values for too often find them misleading.

This definition of the GER affords no room for solar energy, and this is quite deliberate. GER refers to the amount of the earth energy stock used up (and it is irrevocably used up, for energy can only be used once). Solar energy is a flux, and falls upon us day in day out whether we use it or not. Often we use energy stocks for the manufacture of a product like fertilizer to catalyze the capture of solar energy, which is why, in an early paper (4), I used the phrase "energy subsidy to food production." Energy analysis makes a clear distinction between solar flux and stock energy consumption. Energy analyses of intensified land-based food production have demonstrated how wise it is to separate these two energy sources, for by computing only the GER we can quite accurately relate intensity of husbandry to intensity of energy use (Figure 2) (5).

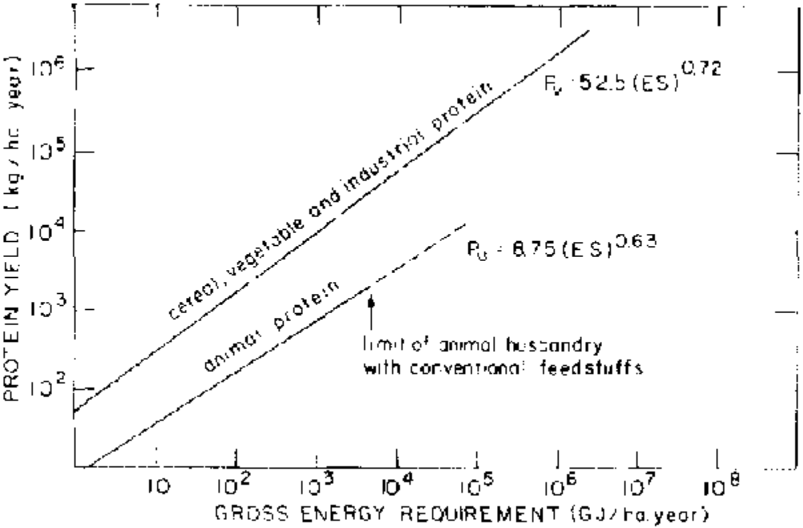

Figure. 2. Protein Yield versus Energy Intensity of Food Production Systems (Source: M. Slesser et al. [5])

One final point is that I have been using the word "energy" in a quite incorrect manner. According to the first law of thermodynamics, energy can neither be lost nor gained. When I say that energy is irrevocably lost, I refer really to its second law potential: at the end of a transformation there is as much heat as there was at the beginning, but the quality of the energy has been degraded. This question of energy quality has to be treated carefully in energy analysis calculations, and leads to a number of different conventions (1, 2).

Why energy analysis?

Economic analysis recognizes that time is a non-renewable resource, so the unit of money today is more valuable than the same unit a year hence; in other words, future income and expenditure are discounted. To be meaningful, this discount rate must exceed the inflation rate, and the difference between these two values dictates the time horizon in the calculation. Ten per cent restricts the time horizon to about seven years; 2 per cent widens it to a century.

In these uncertain days, choosing an appropriate discount rate is more of a value judgement than a careful economic calculation. However, in principle, given sufficient information about costs and prices and markets, calculation can assess whether this or that activity, such as the conversion of organic residues, is a viable activity. What often renders such calculation suspect is the uncertainty surrounding so many of the factors, coupled today with the extreme uncertainty about discount rates and the price of energy. It is thus extremely easy to swing the "economics" in favour of a project or against it according to a broad range of quite reasonable assumptions. Admittedly, if it is proved that such and such a project yields a 100 per cent internal rate of return even in inflation-ridden Chile or Brazil, then it is certainly likely to be worth backing. But much of what we have to deal with lies in areas of much greater uncertainty. Energy analysis seeks to remove a great deal of that uncertainty, but does so at the expense of some loss of information.

As I indicated earlier, money cost enters into ail of the factors of production. Energy requirement looks at only one: the consumption of stored fossil or fossil energy. The problems of inflation, of discount rates, or judging future prices are not considered. On the other hand, the energy requirement of a product reveals nothing about the value the market puts on that product. That remains an empirical, behavioral observation. Many economists view this deficiency to be so great that it renders energy analysis useless, and even worse, to be apparently propagating a single-factor theory of value. This is because economists view energy as just one more input in the production system, rather than a factor like time - a resource that can be used once and only once.

Energy has a unique role. Elsewhere I have argued (6), as have others (7), that, given energy and technology, we can never actually run out of resources. They are abundant, but becoming harder and harder to exploit, and that difficulty can be most conveniently measured in terms of resource energy requirement. Even capital can be so measured, and the problem that is increasing rapidly in the world is the need to devote more and more capital and energy to obtain energy, thus expending more capital to get at resources. It follows that the wise and efficient use of energy is not merely an economic objective, but can reduce a community's capital expenditure.

Thus, an energy analysis that demonstrates the least energy-intensive route to a given product can be a most valuable criterion in system selection, but with a very important caveat: performance must be equal. By performance is meant the provision of the same service or the same intensity of production. For example, it is not unusual to find, in manufacturing processes, that the least energy-intensive route is often the most automated route, and thus the least labour-intensive. Energy minimization calculations have proved to be an excellent guide to the viability of house insulation. When energy analysis is used to account for biosystems, research workers frequently overlook the need to compare similar performance, e.g., similar intensities of production expressed in kilograms of product per unit land area.

Some carefully executed work by US researchers illustrates this point. Pimentel et al. (8) studied corn production, while Rawitscher and Mayer (9) examined energy expended in harvesting various kinds of seafood. In both instances figures show the energy consumption per unit of product without reference to intensity of production. In neither study did calculations go back to the same system boundary as money. The now well known paper of Pimentel et al. (8) on corn production as a function of time falls into an orderly pattern in terms of intensity of production, and his data appear as six points on the curve shown here in Figure 2.

Rawitscher and Mayer (9) discovered enormous variations in the energy requirement for harvesting different types of seafood, and drew some unwarranted conclusions from that information, yet the parallel study of Edwardson (10), who did measure intensities, shows that fish farming data fit on the same curve of production intensity versus energy intensity that is found with normal land-based cultivation.

In considering the analysis of energy costs of integrated systems, from an energy analysis perspective it makes no difference to the procedure whether the system is integrated or not. The judgement lies in comparing the energy analysis of an unintegrated as opposed to an integrated system. It should always be remembered that systems are there to serve people; people eat food and consume goods, and people generate their own energy requirements; this, too, should enter into the calculation.

Thus, energy analysis leads to a series of numbers, initially expressed as so much energy per product, and should be related to the level of intensification and integration (Figure 2). The next step, upon which much research still remains to be done, is to link energy requirement to relative costs. It is now increasingly appreciated (1, 111 that a doubling in the price of energy can eventually double prices, and that energy requirement influences the rate of change.

Net energy intensity

Energy analysis of biological systems reveals its strength most clearly when dealing with the net energy of systems aimed at producing energy, i.e., biomass systems (Table 1). Net energy is the output energy of the system minus all of the energy equivalents of inputs drawn from other parts of the economic system expressed as GJ/ha* yr.* The decision on which process to espouse will then depend on the relative value of a GJ of energy in relation to a hectare of land. Today a barrel of oil, delivered on site, costs perhaps US$20. Table 1 presents data on alcohol produced by enzyme hydrolysis of cassava tops. The net energy of such a process is in the order of 2.6 barrels of oil per hectare of land per year. Thus, the process can only be economical if land rent is less than $20 x 2.6 = $52/ha, which is a low price for land. Process 2 in the table can never be economical. Processes 3 and 4 are viable at land rents of less than $104 and $160 per ha, respectively. If land rents already exceed these levels, biomass systems can never succeed unless land is deliverately taken out of the market system.

TABLE 1. Net Energy of Photo-Biological Fuels

Fuel	Raw material	Process	Net energy* GJ/ha	Equivalent barrels of oil/ha
Alcohol	Cassava tops + tubers	1. Enzyme hydrolysis	17.	2.6
Alcohol	Eucalyptus	2. Acid hydrolysis	- 180	- 27
Methane	Cereal straw	3. Anaerobic digestion	34.	5.2
Pyrolytic oil	Eucalyptus	4 Flash pyrolysis	52.	8.

Source: Rawitscher and Mayer 19). Net energy is the energy content of the product minus the GER of ail the inputs to make the product, but not counting solar energy, whose contribution is a function of land area, climate, latitude, and plant type

Net energy is related to cost. Consider a system of h hectares, having a land rent of r \$/ha yr and a production system (growing, harvesting, and conversion) having an amortized cost of c \$/yr and current inputs of p \$/yr, yielding a gross output of Q GJ of biomass energy. If m is the internal recycle of that biomass energy, the apparent energy output of the system is y = Q - m. The true net energy is less, because c + p have an energy requirements given by c x lc + p x lp, where lc and lp are the energy intensities of capital and inputs, respectively (GJ/\$).

Net energy/ha x yr, $N = \frac{Y-(c \cdot l_c + p \cdot l_p)}{h} \, GJ / hayr$

While costs are $G = \frac{r \cdot h + c + p}{y} \$ / GJ$

From this it follows that, $G = \frac{a}{N} + b$

where $a = r\left\{1 - \frac{(c \cdot l_c + p \cdot l_p}{y}\right\}$

and $b = \frac{1}{y}(c + p)$

That is, cost drops as N increases. Empirical evidence on the few systems for which data are available suggests that biomass becomes economical at a net energy of about 100 GJ/ha x yr at present energy prices.

It is not always realized by proponents of biomass energy how land-intensive it is. Table 2 lists the land area that must be sequestered for one year to provide certain economic services (assuming a net energy of 100 GJ/ha x yr).

TABLE 2. Land Areas Sequestered for One Year for Biomass System of 100 GJ/ha x yr Net Energy to Provide the Services Listed Below

3,000 mile flight in Boeing 707	.15 ha/person
3,000 mile flight in jet	.38 ha/person
Trucking 10 tons 1,000 miles	.23 ha/ton
Air freighting 10 tons 1,000 miles	2.2 ha/ton
Making copper	1.0 ha/ton
Making nitrogen fertilizer	.35 ha/ton
Pumping 1,000 m of irrigation	.4 ha/1,000 m

	or
water from 100 m depth	.3 acre/acre-foot

What criteria are offered by energy analysis?

It is assumed that the criteria of social acceptability and pollution levels are analyzed separately. Energy analysis is a tool that offers three types of criteria:

a. A statement about actual energy use, direct and indirect. This is an accounting process. It is not difficult to do, but is often done inaccurately through failure to consider all factors. It can be used to interpret the impact of energy prices on costs.

b. A criterion of economic attractiveness. Here the task is to compare the GER of alternative methods, or to optimize around the least energy-intensive route per unit product, taking into account the GER of all inputs. However, this cannot be considered independent of the production intensity required. Table 3 and Figure 2 show how, even with skilful husbandry, intensification demands an energy requirement.

c. Evaluation of the net energy of biomass systems.

TABLE 3. Output of Selected Natural and Other Systems

	Energy ratio (output/fossil fuel input)	Net energy GJ/ha-yr
Kung Bushman, Kalahari Desert	infinite	.003
Shifting cuttivators, Congo	infinite	.52
Tsenbaga tribe, New Guinea - yams	infinite	.47
sweet potatoes infinite	.40	

Dodo tribes, Uganda	5.0	.64
Subsistence agriculture, indict	14.8	9.6
Rice, Tanzania	23.4	3.6
Corn, Mexico	30.6	28.5
Peasant farming, China	41.1	274.

Conclusion

Energy analysis offers a means of judging the appropriateness of a system, or its optimal form. This cannot be done without strict concern for the conventions, taking the analysis back to the same system boundary as money. The use of energy as a numeraire undoubtedly means loss of some information, so that for an immediate decision affecting a matter of short duration, money remains the best criterion. However, as the decision period stretches into the future, energy can provide a useful and stable alternative criterion.

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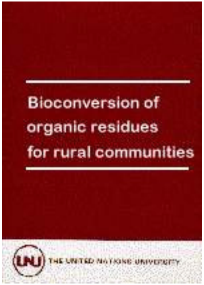
Bioconversion of
organic residues
for rural communities
THE UNITED NATIONS UNIVERSITY

Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Analysis of bioconversion systems at the village level

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Introduction

The diversity of residue utilization in rural communities is so great and the amounts of residue so difficult to measure that a complete analysis of bioconversion systems is a difficult task. In such a situation, choosing one method of utilizing organic residues over another has to be based strictly on tradition and intuition rather than on rational procedures, if these can be found. It is therefore necessary to evolve procedures for deciding the best mode of residue utilization. This article attempts to do this in the first part, as shown in Table 1. In the second part, some quantitative comparisons are made based on data obtained in this laboratory, referred to as MCRC. In the third part, some developmental possibilities are indicated for the future. Though an attempt has been made to obtain information from the South and East Asian regions, the background material is based mainly on the Indian experience.

TABLE 1. Analysis of Bioconversion Residues

1. Approach to bioconversion analysis
2. Some results and costs from integrated systems
3. Future developmental possibilities

Approach to bioconversion analysis

Barnett's and companion articles in Biogas Technology in the Third World: A Multidisciplinary Review (1) provide an admirable framework for evaluation of alternative decisions in biogas systems. These references should be required reading for decisionmakers in the rural energy area. The present study may be considered complementary because it looks at bioconversion in general. The analysis is restricted to bioconversion for energy, feed, and possibly food.

Table 2 demonstrates the alternative possibilities for using a common residue, i.e., straw. What criteria should be used by rural people to derive the optimum benefit from the straw? As can be seen in the table, the farmer has a number of choices: how does he decide whether to sell that straw in exchange for other goods, digest it for energy, or use it as fuel or feed directly? It is thus necessary to evolve some simple rules to enable him to make a decision. If self-reliance in energy and feed is the goal considered politically desirable, then the man who owns the straw should clearly be steered away from marketing it for alternate uses not leading to energy and feed.

TABLE 2. Various Present and Future Uses of Straw

Straw and similar residues

1. Building material/composites

2. Combustion

3. Feed for animals

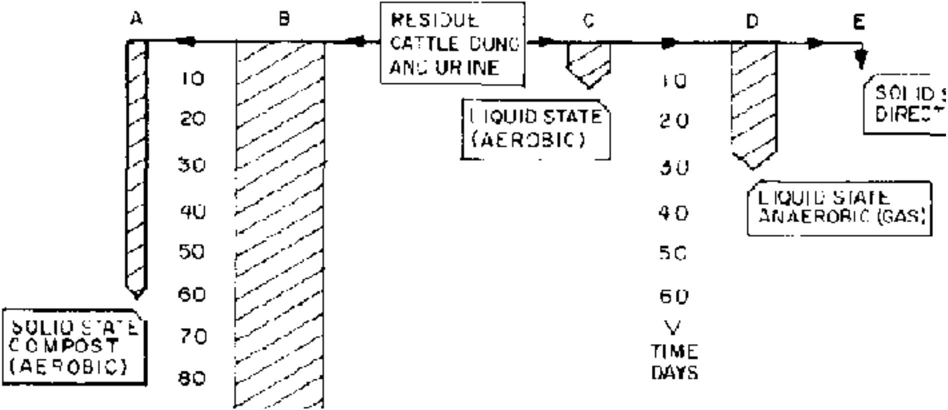
4. Ensilage and/or storage

5. Biogas

6. Any alternate bioconversion (For example, termites, mushrooms)

7. Any alternate marketability (For example, packing materials)

This is, in many ways, the crux of the problem. What are the socio-political and socioeconomic targets for the rural areas? It seems that unless a determined effort is made to propagate self-reliance, the increasing demands of population, industries, and cities will continue to denude the rural areas even of residues, and rural people will be forced to substitute high technology products, such as kerosene, for their basic needs. However, it is true that even for strictly bioconversion processes, the choice is not obvious, nor are the criteria for making the choice. Figure 1 shows various possible ways to use cattle dung and urine. Such schemes can be visualized for other residues. However, even for the same residue the scheme might vary from place to place.



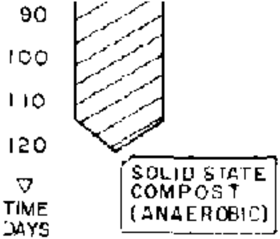


Figure. 1. Scheme for First Use of Dung from Cattle in a Rural Indian Community (including processes not in use now)

In looking at alternate possibilities for residue bioconversion, two considerations are of the utmost importance: (a) time, and (b) tradition and acceptability. Figure 1 accounts for these by using the width of the arrows for popularity or tradition: the broader the arrow, the greater the usage of the method. In typical marginal communities, anaerobic manure piles are the rule (process B), perhaps because of ignorance about other methods. This method of bioconversion is also the most time-consuming, as shown by the length of the arrow. For other residues, the most acceptable mode might be the most rapid one because of the need for capital generation. Process A is very efficiently practiced in China, but not to a great extent in India. However, it could be made popular in India.

Process C is for feeding the manure directly to algae/fish ponds, a process that is common in Southeast Asia, e.g., the Philippines. It is not widely practiced in India, though it happens in many stagnant bodies of water naturally. Process D is the biogas process, which could become widely acceptable provided that the capital and technology inputs are there. Process E is almost unknown in the rural areas, though it has the great advantage of being quick. This involves drying the dung, pulverizing it, and feeding it in admixture with bran, etc., directly to poultry. The present practice is for village chickens to grub around in dung heaps, because farmers provide very little feed to poultry.

In the case of dung utilization, time is considered a zero-value entity; if the option for the residue were biogas generation (D), followed by A or C on the slurry, the time needed would still be very much shorter than that required for process B. Thus, there is a need to evolve a system, perhaps a judicious mix of all the processes, that will optimize the output to the farmer. This figure is presented to emphasize the need to build in the rate of biomass production or use along with energy usage rate. Quite often developmental efforts do not include the time component. An example of this is the large effort spent on upgrading cellulosic waste. Unless an alternative is available simultaneously, a waste such as bagasse will continue to be burned in huge quantities, regardless of its potential for conversion to fodder and food.

Table 3 presents all the variables that have to be considered in making a decision on a bioconversion process. If the residue is seasonal, then the process should be designed with minimum idle time for any equipment. This is the kind of information that has to be included as an input under item 1. Similarly, collection efficiency and analysis of residue have to be determined. For items 2 and 3, consideration should be given to whether the residue is individually owned and used or is used by the community and also to whether the desired benefit is short-term capital generation so that the village can then have longer-term benefits or whether planning should be for the long run. Usually, in the poorer Indian villages, it seems advisable to sacrifice even efficiency (if necessary) for quick capital generation, because this is what is desperately needed. In any case, it appears that technology, to stay useful in the poorest surroundings, should be highly adaptive, evolutionary, and integrated.

TABLE 3. Considerations in Choosing a Bioconversion Process

1. Nature of residue	Seasonal/perennial? Collection Efficiency?
2. Ownership of residue	Individual/community?
3. Desired benefit	Capital/fodder, food/energy? Short or long-term? For one man or community?

4. Technology	Inputs - advanced or low availability?
5. Capital	Inputs - high or low availability?
6. Labour	Skill level? Availability/seasonality?
7. Energy	Inputs - high or low availability?
8. Land	Input-availability?
9. Delay loop	Time for finished steps of bioconversion
10. Other factors	Possibility of employment generation Health and environment Tradition Alternate marketability (other than bioconversion) Politics

Items 4 to 8 list the main requirements for capital, energy, land, etc. in terms of input and availability. The inputs that have to be listed in such an analysis are based on proces-specific considerations and availability on region-specific considerations. For example, a process such as yeast culture might involve high energy input in a low energy availability environment and, therefore, be undesirable. Items 9 and 10 are equally important. A process might have to be rejected because the residue is needed urgently for an alternate use; therefore, the time rate of utilization and availability of the end-product become paramount considerations. Also, environmental factors and employment possibilities might dictate the total choice of a bioconversion process.

Thus, a proper analysis of the bioconversion of organic residues needs to encompass all possible factors and combinations. Usually the choice is not as difficult as it appears, because very few residues are available for bioconversion, except in the more prosperous villages. These, however, are a minority. In some areas where MCRC is active, the choice seems to favour a process that will lead to initial capital generation. Once capital is generated, time rate of utilization becomes less important and more elaborate, but more efficient, designs can be put into use.

To show how the factors in Table 3 are applied, the use of a residue, biogas effluent, for three bioconversion processes leading to poultry feed or fodder is discussed next. All three processes have potential application in the rural areas, though perhaps not in the immediate future. In the next section, processes leading to different end-uses, energy and fodder, are considered and compared.

Consider the mass culture of algae, yeast, and photosynthetic bacteria on biogas effluent. Spirulina has been grown by MCRC on such effluent, unfiltered (2 - 5 per cent of the total culture), with an initial boost of 50 per cent by weight in Zarrouk's medium (2). The open-air culture is harvested every other day and dried in solar driers. The skill level needed is high-school-trained workers; other than that, there are no special requirements. The methods, culture ponds, etc., are described in MCRC's Technical Notes (3). The average yield during the months of June to September 1978 was 10 g/m/day in ponds with a maximum depth of 30 cm. This was a period of unusually heavy monsoon.

Compared to the yeasts, algae cultures, especially the blue-green algae, are very slow yielding. Irgens and Clarke (4) have reported the possibility of yeast culture in anaerobic digester supernatant supplemented with 1 - 2 per cent carbohydrate. The energy and skill requirements are very high, especially in the harvesting cycle. Unless the yeast is used for feeding as a slurry, this process might not, in spite of its higher yields, be adaptable. However, the potential for single-cell protein production at the rural level is high because of the low land requirement (see, for example, Slesser [5]), high nutrient value, even accounting for nucleic acid content, and availability of substrate.

The situation with photosynthetic bacteria (6) is similar, except that the yield is even higher. At MCRC, work is continuing on cultural photosynthetic bacteria on gobar gas effluent in inexpensive, sealed PVC bags. Harvesting the biomass is difficult, so the slurry must be fed directly. The land requirement for this procedure is low, but the skill, energy, and monitoring demands are very high. The comparison is given as an example of the choices available. The best choice would obviously be for algal cultures. with yeast as a future possibility.

Deciding among widely differing end-products is even more difficult. For example, if the choice is between making compost out of a residue or converting it to energy or to edible biomass for animals or humans, comparison must be made of the benefit of something that is expressed in megajoules versus something that may have an additional value (other than energy) as a protein source. The mere caloric value of a foodstuff is inadequate as a basis for comparison with other materials as far as its benefits are concerned. There is a need for a common yardstick that combines the various uses of organic residues and presents one basis for comparison. MCRC is working on this problem.

Some results and costs from integrated systems

Figure 2 shows a system of algal ponds with a biogas system in actual operation in a village. This system has been in operation since September 1978 and is run by local people. Table 4 shows the physical data and some of the costs associated with this system. The technical details are essentially as described in MCRC Notes (3).

TABLE 4. Costs and Other Data for an Integrated Algal Pond System

Location: Injambakkam Village				
No.	Item and Description	Cost Rs	Depreciation Rs	Remarks: US$1 = Rs 8.00
			(per cent/yr)	
1.	Digester	878	31.00 (5)	Includes

				labour, depreciation on materials
	MCRC design 4 - 5 cattle			
2.	Geodesic support (MCRC)	322	14.60 (5)	Same as above
3.	Gas container	175	88.00 (50)	Depreciation on total
	Transparent PVC + coconut thatch			
4.	Piping and burner	100	10.00 (10)	

	bought off the shelf			
5.	Algal ponds	618	207.00 (50)	Price/m' = 34.34
	Claylsand bund lined with 1,000 g			
	(HDPE)			Depreciation on materials
	Exposed area: 3 m + 6 m + 9 m			
6.	Solar driers	100	40.00 (50)	Price/m = 33.00
	(MCRC)			Depreciation on materials

7.	Buckets, screens, etc., bought off the			
	shelf	50	50.00 (100)	
	Totals	2,243	440,60	

8. Interest on borrowing 4 per cent/year = Rs 92.00 (4 per cent rates available for poorer sections)

I merest plus depreciation Rs 532.00

Working days/year 300

Average yield 10 g/m /day or 54 kg/yr

Credits: biogas plus slurry as manure (when not used for algae)

Estimated share of capital towards algae: Rs 6.001kg

Labour: 1/2 man day/day for operation; labour component of capital: 25 per cent

Table 5 shows some actual data from a biogas effluent-fed algal pond growing Spirulina. The second column shows that a medium consisting of one-half Zarrouk's formula (2) plus 2 1 of unfiltered biogas effluent every other day gives satisfactory results. The culture volume was, on average, 150 I; the area exposed was 2 m /pond; and an initial start of 51 of biogas effluent was added to the culture. Harvesting the culture every other day yielded more than harvesting every day. Occasionally, a bicarbonate boost was given to the ponds to keep up the pH. Small amounts of HPO4 and NO3 were added primarily to the pure synthetic medium culture, but also occasionally to the other cultures.

TABLE 5. Spirulina Growth on Biogas Effluent - Yield and Other Details

Yield dry weight in gas

Number	Date	Pond PC2 (2m) - initial dose full Zarrouk's	Pond PC3 (2m)- initial dose 1/2 Zarrouk's+ 5% v/v biogas efl.	Pond PC4 (2m) -initial dose 1/4 Zarrouk's + 5% v/v biogas efl.	Remarks
1	5 Sept.	1978 72	110	102	HCO_3, no_3 PO_4
2	7 Sept.	60	45	35	"boost" TO REPLACE
3	9 Sept.	50	33	47	carbon uptake by

4	**11 Sept.**	**20**	**45**	**52**	**algae:**
5	**13 Sept.**	**35**	**50**	**40**	**pond PC2, EVERY**
6	**17 Sept.**	**45**	**65**	**-**	**2nd day after**
7	**19 Sept.**	**50**	**90**	**75**	**pond PC3, ever**
8	**21 Sept.**	**47**	**40**	**65**	**25th day, plus**
9	**23 Sept.**	**30**	**-**	**_**	**21 biogas efl, 2nd day after harvest;**
10	**27 Sept.**	**28**	**25**	**27**	
11	**29 Sept.**	**25**	**33**	**45**	**pond PC4, ever**

12	**3 Oct.**	**20**	**52**	**42**	**21 biogas efl.**
13	**5 Oct.**	**20**	**45**	**35**	**2nd day after harvest.**
	Total	**502**	**693**	**565**	
Yield in gas/m/day		**8.36**	**10.88**	**9.41**	
Cost of initial chemicals per kg of algae		**Rs 3.05**	**Rs 1.17**	**Rs 0.67**	**Based on 300 days/year**
Cost of "bost" chemicals per kg of algae		**Rs 20.15**	**Rs 2.48**	**Rs 5.98**	

The average culture temperatures varied between 27 C at 0800 hours and 34 C at 1600 hours. The lux readings were averaged at 20,000 lux (0800 hours), 80,000 lux (1200 hours), and 16,000 lux (1600 hours). To prevent photo-oxidation, coconut thatch covers were used for the first three days and between 1100 hours and 1500 hours every day. The pH ranged between 9.5 and 10.5.

Based on the data obtained here (work is continuing), some calculations are presented to evaluate and compare different bioconversion modes. As pointed out earlier, this kind of evaluation has to remain subjective until more quantitative yardsticks are evolved,

Consider a family with five cows, and assume one year of operation. Then assume:

1. 80 per cent collection efficiency (7),
2. 10 kg wet dung/day of 18 per cent dry solids (8),
3. carbon in dung= 30 per cent by weight of dry solids C/N ratio = 18 (8), and

4. gas yield of 0.067 m /kg wet dung of 65 per cent CH_4, 30 per cent CO_2 (8), and the remainder H_2O.

Calculation of carbon balance:

5 x 10 x 0.18 x 365 x 0.30

cows kg/cow dry days C/dung

= 788 kg C/yr, entering the system

(Mol. wt. of gas = 24.5, with no correction for normal conditions)

0.067/22.4 x 365 x 50 x 0.8 x (0.65x12+0.30x12)

moles of gas days kg collect C/CH_4 C/CO_2

= 498 kg C/yr, leaving as biogas 788 - 498 = 290 kg C/yr, leaving in slurry

Based on MCRC's experience, if the slurry is to be fed into algal ponds every other day, approximately 4,0001 of culture ponds are needed. This can be accommodated in ponds of about 14 m with a depth of about 0.3 m. The yield of algae over 300 days of pond operation can be expected to be 42 kg (at 10 g/m /day). If two ponds are used, the yield is doubled by feeding each pond alternately.

If carbon comprises 50 per cent of the algal biomass and nitrogen 9 per cent, then C utilization is 17 per cent based on the carbon in the slurry, and nitrogen utilization is about 21 per cent. This is for 150 days of feeding slurry into one pond.

Table 6 shows a projected comparison of five modes of dung use without reference to cost. It must be emphasized that where no bibliographic references are given, the data were obtained or estimated by MCRC. They have to be checked again; an attempt, however, has been made to be conservative.

The first three items in the table are self-explanatory. The fourth and fifth items involve one use of dung as compost. This is to grow Sesbania grandiflora (agathi) trees, highyielding leguminous trees, growing indigenously all over South India. They are used for fodder, fuel, and building wood. Our experience is that 9 to 12 months after planting, the trees grow to 6 m and weigh an average of 16 kg. However, the yield given in the table is yield over unfertilized land. T.M. Paul (13) has demonstrated that barren, rocky land can be used to grow trees. If such land is used, the cultivation of tree crops becomes worthwhile. If land has to be paid for, the cost goes up sharply; in fact, up to 80 per cent of the final value of the crop can be ascribed to land value (12).

Comparison of end-products from bioconversion steps seems to favour a conventional agricultural crop until it is realized that in most villages, land and water are at a premium. However, each situation is different and the analysis here and in Part I may determine the best usage of the residues.

Future development possibilities

Organized bioconversion of residues seems to be practiced most in the People's Republic of China (14), but it is in its infancy in other less developed countries. However, the possibilities are immense with both conventional and newer processes. A survey of Microbiology Abstracts, Section A (15), revealed at least 25 papers* on processes applicable to rural residues. Thus, a determined effort to work at the rural level on rural residues would yield the best results.

This section indicates some possibilities for bioconversion in the future. Residues from industries situated near rural centres are also listed, because the waste from a medium-sized industry will probably suffice for a whole community. The possibility of generating employment from use of industrial waste should not be ignored. In the Indian context, large industrial undertakings situated near the outskirts of townships and generating usable waste should be encouraged to recycle and re-use the waste instead of resorting to expensive treatment not leading to agricultural products. This would also prevent pollution of the neighbourhood.

Two requirements have to be met for widespread propagation of bioconversion methods: (a) designs for cheap fermenters, and (b) culture or inoculum banks to supply starter cultures. This is similar to the large-scale effort now being launched to supply blue-green algal cultures (16).

If these facilities are provided, and this does not seem too difficult a task, various kinds of residues can be used (Table 7). The table gives only a representative sample and is not meant to be comprehensive.

Locally available grain, millet, and weed residues are added here to re-emphasize the need to make the best use of existing wastes by supplying starter cultures for better ensilage, or by supplying better designs of biogas digesters or fermenters. The available quantity is so vast that commensurate work seems to be called for in order to solve the urgent problem of food, feed, and energy shortages. In many parts of India, harvested straws rot because the harvest and the monsoon are concurrent. Even good drying systems to prevent deterioration (negative bioconversion?) will go a long way to alleviate the problem. Providing every reasonable-sized community a 6 m x 6 m drying platform of hard plastered mud or cement with embedded pipe flanges in a grid would help the villagers dry and preserve their crop residues more effectively. The pipe flanges are used as anchors to fix tent driers of plastic or thatch.

Items 2 and 8 in the table are examples of the variety of process liquors now being underutilized. Paddy steep liquor is available in millions of litres in most rice-producing countries as a result of the parboiling process, and makes nutrients available for fermentation (17). Similar liquors are biogas effluent (4), silk spin liquor (conservatively estimated at about 50 million I per year in one district to Karnataka State alone), coconut water (0.5 x 10(6) tons per year) (18), turmeric" and areca-processing liquors. All these liquors need to be supplemented by a molasses or glucose source for yeast manufacture; they supply N. P. K, and essential vitamins.

Items 3 and 9 point out the need for a close look at CO_2 as a resource (19). Both biogas as generated and combustion stackgases are thermally valuable as well as being rich sources of CO_2 for algal cultures. These gases, being neutrally buoyant, can be transported in balloons to desired locations. Prosopis and forest residues are extremely valuable resources that are now used only for burning. Thayer (20) has grown cytophaga on such material to make fodder. Items 5 and 11 are very effectively used in China (14), and their use should be propagated in other countries.

Regarding item 6 in the table, in India, wherever illicit liquor is brewed, it is done under conditions of very low sterility. Jaggery and acacia bark with some roots and herbs are added to water and sealed in a pot and buried underground. The brew is ready to distill in 10 to 15 days. If the yeast can be induced to multiply under aerobic conditions, it might be a good source of protein. Item 7 refers to the need to develop valuable starch or sucrose residues as cheap substrates for indigenous fermentation. Cotton dust availability in India is 33,000 tons per year (18), and is in a form suitable for enzymatic degradation to glucose, or for 20-day aerobic compost formation. Fish wastes (item 10) can be ensiled in a remarkably simple process (21). The product is a valuable poultry ration and is stable for up to three years. Silkworm cocoons can be dried immediately (to prevent negative bioconversion) and fed directly or ensiled by the same method used for fish wastes.

TABLE 7. Residues Locally Available in Rural Areas and from Proximate Industries

Rural Residues

1. Grain, millet residues, aquatic weeds, etc.
2. Paddy steep liquor, biogas effluent, other processing liquors
3. CO: from biogas
4. Prosopis, etc., forest residues
5. Dung, faecal matter
6. Illicit liquor process adaptation

Industrial and Urban Residues

1. Carbohydrate residues: sago (cassava waste, molasses, spent wash, cotton dust)
2. Paddy steep liquor, silk spin liquor, coconut water, areca, turmeric liquors, etc.
3. CO: from thermal, cement, and fertilizer plants
4. Fish wastes, silk worm cocoons
5. Sewage sludge

This brief review of future possibilities for rural communities would not be complete without a design for a cheap big-solar fermentation device. This design is not now in use, but might serve to stimulate ideas and improvements.

Figure 3 shows a box-type solar cooker (3) adapted for fermentation. This is made of hollow tiles and plastered with cement with a high coefficient of thermal expansion; e.g., lime/wood ash. The cycle undergone is: Expose to the sun to sterilize, cover to ferment, re-expose for broth concentration. To maintain the healthy growth of aerobic organisms, a compressor driven by a biogas engine, or wind power, or bicycle power, is used to aerate the brew. The tiles provide cellular air spaces as insulation during the sterilization cycle. If it is cloudy, wood-fired heat can be used to sterilize the broth. Though this kind of device cannot mass-produce material, it can be used to provide needed protein for village children.

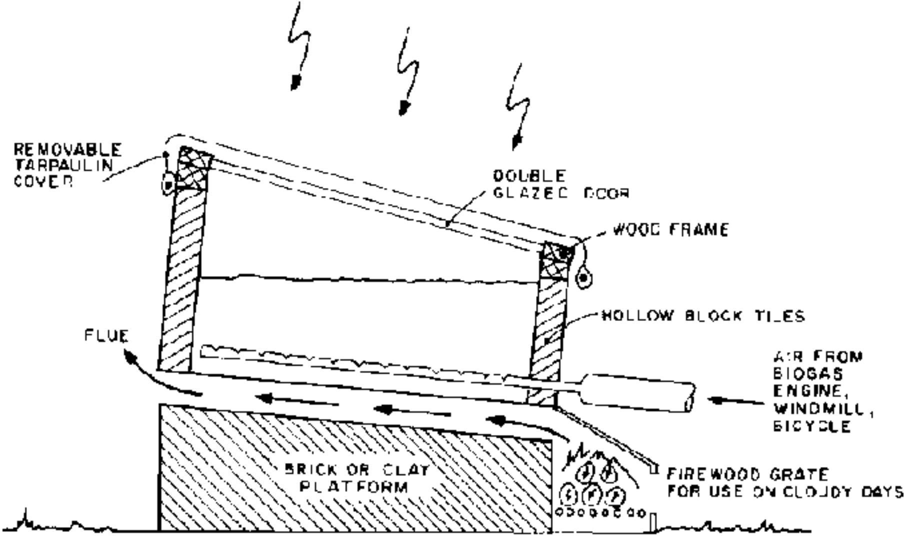


Figure. 3. Box-type Solar Cooker Adapted for Fermentation

Conclusions

This article has focused on the factors affecting bioconversion systems at the village level in a typical Indian community. It is fairly obvious that considerations of economy of scale and many other economic criteria that would be important in large-scale industry are irrelevant where the sole goal is to improve protein-calorie intake by a few per cent and to maintain a small, albeit significant, improvement in the quality of life. Bioconversion, in fact all rural technology, should aim only at modest targets. To do this best, the technology must be local, adaptable, and evolutionary. These three qualities do not preclude sophistication of analysis or thought.

Summary

An attempt has been made to evolve rational procedures for investment decisions on bioconversion systems at the rural level. Some quantitative comparisons are given based on data from this laboratory. Future possibilities for bioconversion development are also indicated.

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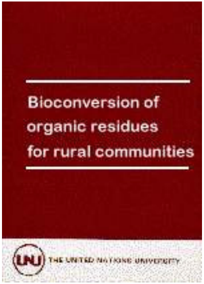

Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Nutritional evaluation of bioconversion products for farm animals

Introduction
Testing procedures for determination of nutritional value

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Introduction

Micro-organisms such as yeast, bacteria, fungi, or algae are the single-cell proteins used for most bioconversion of wastes or other substrates to make food or feed. A crucial question is: What is the nutritional value for man or animals of the final product of the bioconversion process? A second important aspect is the toxicological status of the product. This is the subject of papers by Scrimshaw and Shacklady appearing elsewhere in these proceedings, and my presentation is based on the assumption that the materials are acceptable toxicologically. I will consider some points that must be taken into account when evaluating a bioconversion product for animal feeding.

The main reasons for using micro-organisms in the conversion of agricultural residues are: First, to degrade that part of the residue that is not available for absorption by animals or man when the material is fed as such. In most cases this means that the enzymes secreted in the animal or human gastro-intestinal tract cannot, or are insufficiently able to, break down the material into components that can be absorbed. This pertains to cellulosic, hemicellulosic, and ligno-cellulosic components. The second purpose is to upgrade the nutritional quality of the residue by increasing its protein content, or, for monogastric animals and man, raising its content of essential amino acids.

Of the four categories of micro-organisms involved in bioconversion processes (yeasts, bacteria, fungi, and algae), a considerable amount of information is available about the nutritional value of yeasts. Species of yeast have been used for many years as a valuable component of animal feeds, supplying proteins and certain vitamins. In addition, some of the large-scale industrial SCP processes developed over the past ten years use yeasts that utilize hydrocarbons (i.e., paraffins) as an energy source and carbon and hydrogen for growth and synthesis of cell constituents. The results of extensive evaluation programmes show that these yeasts form a highly valuable source of protein for monogastric animals.

The second category of SCP, the bacteria, have, for many centuries, contributed to food supplies for man in an indirect manner: the protein supply of the ruminant is largely dependent on the bacteria and protozoa abundantly present in the fore-stomach of the animal, which forms, in principle, a large in vivo fermentation vessel.

Bacteria will be used in several large units being constructed for industrial protein production where methane or methanol will provide the energy. The data available show that bacterial material produced in this way also forms a highly valuable protein source.

The last two categories of SCP, the fungi and algae, have until now not been used to any extent in animal feeding, and this is why very little is known about the nutritional value of these products. The scarce data in the literature show variable results and indicate that, for monogastric animals, digestibility may be a problem. ILOB experiments with a fungal product showed reasonable results for digestibility and growth performance in pigs, but the results in poultry were unsatisfactory. Because fungi and algae will most likely be the microorganisms of choice for the small-scale bioconversion units considered in this work shop, a thorough look at the nutritional value of the material produced is essential. I would especially stress the necessity of testing nutritional value at an early stage of process development in order to be able to provide some sort of guidance for that development, for example, the choice of the micro-organism or the relevance of including a special treatment, if possible.

Testing procedures for determination of nutritional value

I shall discuss the procedures that can be applied when testing the nutritional value of new components meant for inclusion in animal feeds. Table 1 illustrates three different possible approaches. The left column shows tests used: analysis, acceptability, digestibility, and comparative feeding trials. These four different types of tests form a chronological sequence of steps in the evaluation procedure. In the columns on the right the efforts involved in each of the steps are given. The figures mentioned in these columns are calculated from the real costs of the experiments under Western European conditions. For the animal experiments they reflect the type of equipment needed, number of animals involved, degree of sophistication, etc. All figures mentioned are calculated as percentages of the total of "Efforts" column I - that is, the total of the efforts involved in a complete, elaborate nutritional evaluation of an SCP developed for production in large industrial operations in highly industrialized countries. It must be realized that the number 100 means, according to standards of the wealthy Western countries, a sum on the order of 400,000 - 500,000 Dutch guilders or US$200,000 - 250,000, and only involves the nutritional evaluation per se, not special toxicological determinations, or time-consuming, expensive multi-generation studies.

"Efforts I" is the most sophisticated evaluation procedure. An evaluation always starts with an elaborate analysis step, including determination of the major components: protein, fat, ash, carbohydrate, but preferably also amino acids, macro elements, and the more important minor elements. Because of the very modest costs involved, it is advisable to perform as many of the relevant analyses as possible, as a complete analytical profile can provide much early information about the potential nutritional value of the product to be tested.

The second step, acceptability trials, includes small, short-run tests with chicks and pigs. Sheep are not included in column I because, in highly developed countries, SCP is usually too expensive a source of protein for ruminants. These acceptability studies determine whether the inclusion of a moderate and a high dose of the test-product in the diet affects feed intake, faeces consistency, etc., as indicators of digestibility and general state of health. Weight gain is also measured as a first, very rough estimate of nutritional value.

The third step in the evaluation programme, determination of digestibility, is a very important one because the result is, to a great extent, a determination of the nutritional value of the product under test. In column 1, complete digestibility trials with chicks and pigs are anticipated. In these trials energy value (metabolizable energy for chicks, digestible energy for pigs) is also determined.

After the results of these first three phases of the programme have become available, a reasonably reliable prediction of nutritional value can be given, provided the test product does not contain specific negative factors not discovered in the acceptability and digestibility trials. The prediction is verified in the last, fourth phase: the comparative feeding experiments. In addition to chicks and pigs, these trials also include an experiment with laying hens. In these experiments, the test product replaces part or all of the usual high-protein components in the diet in order to see how it affects weight gain, egg production, feed conversion efficiency, and product quality.

I should like to emphasize that phase 2 (acceptability) and especially phase 4 (comparative feeding) allow inclusion of toxicological determinations, because the target animals are consuming moderate to high levels of the test product over a prolonged period. In some programmes evaluating commercial products (ILOB work on B.P. yeast, Imperial Chemical Industries, Ltd. [ICI] in the evaluation of the ICI bacterial product), multi generation feeding studies with laying hens and breeding pigs were also included in order to assess the reproductive capacity of these farm animals, and to detect any long-term effects.

TABLE 1. Three Approaches for Determination of Nutritional Value of New Components for Animal Feed

		Efforts (%)			
Type of test		I	II*	III*	
				a	b
1. Analysis		0.5	0.5	0.5	0.5
	chicks	1.5	1.5	1.5	1.5
2 Acceptability	pigs/sheep	2	2	2	2
	chicks	10	4	4	4
3. Digestibility	pigs/sheep	14	6	-	6
	chicks	14	3	3	-
4. comparative	layers	27	5	-	-
	pigs/sheep	31	8	-	5
		100%	30%	11%	19%

Percentage of the total cost of scheme I attributable to individual components. 100% represents 400,000 500,000 guilders or us$200,000 - 250,000 at 1978 prices.

Moderately simplified and greatly reduced evaluation schemes are given in columns 11 and l l l respectively, although these are based on the same principles and follow the same sequence of trials as in the sophisticated, elaborate evaluation scheme of column 1. In all stages of the animal experiments, pigs and sheep are given as an alternative, depending on local conditions. It is assumed that the efforts involved in experiments with pigs and sheep are approximately equal. In both reduced schemes, phases 1 (analysis) and 2 (acceptability trials) are maintained to the same extent because they are relatively simple and cheap and yield much useful information. In phase 3, determination of digestibility, the study is considerably simplified because the test is carried out with only one level of the test product in the diet in one test period instead of the two test periods used in column 1. The result of this simplification is that the figures for digestibility become less reliable, but when the study is carefully done, a good measurement of nutritional value can still be obtained. It is possible that an even simpler test for digestibility could be used by an in vitro method, but it remains to be determined whether existing in vitro methods give reliable results with the kinds of SCP products under discussion in this paper.

TABLE 2. Effects on Growth and Mortality in Chicks Fed Fishmeal and Yeast Diets with and without Vitamin E and Arginine

Diets	Weight gain 0 - 5 weeks (%)	Mortality 1%)
30% Fishmeal	100	2
30% Fishmeal + vitamin E	95	5
30% Fishmeal + vitamin E + arginine	122	6
30% Yeast	50	70

30% Yeast + vitamin E	58	47
30% Yeast + vitamin E + arginine	68	63

The experiments mentioned in phase 4, comparative feeding trials, are also simpler in terms of number of animals per trial and duration of the trials. In the moderately reduced scheme 11 a six-month experiment with laying hens fed one level of test product is still included; in scheme III it is omitted, and it is assumed that the results in chicks will give a sufficient predictability of the effects on laying hens.

The total effort involved in scheme 11 is only 30 per cent of that in scheme I and it is reduced to 11 and 19 per cent, respectively, in schemes III a and b. The difference between schemes III a and b is as follows. In scheme III a it is assumed that chicks will provide satisfactory information on digestibility. A further testing of the product in pigs or sheep can be omitted because it is very likely that a product showing satisfactory results in poultry will have an equally good, or even better, nutritional value for pigs or sheep. In scheme III a the chick test of digestibility is followed only by a five week comparative (chick experiment) feeding study with chicks.

When the chick digestibility test does not show promising results, we use scheme III b and continue with a check of digestibility in pigs or sheep and, if relevant, follow this with a comparative feeding trial in pigs or sheep.

The schemes shown in the table, of course, do not mean that these are strictly defined programmes that must be used, but they can be considered as guidelines that can be followed, depending on local conditions and circumstances. As has been noted before, the scheme indicated in column I is a full-scale, elaborate nutritional evaluation programme of an SCP from a large industrial operation. The moderately simplified scheme 11 can be used to test a product from a small industrial plant, for example, a regional co-operative.

TABLE 3. Effects on Growth and Mortality in Chicks Fed Fishmeal and Yeast Diets with and without Selenium

Diets	Weight gain 0 - 3 weeks (%)	Mortality (%)
30% Fishmeal	100	7
30% Fishmeal + 0.2 ppm selenium	101	3
30 % Yeast	70	53
30% Yeast + 0.2 ppm selenium	80	2

The markedly trimmed schemes III a and b may be used in the evaluation of material from a village or multi-village unit.

In conclusion, I should like to present one example to illustrate that, when evaluating a new product, care must be taken not to confuse nutritional defects with toxicity. During the nutritional evaluation of yeast grown on e-paraffins or gas oil, an experiment was carried out in which chicks were fed semi-synthetic diets with fishmeal or Yeast, respectively, as the sole source of protein. After four weeks, about 50 per cent of the yeast-fed chicks had died, whereas only one of the fishmeal-fed chicks had dies. Because at that stage of the yeast evaluation we already knew from the results of rat and other chick experiments that true toxicity was a very unlikely explanation for the phenomenon observed, we undertook a closer look at the nutritional characteristics of the yeast, as summarized in Tables 2-4.

In the experiment just described, many birds showed symptoms pointing to vitamin E and/or arginine deficiency, so the effect of the addition of vitamin E and arginine was studied. In the fishmeal-fed controls, mortality was always low but adding arginine improved weight gain distinctly. In the unsupplemented yeast group, mortality was 70 per cent and weight gain 50 per cent of that in fishmeal-fed controls. Addition of vitamin E improved weight gain only slightly, but mortality was considerably lower. Addition of both vitamin E and arginine effected a further improvement in growth, but mortality rose once again.

The problem was for the most part solved in the following experiment by the addition of 0.2 ppm selenium. Vitamin E and arginine were added to all rations. Whereas selenium had hardly any effect on chicks consuming the fishmeal diet, it dramatically reduced mortality of chicks on the yeast diet. In addition, weight gain was improved by 10 per cent, although still lagged 20 per cent behind the fishmeal-fed controls (Table 3). This fairly considerable growth depression proved to be caused by the extremely fine, sandy structure of the yeast, which apparently limited feed intake when the diet was fed as meal.

TABLE 4. Effects on Growth and Mortality in Chicks Fed Fishmeal and Yeast Diets in the Form of Meal or Pellets

Diets		Weight gain 0 - 3 weeks (%)	Mortality (%)
Meal	30% Fishmeal	100	5

	30% Yeast	74	0
Pellets	30% Fishmeal	100	2
	30% Yeast	98	2

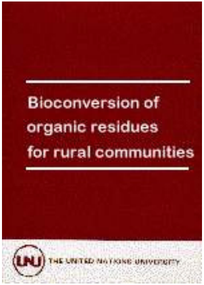
The problem could be completely overcome by pelleting the final feed, as shown in Table 4, which gives the results of an experiment in which meal and pelleted diets were compared. Selenium, arginine, and vitamin E were added to both meal and pelleted diets.

This example was chosen because it gives such a clear illustration of the dramatic effects of a combination of nutritional imbalances, in this case, selenium, vitamin E, and arginine, and effects of the structure of the feed, that might easily have been considered to be symptoms of real toxicity. In this example, the effects were somewhat exaggerated because of the use of semi-synthetic diets in which the test product was the only protein source. In the usual, less

comprehensive evaluation schemes, where the experimental conditions are less extreme - i.e., more realistic test diets and mixtures of proteins - the effects would be less marked, but nonetheless important.

The moral of the story is that, in the process of evaluating a new product, it is essential for the nutritionist and the toxicologist to co-operate as closely as possible. A reliable toxicological evaluation of a product can only be done when the main nutritional characteristics of that product are known; on the other hand, the nutritionist must know all the available toxicological data before he can complete the nutritional evaluation.

Finally, I should like to emphasize once more that very little is known about the nutritional and toxicological properties of fungi and algae, the micro-organisms most relevant for bioconversion processing of agricultural residues. In my opinion, we should urge research in the field as strongly as possible. As important research targets regarding nutritional value, especially for monogastric animals, I would include: Determination of the nutritional value of different relevant species of fungi and algae grown on different substrates and under different conditions; investigation of the influence of the cell wall on this nutritional value and, in connection with this, the effect of special processing methods such as drying, milling, and pelleting.



Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Bioconversion products: toxicology - problems and potential

Summary
References

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Toxicological evaluations present, in general, three problems The first is inherent in the science itself; the others relate to the nature of the material to be evaluated and the circumstances in which its use is contemplated.

By definition, the inherent problem will exist regardless of the type of product or its intended use, and can be stated in very simple terms. Nothing is totally innocuous, so every toxicological evaluation resolves itself into the assessment of an acceptable level of risk because it cannot be based upon absolute criteria.

The problem associated with the nature of the material derives from the fact that the accepted classical evaluation procedures were not developed with bioconversion products in mind. With the exception of biogas, these fall into the category of materials now known, generically, as single-cell protein (SCP), comprising yeasts from fermentation, algae from photosynthesis, and fungi and bacteria from fermentation, with or without photosynthetic intervention. Experimental procedures designed for quantitatively minor additives and pharmacologically active agents must be modified to take account of the practical limitations imposed when evaluating products intended to form a significant proportion of the dietary intake.

The third type of problem - the one concerned with the circumstances in which a material may be used - can be subdivided into two parts. In broad terms, these could be regarded as the practical, and the ethical or philosophical considerations about the use of the product. The former would take into account such factors as whether the material would be used on a regular or intermittent basis and the probable level of intake in either event

The ethical consideration is, in fact, related to the inherent problem of toxicological evaluation in that the circumstances in which a product may be used will have a major bearing on the degree of risk that could be regarded as acceptable. As has already been said, absolute safety does not exist; consequently, in any given situation, the question arises as to the balance between the risk attendant upon the use of a product and the benefit that would accrue. Clearly, this ratio will vary according to circumstances; what might be acceptable in one case could be quite unacceptable in another.

Having stated the problems, it becomes necessary to define them in more depth to see if the potential for solving them exists within the framework of the general programme under consideration.

In the present state of knowledge, it is improbable that any solution to the fundamental shortcomings of the science itself will emerge in the foreseeable future.

The need to determine the acceptability of single-cell proteins as food or feed ingredients required some adjustments to be made in existing toxicological procedures. These had been developed for materials that, although frequently highly active biologically, formed a quantitatively insignificant proportion of the dietary intake. The procedures allowed the construction of response curves to a wide range of dose levels in experimental animals and, in many cases, required the administration of the test material by more than one route. SCPs, on the other hand, were intended to make a significant quantitative contribution to the nutrient intake and would be ingested, thus imposing constraints that did not exist in the case of drugs or similar additives.

Nonetheless, a practical scheme that took these limitations into account, but retained the principles of the classical approach, was developed for yeasts grown on hydrocarbons and was adopted in 1964 by the Central Institute for Nutrition Research (CIVO) in Zeist, Netherlands. Concurrently with this, the Institute for Research in Animal Nutrition (ILOB) in Wageningen, Netherlands, was carrying out the nutritional evaluation of the same materials in farm animals. These studies examined the short-, medium-, and long-term effects of an SCP on growth and reproduction in experimental animals and have been reported in some detail by

Engel (1) and de Groot and co-workers (2 - 5). In the early 1970s, the then Protein-Calorie Advisory Group (PAG) of FAD/WHO/ UNICEF published Guideline Nos. 6 and 7 (6,7) dealing with the pre-clinical and clinical evaluation of novel protein sources, and these were followed by Guideline No. 15 (8). The first two pertained primarily to the use of SCP by man, whereas No. 15 was directed towards use for animals. These guidelines have formed the basis for those subsequently adopted by various national regulatory authorities, and do not differ in principle from the CIVO/ILOB approach

The programmes recommended in these guidelines have proved satisfactory in evaluating the toxicological and nutritional characteristics of SCP. It might be assumed, therefore, that no major problem would be encountered in applying them to any bioconversion products. In practice, this is not so. The reason is that these evaluations are both extensive in scope and expensive in implementation Neither the facilities nor the financial support to conduct them are likely to be available in the areas where the need is greatest. Experience to date suggests that, in these circumstances, the toxicological evaluation of products derived from bioconversion on the farm or in rural communities will almost certainly be neglected. The situation is also aggravated by the fact that the nature and quality of products from organic residues may vary according to the composition of the residues themselves. In contrast to this, SCP produced by industry is generally, and justifiably, assumed to be acceptably constant in composition and to conform with that previously tested.

It is not the intention here to discuss the possible effects of production variables upon the toxicological and nutritional characteristics of bioconversion products other than to draw attention to them as factors that should not be ignored. From what has been said, however, it may be gathered that it would be irresponsible to use these materials as food or feed ingredients without attempting to assess their toxicological and nutritional acceptability. At the same time, it would be unrealistic to expect that, in the circumstances in which they will be produced, they would, or could, be subjected to the exhaustive evaluation applied to SCP produced on a large scale by industrial plants.

This introduces the third type of problem, which, in essence, is whether or not this apparent impasse may be avoided. Bear in mind that no absolute determination of product safety can be made because absolute safety does not exist. The question is, therefore, can a practical method for adequately evaluating toxicity of small-scale rural bioconversion products be designed?

It is suggested that this can be done by a modification of what may be regarded as the classical procedure outlined in the PAG Guidelines, taking advantage of very recent developments reported since they were published.

The modification lies in the area of the long-term feeding studies that have been a feature of the classical approach and that, because of their complexity and duration, have effectively eliminated themselves from consideration in rural projects. These long-term studies for orally administered materials required them to be given at more than one dosage level for the full lifespan of two species of test animal. Administration commenced with the pregnant female because of the possibility of transfer of toxic materials to the fetus, and was continued until only 20 per cent of animals in the subsequent litters were still alive. It is evident that this procedure cannot be applied to the target species for which the product is intended, whether this be man or farm animals. In the case of man, ethical considerations alone would prohibit it, and in farm animals the extended lifespan and the impracticability of having treatment groups large enough to give statistically significant results would preclude such studies. Even using the short-lived laboratory animals, in particular the rat, and evaluation of this nature would require several hundred animals and could take up to four years to complete.

United States Food and Drug Administration regulations, which are probably as stringent as any, propose as acceptable a one in one-million level of risk and consider this to be ". . . of insignificant public health concern" (9). Here may be seen the application of the concept of risk/benefit ratio and the introduction of the acceptability of a risk rather than a declaration of absolute safety. The concept cannot be criticized; the acceptable level of risk is a matter of judgement, and there is nothing to suggest that this has not been the subject of deep deliberation and extensive discussion by those competent to judge At the same time, it must be remembered that the judgement is made in the context of conditions - social, political, economic, and industrial - prevailing in the United States of America.

What is now suggested is that a programme be designed based essentially on short-term studies, that is, chemical analyses of feeding studies in laboratory and/or target species of farm animal, with in vitro or in vivo mutagenicity studies as indicators of possible long-term hazard. In parenthesis it might be added that a consideration of these could be incorporated into a review of PAG Guideline 15.

A considerable amount of information may be obtained in a relatively short time by exhaustive chemical analysis of a bioconversion product. The nature of the substrate and the process conditions may indicate areas of potential danger. Thus, algae grown on waste water, or organisms grown on waste liquor from the paper industry may contain undesirably high levels of toxic elements such as lead, cadmium, etc. If crop residues are used as a substrate, it may be possible to determine whether or not any significant amount of pesticide or herbicide has been carried over into the biomass. The presence of unusual components, or unusually high levels of more common components, should be noted as a possible hazard.

Results obtained by chemical analysis of the biomass should be regarded as indicative rather than predictive of potentially adverse effects. For example, a high concentration of an undesirable element in the biomass does not necessarily mean that it would be transferred to an animal eating that biomass. It might be unavailable biologically and excreted rather than stored. This can, and should, be determined in animal feeding studies.

Short term screening studies on the target species of animal are described in the paper by van Weerden in these proceedings, so little will be said about them here except to add that it would always be desirable to supplement these by a well designed but simple 90-day study in rats. Histopathological examination of the more important organs and tissues will give a very good indication of the likelihood of there being any chronic toxic, but not carcinogenic, effect. Feeding studies with target species of animals can also provide useful information in this respect and, in particular, chemical analysis of the edible portions should determine whether or not undesirable or toxic components have accumulated to an extent likely to present a hazard to the consumer.

There remains the question of potential carcinogenicity. The standard method in current use, as has already been noted, is lifespan feeding studies in laboratory animals. A major disadvantage of this type of evaluation lies in the length of time and the facilities required to carry out a study that will give valid results. It was this that encouraged the search for more rapid alternatives that would require fewer facilities. Tests now exist that do not require extensive animal housing and maintenance facilities, and that can be completed in a few days or weeks.

All of these tests are based on the mutagenic or nonmutagenic activity of the material under examination, involving the use of certain bacteria and mammalian cells in vitro or in vivo. A recent report of the Committee of the European Environment Mutagen Society (10) contains the following passage: "Carcinogenic substances have, in most cases, produced positive results in screening programmes for mutagens in contrast to non-carcinogens. The theoretical basis for this correlation has yet to be fully established although it seems likely from available evidence that DNA damage is intimately involved in both processes. Screening tests for mutagens thus serve a useful additional function in identifying potential carcinogens."

There appears to be no single test that will detect every type of mutation, and it is necessary to employ a battery of tests to cover the whole spectrum. Probably the best known and most widely used single test at present is that developed by Ames and his coworkers (11), in which S. typhimurium mutants have been selected for sensitivity and selectivity in their ability to revert from requiring histidine to histidine independence in the presence of a wide variety of mutagens. While this method is not well suited to the screening of proteinaceous materials as such, it has been used with success on extracts from such materials by Pamukcu et al. (12).

Renner and Mnzner (13) have described the use of various mammalian test systems in the mutagenic evaluation of bacterial protein preparations, and there seems to be no reason why these systems could not be used for other proteins.

Although a considerable degree of expertise is needed in the conduct of these tests, as well as experience in their interpretation, they are now being performed on a routine basis in a number of institutes. Compared to lifespan feeding studies with laboratory animals, they are very rapid and inexpensive. Moreover, they do not require equipment other than that generally found in a moderately well-equipped microbiological laboratory. They appear to be well-suited to the facilites available in the biological departments of universities and research institutes in areas where rural development is receiving most attention.

The present view is that there is a correlation of more than 90 per cent between the mutagenic and carcinogenic activity of the several hundred chemical compounds so far examined. The suitability of various tests for predicting carcinogenicity has been surveyed in a paper by McCann et al. (14). In a recent paper Parke (15), in considering carcinogenicity, mutagenicity, and reproductive effects, refers to a new screening technique of McMahon et al. (16) for mutagenicity, and warns that results of in vitro mutagenicity studies must be interpreted with care before they can be extrapolated to in vivo carcinogenesis.

Although the mutagenicity studies mentioned were carried out on bacteria or in mammalian cell systems, these systems were in laboratory, not farm, animals. There does not appear to be any reason why, with the exception of the dominant lethal test for which sequential matings are necessary, the effect on at least some of the mammalian cell systems could not be examined in the target species of farm animal, possibly combining these studies with short term feeding studies, but to my knowledge. no reports of this nature have been published.

A further advantage of these mutagenicity tests is that, because of their short duration, they could be used to monitor the effect of process changes in the course of development of a production system. This would be out of the question in the case of lifespan studies.

In summary, therefore, it is suggested that the toxicological evaluation of products of bioconversion in rural areas requires a different approach from that taken by large industries. The main divergence from the procedure used in the latter is the substitution of short-term mutagenicity studies for lifespan studies as indicators of potential carcinogenicity. The 90-day rat feeding studies and relatively short-term experiments on target species of farm animals remain common to both situations. It is unrealistic to imagine that many of the products arising from small-scale projects would be evaluated in a manner identical to that adopted by industry. So far, there is no indication that this has been done, even when biomass preparations have been available.

The alternatives are either those suggested in this paper or virtually no testing at all - certainly no tests that would indicate chronic toxic or carcinogenic effects.

Circumstances do alter cases When circumstances require food supplies to be increased as a matter of necessity, the situation is different from that in which additions to the food available are novelties, not necessities It has been estimated that malnutrition in the developing countries is responsible for between six and twelve million deaths annually. In these circumstances, it is suggested that the long-term risk to benefit ratio consequent upon the adoption of the very recent abbreviated testing procedures described here would be acceptable and, certainly, infinitely preferable to the alternative of no tests to indicate such risk.

The problem is not the same in all countries, hence the solution is not necessarily the same. That is the premise upon which the suggestions outlined here are based.

Summary

The non-gaseous products from bioconversion of organic residues fall into the category of materials known generically as single-cell proteins (SCP). Methods for evaluating the potential toxicity of these materials in food or feed preparations have been developed and put into practice in recent years. In common with procedures for the similar evaluation of food additives and pharmacologically active substances required by most regulatory authorities, these

methods are extensive, expensive, and time-consuming

It is doubtful whether either the facilities or the funds to carry out such procedures would be deployed for rural community projects in non-industrial countries There is, consequently, the danger that little or no long-term toxicological evaluation will be performed in these cases.

The suggestion is made that, when a new source of food is just a novelty, the situation is quite different from that prevailing when it is a necessity. A different problem may justify a different solution. To determine an acceptable level of safety in these cases for SCP produced by bioconversion processes, it is recommended that the long-term feeding studies with laboratory animals be replaced by the recently developed tests for mutagenicity, using bacterial or mammalian cell systems. These are rapid and relatively inexpensive; they do not require elaborate equipment, and give a high degree of correlation with the results obtained in studies of in vivo carcinogenicity.*

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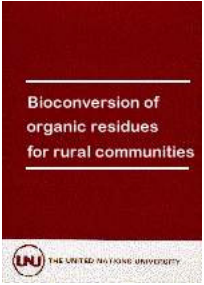

Bioconversion of Organic Residues for Rural Communities

(UNU, 1979, 178 p.)

Nutritional evaluation in humans

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Introduction

It is difficult to realize that, of the total amount of energy devoted to agricultural production, only a small fraction is harvested to be used directly or indirectly for animal and human feeding. Most of the energy is left behind, either in the field, in food processing factories, or feed lots. This unused energy has various forms, and is often of complex chemical composition. It may be biologically inert or highly active; it may be tough or very fragile, and susceptible to rapid deterioration. Most of the time these agricultural residues are a nuisance from the human point of view, for indeed, we call them wastes. There are many examples, but one that illustrates how wasteful agricultural systems can be is the growing of coffee. From 100 9 of dried fruit, only 12 g are actually consumed as solids to make about six cups of coffee (1). For most basic food crops, such as grains and food legumes, the harvest index is only about 0.50.

For various reasons, man is now learning to utilize such wastes, imitating the ways of nature to maintain ongoing biological cycles for the continuation of life in harmonious balance.

The term "waste" describes in a broad, non-specific way the raw material to be utilized, and it is because of its complexity, toughness, and general state that its use in bioconversion systems cannot at present, with a few exceptions, yield products that can be readily utilized directly by man. Therefore, it is difficult to talk about biological evaluation of the products of bioconversion for human use in the context of the raw material itself. It must first be processed. The only known exceptions are algae and mushrooms. This paper presents a discussion of methods used for the evaluation of unconventional products.

Evaluation of products of bioconversion for human consumption

The evaluation of bioconversion products to be used for food must take into account four main problems. These are (i) toxicology, (ii) public health aspects, (iii) food technology, and (iv) nutritional quality. The first two are discussed elsewhere in this volume, while the third, consisting mainly of functionality and organoleptic properties, will be only briefly mentioned here. The main emphasis will be given to the fourth consideration - the nutritive value of potential products in terms of their physiological effects and protein quality.

With respect to nutritional evaluation of novel or nonconventional protein sources for human consumption, the Protein Advisory Group (PAG) documents (2 - 6) outline the methods of procedure, including standards for chemical, bacteriological, and toxicological quality, as well as procedures for feeding tests, including acceptability, tolerance, and protein quality evaluation. Therefore, if bioconversion products produced for human feeding meet these standards, they can be considered acceptable for use as components of food. Four products potentially useful as food sources are products derived from animals fed bioconversion products, conventional fermented foods as used in the Far East, algae, and other single-cell proteins. Before discussing them individually, present methods of protein quality evaluation will be briefly described.

Procedures for nutritional evaluation in humans

Once non-traditional food sources began to be utilized for human consumption, guidelines for their safety had to be established. The PAG documents already mentioned (2, 3) include complete evaluation of novel protein sources in at least two animal species before any clinical trials, using the procedures described in Figure 1.

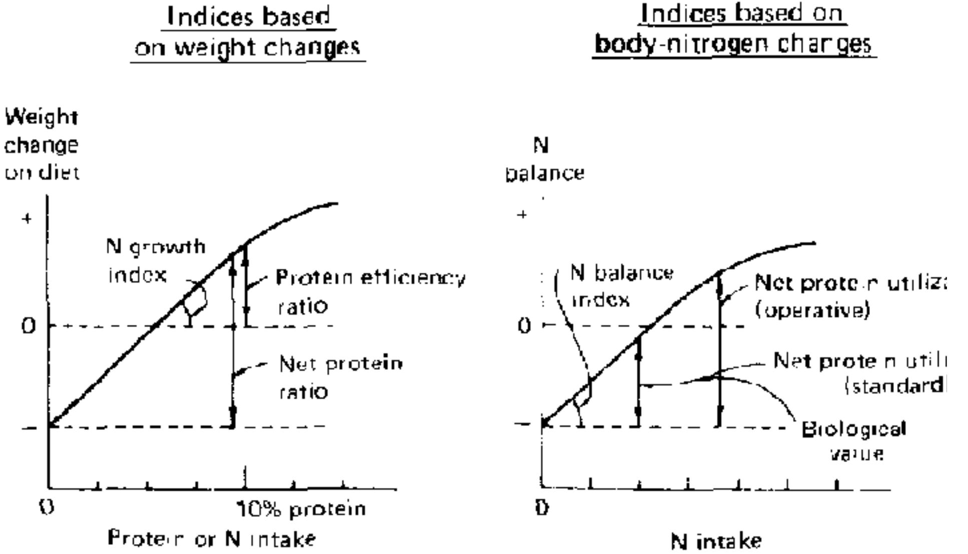


Figure. 1. Procedures for Measuring the Nutritive Values of Proteins

The protein evaluation tests summarized in the figure fall into two categories: Those based on weight gain of the animals, and those based on carcass protein deposition. Most of the methods are one-point assays; however, multiple points are preferred, particularly in view of the linear relationship, which permits a fairer evaluation of the protein under study. For those methods based on weight changes, protein intake is also calculated to determine protein efficiency ratio (PER), net protein ratio (NPR), and others. Carcass nitrogen deposition can be measured either directly in experimental animals, or by the nitrogen balance method, which is applicable to both animals and man. Nitrogen balance is defined as the difference between nitrogen intake and total output in faeces and urine. The methods based on these measurements are net protein utilization (NPU), biological value (BV), and nitrogen balance index (NBI). The former two represent one-point assays; the latter is a multiple-point assay.

The protein quality evaluation method used in our laboratories with children and young adult human subjects is the multiple-point intake technique (NBI), where the material under study is the only source of protein and the only variable, with intake of other essential nutrients, such as calories, vitamins, and minerals kept constant and at adequate levels (Figure 2). Basically, it consists of feeding the protein source, with other non-protein foods providing flavour and texture, at three or four levels of intake, one level below the nitrogen equilibrium line, one or two close to it, and one above. The purpose of such a feeding system is to obtain the relationship between nitrogen or protein intake, or the amount absorbed, and nitrogen balance. This last term - nitrogen balance - is equal to the difference between intake and total excretion of nitrogen as measured in faeces and urine. Regression analysis of the results obtained provides an index of biological value, represented by the coefficient of regression, or the slope of the line when it is calculated from the nitrogen absorbed and nitrogen retained values. The magnitude of the slope is an index of the efficiency of protein utilization. Values approaching one show the highest efficiency. When the regression is calculated between nitrogen intake and nitrogen balance, the coefficient is equal to net protein utilization, and again shows the efficiency of utilization. An example for three protein sources is shown in Figure 3, where the different regression coefficients indicate different protein quality values.

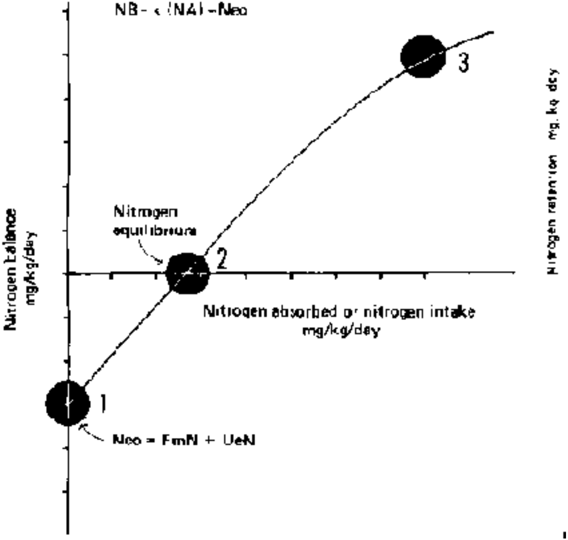
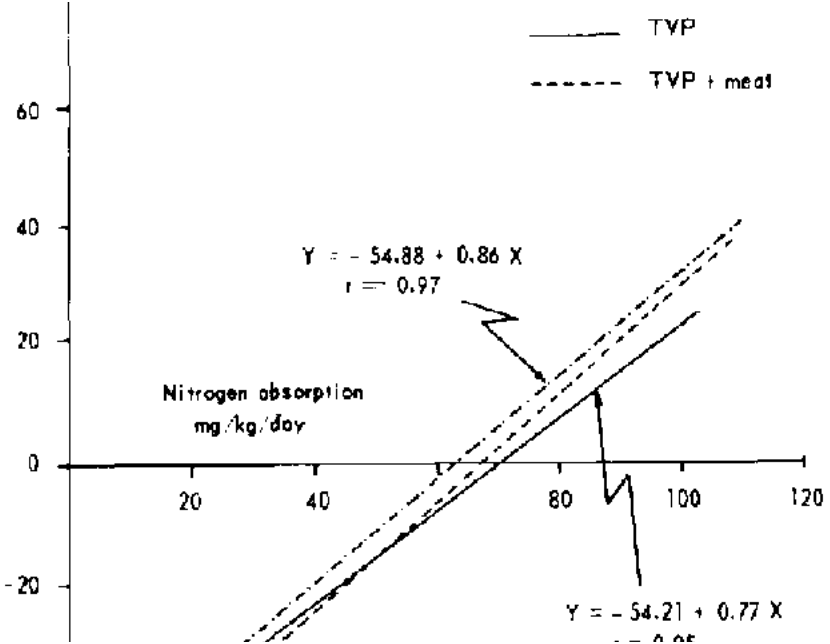


Figure. 2. The Basic Principle of the Nitrogen Balance Index


TVP
TVP + meat
60
40
20
0
-20
Y = - 54.88 + 0.86 X
r = 0.97
Nitrogen absorption
mg/kg/day
20
40
80
100
120
Y = - 54.21 + 0.77 X

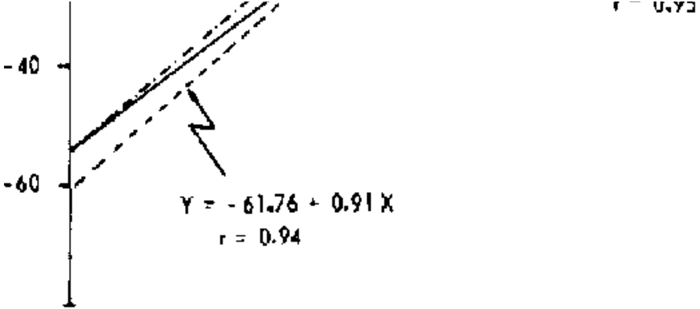


Figure. 3. Nitrogen Balance Index of Texturized Vegetable Protein, Meat, and 50:50 Combination (short method)

This method of evaluating protein quality provides additional data. Furthermore, the point of interception at the equilibrium line indicates the amount of protein required for maintenance purposes. The application of this technique varies to some extent when used in children. The main difference is that diets without nitrogen are not fed to children in contrast to diets fed to adults, for whom this step is necessary in order to promote adaptation to low-protein intakes. Furthermore, protein levels of intake fed to children are higher than those for adults, because children have higher protein requirements to allow for growth.

The duration of this experimental method is usually long because it is a multiple-point assay, and because there is usually an adaptation period before collection of biological material for analysis. The usual time is about 36 days. We recently proposed a modification of this method that reduces the time to nine days for young adults (7), and studies are currently under way to apply it to children. Some data on values obtained by our modified short-term method compared to those from the conventional assay are shown in Table 1. These data strongly suggest that the experimental time may be decreased without major differences in protein quality evaluation results (8).

The evaluation of various food products

Food Products Derived from Animals

Domestic animals such as ruminants, swine, and poultry will probably be fed more and more products containing materials from bioconversion processes. It is not expected, however, that this practice will change the quality of the protein derived from the animals. Changes in the chemical composition of animal tissues may occur, as well as deposition in the tissues of heavy metals, insecticide and herbicide residues, and other additives. If the levels of these substances become too high, the animals will show a decrease in overall performance, which, in turn, should lead to elimination of the product from the feed. If the animals gain weight and show good feed-conversion efficiency and overall performance, it is a good indicator that food products made from such animals will be of high enough quality to be used for human feeding. This, however, does not imply that quality control evaluation should not be carried out on food products obtained from animals fed bioconversion products or biomass (6).

TABLE 1. Protein Intake for Nitrogen Equilibrium Using the Conventional and Short-Term NBI (g/kg) in Adult Human Subjects

Protein source	Conventional	Short-term
Soy isolate	0.67	0.54
Milk	0.63	0.62
50/50 beef/soy	0.59	0 57
Beef	0.64	0.53

Source: Bressani et al. (8).

Conventional Fermented Foods

Fermented foods have been consumed for a long time by populations living in various parts of the world. Although there are several kinds, only three will be discussed in terms of protein quality. These are: (a) foods such as tempeh, a fermented food based on soybeans, a high-oil, high-protein seed; (b) fermented foods based on cereal grains, mainly rice, and (c) fermented foods based on starchy foods such as cassava.

The impact of the fermentation process on the protein quality of the end-product will be considered first. To predict its protein quality, it is essential to know the value of the starting material and the value of the biomass itself. In the case of tempeh, soybean protein is deficient in sulphur amino acids and rich in lysine. The biomass produced on it also contains protein deficient in sulphur amino acids and rich in lysine. Therefore, the protein quality of tempeh will be equivalent to the average of the protein content in the soybean and in the fermented biomass, depending on the amount of protein supplied by each source.

There are no data available on the protein quality of biomass produced on cereal grains. Cereal-grain protein, however, is deficient in lysine, while microbial protein is a rich source of this amino acid. Table 2 shows the nutritional impact of small amounts of yeast added to maize, wheat, and rice. In each case, there is a significant increase in protein quality, suggesting that production of biomass on cereal grains for human feeding would be beneficial to the consumer, assuming that the product would be acceptable organoleptically (9 - 11).

TABLE 2. Supplementary Effect of Small Amounts of Torula Yeast Added to Various Cereal Grains

Cereal grain	Amount of torula added (%)	Protein quality PER
Maize	0	1.23
	3	2.06
Whole wheat	0	1.81
	4	2.17

Wheat flour	0	0.82
	8	2.18
Rice	0	1.87
	6	3.13

Sources. Bressani and Marenco (9); Jarquin et al (10); Elias et al. (11).

There have been few nutritional studies on the protein value of biomass grown on starchy foods. Therefore, to predict its possible use, the analogy of supplementing cassava with beans will be used. SCP and legume foods are also deficient in sulphur amino acids and rich in lysine. The results in Figure 4 show that body weight in rats is maintained when cassava is supplemented with 30 per cent of beans, providing 7.5 9 of protein. However, when bean protein is supplemented with methionine, the body-weight gain of rats fed the bean-cassava diet is maintained with only 15 per cent of beans, providing about 4.5 9 of protein. These results imply that, in order to increase protein content in starchy foods by biomass production, the protein content should be higher than 8 per cent to maintain body weight in experimental animals.

Algae

Algae have been used as food for centuries. They form a part of the diet of the people living around Lake Chad in Africa, and were eaten by the Aztecs in Mexico. Among the several thousands of green and blue algae known, the following have been found adequate for large- or small-scale cultivation: the green algae, Chlorella vulgaris, Scenedesanus acutus, Coelastrum proboscideum, and the blue-green algae, Spirulina maxima. The following discussion of algae is based on information from other laboratories, as we have not gone beyond chemical and animal studies with Microcystis sp. (12).

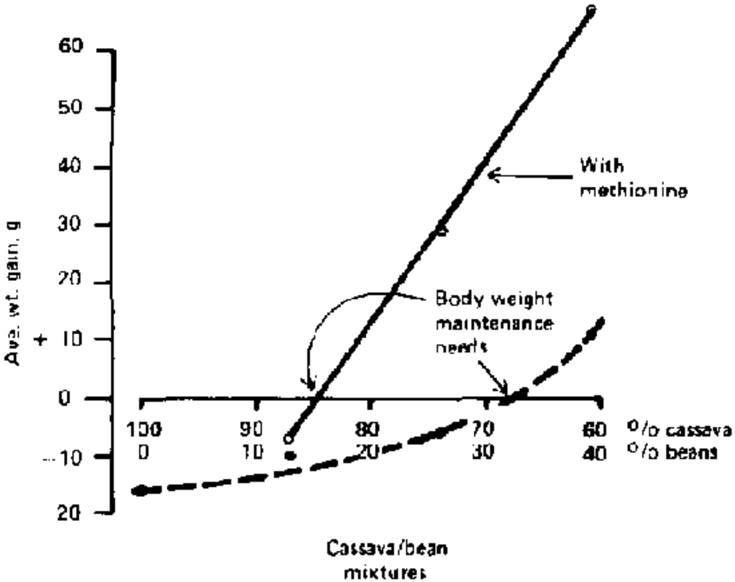


Figure. 4. Nutritional Significance of Bean Protein Quantity and

Quality to Cassava-Based Diets

TABLE 3. Some Observations Made on Human Subjects Fed Algae Protein (10 to 500 g/day)

Unacceptable smell
Disagreeable flavour
Poor appearance of food
Gastro-intestinal discomfort
Poor digestibility of nutrients
Nausea at high levels of intake
Urine and blood analyses normal
After additional processing:
More acceptable organoleptically
Gastro-intestinal problems persisted

Not many results have been reported recently on nutritional evaluation trials using algae grown on different types of biomass for human subjects. This is probably not due to a lack of interest in manufacturing such products, but rather to the initial results obtained in 1963 - 68 that showed a variety of adverse effects in subjects fed algae or other SCPs. As shown in Table 3, clinical trials with algae were particularly discouraging (13 - 17). Most materials containing algal protein showed low digestibility for most nutrients, and caused gastrointestinal discomfort. Unacceptable smell, taste, and disagreeable flavour produced nausea. However, it became evident that further processing by alcohol extraction improved the product significantly.

In more recent reports, materials produced and processed by improved technologies have yielded products that offer more promise. Some of these results are shown in Tables 4 and 5, indicating better protein digestibility and biological value, while urine and blood analyses are no different from those observed after feeding casein, a universally acceptable protein. However, it is costly to create acceptable foods from algae. These results suggest that the production of such materials for rural communities would be better directed towards animal feed, where they will be more beneficial to man in the long run.

Concept of productivity

Economic considerations in systems of food production, whether they are food crops, livestock, or bioconversion products, take into account only the total amount produced, with little regard to whether the products will be used efficiently. In view of this, we define productivity as total production per hectare, or per unit of weight or volume, corrected by a food technology factor and by a nutritive value factor (18):

TABLE 4. Protein Quality of Chlorella, Yeast, and Casein in Human Subjects

Dietary protein	Nitrogen intake g/day	Nitrogen balance g/day	True protein digestibility	Protein quality B.V. %

			%	
Casein + RNA	4.25	- 1.00	95	66
	7.84	+0.33	99	52
Chlorella	4.83	+0.28	89	79
	7.81	+0.05	82	60
Torula	4.51	- 1.23	83	70
	8.20	+0.39	87	58

Source: Waslien et al. (17).

Productivity = Production/ha x Food technology factor x Nutritive value

This equation is applicable to production of foods from soil or other sources, such as those described in these proceedings, and is applicable to evaluation of feed for animals and also food for human consumption.

The term "food technology" in the formula has two components. One is related to those characteristics of a food or product that introduce functionality, texture, and structure to food systems. For example, the high-yielding variety of rice IR8 was not accepted by the consumer because it did not meet the eating quality associated with rice. The second component is related to the capacity of the product to undergo processing without physical, chemical, or microbiological deterioration. An example would be milled Opaque-2 corn, which has a low yield of grits because of the nature of the endosperm. In the area of biomass, specifically algae, the green colour is an example of the first food technology component, and bacteria-induced deterioration is an example of the second.

The nutritive value factor in the equation is related to the efficiency with which the nutrients of the food products, whether they are calories, proteins, or any other specific nutrients, are utilized.

One example that shows the effect of better land use through a more efficient utilization of the protein in cereal grains is presented in Table 6. For children, the amount of protein from corn needed for equilibrium, that is, neither weight gain nor loss, requires cultivation of 69 and 182 kg/yr of Opaque-2 and common maize, respectively. These amounts of protein are lost in faeces and urine because the figures represent the condition at protein equilibrium, and are equivalent to 0.013 and 0.035 ha per person per year. For adults, the results show the same trend; i.e., less land use due to more efficient utilization of the nutrients in Opaque-2 maize than those in common corn. Therefore, productivity expressed in production per unit area should also include the efficiency of utilization of the crop produced. Even with the 10 - 15 per cent lower yield and a slightly lower food technology factor, Opaque-2 maize has a higher productivity than can be derived from common corn.

TABLE 5. Urinary and Plasma Uric Acid Levels of Men Fed Nucleic Acid Added to Casein and as Found in Algae and Yeast

Diet	Nucleic acid intake (g/day)	Uric acid (mg) Urine/day	Plasma/100 ml
Protein-free	0	394	5 4
Casein + RNA			
25 g prot	1.8	562	6.9
50 g prot	3.7	886	8.7
Chlorella			
25 g prot	1.7	605	7.4
50 g prot	3.6	872	9.7
Torula			
25 g prot	5.0	942	10.2
50 g prot	10.3	1,536	12.6

Source: Waslien et al. (17).

Table 7 shows the significance for productivity of low and high digestibility bean protein. Using the results from nitrogen balance studies, it can be seen that low digestibility results in poor land use because significant amounts of N are lost in the faeces in comparison to N loss when a material of higher digestibility is fed.

TABLE 6. Amount of Corn Protein Found Experimentally to Be Necessary for Nitrogen Equilibrium in Children and Adult Subjects

	Type of corn Opaque-2	Common
Children		
g protein/child/day	16.8	45.0
g corn/child/day	188	500
kg corn/child/year	69	182

ha/person/year	0.013	0.035
Adults		
g protein/head/day	27.9	43.8
g corn/head/day	250	547
kg corn/head/year	91	200
ha/person/year	0.018	0.040

The above is based on a yield of 5,000 kg/ha.

TABLE 7. Efficiency of Land Utilization in Terms of the Protein from Beans (Phaseolus vulgaris)

	Protein of 64% digestibility	Protein of 84% digestibility
Yield of beans/ha, kg	1,000	1,000

Yield of protein/ha, kg	230	230
Protein absorbed/ha, kg	147	193
Protein waste/ha, kg	83	37
Waste as beans/ha, kg	360	160
% land poorly utilized	36	16
Nitrogen intake	227	227
Faecal nitrogen	81	36
Urinary nitrogen	109	109
Nitrogen absorbed	146	191
Nitrogen retained	37	82

Finally, energy inputs into agricultural production systems are also affected by the quality of the end-product. Table 8 shows calculation of agricultural and nutritional efficiency using data from Pimentel et al. (19).

With respect to nitrogen input, agricultural efficiency for corn is 0.61 whether it is common or Opaque-2 maize. However, the nutritional efficiency of the nitrogen input is 0.44 for Opaque-2 maize and a significantly lower value of 0.19 for common corn. For energy inputs, the returns of agricultural efficiency for both types of corn would be 2.82; on the other hand, the nutritional efficiency of the energy input would be 1.35 for Opaque2 corn and a very low value of 0.87 for common corn.

TABLE 8. Agricultural Productivity of Cereal Grains of Improved Nutritional Value Out put/input

Parameter	Output/input Common corn	Opaque-2 corn
For N inputs in corn production		
Agricultural efficiency (grain)	0.61*	0.61*

Nutritional efficiency For energy input in corn production	0.19	0.44
Agricultural efficiency (grain)	2.82.	2.82*
Nutritional efficiency	0.87	1.35

* Equal yields/ha were assumed.

These calculations indicate that, independent of the nutrition problem, there are practical advantages in producing food grains of the highest possible protein quality.

Conclusions

As I indicated in the introduction to this paper, the harvest indices from food crops are small, and the amounts of potential energy left in the field are very large. Even smaller indices are obtained after food is processed, indicating still greater wastes. As the papers in this proceedings show, there are various products that can be made by bioconversion. In my opinion, especially in rural areas, priority should be given to processes that will convert wastes into materials that will induce better structure and fertility in soils and hence make them more productive. Second, biogas production also has potential and is a system that is compatible with bioconversion processes. A third approach would be to produce biomass that, without any further processing, can be used as animal feed. Some wastes can be converted into foods for man, but because of the types of raw material used and the subsequent processing needed to make such products wholesome for human consumption, large-scale industries are required. Quality products can thus be made to enter the present food consumptions systems.

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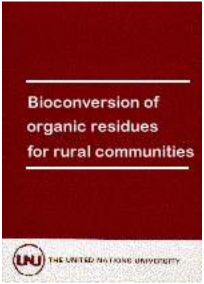
Discussion summary: Papers by van Weerden, Shacklady, and Bressani

Asked about the meaning of the term "technological quality" of proteins, Dr. 8ressani replied that the phrase was used to indicate how amenable (or otherwise) protein preparations are to normal domestic or industrial processing. It was recommended that new preparations should be evaluated in terms of their replacement for other protein sources rather than in absolute terms. This is, in fact, the normal procedure when evaluating food mixtures for human consumption.

Senez, commenting upon van Weerden's paper, pointed out that the rations containing yeast in the experiments he described were generally supplemented with methionine. With regard to the apparent differences in species response to the fungus tested, he wished to stress that it related to only one out of several thousands of fungi that might be used. van Weerden agreed with both comments, but said that the latter served to underline his contention that we know very little about this very large subject.

Stanton commented upon the one in one million level of risk mentioned by Shacklady and said this was close to the natural frequency of mutation of many bacteria. He also suggested that Tetrahymena pyriformis could be a useful organism for field-workers comparing or evaluating potential feed ingredients. In reply, Shacklady said that the one in one million possibility of error referred, not to mutagenicity studies, but to lifespan feeding studies on experimental animals, and simply indicated the magnitude of the studies acceptable to the FDA Regarding T. pyriformis, this has been used by some workers as an index of protein quality, but it has a number of disadvantages, one being that it does not have an absolute requirement for lysine, frequently the first limiting amino acid in cereals. As far as Shacklady knows, it has not been used in mutagenicity studies, the most commonly used organisms being Salmonella typhimurium mutants along with those of Escherichia cold and Bacillus subtilis.



Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Biomass from organic residues for animal and human feeding

References
Discussion summary

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Experience with the attempted development of useful, safe, and commercially acceptable single-cell proteins products from petroleum hydrocarbon substrates gives an indication of the nature of the health problems and associated issues likely to be encountered in the development of biomass for similar purposes from plant and animal wastes Time after time, combinations of substrate, organisms, and processes that were demonstrated to be technologically feasible and economically viable have had to be abandoned because questions of safety arose that either required unacceptable added costs to eliminate hazards or resulted in regulatory or political obstacles impossible to surmount within economically feasible time limits.

From the beginning, fears were expressed that organisms selected, even if normally nontoxic, might undergo mutation to toxic strains or become contaminated by toxic strains. Concern also focused on the possible carry-over of toxic substances from substrates into single-cell products intended for direct human consumption, or into products for human consumption from animals fed these materials These concerns have proven extremely difficult to allay by the scientific method and have persisted long after extensive research has provided seemingly scientifically conclusive assurances. In Italy, neither British Petroleum (BP) nor Liquichimica was able to obtain authorization to operate plants already constructed, although in the judgement of the PAG and other experts all scientific questions had been answered satisfactorily (1).

In Japan, consumer alarm resulting primarily from an erroneous research report, exacerbated by unfortunate nomenclature, became a political issue and has blocked all efforts to produce single-cell protein from hydrocarbons in Japan even for animal feeding.

In addition to these issues, which, from a scientific point of view could be dealt with by extensive analytical procedures and by studies in a variety of experimental animals, problems arose that could not be predicted from the studies on experimental animals and proved, in some cases, to be of critical importance in determining feasibility. These were adverse organoleptic properties that could not be readily masked, and allergic reactions in some human subjects (2, 3). Sensitized individuals became susceptible to relatively small quantities and manifested cutaneous or gastro-intestinal symptoms at best unacceptable, and at worst, alarming and temporarily disabling. Because these were apparently caused by relatively small protein molecules, either present originally or resulting from nucleic acid reduction or other treatment, they could be removed by suitable processing procedures, but at significant additional cost.

Other health issues were also raised, often without any justification, but no less troublesome for this reason. It was suggested that working with live organisms could be hazardous to workers or to surrounding communities (perhaps an unconscious confusion with the escape of disease-producing organisms from the laboratory or publicized aspects of the controversy over the safety of DNA-recombinance research). The objection was also made that production of these materials might have other health-related environmental effects, ranging from atmospheric to thermal pollution. Problems with both added cost to the production of SCP on gas oil by BP in Lavera, France that tipped the balance against economic feasibility.

Based on these and other experiences and some of the additional information already presented, it is possible to develop a check list of health-related issues that might arise as a consequence of efforts to develop products involving microbial growth on vegetable and animal wastes (which the euphemism "residues" will not eliminate). I will refer to the primary material consisting of substrate plus a complex mixture of organisms as MBP (microbial biomass product). Table 1 lists the assurances necessary for application of microbiological techniques to the use of plant and animal residues for the production of either MBP or SCP for animal or human consumption.

TABLE 1. Assurances Necessary for Application of Microbial Techniques to Organic Residues for Either Animal or Human Feeding

1. Regulatory approval
2. Economic feasibility
3. Environmental acceptability

a) aesthetic issues
b) health issues

4. Favourable political climate

For animal rations, and of course also for human feeding, there must be assurance that the species of organisms involved are in themselves non-toxic. Even when a given organism under one set of conditions can be demonstrated to be nontoxic in acute feeding trials at high levels, fear of harmful mutations will persist, especially if other strains of the species or of closely related species are known to be toxic. Where mixed cultures under non-sterile conditions are involved, as in practical village level fermentations, there will be concern not only for the possibility of toxic species developing under some circumstances, but also that pathogenic species may become accidental contaminants (Table 2). The former (toxicity of the primary organisms) must be answered by either experimental or practical feeding studies, and the latter (introduction of pathogens) by the necessary precautions and conditions.

TABLE 2. Health Aspects of Biomass from Organic Residues

Safety of species

(a) of primary organisms
(b) of usual contaminating organisms
(c) possibility of accidental introduction of pathogenic species (e.g., botulism, salmonellosis)

The problem of mycotoxins requires special consideration because they may be introduced by vegetable substrates on which there has been prior growth of a toxin-producing mould, especially Aspergillus flavus. It is possible that mycotoxin levels unassociated with signs of toxicity in practical feeding of animals may result in mycotoxins in the food product, milk being the prototype example.

The very heterogeneous substrates provided by waste materials raise many questions. These include the possible accumulation of unacceptable concentrations of such heavy metals as lead, mercury, copper, zinc, arsenic, cadmium, and cobalt, and of insecticides, herbicides, larvicides, and other toxic chemicals. Toxic metabolites are always a theoretical possibility, and elimination of foreign bodies may be a problem (Table 3).

TABLE 3. Health Aspects of Substrates Used for Microbial Conversion of Organic Residues

Safety of substrates

(a) pathogens
(b) heavy metals (Hg, Cu. Cd, Pb, Al, As)

(c) pesticide residues
(d) drug residues
(e) toxic metabolites
(f) foreign bodies

Even when it can be shown that the proposed biomass (either MBP or SCP) produces excellent results in experimental and practical animal feeding, the lives of food animals are relatively short and their growth may not reflect the effects of residual compounds that could, in theory, have adverse consequences in long-term use by human subjects. For example, Toprina and Liquipron are the trade names for yeast grown on petroleumhydrocarbon substrates and proposed for commercial production in Italy. It was necessary to prove that the odd-numbered carbon-chain fatty acids seen in the fat of animals fed Toprina or Liquipton were naturally occurring compounds metabolized normally through usual biochemical pathways (4). It was also established that cell function of the various tissues was unaffected by the presence of odd-numbered carbon-chain fatty acids even when they were present in relatively large amounts (e.g., ref. 1, 5). Similar questions might be asked regarding the edible products of animals fed on MBP.

Sometimes a substrate can increase the likelihood of disease transmission when an animal product is improperly processed or handled; for example, an increased risk of salmonellosis. Fish grown in a pond contaminated with raw sewage may introduce pathogens into the environment even when the cooked fish is quite safe. In theory also, the use of plant residues could result in the appearance of plant steroid hormones in unacceptable amounts in animal products, but to my knowledge, this has never been reported except from direct consumption of certain plant species.

Obviously, the MBP must have an acceptable nutritional value for animal feeding and not cause unacceptable flavours in the resulting products.

For direct human use, these products must not only satisfy all of the conditions for animal feeding, but also a series of additional criteria. It must be established that there is no possibility of consuming, in the products of animals fed MBP, substances that might be mutagenic or carcinogenic in prolonged human feeding, or teratogenic when fed to women during early pregnancy. It is not practical to determine this by human feeding studies, but rather by appropriately designed multi-generational and reproductive studies in experimental animals.

Of more practical significance is the possibility that feeding the material directly to humans may cause cutaneous or gastrointestinal responses of an allergic nature in an unacceptable proportion of human subjects. This must be detected in advance by well designed double-blind feeding trials in a sufficiently large sample of human subjects for at least 30 days. Because occasional allergic responses will be found to all protein foods, particularly common with peanuts, milk, and eggs, absolute freedom from allergenicity cannot be expected.

MBP for human consumption must also have favourable organoleptic characteristics or functional properties, or both, that favour its use.

The social and anthropological considerations associated with SCP and MBP heavily overlap, but are far from identical with the health considerations. Concerns of the public and of politicians are usually expressed in health terms, although in some cases objections have been aesthetic in nature with no scientific basis. At the village level, concepts of acceptable practices are culture-specific, and extrapolations from the attitudes of one culture to those of another must be avoided. For example, latrines built over fish ponds to admit human faeces directly into the water are used effectively in some cultures but would be totally unacceptable in others. Obviously, orthodox Muslims would not accept an integrated scheme for swine and algae production.

Cultural obstacles may also be subtle and unrecognized by outside planners and organizers until the reasons for failure of a seemingly feasible programme are examined in depth. Cultural resistance to a village-level project may not be due to concerns about the process or product itself, but rather the proposed method of introduction may not fit the social practices of the village. For example, the proposal may require men to play a role that is traditionally for women, or depend on new, difficult-to-introduce patterns of social or economic co-operation among families. If it undermines traditional authority patterns in a village, strong resistance may be encountered.

The time to determine social and cultural attitudes and barriers is before a programme is formulated or announced. Such investigations can lead to the conclusion that a project should not be attempted, but it is to be hoped that they will also indicate approaches that will give a proposed project a better chance of success.

Whether animal or human feeding is the intended use for an MBP, certain problems will be common to both, and, as listed in Table 4, these are directly or indirectly health-related. In many countries, MBP, like SCP projects, may require regulatory approval. Economic feasibility is, of course, essential and will depend, in part, on the attitude of regulatory authorities and the potential consumer. MBP products will also be vulnerable to environmental costs and environmental acceptability. These include concern for possible adverse effects on water quality, including increased BOD, water-borne infections, infectious disease vectors in water, pollution with heavy metals and pesticides, or undesirable odours and tastes. Competition for alternate uses of land or water may also be a consideration.

TABLE 4 Assurances Necessary for Application of Microbiological Techniques to Organic Residues

For animal use

(a) safety of species
(b) safety of substrates
(c) safety of animal products

(d) nutritional value

For human use (additional considerations)

(e) lack of allergenicity
(f) lack of mutagenicity/carcinogenicity
(g) lack of teratogenicity
(h) favourable organoleptic or functional characteristics
(i) cultural acceptability

All of the above may be factors in determining whether the political climate will be favourable to, or at least not in opposition to, specific MBP or SCP development. This will, in turn, be heavily influenced by perceived health risks and benefits of the kinds mentioned above, whether or not these are real or imaginary.

Governments and the public tend to be frightened by possible new hazards introduced by science and technology, and strangely complacent about existing ones of far greater magnitude. Given the importance of ensuring favourable attitudes on the part of politicians and the public, it will be important to avoid some of the mistakes made in hydrocarbon-SCP development and to try to assure positive attitudes towards the safety, nutritional value, and usefulness of MBP.

As already suggested, nomenclature may play a significant role in public perception of health considerations. Single-cell protein is not a scientifically accurate term, because all protein comes from single cells, but it was selected in my office at MIT and introduced as the title of the first conference on proteins from yeast and bacteria, held at MIT in 1967. It was chosen in preference to "microbial protein" and other names that already had negative connotations. The term "SCP" has been applied to describe the biomass consisting entirely of the cells of a single organism, or a limited number of species, produced on relatively pure substrates. Needless to say, it met a need and came rapidly into world-wide use. It is now proposed that we apply the new acronym MOP (for microbial biomass product) to the complex mixture of substrate and micro-organisms produced by the fermentation of unrefined animal and vegetable wastes. It is obviously intended to complement the term SCP and to avoid the use of the latter when referring to the complex combinations of substrate and micro-organisms that are the main concerns of this workshop.

It seems likely that the production of biomass for human consumption from carbohydrate rather than from hydrocarbon substrates will continue to fall mainly in the category of SCP, where safety of substrates and organisms can be assured by animal and human testing and careful controls. However, these are not usually produced by village-level processes, much less household ones. There is one category of MBP that might readily be developed for human consumption, utilizing substrates that are already edible and need merely to be upgraded organoleptically, functionally, or nutritionally by the microbiological process, This is the basis of such traditional foods as tempeh, ontjom, and bongkrek, already mentioned by Steinkraus at this workshop (6). It is entirely possible that more such foods can be developed, but each will either be an outgrowth of traditional practices confirmed by usage, or will require the kind of preclinical and clinical testing described in PAG Guidelines 6, 7, and 12 (7 - 9).

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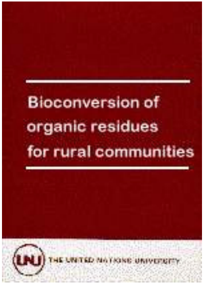
Discussion summary

In commenting on Scrimshaw's paper, La Rivire felt it necessary to record the effect of government actions upon factors affecting food production. The entire farming system in Western Europe and the United States depends on government subsidies to the extent that in the US some farmers have received subvention not to grow certain crops. Government subsidies might well be used to encourage the production of the bioconversion materials discussed in the papers at this conference.

The discussions closed with comments on the necessity of differentiating the qualities of energy in analyses of that factor. Although this is a complex evaluation, it is absolutely necessary if valid comparisons among different systems are to be obtained, a sine qua non for their practical application in rural communities.



Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Appropriate biotechnology - summary remarks

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The United Nations University is a structure for joining forces, and it is consequently most appropriate that this conference has taken place with two such fine organizations as INCAP and ICAITI as co-hosts. Hearing Drs. Scrimshaw, Burgers, Tejada, and Dengo outline the aims of those organizations has obviously served as a source of inspiration for the participants.

Summarizing a conference of this type is, however, a bit unfair because one tends to underestimate the value of the contacts that are established outside the formal structure of the meeting. On this particular occasion the value of those contacts has been quite obvious, and can certainly be partly traced to a most hospitable environment. However, I think there is general consensus that C.A.

Shacklady, R. Bressani, and the other organizers should also take much credit for having made up such a catalytic mix of professionals, nationalities, and interests. This mix has taken its intellectual substrate from the products of photosynthesis, but its interactions have certainly not been restricted to the hours of the day when the sun was shining over this beautiful country.

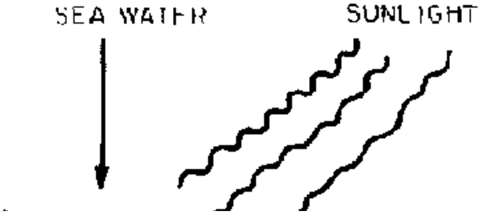
However, my charge is to summarize the formal meetings, which have surely provided much food for thought to the United Nations University Task Force on Bioconversion of Organic Residues for Rural Communities. This now requires a monumental digestion effort, but its Chairman, P. van der Wal, as well as W. Barreveld from FAO, simplified matters by starting the conference with overviews on the availability, composition, and nutritional value of the various organic residues that the meeting should consider. van der Wal reminded us of the fact that providing better and more equitably distributed food is a multi-faceted problem where the utilization of organic residues could play a central role. However, an effective strategy requires a comprehensive review of alternative treatments (physical, chemical, and biochemical) as well as a practical evaluation of various conversions, both via the microbial route and through animals. With straw as an example of one usable substrate, later speakers illustrated how different process combinations might possibly be used. M.G. Jackson, for instance, described how alkali treatment of straw could improve the efficiency of ruminants acting as bioconverters. Their dung might then be regarded as the raw material for composting, as described by T. Matsuzaki, or for biogas production before the mineral nutrients are finally returned to the soil. Alternatively, this particular residue could indirectly be converted to human food by R. Alicbusan's mushroom cultivation method, before the straw residues are digested or returned to the field. To such established methods may now be added a range of new possibilities like the Purdue (Tsao) technique to solubilize cellulose, or microbial digestion with microorganisms, such as Aspergillus terreus, described by H. R. Srinivasan.

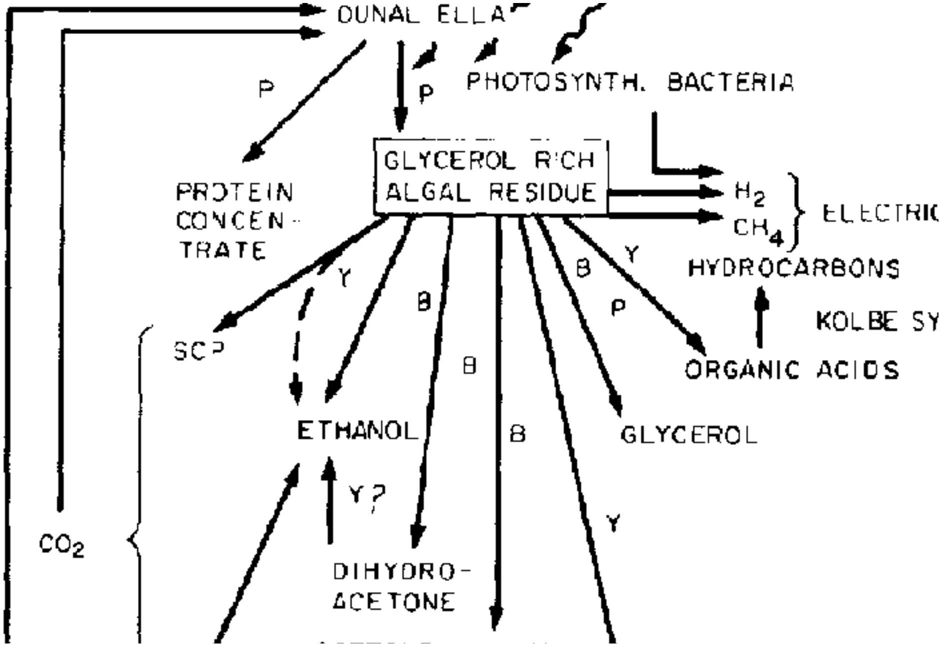
W. Barreveld and several subsequent speakers emphasized the dynamic character of the agricultural residues that could be regarded as a nuisance, a waste, or a resource out of place, depending on the circumstances. severe constraints on their use are: scattered production, seasonal availability, lack of know-how, social restrictions, transport costs, and pollution. Lack of credit is another serious hindrance. Pollution was again underlined by M. la Rivire, when he reviewed the environmental impact of waste materials, and cited sewage treatment as man's largest single big-industry. This, however, developed without much consideration either for the potential of applied microbial ecology or for the energy costs of the aerobic process. However, the attitude with regard to the management of night soil and fish pond fertilization is now changing in a direction that could greatly serve rural development. This was underscored by J. Bardach in his discussion of the value of fertilization with faecal matter, for instance from ducks, in aquaculture ponds. He described the potential of fish ponds, but also warned against recommending aquaculture to people who are not ready for this relatively exacting technology. It must take into account not only such things as stocking density, flow rate, and oxygenation but also the interdependence of food webs that could be very different in various parts of the world.

Z. Berk's data on fish pond fertilization and on the feed value of sewage-grown algae were promising, because, even if algae do concentrate heavy metals, these do not appear in the meat of the animals consuming feeds fortified with algae. Drying costs have been a serious constraint, but this has been partially overcome by heat-drying, which also increased digestibility. Fish, poultry, and pigs would be the natural consumers of algal feeds, but T.R. Preston's emphasis on the importance of so-called "by-pass nutrients" as feed-back controllers of fodder consumption in ruminants forcefully brought home not only the significance of protein-rich leaf crops as fodder, but also the possible significance of algal blooms on the metabolism of ruminants. These animals are, of course, powerful methane producers, but this carbon loss attracted less attention from the participants than the deliberate production of biogas in digesters As shown by E. DaSilva, this is now an established rural practice in many parts of the world, but R.

Rolz reminded the participants of the great scope for further developments, and of the need for further technical and economic evaluation As far as the input is concerned, T.K. Chose showed how conversion efficiency could be improved by choosing a suitable mix where water hyacinth and algae could be important components. G. Shelef stressed the potential of sewage-grown algae as fodder, but also indicated how algal ponds could be directly integrated with biogas production. This could also benefit from the application of high technology both in the form of materials, for instance the bag-digesters mentioned by E. DaSilva, or concepts like a geodesic dome structure described by C.V. Seshadri.

With regard to solid agricultural wastes, J. Porter gave an overview of the potential of microbial processes for turning a wide range of organic residues into valuable products, ranging from D-lactic acid from sulphite liquor, to mushrooms grown on ligno-cellulosic materials. In certain instances, like the Brazilian alcohol project, the quantities of biomass produced as a by-product can become very large and might be highly suitable for fodder use. Such integrated utilization of photosynthetic products will certainly assume growing importance, and is a feature of many advanced processes like the Israeli production of glycerol from halophilic algae. Ben Amotz and Avron not only get 8 9 of intracellular glycerol per square metre of pond surface per day, but also 11 9 of protein and 400 mg of carotene (1). As indicated by Figure 1, which is taken from work on Dunaliella algae in my own laboratory (2), the fermentative upgrading of the lysates opens up the opportunity for running biosystems not only in the humid tropics, but also in arid lands that comprise quite a bit of the earth's surface (Table 1). Figure 2 shows how an integrated system for making a liquid fuel out of this photosynthetic product might look (3).

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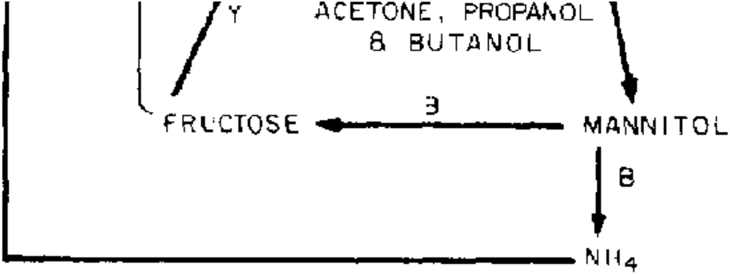


Figure. 1. Possible Routes for the Utilization of Photosynthetically Produced Glycerol. B = bacteria; P = processing; Y = yeast. (From Heden [2])

TABLE 1. Primary Productivity of the Earth - Distribution of 155,200 Million Tons D.W./Year on 510 Million Km

	%	Area	% productivity	Net
Continents	29.2		64.6	

Forests		9.8		41.6
Woodland		1.4		2.7
Tundra and desert		5.1		1 5
Grassland		4.7		9.7
Bare desert		4.7		0
Cultivated land		2.7		5.9
Fresh water		0.8		3.2
Oceans	70.8		35.4	
Reefs and estuaries		0.4		2.6
Continental shelf		5.1		6.0
Open ocean		65.1		26.7
Upwelling zones		0.08		0.1

Totals:	100	100	100	100

Source: H. Lieth, 2nd National Biological congress, 1971.

Admittedly, processes of this kind are not yet appropriate for village-level applications, but they underline a possible future projection from a simple start with robust systems to a diversified agro-industrial development. In fact, the potential of genetic engineering and effective starter management should not be underestimated when considering appropriate biotechnology. This is very far from being a second-rate technology. Indeed, it is often far more difficult to develop a simple process than to apply the materials and control theory for advanced technology. Against this background, I am sure that I speak for all of us who come from industrialized countries when I express admiration for the achievements in the developing parts of the world as they have been described at this meeting.

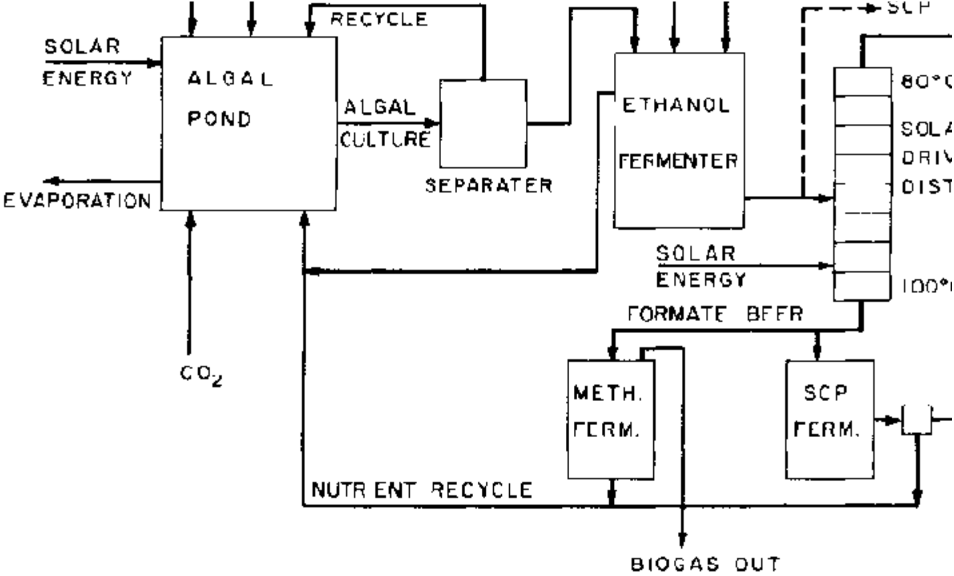


Figure. 2. Hypothetical Integrated System for Ethanol Production

(From Williams et al. [3])

Modern big-engineers have much to learn from the traditional fermented food practices that K. Steinkraus reviewed as a means to improve digestibility, keeping quality, and vitamin content of many agricultural products. In the humid tropics, perhaps the lactic fermentations that were mentioned by R. Stanton deserve special attention. Personally, I feel that this preservation technique might also have significance as a means to permit fermenter operation at the village level. After all, a village fermenter might have to be made from wood or ferrocement and might be expensive or difficult to sterilize by steam. Of course, one could use -propiolactone, which easily hydrolyzes to a non-toxic chemical (4), but perhaps a more realistic approach would be to alternate lactic fermentations with some that are more prone to contamination. This would be much along the same principles as using alternative crops to avoid insect pests.

In the area of fermented foods, the Japanese developments summarized by H. Ebine illustrated how many of these traditional systems can be improved and modified, and C. Cooney underlined the scope for innovations in rural-level microbiology when he pointed out the potential of immobilized cell techniques and biocatalysis in solid substrate systems. In this latter category, the process for protein fortification of cassava starch described by J.C. Senez illustrated a highly suggestive new approach. This seemed to have the characteristics of an appropriate biotechnology, provided, of course, that a reliable system for starter distribution can be established. That problem should be a challenge to both bio-engineers and to experts on logistics. In fact, the multitude of opportunities described at this meeting, and the innovative applications at the village level described by G.S. Venkataraman with regard to biofertilizer production, and by C.V. Seshadri on wind-power systems, require the overview of a systems analyst. M. Slesser described such an approach, which not only distinguished between energy stocks and energy fluxes, but also brought land use and the economic aspects of various investments into focus. This is obviously an essential feature, because major emphasis must be put on the basic purchasing power of the poorest segment of the target population.

In this connection, I wish to cite a few lines from the report of Working Group II that met in Houston in early November 1978, under the chairmanship of Dr. A. King (5). It notes: "There is an increasing awareness of the interdependence of nations, problems, scientific disciplines and objectives. This is leading to a gradual acceptance of a holistic and integrative approach to the problems of development. These terms, holistic and integrative, are to be understood in several senses. Firstly, the problems of a nation, of a city, of a village are to be seen as interconnected to the extent that they have to be tackled simultaneously and as a complex rather than separately and sequentially. Again they all possess economic, social, cultural, and political facets which have to be considered together and cannot be resolved by the politician alone, or by the scientist, engineer, or economist in isolation. Thus with regard to resource utilization, it is necessary to consider all the available resources, agricultural, forest, soil, water, micro-organisms, plants, animals, men and women." Funds and equipment may be important, but ". . . many excellent schemes and devices of proved value remain un-used at the field level when motivation and incentive are lacking. Any national campaign for bioresource development must therefore take into account the need to generate motivation for their use by demonstrating how the individual family and village would benefit from the use of the new possibilities and providing initial incentives for this."

I was interested to note that R. Alicbusan also underlined this need. Statements such as those cited above illustrate awareness about important constraints, but also a guarded optimism that a trans-disciplinary effort will yield a rapid effect. This may perhaps be true in the production of fuel and fertilizer, but is a different kettle of fish in the case of food and fodder products. From this point of view, it was probably wise to conclude the meeting by a series of reminders about the complexity and expense of testing acceptability, digestibility, and toxicity, which are, of course, essential adjuncts to the chemical analysis of food and fodder products. E.J. van Weerden's example of the selenium and pelletization effects in an SCP test was certainly a warning for many of us.

The problem of evaluating the quantity of protein addition needed to achieve a significant effect in human foods was illustrated by R. Bressani's bean/cassava studies. Foods based on algae might also require extra inputs from food technologists, even if the nucleic acid content does not seem to offer the same problem seen in yeasts, fungi, and bacteria. The latter group also requires special attention as far as toxic compounds are concerned. The great variety of products now being discussed may actually require methodological shortcuts limiting the need for large-scale animal testing. C.A. Shacklady was optimistic that such short-cuts are indeed possible, and brought a reasonable risk/benefit analysis within sight. The general approach would be a combination of extensive chemical analysis with in vitro mutagenicity tests and limited animal tests followed by careful autopsies.

A similar optimistic note could be detected in N.S. Scrimshaw's review of the public health aspects and earlier fears, political overtones, and cultural resistance that had influenced SCP development. In fact, the health problems still discussed in the context of SCP production can now be resolved by an appropriate test matrix. Village-level products, however, present a wider range of problems that must be considered. The successful feeding of microbial biomass product to farm animals is in itself a satisfactory test, but MBP for human consumption will require string gent tests in several species of experimental animals before careful tolerance and nutritional studies in human subjects.

Many of the techniques discussed have a very wide application, which is important because it means that the developing and industrialized countries have common interests that should stimulate joint-research efforts. In fact, the intermediate technology that the less developed countries need now will have a lot in common with the equilibrium technologies that the industrialized countries are likely to need in the beginning of the next century (Figure 3). That will be a time when we will have to start thinking about closing the carbon cycle, and the size of the fossil fuel reserves (Figure 4) will force the saving of energy in food production (Table 2) and in the choice of substrates. The change from a cowboy to a spaceship society, to use G. Shelef's expression, has in fact already started, as expressed by the peculiar abbreviations that are now beginning to appear in the literature (Table 3) and by the mushrooming of so-called autonomous houses that operate at a very high level of recycling (Figure 5).

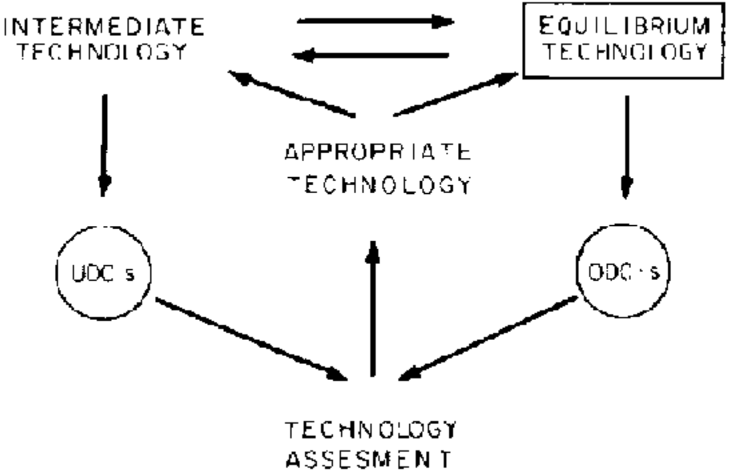


Figure. 3. The Interaction between Intermediate and Equilibrium Technology. UDC= underdeveloped countries; 0DC = overdeveloped countries

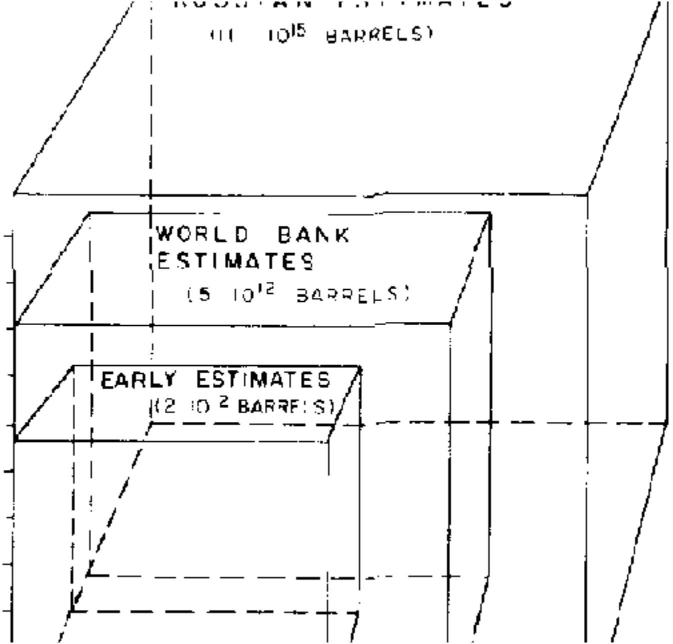
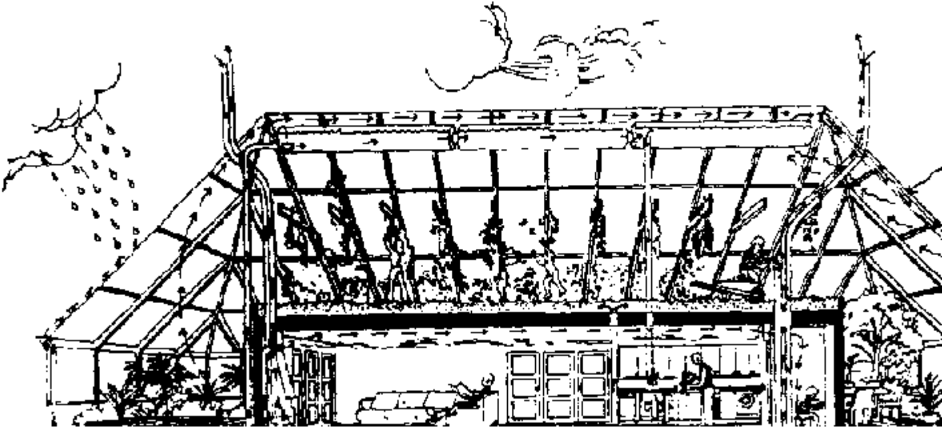

(1 10^{15} BARRELS)
WORLD BANK
ESTIMATES
(5 10^{12} BARRELS)
EARLY ESTIMATES
(2 10^{12} BARRELS)

Figure. 4. Various Estimates of the Size of Fossil Fuel Reserves



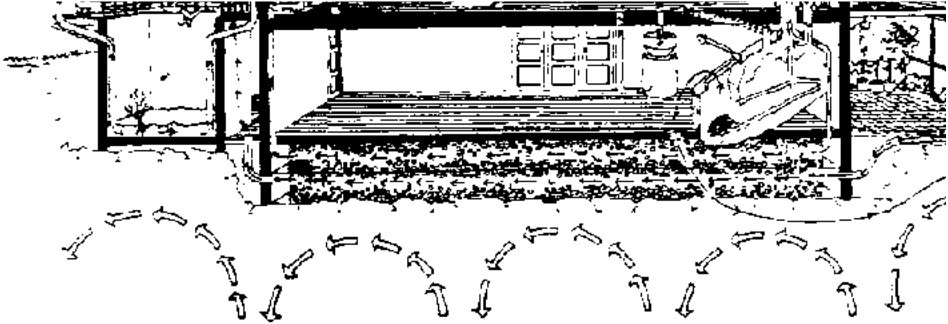


Figure. 5. The "Nature House" at Saltsjbaden outside Stockholm. (Copyright Ark. Bengt)

By using some imagination, many experts (cf. Europe 2000) already see the communications and biotechnology explosions driving us towards highly decentralized societies devoid of the slums and shantytowns that have now become a cancer in our civilization. The full and intelligent utilization of the bioproductivity of this planet may be our best chance to alleviate the negative aspects of urbanization, which are not only caused by city pull, but also by a rural push brought on by capital- and energy-intensive agriculture (6). Increased productivity is certainly essential, but there is every reason to ask if more efficient utilization of organic waste materials does not offer alternatives to our current practices. The Natural Resources Programme and the World Hunger Programme of the UN University have jointly chosen a singularly important focus for their efforts. A problem that is recognized becomes a challenge, not only for large organizations, but also for us who have had the privilege of participating in this highly stimulating workshop.

		Molasses	Methane	Methanol	n-Paraffins	Soli agric wast
SCP output (t/year)		50,000	50,000	50,000	100,000	50
Land area (ha) used	production site	8	12	12	20	0.1
	substrate cultivation	18,000	–			20
	total	18,008	12	12	20	20
SCP yield (kg/ha/year)		2,800	$4,167 \times 10^3$	$4,167 \times 10^3$	$6,000 \times 10^3$	2,50
Actual protein* yield (kg/ha/year)		1,764	$3,334 \times 10^3$	$3,334 \times 10^3$	$3,150 \times 10^3$	1,37
Energy subsidy (GJ/ha/year)		134	541 710	487 539	585 000	11
Estimated manpower**		200	200	200	375	1
Ton protein/man year		160	200	200	170	3

Source: C. Lewis, "Energy Requirements for Single-Cell Protein Production," *J. Appl. Chem.* 26: 268 (1976)

* Crude protein in bacteria, yeasts, and moulds taken as 80, 63 and 55 per cent, respectively.

** Includes direct labour on production site only and excludes personnel involved in raw material acquisition, transpo

TABLE 2. Scale of SCP Production Plants, Yields/Land Area, and Labour Requirements

TABLE 3. Some Space-Age Abbreviations

LOPSOL=	Low Profile Style of Living (Chicago) Hawthorne Woods Environmental Center
IUS=	Storage System Design and Techniques for Optimizing Energy Conversion in Integrated Utility Systems (Batelle, Columbus, Ohio)
MIUS=	Modular Integrated Utility and Total Energy Systems ERDA

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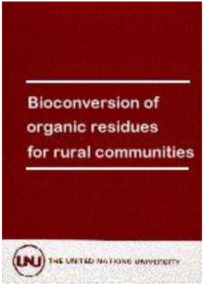

Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Perspectives on bioconversion of organic residues for rural communities

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Introduction

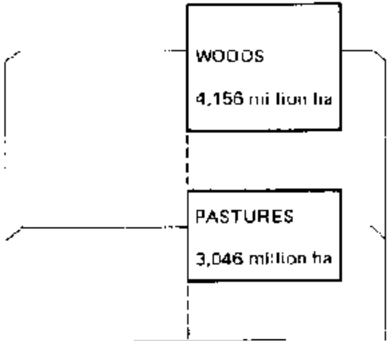
The shortage of food in the world recently prompted the Director General of FAO, Edouard Saouma, to reiterate the special need for food in densely populated rural areas of developing countries (1). We need new food sources, and we should not restrict ourselves to increasing supplies of existing ones to meet this demand (2). In our attempts to develop these potentials we should, however, avoid theoretical overkills (3).

In this paper, I shall try to take these points into account while studying the question of whether new sources can be tapped to a significant extent, and whether these new rural sources can provide food that is affordable, whole some, and acceptable organoleptically. In view of the latter point, I would like to emphasize that, especially in rural areas, consumers are extremely critical. This is by no means limited to developing countries only. In the Netherlands, too, children are taught, "What a farmer is not familiar with, he does not eat."

Sources of available nutrients

An inventory of nutrient sources is rather illuminating (see Figure

1). There are approximately 9,000 million ha of land in the world. Close to 50 per cent of this area consists of forests and shrub lands. Another 35 per cent is pasture and grassland, and 15 per cent is arable land. Of the produce grown on arable land, by far the major part is discarded as residue. This means that approximately 95 per cent of the land areas mentioned in Figure 1 could provide a source of nutrients yet untapped in the sense that their agricultural residues are not being utilized directly for human consumption.



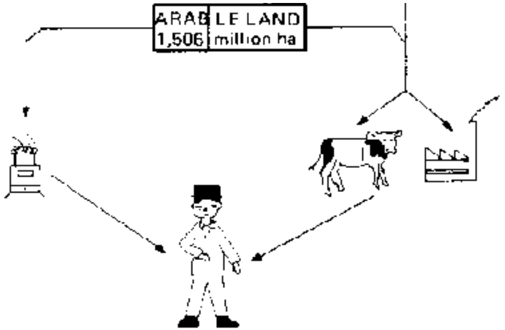


Figure. 1. Land Production of Potential Nutrients

Food science and technology at present concentrate mainly on the 5 per cent of the annual production of potential nutrients that can be used after relatively simple forms of processing, such as cooking or baking. The 95 per cent residue needs considerable processing, be it physical, chemical, or via some form of bioconversion before it can be turned into suitable feed or food. This paper will concentrate on the products that we refer to as organic residues. They are what is left after agricultural production, sometimes left behind on the land (straw), on the farm (manure), or in agro-industries. They are relatively easily available for conversion into food.

Figure 2 shows some of the most important agricultural crops. There is a line along which we can divide these products. On the left side we find the percentage considered to be the main food component of the crops. They can be used without much processing by the human consumer (grain, oil, starch, vegetable protein). On the right side are the residues that comprise approximately two-thirds of the total production.

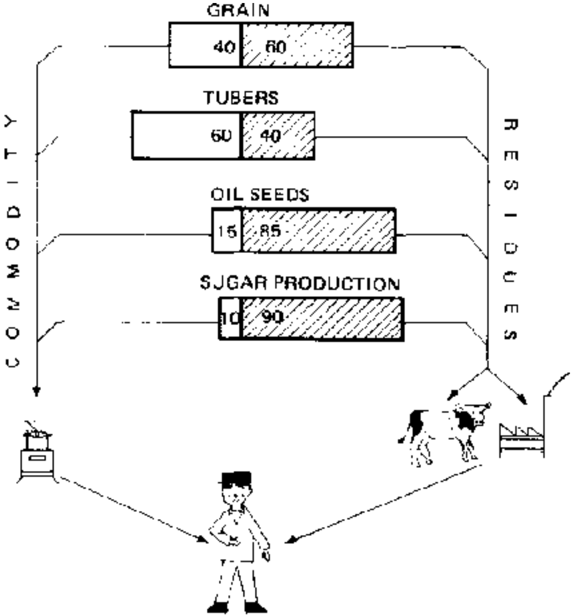

GRAIN
40
60
TUBERS
60
40
OIL SEEDS
15
85
SUGAR PRODUCTION
10
90
COMMODITY
RESIDUES

Figure. 2. Agricultural Crops

Two routes are available to convert these residues into useful products, as indicated in Figure 2: through feeding to animals, or by some industrial process.

Because these residues form the major part of agricultural production, their conversion into food via efficient and safe systems deserves far more attention than we have paid it so far.

Tremendous efforts are required to make such new systems operational. Therefore, we should concentrate on a limited number of the most promising ones and approach them in a multi-disciplinary fashion.

Those of us involved in developing new conversion systems will agree that the creation of acceptable food from novel sources usually requires animal conversion as a last step. Microbial conversion alone produces, in most cases, biomass, e.g., single-cell protein that is not accepted as a food by most consumers.

The most suitable materials for bioconversion

To identify the most suitable areas in which bioconversion of residues may be important and therefore worthwhile, the residues are divided into three categories, each susceptible to a common method of bioconversion. Cellulose-rich substrates form a total of more than 1,800 million tons annually of renewable resources (Table 1). They are to a great extent found in Asia, and it is therefore not surprising that they consist primarily of rice straw. The present use is often none; in some areas it is used for fuel. Straw could form an extensive base for reeding ruminants. There is no doubt that bioconversion would greatly improve the use of these materials, particularly in rural areas. To what extent in vitro SCP (single-cell protein) production can play a major role here depends greatly on local circumstances and on the results of research efforts in this field.

TABLE 1. Straw Production, 1974 (in millions of tons)

Crop	World	Africa	South America	Asia
Paddy rice	323	8	10	294
Wheat	360	8	10	90
Maize	586	54	58	100
Other straws	441	41	18	123
Total straws	1,710	111	96	607
Sugar-cane	116	9	28	46
Total	1,826	120	124	653

The second major residue category consists of starchy and sugary wastes (Table 2). Because their carbohydrates are more easily accessible, they require a somewhat less difficult form of SCP bioconversion. As shown in Table 2, cassava and sugar beets provide the greatest amount of residue. High productivity in relatively poor soil has made cassava a popular staple food, especially in countries most in need of food.

TABLE 2. Starchy, Sugary Residues (in millions of tons)

Crop	World	Africa	Latin America	Asia
Cassava	106	42	33	30
Sugar beets	482	4	5	39
Bananas	8	1	4	2
Citrus fruits	12	1	3	3
Coffee	5	2	3	-
Total	613	50	48	74

A third category of residue is manure, a by-product of all animal production systems. It is calculated that approximately 1,900 million tons of manure are produced per year.

Characteristics of residues

Residues are not used as foods because they are inedible without some form of bioconversion. Table 3 shows that the chemical composition of most residues is not well balanced. Straw contains 48 per cent crude fibre and 3 per cent crude protein.

TABLE 3. Chemical Composition (% dry matter) of Various Residues

	Grain* straw	Leaf* (grass)	Citrus** pulp	Manure*** (poultry)
Organic matter	95	91	93	77
Ash	5	9	7	23
Crude protein	3	17	7	32
Crude fibre	48	27	14	-
Nitrogen-free-extract	43	44	69	27

* O. Kellner and M. Becker, Grundge der Futterungslehre (1959).

** CVB Cattle Feed Table.

*** F. de Boer and A. Steg (Hoorn), report, "Megista mestdag," part II.

It is hardly a good product for human consumption. Grass has a better composition, but if it were to be used for monogastric consumers like man, there would still be severe problems because of the relatively high crude fibre content. Poor digestibility is another reason for rejecting unprocessed residues.

Table 4 gives the digestibility coefficients of some residues for ruminants. The organic matter of straw is only 38 per cent digestible even for ruminants. For monogastric organisms like man, poultry, and pigs, the coefficients are even lower. Grass is more digestible but less suitable for monogastrics. Digestibility of citrus and animal wastes is reasonable, but not particularly good.

TABLE 4. Digestibility Coefficients in Ruminants

	Grain* straw	Leaf* (grass)	Citrus** pulp	Manure*** (poultry)
Organic matter	38	72	-	72
Crude protein	12	75	42	78
Crude fibre	40	65	80	
Nitrogen-free	38	77	95	69

* O. Kellner and M. Becker, Grundzge der Futterungslehre (1959).

** CVB Cattle Feed Table.

*** F. de Boer and A. Steg (Hoorn), report, "Megista mestdag," part II.

A number of other reasons may make a residue undesirable. Logistic aspects and low drymatter content may be expensive to overcome. Seasonal variability often makes it difficult to manage the material by advanced technology. Chemical and microbial contamination and organoleptic or psychological unacceptability may preclude the use of some residues as food. The above characteristics all present problems that must be overcome if a residue is to be converted to food.

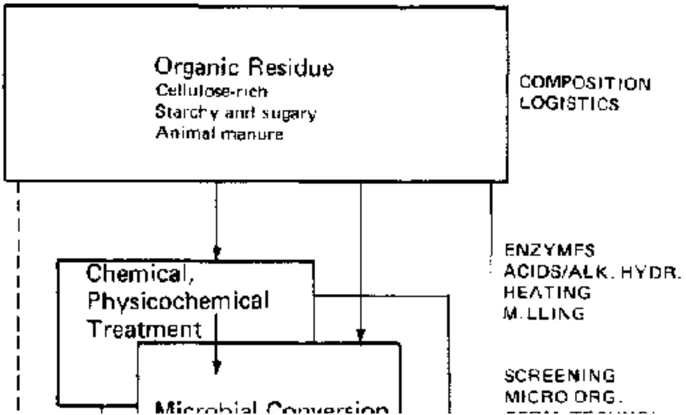
Bioconversion systems

Figure 3 shows the pathways for the bioconversion of residues into food. In the upper box, cellulose-rich, starchy and sugary residues, and animal manure are represented. The lower box shows the goal of bioconversion systems: food for man. In most cases this will be in the form of meat, milk, or eggs.

It is frequently said that there seems to be a certain competition for food between animals and man. One easily overlooks that this is the exception rather than the rule. Most animals are kept for the purpose of producing food for man. They are mainly converters (biological ones) of products inedible by man. As such, they do not compete significantly for human food supplies.

We have many options for making food from wastes. The ones by-passing the animals are represented by the dotted lines in Figure 3. Direct use as food is non-existent, otherwise the product would not be a waste. Chemical and physical treatments of waste seldom create food. Microbial conversion, either direct or after treatment, permits mushrooms to grow and favours the production of fermented oilseed cakes. Unfortunately, this method is not yet used for the conversion of millions of tons of residues to any significant degree.

The solid lines on the right side of the figure represent bioconversion systems making use of animals. Grass, straw, and quite an amount of poor-quality roughage follow the direct route to food. Animal feeds may also be wastes that are treated via chemical or physical means and/or by microbial conversion, which the animal also converts to food. The potential and efficiency of bioconversion should be exploited to a much greater degree. In general, the right side of Figure 3 shows the most realistic potential for bioconversion of the bulk of residues into food.



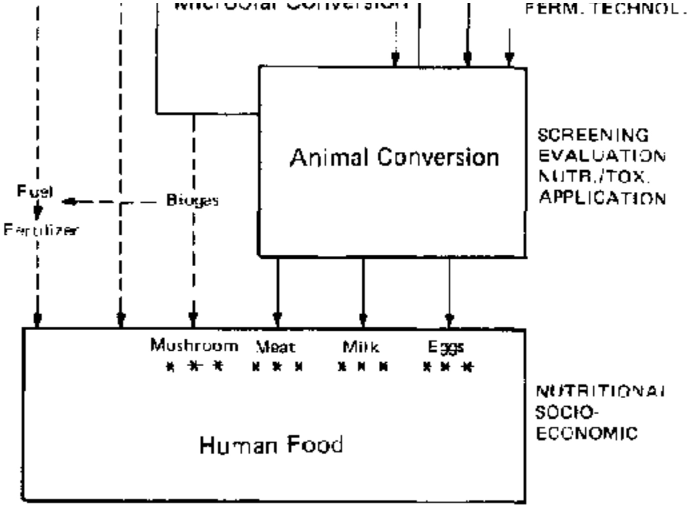


Figure. 3. Bioconversion of Residues into Food

Physical and chemical treatments

The alkali treatment of cellulose-rich materials like straw (1,800 million tons in rural areas) deserves special attention (Table 5). Digestibility for ruminants improves from 45 to 68 per cent when straw is treated. What does that imply? in the major rural areas of India, untreated rice straw provides hardly enough nutrients to maintain the live weight of cattle; in other words, it barely covers the animals' maintenance requirements Assuming that 90 per cent of the feed is used for maintenance, 10 per cent is available for increasing weight, for producing offspring, and for milk production. If digestibility were increased by 50 per cent, it would provide, as in the Table 5 example, a fivefold increase in nutrients available for meat and milk production.

TABLE 5. Effect of Treatment on Straw Digestion in Sheep

Treatment	Organic matter	Digestibility (%)
Alkali	untreated	45

	treated	68
Ammonia	untreated	38 (56)
	treated	52 (69)

Microbial conversion

Alkali-treated straw can be given to small fermentation "plants" located in the rumens of cows, buffaloes, or goats The micro-organisms in these rumens are able to convert the treated residue into protein. The process has been fairly stable through the ages.

Microbial conversion can also be carried out outside the animal through fermentation processes By applying appropriate technology, we should then be able to produce protein products that could be converted into food by monogastric animals like poultry and pigs

If the micro-organisms used remain combined with the remnants of the organic residue that was used as a substrate, we call the product microbial biomass product (MBP). If the micro organisms are harvested and separated from the substrate, we refer to the product as single cell protein (SCP) The composition of SCPs compares favourably with the substrates on which they are grown, as shown in Table 6.

TABLE 6. Comparison of Chemical Composition (%) of SCP with Soybean Oilmeal

	Yeast	Bacteria	Fungi	Algae	Soybean oilmean
Dry matter	96	90	86	94	88
Ash	6	8	2	7	6
Organic matter	90	81	84	87	82
Crude protein (N x 6.25)	60	74	32	52	45
True protein (amino acid- N x 6.25)	47	55	22	46	38

Crude fat	9	8	5	15	1
Crude fibre	-	-	28	11	6
Nitrogen-free extract	20	-	20	12	30

Crude protein content and amino acid composition (Tables 6 and 7) put bacteria, yeasts, fungi, and algae into the category of high quality protein sources such as soybean oilmeal.

TABLE 7. Amino Acid Composition (9/16 9 N) of SCPs and Soybean Oil meal

	Yeast	Bacteria	Fungi	Algae	Soybean oilmeal
Lysine	7.0	5.5	4.8	4.6	6.2
Methionine + cystine	2.9	3.1	2.5	3.2	2.9
Arginine	4.8	4.7	5.2	-	7.2

Histidine	2.0	1.9	2.0	-	2.5
Isoleucine	4.5	3.9	4.1	3.1	4.9
Leucine	7.0	6.3	6.4	7.0	7.6
Phenylalanine + tyrosine	7.9	6.2	8.1	6.0	8.4
Threonine	4.9	4.2	4.4	4.9	4.2
Tryptophan	1.4	0.8	1.4	1.7	1.3
Valine	5.4	4.8	5.6	4.7	5.0

The digestibility of SCP (Table 8) again compares well with conventional high-quality protein sources like soya. Digestibility is lower for algae, and the data are inconclusive. Further evaluation is required.

TABLE 8. Digestibility Coefficients in Pigs

	Yeast	Bacteria	Fungi	Algae	Soybean oilmeal

Organic matter	92	90	79	-	83
Crude protein	90	93	71	54	91
Crude fat	95	87	34	-	34
Crude fibre	-	-	99		
Nitrogen-free extract	94	-	-	-	94
Metabolizable energy (kcal/kg)	3,860	3,720	2,940	-	3,190

It is often assumed that small-scale SCP production can be made operational relatively easily. This is a serious under-estimation of the problems involved. Development of low-key technology that can operate on the scale of a farm co-operative or a village, and that is nevertheless effective and stable, requires elaborate research efforts. Positive results are more likely to be achieved if experienced industrial fermentation research groups participate.

The animal conversion phase

In order to use SCP products successfully, a thorough nutritional and toxicological evaluation is necessary. Nutrient requirements and digestion in animals are species-specific and so is absorption of nutrients after digestion. The metabolism of nutrients and potential toxic substances is also species-specific, as is susceptibility to toxic substances.

The consequence of this specificity is that experimental data obtained in animal testing cannot be extrapolated with certainty to other animal species. The nutritional and toxicological evaluation must, therefore, be done in all animal species for which the product is destined, i.e., the target species. In guidelines for testing the nutritional and safety aspects of novel sources of protein, as formulated by the Protein Calorie Advisory Group of the United Nations System (PAG) (4, 5), this is taken into account.

Table 9 shows digestibility coefficients of a fungal product in two different monogastric species - poultry and pigs. The digestibility of the organic matter, which is close to 80 for pigs, is a mere 24 for chickens. Protein digestibility differs somewhat less dramatically. The table suggests that the difference is probably caused by the difference in digestibility of crude fibre. In the final analysis, the metabolizable energy available for chickens is only one-third of that for pigs. The difference between species is usually less marked, but the figures illustrate that specific reactions of animals must be taken into account in the evaluation of SCP.

TABLE 9. Digestibility Coefficients of a Fungal Product

	Pigs	Chickens
Organic matter	79	24
Crude protein	71	59
Crude fat	34	18
Crude fibre	99	6
Metabolizable energy	2,940	1,000

(kcal/kg)		

When the basic nutritional and toxicological evaluations have been completed with satisfactory results, the product can be submitted for approval by government authorities.

When producing SCP products commercially, biological testing must ensure that they comply with the specifications of the product for which approval was originally obtained. If the product is modified after testing, the initial experimental data may no longer be applicable.

The final stage of testing should include optimum application of the product in the rations for the animal species that will consume these rations in the countries where the product will be applied. Here, too, specific environmental and social factors may play a major role. Table 10 presents the kinds and numbers of animals available for conversion of residues into protein, but the acceptability of their products differs greatly among regions and cultures.

TABLE 10. Number of Domestic Animals in World /in millions)

	World	Africa	Latin America	South Asia	S.E. Asia	Near East
Cattle	1,214	160	266	199	23	46
Buffaloes	132	2	-	73	14	4
Sheep	1,038	159	120	77	3	137
Goats	413	127	41	87	9	62
Pigs	645	8	72	7	25	-
Chickens	6,116	488	721	192	307	236

Summary

For proper application of bioconversion systems, a detailed study of the optimum use that can be made of the biomass produced is necessary.

Only 5 per cent of the annual production of nutrients on land is used directly as food by man. Bioconversion systems making use of micro-organisms for SCP production can help the remaining 95 per cent to be utilized.

In most cases, food-producing farms are essential for making acceptable food for man from SCP. It is advisable to concentrate efforts, to a large extent, on the rural areas while making use of low-key technology that does not require large investments.

For the application of bioconversion, the development of stable village-scale fermentation technology and adequate evaluation of nutritional and toxicological aspects of the biomass produced form major obstacles.

A concentration on resources that are, in terms of quantity and allocation, particularly suitable for bioconversion seems advisable in order to avoid a dilution of efforts.

Of the cellulose-rich materials, straw is the most important. Among the starchy materials, the upgrading of cassava and its by-products to a protein-rich material shows good potential. Farm animal manure is considered a third major raw material that deserves high priority for upgrading.

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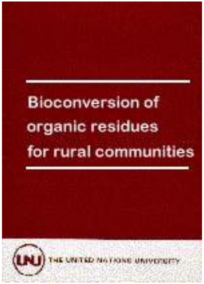

Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Other UNU Publications

(introduction...)

Books

Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Other UNU Publications

Periodical Food and Nutrition Bulletin

The Food and Nutrition Bulletin, which incorporates and continues the former PAG Bulletin of the Protein-Calorie Advisory Group of the United Nations system, reports objectively on all aspects of global malnutrition problems and the broad programmes and new areas of activity needed for combating them. It provides technical information and specialized knowledge related to world hunger, generated both by specific programmes of the University and by other relevant activities, and provides a forum for scientists and scholars to raise and discuss important issues. It includes articles and abstracts of current research work of practical concern to the hunger problem and gives notice of the availability of research papers, reports, proceedings, and other publications of value in solving the problem of global malnutrition.

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808-0015-9 52 pages
Volume 1, Number 2, February 1979 WHFNB-2/UNUP-19 ISBN 92-808-0019-1 48 pages
Volume 1, Number 3, May 1979 WHFNB-3/UNUP-45 ISBN 92-808-0045-0 44 pages
Volume 1, Number 4, August 1979 WHFNB-4/UNUP-52 ISBN 92-808-0052-3 59 pages
Volume 1, Number 5, November 1979 WHFNB-5/UNUP-95 ISBN 92-808-0095-7 59 pages

Books

Protein-Energy Requirements under Conditions Prevailing in Developing Countries: Current Knowledge and Research Needs - FOOD AND NUTRITION BULLETIN SUPPLEMENT 1, July 1979

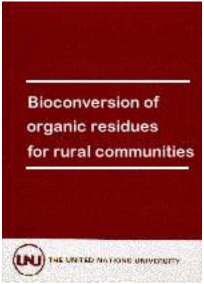
The purpose of this report is to indicate the current stage of knowledge regarding protein and energy requirements and appropriate dietary allowances for various populations living under the conditions prevailing in developing countries and consuming local diets It breaks new ground by bringing together much hitherto unevaluated original data - including to an important degree data generated by the World Hunger Programme's own research projects. In brief, it points up the fact that present international recommendations are inadequate because they fail to take sufficiently into account the protein-energy needs for recovery and catch-up growth following frequent acute and chronic infections and differences in the digestibility and protein quality of local diets. A principal function of the report is to provide suggestions for further needed research.

WHTR-1 /UNUP-18 ISBN 92-808-0018-3 73 pages, 165 x 23.5 cm, paper-bound US$3.00

Conservation and Development in Northern Thailand: Proceedings of a Programmatic Workshop on Agro-Forestry and Highland-Lowland Interactive Systems Edited by J. D. Ives, S. Sabhasri, and P. Voraurai

The Natural Resources Programme, through its associated institution Chiang Mai University, is undertaking an integrated study of the impact on environment of both physical processes and human social and economic interactions between lowlands and mountains in Northern Thailand, seeking more effective ways to utilize resources and improve the quality of life for the residents of the area, and at the same time to provide a model that can be adapted to similar environments elsewhere around the world. This book is a compilation of papers from a workshop on this subject held in Chiang Mai in November 1978, which was attended by experts in fields as diverse as anthropology, forestry, geomorphology, and agriculture.

NRTS-3/UNUP-77 ISBN 92-808-0077-9 21.4 x 28 cm, paper-bound US$10.00 To be published in January 1980.



Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Availability of organic residues as a rural resource

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A residue is a substance resulting from the processing of a product. A residue becomes a coproduct or a byproduct when profitable use is made of it. If this is not the case, the residue becomes a waste, which is defined as a material with no apparent market, social, or environmental value - at times even a negative one - that the producer no longer wants in a given place at a given time. According to these definitions, our task will then be to identify, classify, and quantify residues and to turn wastes into by-products.

The distinction between main product, by-product, and waste is not always clear. Molasses has established itself as a product of world commerce in its own right, yet it is still a waste in certain parts of the world. The meal of soya bean, initially a by-product of oil production, has become a main product, i.e., soy flour. Another sign of independency of a byproduct is when a specific name comes into use for its identification, e.g., middlings, polish, tankage, distillers' grains, and gluten meal.

In addition to the well established by-products, there are the poorer branches of the residue family. They are under-utilized or are completely wasted for a variety of reasons. An FAO project manager has defined these wastes as "resources out of place." This may be too ambitious a statement, because it is exactly the place of production that often creates a major constraint for profitable utilization. However, it shows a positive attitude of looking realistically at wastes as potential resources

Organic residues and their potential end-uses can be classified in a number of ways. This will enable us to pre-select areas on which to focus our activities and assist us in determining our first options for their potential use. In Tables 1 and 2, an attempt has been made at such a classification. The entries marked with an asterisk are of particular relevance to the subject of residue conversion by the action of micro-organisms.

TABLE 1 Classification of Organic Residues

By origin	
Agriculture	- crop and animal wastes
Fisheries	- shrimp heads, fish trimmings, trash fish, etc.
Forestry	- bark, shavings, sawdust, logging wastes, etc.
Related industries	- bagasse, hulls, cakes, pulps, bran, et
Home/community/municipality	- garbage, sewage
By commodity or commodity groups	- animals, beverage industries, cereals fibres, fruits
	and vegetables, milk and dairy products, oilseeds and

	nuts, rubber, spices and essential oils, starchy roots
	and tubers, sugars
By geographical location	- national, regional, rural, etc.
By physical state	- solid, slurry, liquid, gaseous
By type	
Common properties	- meals and press cakes, straws, fruit pulps, etc.
Common main component	- sugary, starchy, cellulosic residues, etc.

TABLE 2. Potential End-Uses of Organic Residues

Food	- fermented foods.
	- beverages*
	- mushrooms*

	- oils
	- proteins
Feed	- direct use
	- upgrading (physical, chemical, microbial *)
	- ensilage*
	- microbial biomass*
Fertilizer	- direct use
	- compost*
	- residue of biogas production*
Energy	- biogas *
	- alcohol*
	- producer gas
	- direct use (combustion)
Construction materials	- boards, panels, bricks

Paper pulp	- Paper, paperboard, packaging materials
Chemicals	- furfural
	- xylitol
	- alcohol *
	- organic acids'
	- polysaccharides*
Pharmaceuticals	- hycogenin
	- antibiotics*
	- vitamins*

Before dealing with the quantitative aspects of residues, some of the constraints that can hamper effective residue utilization should be mentioned. Remoteness of the centres of production becomes a major constraint when local conditions do not allow for absorption of the residue, and costs of transport to other locations are prohibitive.

This is the case with molasses in certain African countries. Scattered production of the residues, which is a common feature in agricultural production, raises collecting costs. Straws and other field-crop residues tend to have this handicap. Residues with a strong seasonal character, unless they can be stored, put a heavy burden on investment costs. Fruit and vegetable canning residues are an example. Dilution of the residue by either processing or washing water quite often makes the residue economically inaccessible. Lack of know-how and/or technologies adjusted to local conditions in scale and simplicity can be a factor obstructing the way to residue utilization. On occasion, reservations and restrictions of a social nature have to be overcome, which, for instance, has been experienced in the application of small biogas units, because of the type and handling of the raw materials involved.

All these possible constraints make it necessary to tread very carefully when considering residue utilization schemes. Apart from the availability of the raw material and the appropriate technologies, the local infrastructure should be carefully looked into. It should not be forgotten either that the incentive for profitable residue utilization is frequently linked with, or dependent on, political decisions This is clearly shown in some industrialized countries where penalties on pollution have shifted the economic feasibility of residue utilization practices. Lack of credit facilities, especially in rural areas, may block a whole utilization scheme even if the other requirements for successful implementation have been fulfilled.

It is, therefore, extremely difficult to prepare a general set of guidelines for the selection and application of residue technologies, because social, economic, and environmental conditions vary with time, and from place to place.

After this general description of some of the main characteristics of residue utilization, the second part of this paper will concentrate on the quantitative aspects of residues.

Availability is defined by the Oxford Dictionary as "capable of being used." This is a state of affairs that one would like to reach after all impeding constraints relevant to supply of raw material have either been demonstrated not to exist or have been removed. This also means that the commodity production statistics as published by FAO have little practical value apart from obtaining a general view of the overall magnitude of quantities of residues that are produced. A typical example is rice bran oil. In Japan, practically all oil is extracted from rice bran and two-thirds of that is used as edible oil. In India, only one-sixth of the oil present in bran is recovered as crude oil, of which only a small fraction is used in food for humans. Some planners have jumped to the conclusion that there would be an enormous scope for supplementing the vegetable oil supply for human consumption in Southeast Asia, forgetting that, in contrast to Japan, most of the rice milling is done in small-scale mills, making solvent extraction a much more difficult and costly technology to apply.

The above considerations motivated FAO in 1977 to initiate a survey with the aim of obtaining more information on the actual availability of residues, in particular those that are now being wasted. Some 450 institutions (including government departments) and persons, mostly in developing countries, known to be engaged in residue utilization, were contacted by questionnaire. The emphasis was put on collecting information on quantities within constricted areas, present utilization or disposal practices, existing constraints towards increased utilization, and proposals for utilization schemes. The survey involved 128 countries; responses were received from 57 with a total of 115 completed questionnaires. For 45 countries sufficient information was received to make possible the preparation of a first country profile. In total, 72 project ideas for research, development, and demonstration projects on a national basis were received.

It must be borne in mind that, although this survey has been a first useful step towards quantitative appraisal of residues, it remains a collection of contributions mostly from individuals. The survey is, therefore, far from complete, but FAO hopes to make this a continuing effort.

In addition, it should be mentioned that, in spite of the emphasis on constricted areas, the figures on quantities are again mostly of a general nature without reference to the area in which the residues are produced.

Nevertheless, several conclusions can be drawn from the survey. The use of cereal residues was reported most often (22 countries!, followed by residues of the sugar industry (20 countries). The beverage industry (19 countries) and animal by-products (18 countries) followed closely. In a middle group of 12 to 15 countries, fruit and vegetable residues, forestry residues, oilseed processing waste, and residues of fishery industries were featured. Little information was received on starchy roots, municipal wastes, rubber, or dairy by-product residues.

The actual utilization and disposal for residues showed a rather uniform pattern. Burning in the field, ploughing under, and use as roughage and litter for animals is most frequently applied to straw, stalks, and other bulky agricultural residues. Some wet agricultural residues are used as feed, but the bulk seems to be wasted. There is considerable wastage in the effluents of certain processing industries, such as brewing and palm oil, olive, coffee, and fish processing. A number of residues are used as an energy source, e.g., bagasse, husks, and wood processing residues.

The constraints impeding the increased or improved utilization of residues as reported by the survey are very much the same as mentioned earlier in this paper. From the replies, lack of appropriate technologies and qualified personnel rank as the biggest constraints, followed by difficulties of collection due to poor road networks and transport facilities. Lack of financial means is often mentioned, as well as the uncertainty of marketing outlets.

The type of assistance requested centres mainly on requests for technical advice, implementation of research, demonstration projects, and financing.

For the 72 project proposals received through this survey, the following sub-division applies:

animal by-products and residues	8
beverage industry residues	8
cereals	6
fibres (natural)	3
forestry and cellulosic residues	10
fruits and vegetables	6
marine and fresh-water products	8
oilseeds and nuts	5
rubber	1

sugar	3

Milk and dairy, municipal and domestic wastes, and starchy roots and tubers are incorporated with other residues in a group of 14 under the heading "various."

There are 20 proposals that make a direct reference to microbiological conversion: nine for biogas (Burma, Cyprus, Jamaica, Korea, Mauritius, Senegal, Spain, Thailand, Regional Central America); five for biomass protein (Algeria, Peru, the Philippines, Somalia, Thailand); one for composting (the Philippines), and four unspecified (Colombia, Egypt, Malaysia, and the Sudan). However, it is likely that more proposals would qualify for microbiological activities.

The figures and proposals from this survey now at hand can be seen and used only as an indication. Any activity in a selected priority area should, however, be preceded by an on-the-spot, in-depth feasibility study. It is FAO's intention to increase and improve knowledge on residue availabilities by periodical updating of data. This will be done concurrently with the revision of the Directory of Institutions, the Compendium of Technologies, and the Bibliography, which were published in 1978. All relevant documents can be obtained free of charge from FAO Headquarters in Rome.

With the first phase of this systematic effort to establish an information data base on residue utilization concluded. FAO will now put increased emphasis on field project development A number of such projects are already being implemented for fertilizer, feed, and energy in particular

An intensified search for the exploitation of the microbe in residue utilization, especially when directed to technologies that can be transferred and applied successfully at the village level, should have full support. FAO will be happy to co-operate within the limits of its programme scope and means.

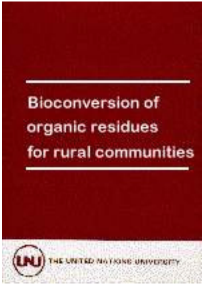
Discussion summary: Papers by van der Wal and Barreveld

At issue was the implication, drawn from the preceding papers, that it is less desirable to return agricultural residues to the soil than to process them for feed or other purposes. It was pointed out that ploughing back the residues helps to prevent erosion, thus conserving soil and water and maintaining the soil structure. An estimated 3,000 million tons of topsoil are said to be lost annually in the United States from the cultivation of corn, cotton, and other crops, in addition to the loss of 123 kg per hectare of nitrogen by the removal of residues.

Ploughing back residues significantly improved subsequent crop yields in the Guatemalan highlands where the soil had an initial humus content of less than one per cent.

While examples of the benefits of returning residues to the soil could be given in some instances, in other places there would be no such advantage. In these cases, the chemical treatment of straws before their use for feed could be a better method of residue management. It is simple, it has been demonstrated to be practical, and there is a demand for the feed, although the economics and magnitude of various methods of treatment in any particular set of circumstances remain to be determined.

Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)
Micro-organisms as tools for rural


Bioconversion of
organic residues
for rural communities
THE UNITED NATIONS UNIVERSITY

Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Micro-organisms as tools for rural processing of organic residues

References

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Introduction

Micro-organisms have been closely associated with transforming or cycling organic matter in nature for as long as such material has existed. But it has only been within the past 100 years that certain of these associations have become known, or that advantage has been taken of helpful microbes in rural agricultural practices. Predictions are, however, that greater use will have to be made of beneficial micro-organisms.

I need not discuss the important part micro-organisms play in the production of humus, nor how they help cycle all elements or substances in the soil and thereby provide the nutrients necessary for healthy crops. These topics are beyond the scope of this paper. Neither will I discuss in depth how microbes fix an estimated 150 to 175 million tons of atmospheric nitrogen per year, which is several times more than the total commercial production of nitrogen fertilizer in 1977; nor how micro-organisms may be degrading over 1,500 million tons of pesticides and large quantities of other complex synthetic substances that find their way into the environment each year.

The concept of utilizing excess biomass or waste from agricultural and agro-industrial residues to produce energy, feeds or foods, and other useful products is not necessarily new. For centuries agricultural residues and wood have been used as sources of fuel, food, construction materials, and paper-making, as well as for other purposes. Recently, fermentation of biomass has gained considerable attention because of the forthcoming scarcity of fossil fuels, and because it is necessary to increase the world food and feed supplies - especially those high in protein.

Most attention today is being given to the possible use of micro-organisms to convert relatively high-quality biomass (corn and grains, sugar-cane juice, etc.) to fuel. Although this topic will be discussed later, certain technical and economic restrictions exist that must be removed if significant fuel production is to result from fermentation of such high-quality biomass, because these substrates have other important possible uses. This does not mean, however, that residues from farm crops, livestock feedlots, agro-industries, forest operations, and other similar practices should be excluded. This is especially so in circumstances where their removal does not eventually reduce the quality of the land, permit soil erosion, or produce other harmful effects on crops.

A logical classification of agricultural and agro-industrial materials has recently been published by Rolz (1) His data (Table 1) illustrate the variation in the structure of the substances, and the nature of the by-products that may be available for utilization by micro-organisms

TABLE 1. Classification of Agricultural and Agro-Industrial By-products

Group	Predominant compound	Activity	By-product
I	High proportion of di- and mono-saccharides	Sugar-cane growing and processing	Molasses
		Pulp elaboration	Sulphite liquors
		Cheese-making	Whey
II	Di- and mono-saccharides with some structural polysaccharides	Fresh fruit collection centres	Rejected or damaged fruit
		Rum and liquor making	Wash waters

III	Mixture of soluble organic compounds, including starch, sugars, proteins, pectin, acids, etc.	Fruit and vegetable processing	Wastes from washing, peeling, and blanching
		Tuber and grain processing	Wastes from sorting ar washing
		Coffee processing	Washing and pulping waters
		Meat processing (beef, pork, poultry)	Washing and scalding waters
IV	Complex mixtures of structural	Fruit and vegetable	Peels, insoluble solids from pulp and seeds

	polysaccharides and other compounds such as proteins, lipids, etc.	processing	
		Animal and poultry production	Manure
		Animal slaughtering and meat processing	Suspended solids
		Coffee processing	Pulp
		Sugar-cane and oil palm processing	Residual solids

		Alcohol and alcoholic beverage processing	Residual solids
V	Structural cellulose and lignin in high proportion	Cereal, sugar-cane, and rice growing and processing	Straw, husks, bagasse
		Corn growing and processing	Stocks and cobs
		Citronella and lemon grass processing	Bagasse
		Coffee and cacao processing	Husks
		Cotton seed processing	Hulls, linters

		Forest processing	Bark, sawdust, wastes

Source: Rolz (1).

Several calculations have been made of the quantities of biomass produced annually in the world by photosynthesis, and the resulting agro-industrial wastes One estimate is that 1.7 x 10(11) tons of biomass are produced annually, and that 98 per cent of this amount is not used in an economically sound manner DaSilva, Olembo, and Burgers (2) present data on some agricultural residues in six European countries (Table 2); these constitute about 98 million tons each year. For other countries, the three authors estimate the following: Malaysian oil palm and rice mill wastes in 1974 were 3 million and 250,000 tons, respectively. In Egypt, 600,000 tons of maize cobs, 1.5 million tons of dry rice straw, and 40,000 tons of sugar pith residues accumulate annually. About 100,000 tons of sugar-cane bagasse are burned in Bangladesh each year. In Western Australia, 10 million tons of wheat and barley straw and chaff are produced annually. Recent similar estimates for the United States by Pimentel and associates (3) are presented in Table

3.

TABLE 2. Agricultural Wastes in Certain European Countries

	Amounts in tons		
Country	Cereal straw*	Corn stover	Beet pulp by-product
Belgium	1,760,000	-	120,000
Federal Republic			
of Germany	8,600,000	-	700,000
France	26,000,000	9,000,000**	1,100,000
Italy	8,850,000	4,000,000	
Netherlands	1,350,000	-	110,000
United Kingdom	26,000,000	-	375,000

Data from Battelle Document 75712, Courtesy DaSilva, Olembo, Burgers (2).

* Amount varied in different countries from 1.5 to 5.0 tons/ hectare.

** Yield 1.8 tons/hectare.

TABLE 3. Sources of Biomass Available Annually in the United States

Source	Available Hypothetical Mt, dry	Ready Mt, dry	Energy conversion kcal x 1012
Livestock manure	255	128	27
Crop remains	430	0	0

Food-processing wastes(20 - 70% moisture)	4	4	18
Food-processing wastes(70 - 90% moisture)	14	14	10
Forestry remains	340	44	50
Forestry-processing wastes	81	20	85
Fuel-wood production	10	10	40
Fuel-wood plantations	60	60	52
Hydrocarbon plantations	16	16	13
Aquatic plants	17	3	0.6
Urban refuse	123	66	41

Industrial wastes	40	5	4
Municipal sewage	13	2	1 3
TOTAL	1,403	372	341,9

Source: Pimentel et al. (3).

Before any organic residue or high-quality biomass material is considered for microbial conversion to other substances, a number of factors must be taken into consideration. For instance: (i) Is there a ready and continuous supply of the raw product to be converted? (ii) If the material is removed from cropland or forests, will this contribute to soil erosion and depletion of plant nutrients? (iii) Are expensive equipment and large amounts of capital necessary for the processing? and (iv) Are such things as an external energy supply and large amounts of water necessary?

After considering the above factors, the following question may be asked: Which microorganism or microorganisms possess potentials for the bioconversion of the organic material under consideration?

First, we must keep in mind that in natural conditions the indigenous microbial flora is only one component of a complex, dynamic biomass undergoing interaction in the transformation of organic matter. Only in a few cases can any one species or genus be given sole credit for natural bioconversions. For example, in the transformation of green fodder or forage crops into silage, the complex fermentation process involves plant enzymes as well as several groups of microorganisms present in the fodder and in the environment. Likewise, in the production of biogas from organic wastes, methane bacteria may be responsible for the gases produced, but this is not the only biological process taking place in the digester.

Even though mixed cultures of micro-organisms are usually involved in the transformation of organic residues, there are cases where pure cultures of bacteria, yeasts, moulds, or enzyme preparations can be used for processing such materials; these will be discussed later

Because other papers in these proceedings are also devoted to topics that can be included under the broad title of this paper, the following discussion will be restricted to a few possible microbial processes involved in the transformation of by-products or residues listed in Tables 1-3. Some of these processes have been, or can be, adapted on a small scale to rural regions, but others currently require fairly sophisticated knowledge or equipment for operation.

One of the major problems facing us today is how to adapt technical skills to various regions where people differ in their cultural or social customs, where natural resources vary, where the economy is dissimilar, or where environmental conditions may limit certain processes. More careful thought must be given in future developments as to whether the so-called "high technology" will be the best choice for people in every nation, or whether more attention needs to be given to what Norman refers to as "soft technologies" (4); Hedn speaks of as "self-reliance in an equilibrium society" (5); or what DaSilva, Olembo, and Burgers consider "low capital" vs. "high capital" technologies (21. The results presented in this Symposium can help point the way for leaders in various countries to make certain important decisions for future development.

An extensive discussion of even the major organic residues that can be utilized by microorganisms in a rural environment cannot be covered in one article. So I have selected only a few substances from the groups used for classification in Table 1.

Microbial utilization of mono- and di-saccharide residues

The by-products (molasses, sulphite liquor, whey) listed in group 1, Table 1, are rich in fermentable sugars, and they serve as a major source of carbon for a great variety of micro-organisms. At least 5,000 microbial metabolic products have been isolated from solutions in which the simpler sugars have served as the main source of carbon for metabolism by micro-organisms. These metabolites include not only simple alcohols, organic acids, gases, antibiotics, vitamins, enzymes, toxins, etc. but also some unique compounds whose use or function remains unknown. Great opportunities exist for finding uses for some of these substances, or for developing technologies that may be applicable to rural processing of such materials.

Molasses

Large quantities of molasses are produced in countries where sugar-cane is grown and processed. Rolz, for example, estimates that over 6.3 million tons are available annually in the major sugar-cane-growing countries of Latin America (1).

The sugar in molasses can be metabolized by many micro-organisms and by several known pathways. The particular pathway followed, and the end-products produced, depend not only on the particular microbe, but also on a variety of environmental factors.

Special strains of Saccharomyces cerevisiae, S. fragilis, and Candida utils are used in the baking industry, as feed and food supplements, and for other purposes. World production of such yeast is over 300,000 tons per year. The raw materials for cultivation of such yeasts are generally a mixture of molasses, ammonium salts, and other essential inorganic salts.

In recent years the production of filamentous fungi as a source of protein has been emphasized. Espinosa et al., for example, have shown that the growth of Verticillium sp. on cane blackstrap molasses and coffee-waste water is technically feasible (6).

Mushroom mycelium has also been grown in molasses, as well as in vinasse, a waste product from the distillation of fermented sugar-cane juice.

Perhaps the greatest potential use of molasses, other than as a sweetener in foods for human consumption, and as a livestock feed supplement, is for the production of ethanol by fermentation, or as a feedstock for the manufacture of other useful products. The fermentation of molasses to ethanol by yeast is not an especially complex process, and it can be easily adapted on a small scale to rural areas. In Brazil, however, the production of ethyl alcohol from sugar-cane, manioc, and other tropical plants has become a major project of the government to reduce petroleum imports (Figure 1). Approval was given by Brazil's National Alcohol Commission for government financing in the amount of US$800 million in 1977 for over 30 of the 170 proposed distilleries. The plan calls for increasing alcohol production to over 3,800 million I by 1982. As fossil fuels become scarcer, many nations may need to turn to the ethanol fermentation of waste saccharide materials as a source of energy (7).

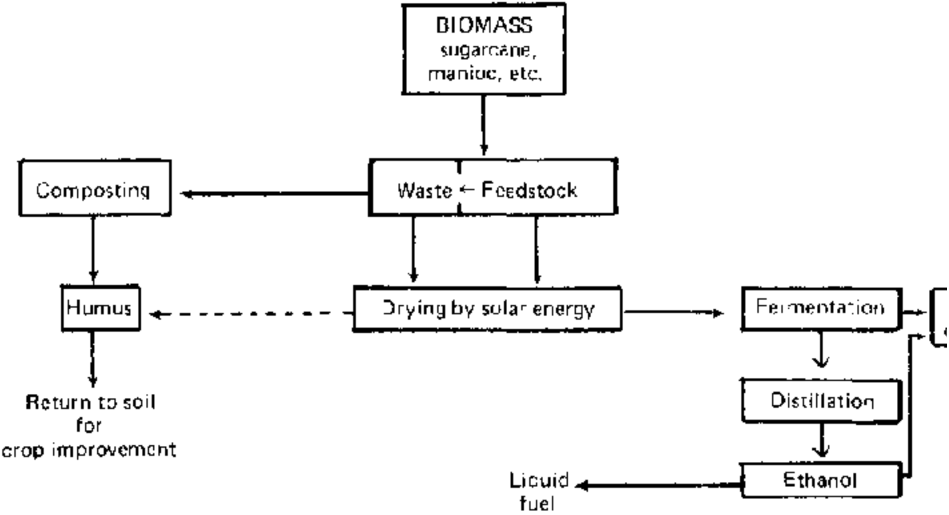


Figure. 1. Fermentation of Biomass to Ethanol or Other Organic Chemicals, and Other Organic Chemicals (From Altepohl [7])

Sulphite Waste Liquor

Several million tons of sugar occur in the sulphite liquor that results from the production of paper products; most is discarded in the United States (Table 3), and similar amounts are probably considered waste in other countries. Apart from the fact that sulphite liquor from the paper mills causes a disposal problem, it is also an economic loss because it can be converted into single-cell protein (SCP), ethanol, or D-lactic acid.

Candida utilis has been used for alcohol and feed yeast production from paper mill waste because it has a high tolerance for sulphite and can convert both hexoses and pentoses into yeast protein. A commercial operation called the Pekilo Process has been developed in Finland for the production of single-cell animal feed. Spent liquor from sulphite pulp mills is used as the substrate, and the fungus Paecilomyces variotil, which consists of 55 to 60 per cent protein, is used in the fermentation process. The first Pekilo plant built produces about 10,000 tons of single-cell protein annually.

Lactobacillus pentosus seems superior to other bacteria for producing D-lactic acid from sulphite waste liquors. Estimates for a mill producing 100 tons of pulp daily are that over 3 million kg of lactic acid can be manufactured annually.

Mushroom mycelium has been grown in sulphite waste liquor, and the process has been granted a patent.

Whey

In countries where cheese-making is important, large volumes of whey accumulate and must be disposed of as a waste, as profitable uses have not been found for the material. Development of new uses for whey would do much to reduce the waste and avoid the loss of milk nutrients. The possibilities for such developments offer some of the most interesting challenges in applied science.

Whey has some limitations as a substrate for attack by micro-organisms because fewer microbes utilize lactose than other sugars such as glucose. The best suited organisms for fermentation of whey are lactobacilli and certain yeasts.

Lactobacillus bulgaricus is capable of converting over 90 per cent of the lactose in whey to DL-lactic acid, and the organism is now used commercially for this purpose. Various lactosefermenting yeasts (Saccharomyces fragilis, Candida pseudo-tropicalis, or Torula cremoris) can convert the sugar to various products without altering the other nutrients in whey; this has become a commercial process for producing lactose-free whey and ethanol (80 to 90 per cent conversion of the lactose).

Several hundred-thousand tons of yeast for baking, feed, and food supplements have been manufactured for many years, utilizing low-grade sugars as a substrate; the demand for such protein is increasing. Recently a new, continuous-flow, closed-system plant has been put into operation to produce the lactose-fermenting yeast Candida utilis from whey. The plant is capable of manufacturing 7,500 tons of yeast annually.

Other Saccharides

Juices from various fruits, leaves, and stalks of plants contain sugars that can be grouped in categories I and II (Table 1). Many of the materials are abundant and cheap, and could be readily converted by microbial processes to useful substances. One example may be mentioned.

Agave juice from plants growing on arid lands has been used experimentally as a substrate for SCP production (8). Both pure cultures of yeast (Saccharomyces carbajali, Candida utilis, etc.), and mixed cultures of yeast, fungi (Ustilago maydis), and bacteria (Corynebacterium glutamicum, Brevibacterium flavum) were used to produce the SCP biomass. The yields of high-quality microbial protein obtained were good (20 g/l) from a 24hour semi-continuous operation. Indications are that a plant would have considerable socioeconomic impact on production in Mexico, where protein feed and food are badly needed.

Microbial conversion of starchy residues

There is extensive literature on the utilization of starch-containing materials by microorganisms. Although not al) microbes are capable of producing enzymes (amylases) that attack starch, amylases have been found in many species of bacteria, streptomyces, yeasts, and moulds. The following species appear to be the most active (9).
Bacteria:

a-amylase: Bacillus subtilis, B. macerans, B. amyloliquefaciens, B. stearothermophilus, Clostridium acetobutylicum

b-amylase: Bacillus cereus, B. megaterium, B. polymyxa

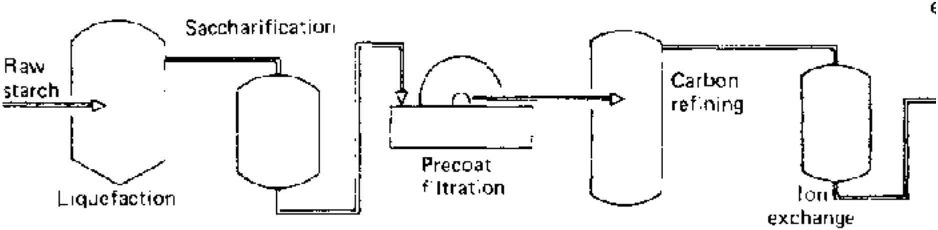
Moulds: Aspergillus oryzee, A. niger, A. fumigatus

Two examples may be mentioned briefly where substances rich in starch are converted by the organisms mentioned above to useful products.

Aspergillus fumigatus, a thermophilic mould, has been used to make single-cell protein from cassava (10). Because this process is not complex and produces good yields of protein, it could be adapted to rural areas. Cellulolytic fungi (Trichoderma viride, basidiomycetes) have been employed with commercial amylases to enhance the saccharification of cassava starch; the hydrolysate served as a better substrate for the alcoholic fermentation by yeast (1 1).

The second example is currently a successful commercial process, but because of its nature it could possibly be adapted to the production of sugar "sweetener" in rural regions. In the United States, in 1977, over 2 million tons of fructose-sweetener corn syrup were manufactured from corn starch, using over 1,000 tons of microbial amylases and glucose isomerases.

The manufacture of high fructose corn syrup is now a continuous process, employing immobilized enzymes. The saccharification of the starch is accomplished by the combined action of acid and microbial amylases from bacilli, and the resulting maltose-glucose solution is then subjected to isomerization to yield fructose (42 per cent), glucose (50 per cent), and some higher saccharides (Figure 2). Several commercial processes employ preparations of isomerase from Streptomyces sp. (S. albus, S. olivaceus, S. wedmorensis, and mutants of several kinds), but several bacterial species (Bacillus coagulans, Pseudomonas hydrophilia, Escherichia freundii, Nocardia asteroides, etc.) and aquatic actinomycetes (Actinoplanes missouriensis) yield considerable amounts of glucose isomerase (12, 13).



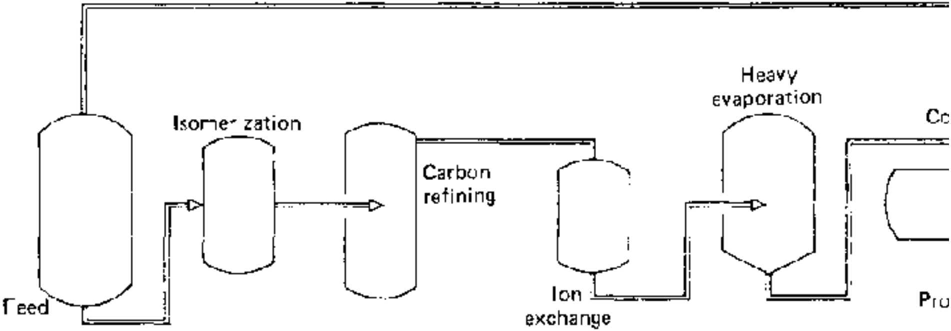


Figure. 2. Flow Chart for the Production of High-Fructose Corn Syrup from Cornstarch (From Mermelstein [12])

Many other agricultural residues and agro-industrial wastes belong to this group of substances, which are rich in starch, pectin, sugars, organic acids, and even some nitrogenous compounds. They include cull and wash materials from fruit, vegetables, meat, and other foods being processed. In the United States, Pimentel and associates (3) estimate these materials to be several million tons annually (Table 3). For example, Aspergillus niger will convert 97 per cent of the sugars from brewery-spent grain liquor to fungal mass suitable for feeding purposes (14). Similarly large quantities of wastes occur from washing and pulp waters from coffee processing in Central and South American, Asian, and African nations (1,15-17) These substances offer considerable challenge and promise for future developments, and micro-organisms play a part in their utilization. According to a review by Han and Smith, they can best be utilized for what they call one of the five F's: fuel, fibre, fertilizer, feed, and food (18).

Microbial conversion of complex mixtures of compounds (Polysaccharides, Proteins, Lipids, etc.)

The residues in this group (Table 1) consist of mixtures of various complex compounds resulting from several agro-industrial activities. Some of the compounds are soluble, others are colloidal or solid (1). In certain cases the residues may be fairly uniform in character (peels from potatoes or apples), whereas in other instances the material may be of varied composition (manure).

Under natural conditions, rarely are substances in this group transformed by a single microbial species. Rather, a mixed flora is usually responsible for the conversions that occur. Thus, it is generally impossible to single out separate species as being responsible for any transformations that take place. Some of the residues are such, however, that they could be utilized for alcohol fermentation or SCP production by yeast, or they could serve as a substrate in rural areas for biogas production, and for algal culture. Because these processes are currently receiving considerable attention, and it is not easy to single out other unique processes where pure cultures can be employed, the reader is referred to reviews by Rolz (1) and DaSilva et a). (2), and the treatise on methane generation from human, animal, and agricultural wastes (19).

Microbial utilization of cellulose and ligno-cellulose residues

The most abundant renewable biomass on earth consists of cellulose, with between 5 and 15 tons per person being synthesized annually by photosynthesis. Much of the cellulose in nature is bound physico-chemically with lignin.

Because lignin is highly resistant, it protects cellulose against attack by most microbes, and it must be degraded by chemical or biological means before the cellulose can be utilized. Some higher fungi such as the basidiomycetes (Planerocheate chrysosporium) can degrade lignin, and mush rooms (Lentinus, Volveriella, and Pleurotus species) convert ligno-cellulose directly into fungal protein suitable for human consumption.

Table 4 lists some cellulose-utilizing organisms together with the general products they form, and their current status of development as useful agents. Brief mention may be made of each of these groups.

TABLE 4. Products of Some Cellulose-Utilizing Organisms

Group	Product formed	Current status
Volvariella sp.	Human food (mushrooms), animal feed	Produced commercially
Lentinus edodes	Human food (mushrooms), animal feed	Produced commercially
Pleurotus sp.	Human food (mushrooms). animal feed	Produced commercially
Bacidiomycetes:		
Phanerochaete chrysosporium	Delignified cellulose for use as feed, fibre, or further conversions	Under research

Thermoactinomyces sp. and other thermophilic actinomyces	Human food (SCP), animal feed	Under research
Trichodenma viride	Cellulases for converting cellulose to sugars, animal feed (SCP)	Under development
Clostridium thermocellum	Cellulases for converting cellulose to sugar, ethanol, acetate, lactate, and H2; animal feed (SCP)	Under research
Pseudomonae fluorescent var. cellulosae and similar bacteria	Animal feed, cellulases for converting cellulose to sugars	Under research

Cellulomonas sp. plus Alcaligenes faecalis	Animal feed	Under research
Candida utilis	Animal feed	Under research
Thermophilic sporocytophaga	Animal feed, ethanol, acetic acid	Under research

Volvariella Species

Mushrooms of the genus Volvariella (V. volvacea, V. esculenta, and V. diplasia) are cultivated mainly on rice straw and similar cellulosic materials by individual families in Asia and Africa Commercially, mushrooms in this genus account for about 4 per cent of the world production of some 916,000 tons. They have promise of expanded use in regions of the tropics where the grain is grown Production usually involves simply inoculating pre-soaked straw in flat stacks with spores (spawn), maintaining optimal moistures, and harvesting several crops of mushrooms. The spent straw is used to inoculate new straw stacks, and is a rich animal feed (20).

Lentinus edodes

The mushroom Lentinus edodes has been cultivated for centuries in China and Japan, where it is commercially produced in a multi-million-dollar industry; it accounts for about 15 per cent of world production. (Both in Asia and more especially in western countries, Agaricus bispora is the most important mushroom species and accounts for about 75 per cent of world production [20].)

L. edodes has potential for bioconversion of lignified residues and low-quality wood into fungal protein. Such protein is easily digested by ruminants, but its use as a feed supplement has received little attention.

Pleurotus Species

Mushrooms of the genus Pleurotus (P. ostreatus, P. sajorcaju, P. florida, P. cornucopiae, etc.) are called "White-rot" fungi, and they decompose lignin and polysaccharides in wood. They have potential in the conversion of waste and low-grade wood into protein-rich food for human consumption. P. cornucopiae is grown commercially in Japan, but none of the species is grown in western countries. P. ostreatus and P. florida have temperature optima near 30 C, making them promising for processing organic residues in the tropics. All can be cultivated on mixtures of sawdust and grain, manure, and food processing wastes (20 - 22).

Basidiomycetes

Wood-decaying fungi, such as Phanerochaeta chrysosporium, are widely distributed in northern countries where they are commonly called "white-rot" fungi. P. chrysosporium decomposes both the lignin and cellulose in wood; it is unique in that (i) it produces copious quantities of spores, making it easy to transfer; (ii) it is thermotolerant, growing rapidly at 35 to 40 C, but also well at 25 C; and (iii) it has simple nutritional requirements. This fungus has been fed to fish and rats as a source of protein, but it has not been studied extensively as a nutrient for other animals. It should be considered as a means of converting wood processing residues and other lignified wastes into partially de-lignified products for feed or fibre use, or for further conversions (23).

Thermoactinomycos Species

The thermophilic, cellulolytic, and starch-utilizing actinomyces, such as Thermoactinomyces sp., may provide an opportunity to produce single-cell protein for feed supplements in tropical climates. The thermoactinomyces do not utilize ligno-cellulose directly, so treatment of such complex materials would be necessary. However, they grow rapidly at 55 to 65C under aerobic conditions on a variety of cellulosic and starchy materials plus other simple nutrients. According to preliminary results of Humphrey and associates (24), cell yields of 0.45 9 cell/g cellulose utilized can be obtained in 20 to 24 hours; apparently four cell-bound enzymes are involved in the degradation process.

Trichodorma viride

Although a number of fungi are cellulolytic, only a few produce cell-free cellulose in sufficient quantity to be useful for large-scale development. Trichoderma viride and a number of its mutants do produce a stable cellulose that is capable of degrading cellulose (Figure 3). The fungus grows rapidly on simple media in the pH range of 5.0 to 2.5, thus reducing to a minimum contamination from other microbes. The broth containing the enzyme is then mixed with pure cellulose, or with treated lignocellulose to remove the lignin, and a glucose syrup results.

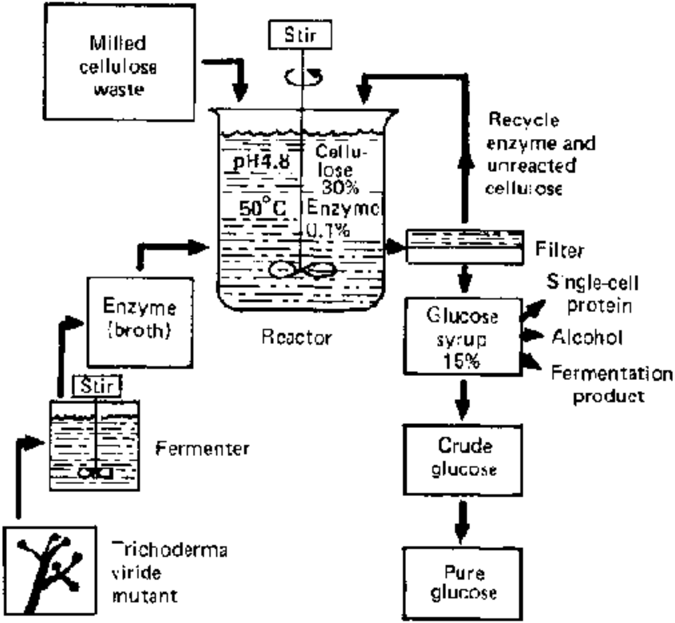

Milled cellulose waste
Stir
pH4.8
Cellu-lose 30%
50°C
Enzyme 0.1%
Recycle enzyme and unreacted cellulose
Filter
Reactor
Enzyme (broth)
Stir
Fermenter
Trichoderma viride mutant
Glucose syrup 15%
Single-cell protein
Alcohol
Fermentation product
Crude glucose
Pure glucose

Figure. 3. Enzymatic Conversion of Waste Cellulose to Glucose Sugar

The Japanese are producing cellulose commercially from J. viride on a limited scale using the Koji process, and considerable research is being done in several laboratories to obtain mutants that yield more enzyme. The use of cellulose from T. viride holds great promise as a tool for processing cellulose residues (25 - 27).

Clostridium thermocellum

The only known thermophilic, anaerobic bacterium that degrades cellulose is Clostridium thermocellum. The organism has simple nutritional requirements and grows at higher temperatures (50 C) than do most bacteria, which has the advantage in a fermentation process of being less prone to contamination by other organisms. In pure culture, the chief products from cellulose (or treated ligno-cellulose) are cell mass (protein), acetate, ethanol, lactate, H_2, and CO_2. In a mixed culture, C. thermocellum and Methanobacterium thermosutotrophicum, yield from cellulose are cell mass, methane, and acetate (27, 28). This is not a process that could be easily adapted to rural areas unless proper equipment were available but it could be used to produce either ethanol or biogas (methane) from cellulosic wastes.

Pseudomonas flvorescens var. cellulosee, Cellumonas Species, Cellvibrio Species, and Other Cellulose-Degrading Organisms

Species in the genera Pseudomonas, Cellulomonas, and Celivibrio utilize cellulose, but they apparently are unable to degrade ligno-cellulose. Co-fermentative studies on cellulose have been conducted using P. fluorescens and Candida utilis, Cellulomonas species, and Alcaligenes faecalis, and with Cellulomonas flavigena and Xanthomonas campestris Supposedly, cofermentation of cellulose with a non-cellulolytic organism increases the rate of utilization of soluble sugars produced in the process and thereby hastens the reaction (29). In fact, Casas-Campillo and colleagues (personal communication, 1978) have found that C. flavigena and X.

campestris together are much more active against cellulose than are T. viride or combinations of other organisms.

Thermophilic Sporocytophaga

The Sporocytophaga (Sporocytophaga myxococcoides, etc.) digest cellulose and other components of cell walls, but not ligno-cellulose. A thermophilic strain that grows at 55 to 65 C has been found. This organism might be useful for the production of cell mass, ethanol, acetate, and lactate from cellulose.

Algal culture as a source of biomass

For many years algae have been used by the shoreside populations of Lake Chad and Lake Texcoco (Mexico) as a source of food, and one algal species (Spirulina sp.) is now produced commercially in Mexico at the rate of several thousand tons per year.

Certain big-engineers and microbiologists believe that carefully selected genetic strains of algae (Scenedesmus acutus, Spirulina maxima, Cosmarium turpinii), or photosynthetic bacteria (Rhodospirillum sp. or Rhodopseudomonas sp.) are the organisms of choice for the production of single-cell protein (30, 31). Such microbes contain about 65 per cent crude protein of moderately high biological value. The protein appears to be well utilized by animals. In addition, most species are as good a source of the B vitamins as yeast, and they contain ascorbic acid.

In addition to algal biomass having many uses, the process can be used to help purify sewage, livestock manure, and other agricultural wastes. A unique feature proposed by Colombo (31) is the cultivation of the algae in plastic tubes that can be extended for considerable distances in arid regions over land that is not useful for cultivating crops. Such a system takes advantage of solar energy, saves water, requires little capital and labour for development, and can be used either in the rural areas of less developed countries or on a larger industrial scale.

Microbial utilization of silviculture biomass

Several excellent reviews have been published on biomass production from forest ecosystems (32, 33), and data (Table 3) indicate that forestry remains and processing wastes are not fully utilized today. Chemical products that can be obtained from forestry biomass are ammonia, methanol, ethanol, fuel gas and oil, and charcoal. Ethanol fermentation by yeast from wood hydrolysis could become competitive within 10 to 15 years (32). But, as with methanol production from wood, the demand for ethanol will be satisfied for the near future by existing synthetic sources, unless it becomes necessary to use it in gasoline blends.

Micro-organisms and marine and freshwater biomass

Other sources of biomass deserving mention are marine plants, such as giant seaweeds (kelp), from the waters of the tropical and temperate oceans, and the so-called weeds, such as the water hyacinth.

Although the technology has not been proven, ocean-based kelp farming has some attraction for two reasons: (i) kelp is fairly efficient in converting sunlight into stored energy (2 per cent), and (ii) land and terrestrial waters are not constraints. Experimental data on marine plants have been collected by Wilcox of the US Navy's Ocean Food and Energy Farm Project (34). All aspects of this programme are interesting, but the only data involving microbiology are those concerned with the production of methane as a source of energy from kelp by anaerobic microbial digestion. In addition to methane, certain by-products remain in the sludge and liquid of the digester, which can be used for nitrogen fertilizer or animal feed supplements

There are no major nutritional deficiencies in kelp for mesophilic, anaerobic, methaneproducing microorganisms, so they grow readily on a slurry of the material. One precaution is that the salt concentration of the raw slurry must be reduced. An interesting research project would be to develop strains of methane-producing micro-organisms that are more salt-tolerant.

Economic studies indicate that the cost of methane production from kelp fermentation may range from US$2 to US$7 per GJ (per million BTU), depending on credit values received from feeds and other by-products. Thus, entry to the fuels market for kelp-derived methane will require research to provide a cheaper product, and capitalization. If preparatory methods for handling the kelp, and the fermentation, could be carried out in the open ocean where wind, wave, and solar energy could be used, the cost of the methane could be reduced below current land based fermentation processes.

One of the most prolific plant colonizers of rivers and lakes is the water hyacinth, which has spread in recent years from its natural habitat in South America to at least 50 tropical and sub-tropical countries around the globe. A few plants can multiply and spread over an area of 120 yd(2) of water in several months, depending on the nutrients in, and temperature of, the water, and the plant mass may represent many hundred tons of hyacinth.

Such water weeds are an environmental disaster in some countries because they interfere with water transportation and fishing, and they can be a health hazard as well by providing a suitable breeding site for the malarial mosquito. Ironically, the water hyacinth may be a promising candidate for solving needs of animal feed, energy, and control of water pollution, and in this regard, micro-organisms can play an important part.

Water hyacinths contain most of the essential nutrients for animal growth, but making a palatable feed from them is not easy because of the high moisture content of the plants. Research indicates, however, that the plants can be converted into silage by placing chopped plants in a closed container and allowing them to undergo microbial fermentation for about a month. Such silage has been shown to be highly palatable to sheep and other animals.

Potentially, the water hyacinth may be used as a source of energy, and for the purification of sewage. Considerable research has been done on these subjects, especially by Wolverton and McDonald at the NASA Space Technology Laboratories in Bay St. Louis, Mississippi (35). Biogas or methane production from the microbial anaerobic decomposition of water hyacinths has been investigated only on a laboratory scale. Many factors, such as carbon to nitrogen (C/N) ratios and temperature, affect the amount of gas and residue produced from the microbial digestion of the plant material. Based on research, it has been calculated that one hectare of water hyacinths can produce enough biomass each day to generate between 90 and 180 m of methane gas, and at the same time 0.5 ton of residue useful as a fertilizer. Further research is needed on the use of water weeds as a substrate for microorganisms.

International studies on processing organic residues

Considerable work is being done in several countries on the microbial production of food, energy, enzymes, and other useful substances from natural and agro-industrial wastes.

Some of these processes are, or could be, adapted to rural areas where the residues originate. A few examples are listed in Table 5, from the paper by Olembo (36) in the monograph on the Global Impacts of Applied Microbiology and Its Relevance to Developing Countries (37).

TABLE 5. Products Obtained in Various Countries from Residues Using Micro-organisms

Country	Product	Residue material	Organism
Egypt	Microbial protein	Bagasse. rice hulls, distillery slops	Candida util C tropicalis
Chile	Microbial protein	Fruit peels, papaya wastes	Yeast
Guatemala	Animal feeds, alcohol, enzymes, etc.	Bagasse, fruit wastes, coffee-bean by- products, cotton cake, etc.	Bacteria, yeast, fungi, algae
Indonesia	Ontjom, tempe	Soybean, peanut	Neurospora

	mate, kedele	presscake	sp Rhizopus sp.
Israel	Fodder yeast	Citrus peels, cannery wastes	C. tropicalis
Malaysia	Fish sauce, poultry feed, glutamate, vitamins	Fish wastes, tapioca rejects, rubber and palm oil effluents	Bacteria, Chlorella sp
Philippines	Vinegar, nata di, coco	Copra extraction waters	Torula sp. Leuconostoc sp.
Sri Lanka	Vinegar, acidulants	Molasses, copra waters	Torula sp.
Thailand	Microbial protein, fish sauce, etc.	Fish rejects, tapioca, coconut, vegetable wastes, etc.	Chlorella sp Torula sp.

Source: Olembo (36); data from UNEP/U/ICRO Training Courses.

The main objectives of the studies reported range from the need for an increase in protein food production to pollution abatement, and from industrial expansion to innovative research on the use of beneficial micro-organisms to improve the environment and welfare of human beings throughout the world.

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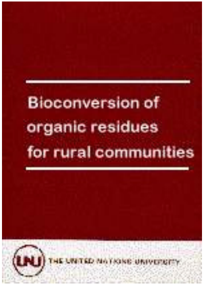
John Roger Porter, a much appreciated participant at the Guatemala conference and contributor to these Proceedings, died suddenly in May 1979. A highly productive and renowned microbiologist and former Head of the Department of Microbiology at the University of Iowa, Dr. Porter was a member of the Science Information Council of the National Science Foundation and a member of the National Board of Medical Examiners in Microbiology. He served as Chairman of the Advisory Committee on Scientific Publications of the National Institutes of Health, and was the recipient of the Pasteur Award in 1961. As Editor-in-Chief of the Journal of Bacteriology for ten years, he compiled and edited the 50-volume index for the Journal. His text Bacterial Chemistry and Physiology was widely used. A man of great warmth and personal charm, Dr. Porter will be greatly missed by his friends and colleagues.



Bioconversion of Organic Residues for Rural Communities

(UNU, 1979, 178 p.)

Production of feed as an objective for bioconversion systems

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Introduction

The use of agricultural waste as feed, directly or after some degree of processing, must be as old as agriculture itself. It is appropriate to point out, although the fact is fairly obvious, that the scope of the concepts "waste" and "residues" is not determined by an exact, technological definition. Thus, perfectly good bananas may constitute a waste under conditions of gross excess in supply over demand. Bran, once a residue of wheat flour production, has recently become a valuable product of the flour mill as a result of the increase in demand for food fibre. Often, the reason for treating a certain material as waste is the lack of adequate technology for upgrading it. Cashew "apples" are a well known example of this type of residue. One of the practical consequences of this situation is the impossibility of developing a universal solution, applicable to all types of wastes. In this presentation, I propose to review the general characteristics of the feed route as a process of big-regeneration.

General characteristics

The success of "wastes" such as oilseed meals, fish meal, and rendering plant by-products as well established feed ingredients may create the false impression that the use of any waste as a feed is an easy, straightforward process. In reality, the feasibility of big-regeneration of wastes for feeds requires the solution of many problems that can be divided into two groups: techno-economic factors and health problems

Techno-Economic Factors

The production of animal feed could be the most profitable way of waste utilization in small communities. The feed route represents the highest immediate cash return because demand for feed is huge and stable, and the technologies involved are not too sophisticated. Marketing is relatively easy; the introduction of an unconventional feed is much easier than that of an unconventional food. Unfortunately, there are also many cost factors that may limit the apparent profitability of the feed approach.

Problems of acquisition

To quote Zucker (1): "Wastes could be defined as materials with disposal cost, or as products with a negative price." This is true as long as there is no use for a waste. As soon as demand or even signs of potential demand appear, the material assumes a price. Therefore, the cost of acquiring a residue is seldom zero, let alone a negative figure.

Statistics about the quantities of waste produced are certainly impressive. For every kilogram of edible plant product, five to ten kg of residues are produced. The production of one kilogram of beef creates some 25 kg of manure (2). However, wastes are often widely scattered and may be quite remote from the point of utilization or processing. Thus, a cost of collection and transportation is involved.

Lack of uniformity

Rational rearing of farm animals requires a high degree of uniformity in feeds. Most agricultural residues lack such uniformity as a result of seasonal variations, differences in agro-technical methods, and diversity of sources. The modern feedmill technology can cope with variability of ingredient composition within certain limits, but at the village level, variability of the material may become a limiting factor.

The need to process

Many wastes cannot be utilized as such without some sort of processing. For example, cellulosic residues must be partially hydrolized to improve their digestibility. Sloeneker et al. (3) advocated a fractionation process to upgrade feedlot waste. More complex processes, such as the transformation of a waste into a micro-organism biomass, may sometimes be the best way to prepare waste for utilization.

Some wastes require dehydration before they can be used as feed. Removal of water is essential for stabilization, and for the reduction of transportation and storage costs. However, dehydration can be an extremely costly process, and wet feeding, if feasible, should be considered first. A study in Israel on the economics of waste as feed indicated that the most profitable way to dispose of citrus processing waste is to feed it as such to dairy cattle. Fortunately for Israel, citrus plants and dairy farms are not too far apart. This is not the case for many citrus-producing areas in the world.

Ensilage is a process of great value in the production of feed from waste. It may be regarded as an in-storage stabilization process, resulting, if properly done, in considerable improvement of the microbiological and nutritional quality of the feed. Thermal processes or treatment with chemicals such as acids or formaldehyde may be necessary for the destruction of pathogenic organisms.

Nutritional "value" of residues

"Value" is put in quotes to emphasize its commercial rather than biological significance. In other words, how much money is a certain waste material worth in a specific application as feed? Obviously, this value is determined not only by strictly nutritional characteristics such as nutrient composition, digestibility, presence of anti-nutritional factors, palatability, and tolerance, but also by usage characteristics such as convenience, stability, effect of the feed on the acceptability of the final product (e.g., effect on colour of egg yolk or on the flavour of milk, etc.), aesthetic barriers, or plain traditionalism. For these and other reasons, the value of wastes as feed is often considerably less than the value that would be assigned to them by a computer programmed for least-cost feed formulation.

Health Factors

The question of health factors in feed from waste should be examined from two aspects: (i) Factors associated with the effect of the feed on the health of the animals consuming the feed. We designate these factors as primary toxicology, primary parasitology, primary microbiology, etc. (ii) Factors affecting the wholesomeness of the final animal products (meat, eggs, milk, etc.). These factors are the subject matter of secondary toxicology, parasitology, microbiology, etc.

The evaluation of primary safety is relatively simple. The customary feeding trials will show the presence or absence of acute toxicity or the danger of outbreak of infectious diseases. Chronic effects, or effects that can be detected only after many generations, are usually of no consequence, except perhaps in the case of animals raised for reproduction. Whenever we intend to use a waste material as an ingredient of the diet for only a certain portion of the life span of the target animal, health hazards should be evaluated in relation to animals of corresponding age. Thus, there is no justification for the rejection of a certain feed ingredient on grounds of toxicity to newborn animals if the feed is not intended for use as a starter, but rather as a fattening or finishing ration.

The question of secondary safety or transmitted health hazards is much more complicated. The basic philosophy and methodology of evaluation are still debated and no accepted standards are available. This is well illustrated by the vagueness of the following statement from the PAG Guideline No. 6 for Preclinical Testing of Novel Sources of Protein (4): "Products intended for incorporation into animal feeds may not require as extensive testing as is suggested here for human foods, but foods derived from such animal sources must be considered from the viewpoint of the possible presence of residues in meat, milk, or eggs, transmitted from animal feeds. Controlled tests in farm animals may contribute useful information concerning safety or nutritional value for man." A later PAG Guideline (5) is more specific as to primary safety, but as vague as the earlier one on the matter of safety criteria for the edible animal end-product.

The following is a list of health and safety factors to be considered in the evaluation of an agricultural waste as feed: pathogens, heavy metals, pesticide residues, drug residues, toxic metabolites, and foreign bodies (e.g., metal, glass).

The application of some of the general principles discussed above will now be examined in two specific cases: recycling of manure and the use of sewage-grown micro-algae.

Manure as feed

Systematic investigation of the use of animal waste as feed began in the 1940s. Today, manure is being used in many countries, and this use is either regulated by laws and standards, or simply tolerated in the absence of sufficient legislation (6).

In animal nutrition, manure is of interest mainly for its nitrogen, or as a source of roughage for ruminants. Dry cattle or pig manure contains 2.5 to 3 per cent nitrogen, dry poultry waste twice as much. As a rule, half of the nitrogen is non-protein nitrogen, which is well utilized by ruminants but not by monogastric animals. Flegal and Zindel, working with broiler chicks, reported that "Feed efficiency was inversely related to the level of dried poultry waste in the diet" (7). Yet, more recent research seems to indicate that, to some extent, rats can utilize the uric acid present in poultry waste (8). With respect to fish, Kerns and Roelofs reported that growth of carp is depressed by the presence of poultry waste in a pelletized diet (9). On the other hand, mullet and catfish have been reported to grow well on diets containing 25 to 30 per cent dried poultry waste (10).

Fish can utilize non-protein nitrogen in manure added to pond water in appropriate amounts. Rappaport and coworkers observed the effect of pond manuring on the yields of carp and tilapia for three years (11). In the first year, manuring had a slight negative effect on yields. During the second season, ponds fertilized with chicken manure showed a 44 per cent increase in yields of fish over a control pond, and liquid cow manure improved yields by 13 per cent.

The chemical composition, and hence the nutritional value, of animal manures depends, of course, on the diet fed to the animals. Most of the data available refer to animals fed under conditions of intensive industrial husbandry (12). Excreta of less well-fed animals may be expected to be of lower value.

Health hazards are particularly important. Recently in Israel, an outbreak of botulism among dairy cows caused damage in excess of US$2 million. The intoxication was unequivocally traced to processed poultry waste present in the feed. It is feared that the incident may have destroyed the prospects of using poultry waste as a cattle feed ingredient in Israel for quite some time.

Sewage-grown micro-algae

One of the indirect methods for the utilization of animal (or human) excrete as feed is the cultivation of micro-algae on waste water or sewage. The process is aimed primarily at sewage purification and water reclamation, but the resulting algal biomass is of considerable interest as feed. This material, after harvesting, concentration, and drum drying, contains 45 to 55 per cent protein, It can replace half of the soybean meal in commercial broiler rations with no deleterious effect on growth.

In vivo experiments with chicks showed that about 80 per cent of algal protein is absorbable. The metabolizable energy content of the material is 2,000 to 2,800 kcal/kg. In addition to their value as a source of protein and calories, algae also contain carotenoids that enhance the desirable pigmentation of carcass skin and egg yolk. Although the technology is not sophisticated, growing algae requires a somewhat large-scale operation to be profitable. Algae grown on municipal sewage may contain high levels of heavy metals, particularly if the sewage contains industrial waste-water. However, these heavy metals seem to be unabsorbed by chicks and do not appear in the composition of edible tissues and bones. In the light of the results of four years of research in our laboratories, algae grown on sewage seem to be safe and valuable as a feed ingredient for poultry and fish.

Conclusion

In summary, the production of animal feed provides one of the most logical routes for utilizing a substantial portion of the enormous potential material represented by agricultural residues. The approach has been part of traditional agriculture for centuries. A wealth of information has accumulated in the past 20 years indicating the feasibility of the processes and identifying their pitfalls. The technologies involved may sometimes be large-scale and require organization, but are not out of reach for rural communities. Legislative action is lagging behind practical implementation, but in the light of increasing economic pressures, dramatic progress may be expected in the near future. *

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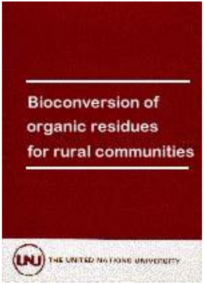

Discussion summary: Papers by Porter, Berk and La Rivire

Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Environmental goals for microbial bioconversion in rural communities

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Introduction

Environmental Goals

The meaning of the word "environmental" has rapidly broadened over the past decade under the influence of the United Nations Conference on the Human Environment held in Stockholm in 1972. The 21 goals the UN Environment Programme has set for itself for 1982 include not only preservation of air, soil, and water quality and of genetic resources but also improvement of the human environment in its widest sense - that is, with respect to water, food, energy, shelter, and the ecologically sound use of natural resources (1). Thus, we now have dovetailing and blurring of demarcation lines between, say, environmental and agricultural programmes and goals. Under these circumstances, I will not attempt to draw up a sharp definition of environmental goals, but, for the sake of expediency, interpret this term, for the purposes of this paper, as pertaining to the protection of human health and of the quality and productive capacity of water and land resources, which will include recycling of minerals and energy recovery from wastes.

Waste may be defined as any material which technology does not yet know how to use at a given time and place. Hence, this term has a specific meaning only in a specific context.

Microbial Bioconversions

Since time immemorial microbial conversions have had an impact on the global environment. Microbes have helped to shape the environment as it is today, and, through their massive action in the bio-geo-chemical cycles of carbon, nitrogen, and sulphur, they help maintain a steady state in the biosphere, for instance, by balancing CO2 fixation by CO2 production in the mineralization process, and by counteracting denitrification by nitrogen fixation. Because these conversions can be influenced by man to only a small extent, we cannot say that they serve environmental goals. Instead, their results have important environmental consequences that we are obliged to accept from nature. Thus, a discussion of these conversions falls outside my mandate; I mention them briefly because the two most important types of man-mediated microbial conversions are, to some extent, intensified versions of natural conversions (Table 1).

TABLE 1. Types of Microbial Conversions

A. Natural conversion processes in bio-geo-chemical cycles, having important environmental consequences.	
B. Man-mediated conversions:	(i) Product-oriented: fermentatior industry. Sterilization and use of selected organisms possible. Usually produces waste.
	(ii) Raw material-oriented: waste

	treatment. Sterilization and use c selected organisms impossible. Serves environmental goals only.

This is least true with respect to the modern bioconversions performed in the fermentation industry, but still, we should not forget that many of its processes also find their early origin in the microbial mineralization of freshly harvested foods like milk, grapes, and cabbage that happened to yield spoilage products that were palatable, more durable, and hygienically safe, in the form of yogurt and cheese, wine, and sauerkraut. The modern processes merely provide rigorous guidance for these desired spoilage processes in order to guarantee a reproducible product. In general, however, the modern fermentation industry is based on product-oriented processes rather than on processes designed to utilize a given raw material. Good examples are the production of antibiotics, pharmaceuticals, enzymes, polymers, and other chemicals, where in all cases the growth medium is selected for optimum formation of high-priced products, at the same time making possible the use of aseptic conditions and selected, pure cultures.

In strong contrast to this are the man-mediated bioconversions of the second type, the microbiological waste treatment processes. Initiated by civil engineers on an empirical basis, these processes quietly developed into perhaps the largest existing microbiological industry without attracting much interest or support from microbiologists and biotechnologists. This is probably explained by the fact that the processes in question are oriented on whatever raw material is given, instead of on a product that is chosen because it can be sold. As there are no profits in the ordinary sense, the installations for waste treatment have to be cheap, and sterilization, which would allow use of selected strains, is out of the question. Furthermore, these processes must be designed so as to cope with waste flows that change in size and composition beyond the control of the plant operator. In fact, they are no more and no less than intensified versions of the natural mineralization process.

These two types of processes have been developed over the past 100 years or so along parallel but separate lines, virtually without interaction. During the past few years, however, we have reached an exciting point where these two lines of development are converging. The environmental crisis, coupled with imminent food and energy shortages, is bringing about co-operation between the two, suddenly creating wider scope for innovation through interaction. On the one hand, the fermentation industry is considering the use of raw materials hitherto designated as waste, and thus tends to serve environmental goals. The industry is also moving from the production of fine chemicals into producing bulk chemicals like ethanol and single-cell protein; the acetone-butanol fermentation, which has survived in Egypt, may well make a come-back.

On the other hand, the waste treatment industry is forced to go beyond its original restricted environmental mandate and seeks ways and means to turn wastes into useful materials rather than merely eliminate their health hazards and nuisance value (Figure 1). This opens the way for new processes that serve multiple goals simultaneously, i.e., pollution abatement and production of energy, food, fodder, fuel, and fertilizer. This includes the interesting possibility of designing processes which would be considered unrealistic when judged from only one point of view, but feasible if judged from several directions.

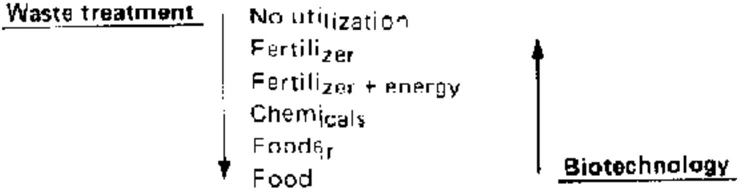
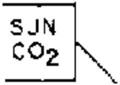
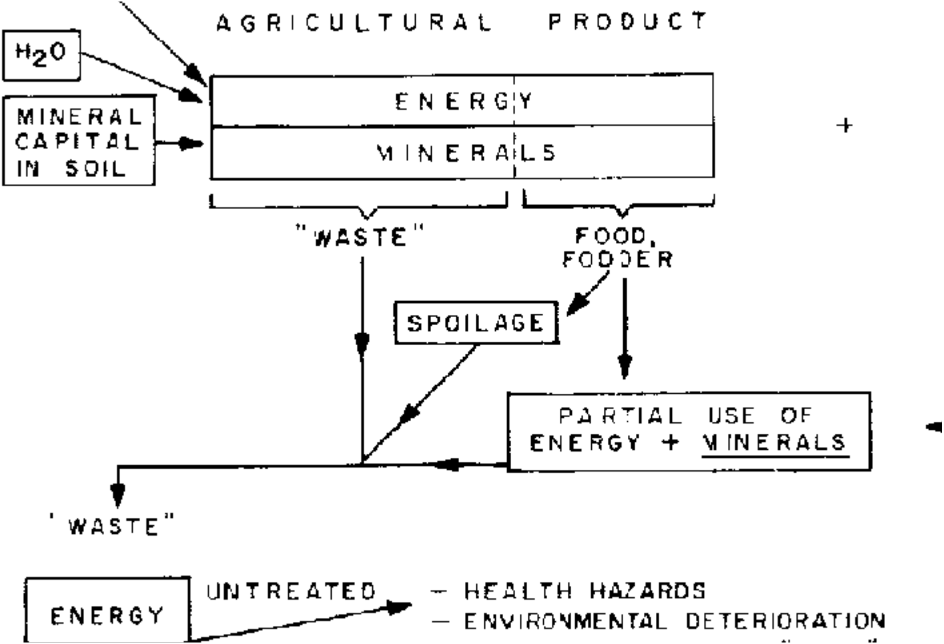


Figure. 1. Evolution of the Aims of Waste Treatment and of the Fermentation Industry

The fact that one-sided judgements still too often prevail should not discourage the scientist. It is better to have a process that is economically unfeasible but environmentally sound than to have no process at all. Economic considerations and yardsticks, like soy prices, are man-made and reflect the political will of the day; unlike the laws of nature, they should not be taken too seriously.

In taking a closer look at what conventional waste treatment achieves, I am strongly tempted to use the subtitle "From sense to nonsense, and back to sense again." In Figure 2, agricultural products are considered to consist of minerals and of energy that the sun has slung around them in the form of organic matter. We then see that only a fraction of the harvested plant or slaughtered animal is actually used for the energy metabolism of, and assimilation by, the consumer; the rest becomes human or animal waste, a spoiled product, or waste consisting of unused parts of the original product.




AGRICULTURAL PRODUCT
H2O
MINERAL CAPITAL IN SOIL
ENERGY
MINERALS
+
"WASTE"
FOOD, FODDER
SPOILAGE
PARTIAL USE OF ENERGY + MINERALS
"WASTE"
ENERGY
UNTREATED
— HEALTH HAZARDS
— ENVIRONMENTAL DETERIORATION

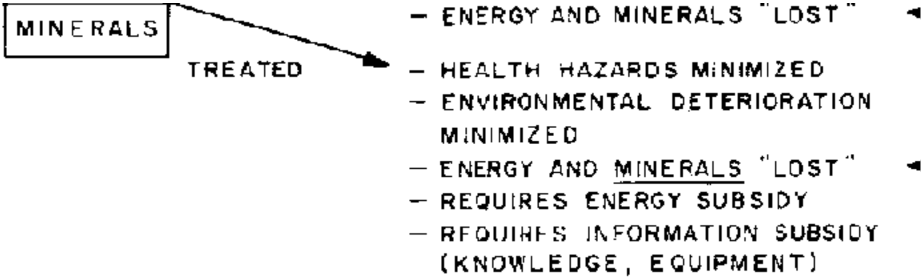


Figure. 2. Fate of Agricultural Products; "lost" minerals have to be replaced in order to keep production capacity constant.

If all these forms of waste remain untreated or unused, they pose a threat to the environment; human and animal wastes carry well known health hazards, while organic matter, apart from its odour nuisance, threatens the oxygen balance of surface waters and discharge minerals leading to eutrophication. These threats are not significant as long as population density is low and the degree of dilution high - conditions that permit natural mineralization to cope effectively with the disturbance. When waste concentrations rise to the point where natural purification is overtaxed, it makes sense to provide for waste treatment.

Most of the processes used are oxidative microbiological conversions that dissipate the energy and the minerals contained in the waste and even require, for aeration, an amount of energy roughly the same in magnitude as that present in the original waste. This does make sense as long as energy and minerals are cheap and plentiful and as long as the discharged minerals do not cause eutrophication. However, when discharged phosphorus and nitrogen compounds reach levels in the receiving waters that do cause eutrophication, further treatment, the so-called tertiary treatment, which "unfixes" the bound nitrogen in the waste (at great expense) by transforming it through denitrification to nitrogen gas, becomes necessary.

The treatment also precipitates the phosphates as insoluble aluminium or ferric salts that have no fertilizer value. It is at this stage where the borderline between sense and nonsense is being approached, especially when prices of energy and fertilizer are mounting, thus calling for a re-orientation of the process which brings recovery of energy and minerals within reach. Once thinking along these lines begins, another striking element of inefficiency comes to mind: high-quality water is often used for the transport of wastes, especially of the domestic type. This is not only wasteful but also impedes treatment and recovery by over-diluting the waste.

Thus, the question we have to discuss is: how can the arsenal of available bioconversions outlined above be made to serve environmental goals in rural communities, including not only health and water quality preservation, but also promotion of mineral and energy economy?

Rural Communities

To conclude this introduction, I shall say a few words about the important boundaries the frameworks of rural communities impose:

a village is not a spaceship. This means that, in creating some degree of self-sufficiency, we are not only bound by the prevailing availability of energy and material, including water and minerals, but also by the constraints of the information economy. Rural self-reliance cannot be assured by mere import of information in the form of prototypes; we also need a "lock and key" complementary process brought about by training the population if the imported processes are to perpetuate themselves. Because training requires free time and other resources, the capacity of a village to incorporate a training component is limited. Hence, if we want to avoid irresponsible use of the "black box" principle the methods introduced have to be simple, rational, and transparent. Most of all, the goals they are to serve must be perceived from within and not merely imposed from outside. Microbiological methods create a special problem here because microbes must be recognized as both friends and foes, even though they are invisible to the naked eye Also, acceptance of environmental goals, especially those with long-term effects, will not be easy

The matrix of types of wastes, conversions, and goals in Table 2 will serve as the skeleton for a more detailed discussion. The many inter-relationships obviously create such complexity that only an arbitrary approach can provide a semblance of order In the following discussion, health will be combined with water economy, and energy economy with that of minerals.

TABLE 2. Matrix of Waste Types, Conversions, and Their Goals

Waste types Human	Conversions Oxidative	Photosynthetic	Goals Health
Animal	- Activated sludge	- Oxidation ponds	Economy of
Agricultural	- Trickling filter	- Fish ponds	- water
Industrial	- Oxidation ditch		- minerals
	- Composting	Anaerobic	- energy
-Mushroom	- Digestion	- fodder	

production			
	- Fermentative		
	upgrading		- food

Health and water economy

General Considerations

Besides potential toxic effects of industrial wastes, human and animal wastes pose the gravest health hazards because they carry the pathogens of the water-borne diseases. In addition to hygienic quality of water, the quantity available is also important. Some so-called water-borne diseases (2) can be prevented if sufficient washing takes place, even with water of less than drinking quality (Table 3). Also, vicious circles of water-borne infections occur in farm animals, e.g., Salmonella in pigs (3).

TABLE 3. Classification of Infective Diseases in Relation to Water Supply

Category	Examples	Relevant water improvements
1. Water-borne infections:		Improve quality
(a) Classical	Typhoid*	Aim for maximum microbiological quality o water
	Cholera*	
	Bacillary dysentery*	
	Amoebic dysentery*	
(b) Non-classical	Infective hepatitis*	Improve microbiologica quality of water
	Gastro-enteritis*	
2. Water-washed infections:		Improve quantity

(a) Skin and eyes	Skin sepsis and ulcers Trachoma	
	Conjunctivitis	
	Scabies	
	Yaws	Provide a greater volum of water, facilitate access, and encourage its use
	Leprosy	
(b) Diarrhoeal diseases	Bacillary dysentery*	
	Amoebic dysentery*	
	Infective hepatitis*	
	Gastro-enteritis*	
3. Water-based infections:		Specific measures:

(a) Penetrating skin	Schistosomiasis	Reduce contact with infested water
(b) Ingested	Guinea worm	Protect water source
4. Infections with water-related insect		
vectors:		
(a) Biting near water	Sleeping sickness	Clear vegetation
(b) Breeding in water	Onchocerciasis	Avoid need to visit source
	Yellow fever	Provide reliable supply
5. Infections primarily of defective Sanitation:	Hookworm	Provide sanitary fecal disposal
	(To some extent, most diseases in	

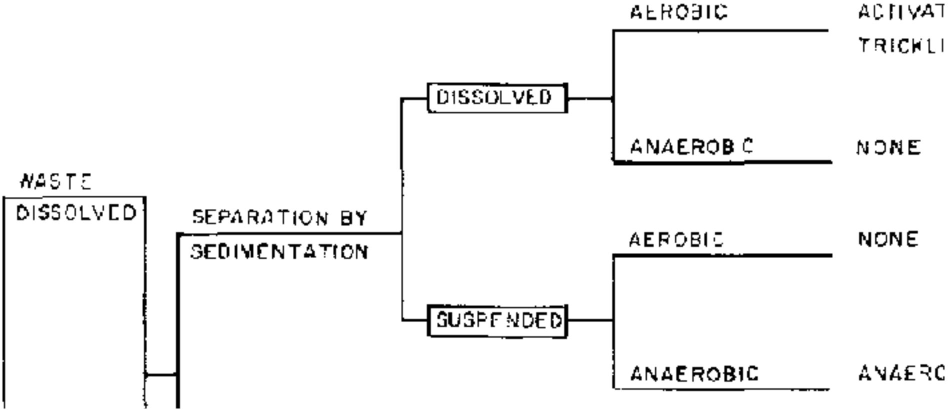
	previous categories also)	

Source: Pacey (2).

* These diseases may be spread by any process that allows material from human faeces to be ingested; i.e., they may spread either as water-borne or as water-washed infections.

Microbial methods for destruction of pathogens are, in addition to self-purification after dilution in surface waters, found to coincide with those of conventional waste treatment that have built-in mechanisms for destruction of pathogens. One example is parasitism by Bdellovibrio through the action of bacteriophages and photooxidation. This may lead to destruction of 90 - 99 per cent of pathogens and a reduction in biological oxygen demand (BOD).

In screening the array of existing biological treatment methods (Figure 3) for suitability in energy-poor rural areas, oxidative methods are disqualified because they are costly, consume energy, and deplete the land of minerals. In addition, conventional waste collection and transport systems must be discounted in many cases because they require a sewerage system which uses and contaminates large quantities of water. Also, dilution precludes methods like drying followed by incineration, and, even more important, dilution prevents composting.



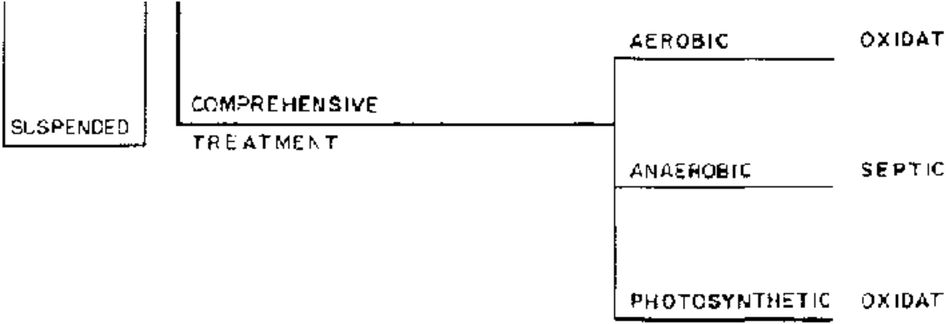


Figure. 3 Survey of Biological Treatment Methods for Organic Wastes

Thus, the anaerobic and photosynthetic methods appear to be the best candidates for rural application, and from the health and water-quality point of view, no objections arise. This is not the case with waste collection and transport in the undiluted state, which has definitely higher health hazards than are occasioned by the flush toilet sewerage method. Because the latter is generally too expensive, night soil collection coupled with special sanitary practices will ultimately be the best choice.

Conclusions

1. Emphasis should be placed on hygienic collection of undiluted human and animal wastes at the source, to be followed either by immediate anaerobic digestion, or by hygienically safe transport to composting sites. Study of the equipment required has been neglected for a long time, but recently the World Bank has started a comprehensive research project on this subject (4), which has already shown that safe night soil collection in villages is feasible for about one-eighth of the price of conventional sewerage systems. At the 1977 GIAM V Conference held in Bangkok, Nimpuno presented a comparative study of sanitary privies, latrines, and composting toilets (5). Recent reports from the People's Republic of China indicate that utilization of human and animal waste in the undiluted state is widely and successfully practiced and appears to enjoy firm popular support (6).

2. Where space, solar radiation, and water availability permit, photosynthetic waste treatment in oxidation ponds after appropriate dilution is a suitable and cheap method that attains hygienic safety and water quality protection, The method essentially converts organic waste material into algal cell material (Figure 4), which, in conventional ponds, is discharged with the effluent. Harvesting of the algae offers a wide scope of rural applications, as the material may serve as fertilizer, fodder, or as a source of energy through anaerobic conversion to methane.

$$\begin{array}{lll}
\text{BACTERIA} & \text{ORGANIC WASTE} + O_2 & = CO_2 + H_2O + \text{MINERALS} \\
\text{ALGAE} & CO_2 + H_2O + \text{MINERALS} + \text{LIGHT} & = \text{ALGAL CELLS} + O_2 \\
+ & & \\
\hline
\text{TOTAL} & \text{ORGANIC WASTE} + \text{LIGHT} & = \text{ALGAL CELLS}
\end{array}$$

Figure. 4 Transformation of Organic Matter in Oxidation Ponds

3. In cases where the population is traditionally and firmly committed to thorough cooking of the fish they consume, direct discharge of wastes into fish ponds appears to be a valuable

alternative (7). To what extent the fish feed directly on the waste and indirectly on the algae grown from it, remains to be elucidated.

4. Animal wastes lend themselves, in some cases, to fractionation followed by partial refeeding of the protein fraction (bacterial cells), while undigested cellulose can be upgraded by fermentation to serve as a fodder supplement. However, simple technologies for this process have not yet emerged, and special care must be taken to avoid recycling animal pathogens.

5. Conversion of animal waste, like horse dung mixed with straw, into human food in the form of mushrooms represents the most ambitious example of upgrading the lowest-quality waste to a high-quality product in one simple step, skipping intermediate stages in the food chain. This practice is now widely adopted in Southeast Asia (8).

6. In all cases where fresh human and animal wastes are being processed, a minimum sanitary discipline should be taught to the

population, not only with respect to personal hygiene, but also with regard to ground-water quality protection in areas where wells are used for drinking water.

7. Providing an adequate water supply in rural areas is best done by protecting the water source against pollution by waste treatment methods 1 - 3 indicated above. If these are carefully followed, a minimum of final treatment often suffices to produce safe water. Simple treatments include: 48 hours of sedimentation to kill off the cercariae of Schistosomes (2), and slow sand filtration (9) which, through oxidative action by the microbial film, removes both pathogens and the last traces of organic matter. Oil drums can serve as small-scale filters.

8. In situations where water quality is threatened by large amounts of agro-industrial wastes (e.g., from rubber processing), microbial conversions of waste to useful products should receive a higher priority than conventional oxidative treatment.

9. While the dimensions of the problems of the water-health complex are staggering - more than 80 per cent of the world's rural population has "no reasonable access to safe water" (2) - it should be recognized that the problems present themselves in great variety, each demanding its own special solution Moreover, they cannot be divorced from seemingly unrelated factors, for instance, the level of food energy intake, which determines the distance from which water can be fetched (10).

Fertilizer and energy economy

General Considerations

The incentives for energy recovery from wastes are strongest in rural areas of developing countries where the level of energy consumption is low. In the Federal Republic of Germany, for instance, conversion of all available organic waste to methane would produce not more than 1 per cent of the energy annually required (11). In contrast, small amounts of methane sufficient to cook one meal a day and to allow reading for a few hours per night would have a strong impact in areas doomed to remain deprived of electricity.

With respect to recycling minerals, the pressures are somewhat more diversified. In developed countries, the health hazards (methemoglobinemia, carcinogenic nitrosamines) associated with increasing nitrate concentrations in water resources, coupled with the eutrophication hazard, are still leading to costly tertiary treatment, creating an irrational situation in that one may find nitrogen-fixing industries and oxidative waste treatment plants side by side, keeping one another in business at great expense. Obviously, urban areas having large food imports cannot easily return the waste minerals to the land where the food was grown unless these minerals are sufficiently concentrated. As this does not appear to be too difficult a task for chemical technology, some engineering innovation is bound, sooner or later, to cause a reversal of tertiary treatment from mineral dissipation to mineral recycling.

In developing countries, drastic technological innovation is not necessary for the rural areas because the transport problem is much smaller and high fertilizer prices that often have to be paid in hard currency are strong incentives to move from the time-honoured methods of waste-burning and direct manuring to composting and biogas production. Burning is inefficient energy utilization, causes air pollution, and wastes the minerals, while direct manuring has health hazards, leads to nitrogen losses during storage, and wastes the energy of the manure. Thus, it would appear that, through minimization of mineral losses, rural communities can reach the point of mineral self-sufficiency by merely importing quantities of minerals that compensate for minerals lost in exported foods. For nitrogen, microbiological N-fixation is an attractive alternative.

Conclusions

1. Collection of wastes in undiluted form offers the best opportunity for energy and mineral recovery, and on this

account merits high priority

2. Except for cases where effluents from oxidative treatment of diluted wastes can be used for irrigation, mineral economy can only be maximized by composting, anaerobic digestion, or photosynthetic treatment, provided the resulting algae in the latter are harvested.
3. While both the theory and practice of composting need much more study, present knowledge (12) is sufficiently advanced to promote composting practices in which animal and domestic wastes are mixed with soil, solid refuse, and/ or agricultural wastes to achieve the proper C:N:P ratio. Water content, access of air, minimization of nitrogen losses, and capacity to reach sufficiently high temperatures of 40 to 70 C for killing pathogens are critical elements of the process. It is labour-intensive, and in the microbiological "selfheating" process, only part of the energy contained in the waste is put to use for disinfection; the remainder is lost in the form of residual organic matter. However, depending on soil quality, this may be beneficial to agricultural land.

4. Anaerobic digestion maximizes both energy and mineral economy in a felicitous manner for the following reasons (13, 14):

- The process exploits energy better than burning or composting does; the resulting CH4/CO2 mixture can be easily stored, transported, and employed in stoves, lamps, and motors.
- The residual sludge containing the waste minerals is less hazardous, bulky, or obnoxious, and more easily transportable than the original waste.
- Almost all organic wastes can be subjected to anaerobic digestion provided a proper C:N:P ratio is achieved.
- It reduces the need for firewood collection, and hence helps counteract erosion by deforestation.
- It can be carried out at a scale ranging from a small farm (Figure 5) to a large city.

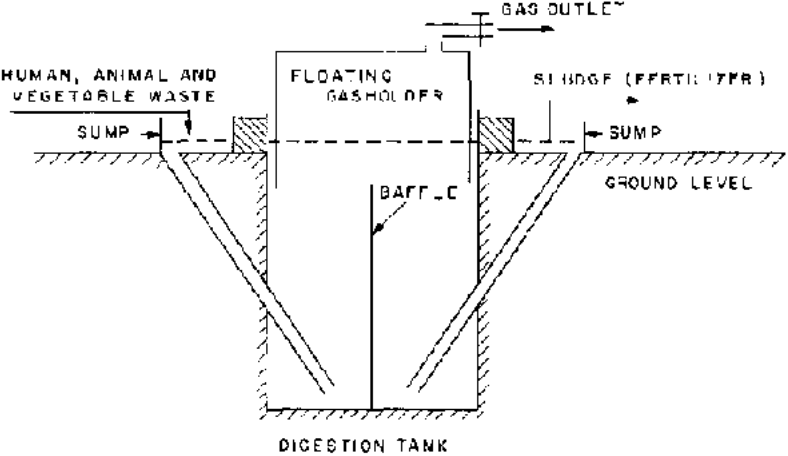


Figure. 5. Cross Section through Biogas Plant with Cylindrical Digestion Tank. Output of residual sludge (fertilizer) proceeds by gravity flow, following input of waste.

- The process can be integrated with other waste treatment or utilization processes; its resulting sludge can serve as a basis for photosynthetic production of algae, which, in turn, can be used for fertilizer, fodder, food, or as a source of biogas through digestion (Figure 6).

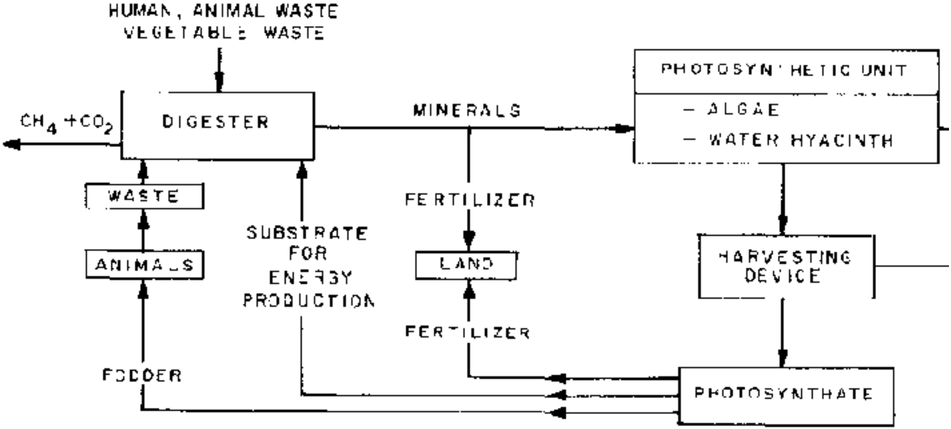


Figure. 6. Simplified Scheme Indicating Various Combinations of

Digestion and Photosynthesis, for the Production of Fodder, Fertilizer, and Biogas

- Operation is simple, provided regular feeding is maintained, and the design of the container allows for the effect of seasonal temperature changes on efficiency of digestion.

While sufficient numbers of prototypes are available for promoting the extension of the method from Asia to Africa and Latin America, it should be noted that this long-neglected process stands to be improved greatly by the research efforts now focused upon it. Improved stirring, operation at high temperatures of up to 60 C, and multiple-stage digestion are all showing promise. In addition, anaerobic treatment of dissolved organic wastes from the potato starch and sugar industries has recently been found feasible and considerably cheaper than oxidative treatment (15). In these more sophisticated processes, advantage was taken of the fact that anaerobic processes have low cell yields and low nutrient requirements, and can be expected to operate at much higher cell densities than oxidative ones, as there is no need for aeration. High cell densities could be obtained by retention of flocci and microbial films that settle on solid surfaces.

The single disadvantage of the method emerges when dung for fuel becomes scarce, a situation which caused dissatisfaction among the poorest rural inhabitants of India in areas where biogas installations had been built.

5. Present photosynthetic waste treatment methods, though effective from the point of view of health and water economy, have not reached the stage where they can be used in rural areas for energy recovery, mineral recycling, and fodder and food production. In addition to the many well-functioning types of oxidation ponds in existence, we should also recognize the convergent development of industrial algal cell production in Asia, based on synthetic mineral culture media and aimed at the markets of health foods and pet bird and fish foods. Also, there are the

traditional practices for harvesting Spirulina from natural habitats where it has persisted for centuries as an important part of the food chain (Figure 7). High priority should be given to research and development of new methods resulting from the "mariage trois" of these three developments. Special attention needs to be focused on: (i) maintenance of the predominance of the desired alga; (ii) cheap harvesting methods, and (iii) the utilization of wastes as substrate. In this regard, the studies of Oswald and Shelev and coworkers, reported recently at the first international symposium on this subject (16, 17), show great promise.

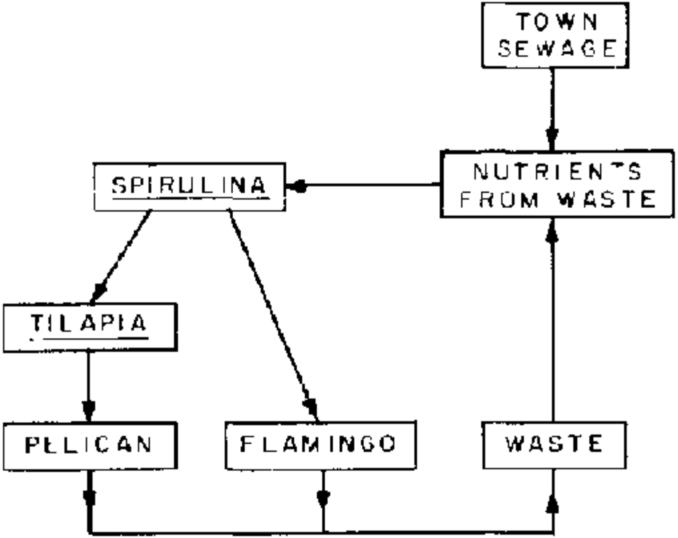


Figure. 7. Simplified Food Chain in Lake Nakuru, Kenya

Concluding remarks

Environmental, agricultural, and industrial goals of rural development are not always in harmony, as shown by the mixed results from building the Aswan Dam. The resulting environmental impact, once the numerous waste conversions discussed in this conference are widely applied, also requires consideration.

No doubt we must expect a selective effect on crop choice and land use. Upgrading the protein content of cassava, for instance, may lead to quantitative and qualitative changes in animal raising practices. In addition, and more important, effects must be expected from successful large-scale industrial bioconversions. As this industry moves from the production of fine chemicals into making bulk chemicals as substitutes for oil and petro-chemicals, the pressure on the land for growing the required carbohydrate substrates will increase competition for land that is used for food production. Thus, bioconversions may well bring about a second agricultural revolution with a new array of crops, products, and wastes that will affect rural ecology and provide a stimulus for further deforestation. This underlines the need for careful, multi-disciplinary assessment of pilot projects for their immediate and long-term ecological and social impact.

Against this background, training and education of the rural population becomes important not only to make the local bioconversions work, but also to make sure that conflicts between environmental and other goals are minimized. Recent developments in the media and telecommunications offer great promise for rescuing rural populations from their isolation from information. Whatever this may bring, the potential of these new tools of instruction should be fully exploited to introduce new instruments for survival and to perpetuate them by creating motivation through effective training and education.

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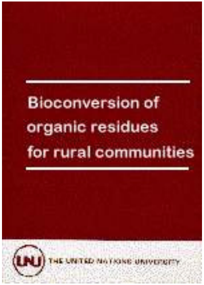
Discussion summary: Papers by Porter, Berk and La Rivire

The discussion was concerned primarily with the microbiological treatment of sewage and the use of the resulting bioconversion products. Some doubt was expressed as to the applicability to rural communities of the methods employed to handle human and animal wastes in cities. There was also some dissent as to whether it was preferable to use the solid waste as a nutrient medium for the growth of algae that could be incorporated into animal feeds, to compost it for fertilizer, or to digest it anaerobically for biogas production.

It was noted that algae grown on these residues contain a variable, but high, percentage of elements generally regarded as undesirable, e.g., lead, mercury, etc. However, in the experiments described by Berk, the level of these elements in the tissues of animals whose diets had contained 15 - 20 per cent of algae as a percentage of the dry matter was no higher than in those of control animals on algae-free diets. It appeared that the elements were present in a form not available to the animal. While this is reassuring in one sense, it creates a problem in another, in that these substances were concentrated in the droppings from animals to which the algae had been fed. Consequently, any further use of the manure from algae fed animals would have to be effected with this in mind.

It was suggested that the methods of utilizing feedlot residues, partly as liquid manure, partly for producing biogas, or even by re-feeding to ruminant animals, might be applied successfully, mutatis mutandis, in developing countries. This led to the concept of fully integrated systems for residue utilization in rural communities. In this connection, the use of algal ponds for fish farming seems attractive because it avoids the need to harvest and dry the algae. The relatively high digestibility of the algal preparations used in the experiments described by Berk was attributed to the rupture of the cell walls during drum drying. However, such a method of drying is not applicable in most rural situations. Less costly alternatives are now being developed for use in village communities.

Reservations were expressed about the feasibility, or even desirability, of transferring technology from industrialized countries to the less technically developed ones. It was emphasized that training is extremely important for the people putting new methods into operation, and audio and visual aids now being developed will be of great help in this regard.



Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Strategies for developing small-scale fermentation processes in developing countries

references
discussion summary

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tropical areas around the world are considered unparalleled green factories where, under mild and appropriate environmental conditions, agro-industrial operations strive to produce cash export crops like coffee, cocoa, sugar-cane, and fruits. the global participation by the fermentation industries is negligible in this region despite much renewable raw material potential in the agricultural wastes from these crops. the reason? simple enough: lack of scientific, technical, and managerial skills.

in tropical countries, the majority of the population lives outside the main cities in what has been loosely termed rural communities. international economic and scientific organizations have recently asked: can small-scale, simple fermentation processes be developed for these groups? if so, what kind of processes should be considered? what type of technology is required?

the first question is what kind of fermentation developments is appropriate for less developed countries? there are several alternatives, among which are the following.

1. traditional units. for example, submerged tanks, using soluble carbohydrate as raw materials to produce antibiotics, enzymes, amino acids, and microbial biomass. however, this kind of operation would compete with existing industries in the developed world. it would, therefore, be unlikely to obtain support from international industrial development institutions.

2. simple, small-scale processes for rural communities biogas and soil conditioners are the best examples. some in the developed world suggest that these are the most feasible for developing countries, but they must be proved to be commercially successful.

3 . a new breed of processes, a new set of rules:

fermentation-plantation units established in rural areas. these should be self-sufficient in energy and utilize all the wastes. in this new technology, solid substrate fermentations and multiple-product units would be favoured. complexity of the unit and products would depend on local conditions. this alternative will probably get some sympathy but very little support from the developed countries, unless dramatic events, such as those which initiated the "new economic order" discussions develop in future.

deciding which alternative is best for all rural communities is unreasonable, as natural circumstances vary from country to country, unless the alternative chosen is regarded as a general policy framework. on this basis, many governments have already endorsed the second alternative. the industrial sector would, however, prefer the last one if it is eventually developed by engineers and scientists in third world countries.

in asian countries, anaerobic fermentation of organic matter, especially animal wastes and night soil, to produce energy (biogas) and to act as a soil conditioner (sludge residue) has been recommended as one of the simplest methods for treating these wastes in order to minimize public health hazards and, at the same time, obtain valuable products two recent reports from international development institutions give an in-depth technological state-of-the-art review (1,2). it is from these reports that the following points are drawn.

practical experience in biogas generation in rural communities overwhelmingly resides in asian countries, e.g., india, the people's republic of china, taiwan, korea, and japan. animal wastes and night soil have been the main substrates. as barnett et al. state, "the technical and economic evaluation of these technologies has often been rudimentary..." and "the data that currently exist on the viability of biogas plants are not only very unreliable, but are obtained from a narrow range of possible plant designs and socio-economic and agroindustrial environments" (2). of the tens of thousands of biogas plants that have been constructed-the majority built not more than ten years ago - it is not known whether they are still functioning (after an initial test period sponsored by governmental agencies), or at what level of efficiency. more information is required before this approach can be recommended for large-scale adoption with any assurance of economic success and cultural acceptance (1).

it is interesting to summarize some of the tasks for research and development recommended in a technical assessment of biogas plants made in india, one of the leading countries in this field (3):

a. more basic knowledge is needed on the metabolic path ways for methane formation.

b. a search should be made for new fermentation materials.

c. more treatment processes should be explored.

d. fermentation components (ch4 evolution?) as a function of temperature, pressure, agitation, solids particle size, viscosity of suspension need to be determined.

e. operation techniques need to be tested, e.g., continuous, one-day feeding, fed-batch, batch.

f. more must be learned about equipment design: building materials, gas holders, heating, gas purification.

g. how will biogas be best utilized (cooking, lighting, power conversion) ?

h. which is the best use of sludge: handling (drying, composting, algae growth, compacting), and will it have value as fertilizer?

i. socio-economic aspects must be considered: cultural acceptance, optimum number and capacity of plants, and infrastructures.

the point is that there is quite a bit of technical experience in small-scale methane generation in rural conditions, especially in asian countries, employing animal wastes and night soil as substrates. but whether this technology could be directly transferred to africa and latin america and be accepted and economically successful is an open question. it is essential that research of a fundamental and applied nature be done with the more abundant ligno-cellulosic agro-industrial wastes.

large-scale methane generation is also being considered in developed countries for treating organic municipal and feed lot wastes (4 - 8). although not necessarily related to rural operation, some of the more complex, recently developed engineering techniques could eventually be scaled down. future technical advances need careful evaluation.

the role that methanogens play in mixed bacterial populations, and how methane is biosynthesized from either acetate or co_2 and h_2 in natural habitats, under mesophilic conditions, as in lake and marine soil sediments, and in the animal rumen have been the subjects of recent reviews (9 - 12). methanogenic bacteria have been shown to alter the metabolic pattern of chemo-organotrophic bacteria. hydrogen produced by them is oxidized to methane by methanogens coupled with the reduction of co_2. this co-operation among bacteria has been called "inter-species hydrogen transfer." it is not an obligatory interaction, but occurs with positive effects for each participating species. it is not exclusive for methanogens; it might be considered a general reaction involving all terminal micro-organisms. a recent example has been described by weimer and zeikus (13) and is illustrated diagrammatically in figure 1. while with clostridium thermocellum growing on cellulose or cellobiose, ethanol and hydrogen are produced, in co-culture of cl. thermocellum and methanobacterium thermosutotrophicum there is complete conversion of h_2 to chin, a shift in the conversion of acetyl co a from ethanol to acetic acid, which results in more electrons being available for h_2 production and hence, methane. no methanogenesis was observed from acetate. the cellobiose was fermented more rapidly than was cellulose.

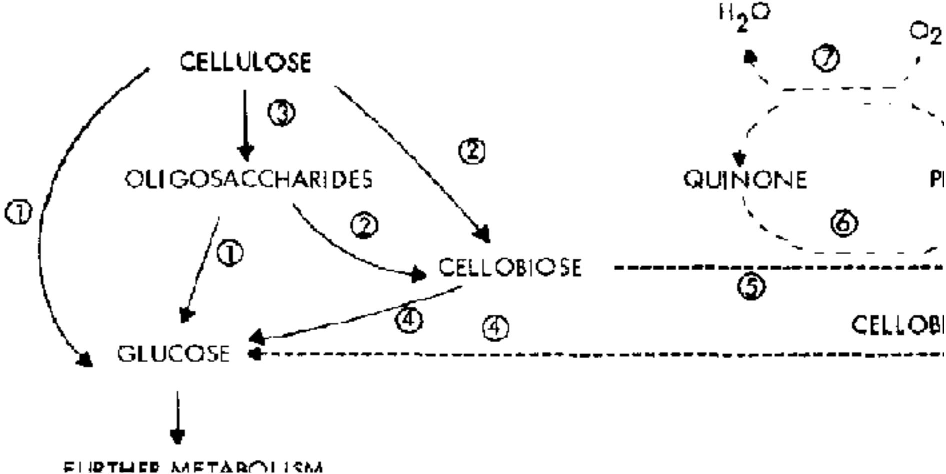
Figure. 1. Interaction between Clostridium thermocellum and Methanobacterium thermoautotrophicum

These comments stress the point that the biogenesis of methane is still a subject for research. More basic knowledge of how mixed bacterial populations are able to attack lignocellulosic biopolymers and eventually produce CH4 and CO2 is needed.

In any event, the degradation of the plant's structural biopolymers like cellulose and hemicellulose will be the rate-limiting sept. This biological reaction occurs in nature either under complete anaerobiosis or full aerobiosis, in mesophilic (20 to 45 C) or thermophilic (above 45C) conditions (14). There is recent experimental evidence that there is a positive correlation between temperature and rate of cellulose hydrolysis until denaturation of enzymes becomes limiting, either under anaerobic (15, 16) or aerobic conditions (17). Biogas production was also enhanced when produced at high temperatures from wastes with a high cellulose content, in this case urban refuse (18,19). Still, the characterization of the cellulose enzyme complex among micro-organisms is only beginning. Cellulolytic enzymes are found widely scattered among the major taxonomic groups, but only in the higher fungi are they a feature of the group as a whole (20) This is one of the reasons why it has been studied in detail in Sporotrichum pulverulentum (21), Trichoderma viride (22), Trichoderma koningii (23,24), Fusarium solani (25), and in a culture of a Thermoactinomyces sp. (26).

Figure 2 illustrates a summarized form of a proposed mechanism for ligno-cellulosic polymers under aerobic conditions. Note that cellulose is degraded to glucose through the concerted action of multiple enzymes controlled by an induced-catabolite repressed system. Lignin is assumed to enter the cycle through redox reactions (dashed lines in the figure) The reader is referred to recent review articles dealing with this very important subject (27

29), whose thorough understanding will give guidelines for the anaerobic degradation of agro-industrial by-products in substrate selection, treatment, operating temperature, number of fermenters and mode of operation, and rate models for biogas production.

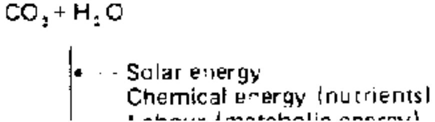


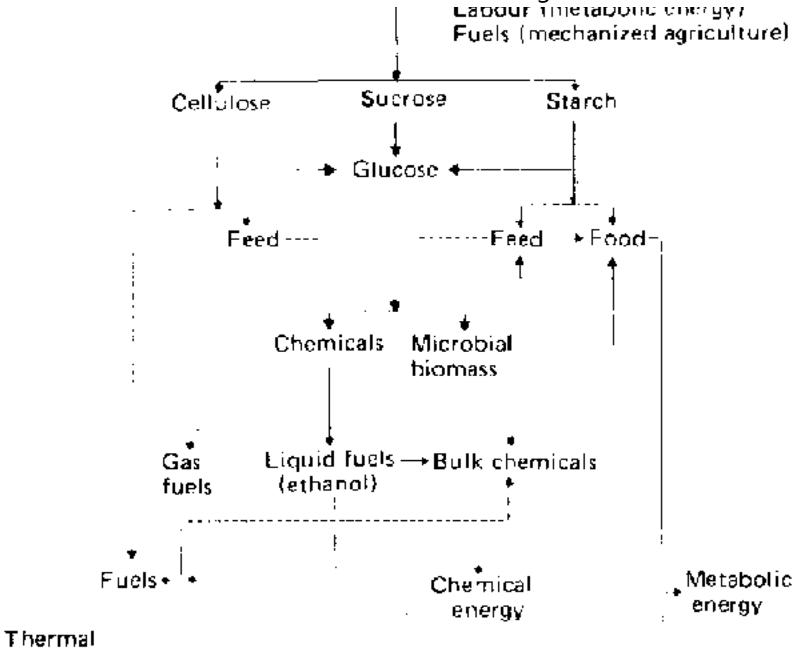
FURTHER METABOLISM

FIG. 2. Mechanism for Cellulose Breakdown. (1) Exoβ1,4 glucanase (β1 glucohydrolase); (2) exoβ1,4 glucanase (β1,4 glucan cellobiohyd (3) endoβ1,4 glucanase; (4) glucosidase (cellobiose); (5) cellob (6) cellobiose: quinone oxidoreductase; (7) laccase.

Figure 2. Mechanism for Cellulose Breakdown.

Because cellulose is the most abundant renewable resource on earth, it has been considered one of the possible future raw materials for fuels, chemicals, feed, and food The Gaden Humphrey diagram shown in Figure 3 illustrates this point (30). This means that many scientists around the world will be working with cellulose as their raw material, and needless to say, a great many technical advances are forecast for the near, mid-, and long-term future.





Labour (metabolic energy)
Fuels (mechanized agriculture)
Cellulose
Sucrose
Starch
Glucose
Feed
Feed
Food
Chemicals
Microbial biomass
Gas fuels
Liquid fuels (ethanol)
Bulk chemicals
Fuels
Chemical energy
Metabolic energy
Thermal

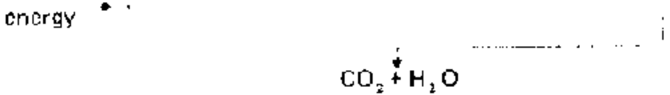


Figure. 3. Modified Gaden-Humphrey Ecological Carbon Balance

Anaerobic digestion of cellulosic by-products for biogas and soil conditioner production should be placed among competing alternatives, and also as a complementary step in an integrated scheme for by-product utilization. It would be a mistake to consider it the only solution to fermentation schemes for small-scale processing in rural areas. This would be frustrating and a serious limitation for further development.

Every raw material available in a region must go through at least a preliminary cost-benefit analysis, as well as local socio-economic review as the first step in strategy selection and process synthesis. In this exercise, all possible products, their cost and demand, should be established. It is not possible to consider all available alternatives in this paper, especially when one considers the heterogeneity and diversity of agro-industrial products (31). As an epilogue, therefore, a qualitative analysis will be made on the utilization of an important byproduct of coffee-producing countries: coffee pulp.

Coffee pulp is the skin of the coffee fruit. It represents 40 per cent by weight (fresh) of the fruit, and is separated from the fruit by mechanical action with the help of water. Another coffee by-product is mucilage, which can be removed from the depulped fruit by natural solid fermentation. It represents 20 per cent by weight (fresh) of the fruit. Both can be obtained together without introducing drastic and costly changes in coffee processing itself. As a matter of fact, it would be better to depulp the fruit with a minimum amount of water. The same water could be used to separate most of the mucilage from the fruit, leaving natural fermentation to finish the process. The water could be circulated and treated later on.

During the last few years, the total quantity of coffee pulp produced in Central America has varied between 800,000 and 1 million metric tons. There is a wide variation in the number and capacity of coffee processing units, at least three orders of magnitude in daily rate. Some of them are easily accessible by road or train; others are quite isolated in mountainous regions.

The pulp is now disposed of in an inefficient manner. It is usually dumped in open piles and left there for several months. After that storage period, it is mainly used as an organic fertilizer or soil conditioner in the coffee fields. Several things are wrong with this system For instance, in most of the pile, anaerobic conditions are rapidly established and putrefactive fermentation sets in. This causes very bad odours, and the pile becomes a haven for insects. Moreover, constant flow of pulp liquor leaches out of the pile and is usually channeled directly to the rivers or into open oxidation ponds, contributing to serious water pollution and, again, bad odour. Pulp has occasionally been used as ruminant feed, but because of improper handling and storage, results have been contradictory and not reproducible.

There are alternatives for coffee pulp processing that should be explored. Pulp is a potential fermentation substrate. It should be obtained as fresh as possible from the coffee processing units, and depulping should take place with a minimum of water or none at all. The alternatives are:

a. to use the fresh pulp in one of the following ways:

(i) composting it by controlled aerobic solid state fermentation;

(ii) mixing it directly with other feed ingredients and using it as feed for cattle;

(iii) mixing it with feed ingredients and then ensiling;

(iv) drying it and use it as feed;

(v) using it to produce biogas and organic fertilizer through controlled anaerobic fermentation;

or

b. to treat the pulp to remove excess water and soluble compounds from the solid matrix, use the liquid portion as a substrate for microbial biomass production, and use the solid matrix as in alternative 1.

Local conditions will dictate which method is most appropriate Research is needed on all of them. At ICAITI, we are developing the technology for the following systems:

a. Small-scale composing of fresh pulp - demonstration unit.

b. Large-scale composting of solid matrix with previous liquid separation - pilot plant.

c. Biomass production from the liquid (submerged production of filamentous fungi) - pilot plant.

d. Biogas generation from the liquid portion - rate and and modeling studies.

Previous work on fungal biomass production has already been published (31 - 38).

From the above examination of processing alternatives for coffee pulp, it can readily be seen that organic fertilizer and feed are the preferred products. The former can be produced directly under aerobic conditions (compost), or by producing biogas as a byproduct through anaerobiosis.

In order to give sound answers and not biased approximations to questions on which product is better and what alternative should be chosen, two conditions are required. (i) adequate experimental data, and (ii) knowledge of local conditions. Research activities carried out at the site will provide the answers.

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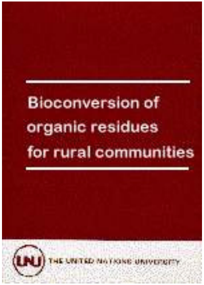
Discussion summary

A critical factor in biogas production is the efficiency with which stored solar energy can be converted to usable methane, and it was stated that simple modifications of existing techniques could at least double methane production.

There was some criticism of the principle of evaluating processes on the basis of cost/benefit ratio. This was linked to the difficulty of attempting forward projections in this area, since too much attention to economics, as understood in industrialized societies, could be prejudicial to the initiation of processes. For example, in Marseilles, the energy generated by a sewerage plant serving one million people is just enough to operate the plant, no more.

In the selection of any strategy, it is necessary to consider both economics and logic. Finally, the selection must rest on a personal judgment of the balance between the two that a particular set of circumstances would justify. This prompted the comment from Seshadri that, in his view, a conflict between advanced and so-called "appropriate" technology is imminent because the latter now tends to replace the former. Increasing attention is being given to technology appropriate for the ecologic and economic conditions, particularly in various rural areas in Africa, Asia, and Latin America.



Bioconversion of Organic Residues for Rural Communities (UNU, 1979, 178 p.)

Production of microbial protein foods on edible substrates,

food by-products, and ligno-cellulosic wastes

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Preface

Dr. Noel Vietmeyer of the Board on Science and Technology for International Development, National Academy of Sciences (US), reported discussing the miracle winged bean plant with an influential Filipino family. When he showed them that the beans were already growing on a fence in the servants' quarters, they were disappointed and said, "It's only a poor man's crop." Dr. Vietmeyer commented, "Some of the Third World's best crops may be waiting in the poor man's garden, ignored by science. Merely to have survived as useful crops suggests that the plants are inherently superior. They are already suited to the poor man's small plot and to his mixed farming, his poor soil, his diet, and the way of life of his family and village" (1).

His statement recalled my experiences working with the indigenous fermented foods in Indonesia. It has only been since the Western world began to research and use Indonesian tempeh that the topic has gained enough prestige to encourage Indonesian scientists to research their own foods. An Indonesian scientist told me that, in the past, he would not have had the nerve to approach his administration with the suggestion that he work on this familiar fermented food because he would have been refused permission Only recently have the West and the developing world begun to realize the gold mine of information that is available regarding indigenous methods the developing countries themselves have evolved at the village level to feed people on minimal incomes. We have much to learn about how to utilize our bioresources to greatest advantage in feeding the world of the future. It would be a great mistake not to make maximal use of available village-level technology. However, it would also be a mistake not to recognize the part prestige plays in acceptance of foods, not only for the rich but also for the poor As soon as the Western world adopts a poor man's or a village food, that food takes on enhanced prestige and it tends to be accepted much more widely than before.

Introduction

Hunger and Poverty in the World Today

Hunger and poverty go hand-in-hand in this world where vast millions must support their families on less than US$1 per day. The poor are generally vegetarians, consuming on the average a pound or pound and a half of cereal grains per person per day. They need nutritious, low-cost meat substitutes. As the population reaches 8,000 million in the 21st century, much of the world may be compelled to become vegetarians. There are already an estimated 10 million vegetarians, mainly young adults, in the United States. If vegetarian foods can be formulated with the flavour, texture, and nutritive value of meat, they will likely become acceptable as staples in the diet.

Protein-Calorie Malnutrition

Protein-calorie malnutrition is a serious problem in the developing world today. Insufficient protein and calories not only stunt physical growth but also retard brain growth and mental development. In addition, malnutrition also results in low resistance to infectious disease. This leads to frequent, disabling sickness and partly accounts for the high death rates and low productivity in the developing world (2,3).

Vitamin Deficiencies

Other forms of malnutrition are also widespread in the developing world, among them vitamin A deficiency leading to xerophthalmia and tragic blindness in children, thiamine deficiency resulting in beri-beri, including the rapidly fatal infantile beri-beri; niacin deficiency causing pellagra in some areas; vitamin D deficiency resulting in rickets; iron deficiency anemia; and iodine deficiency resulting in goiter. Vitamin C and riboflavin deficiencies are also found in the developing world.

No country can hope to sustain rapid economic development unless it is accompanied by, and preferably preceded by, adequate nutrition for its people. Malnourished people, perhaps with their potential mental development impaired, and highly susceptible to infectious disease, generally lack the vigour and high level of intelligence a nation needs to develop quickly. Unfortunately, the problem is further compounded by the lack of universal education in the developing world.

Contributions to the solution of nutritional problems

The Green Revolution

What can be done to alleviate the nutritional problems that face the developing world? The Green Revolution has resulted in a vast increase in worldwide productivity of rice and wheat. It has enabled mankind to continue to feed a burgeoning population up to now, but it has not relieved the plight of the millions of hungry and malnourished in the developing world. The basic problem remains essentially one of economics. The food is generally available if the people have the money to buy it, and farmers the world over will produce more food if they can sell it for a profit. However, we have no way at present to improve the economic status of millions of malnourished people, unless the world decides to use the US$350,000 million spent each year on armaments (US$100,000 million of which is spent by Third World countries) to improve the economic and nutritional status of the poor (4).

Thus, we must look for alternate ways of increasing the food supply or modifying the distribution of cereals and legumes between animals and man.

Increased Utilization of Cereals for Feeding Humans

For example, on a worldwide basis, about 400 pounds of cereal grains are available per person per year (5). In the developing world, cereal grains are generally consumed by humans. In the United States, about 2,000 pounds of cereal grains are available per person per year. Of this, about 200 pounds are consumed directly in foods such as bread, cereals, etc. The rest is used for animal feeds and alcoholic beverage production. If Americans alone became vegetarians, releasing the grain now fed to animals, we could feed approximately another 800 million people a basic cereal diet.

Development of protein-rich vegetarian meat substitutes in the western world

Spun Soy Protein Analogues

Americans and other Westerners are not likely to become vegetarian at this point, but there have been some interesting trends in the West that will eventually favour our becoming more vegetarian. This has included the development of meat analogues, principally from soybean (6).

Meat analogue is an industrial term for meat substitutes or synthetic meats made principally from plant proteins. The basic technique is to extract soybean protein and concentrate it to above 90 per cent purity. The protein is then extruded through platinum dies and chemical baths to form very fine filaments similar to hair, which are then combined to form a fibrous meat-like texture. Meat flavours and fats are added. Synthetic bacon bits ("BaCOS," General Mills, Inc., Minneapolis, Minnesota) have been on the market for some time. Synthetic hamburger bits used widely in chili and other soup-like dishes are also on the market, and synthetic roast beef, ham, chicken, etc., have been developed.

Extruded Soy Nuggets

Even the large meat companies have been developing meat analogues. Swift and Co. (Chicago, Illinois) has evolved a process whereby soybean, usually in the form of grits or soy protein concentrate, is tempered with water, mixed with desirable flavours, and processed through a machine (Wenger Extruder, for example) in which the thick dough is exposed to high pressure and temperature. As the material emerges from the extruder, it develops a puffed structure, or emerges as a chewy, meat-like nugget. There is little question that these meat analogues will be an important addition to future diets.

All of this has taken place in the West, where meat consumption is a large and very important part of the diet. Wider use of lower-cost meat analogues may reduce the need for real meats. It is also a way of directly consuming legumes in a form acceptable to meat-eating consumers.

Miller, Rank, Hovis, MacDougall Mould-Mycelium-Based Meat Analogues

The Miller, Rank, Hovis, MacDougall Research Group in England developed an alternative method of producing meat analogues. In their process, they grow an edible mould (Fusarium sp.) on low-cost starchy substrates, adding inorganic nitrogen (for synthesis of protein) and minerals to produce a type of single-cell protein (SCP). The mould mycelium, which provides the fibrous meat-like texture, is grown in tanks, recovered by filtration, and meat flavours and fats are added (7,8). The process is particularly adapted to production of synthetic chicken breast meat. It has been licensed by a large US company, and it is likely that the mould-mycelium meat analogues will eventually appear on the American market. They are already being market-tested in Europe.

These mould-mycelium-based meat analogues are produced by highly sophisticated technology. They are entirely beyond the economic means of the poor in the developing world at present.

This is true also of all canned, frozen, and most dehydrated foods that are so important in the developed world. Thus, we must look elsewhere if we hope to contribute to improved nutrition among the poor.

Significantly related to future food and feed production is microbial farming, or SCP production.

SCP Production on Hydrocarbons

SCP production on inedible substrates such as hydrocarbons is one of the great developments in modern applied microbiology (9). Single-cell protein consists of cells of bacteria, yeasts, mould, or algae containing, respectively, up to 80 per cent, 50 per cent, 40 per cent, 40 per cent protein on a dry weight basis. SCP production requires no arable land; it can be produced in the desert. While grasses such as elephant grass and alfalfa double their cell mass in two to three weeks, bacteria and yeasts double their cell mass within two to four hours. Thus, 1,000 kg of yeast can produce

12,000 kg of new cells containing 6,000 kg of protein in a 24-hour period. The selected micro-organisms use hydrocarbons as a source of energy for growth, and inorganic nitrogen for synthesis of protein. Their remaining nutrient requirements are minerals and a sufficient supply of oxygen (10).

This "microbial farming" was so promising that it was estimated that by the 1980s, 3 per cent of the total protein produced in the world would be in the form of SCP (11). Initially, it was assumed that hydrocarbon-grown SCP would be used primarily as animal feed, thus releasing vast quantities of cereal grains and legumes, for example soybean, for use in feeding humans. Unfortunately, the cost of petroleum unexpectedly rose so high that production of SCP on hydrocarbons can no longer compete with the cost of producing soybeans or fishmeal.

SCP Production on Ligno-Cellulose

Because of the limited supply of petroleum for energy and its consequent cost, it is unlikely that it can serve as a substrate for economical SCP production in the future. However, production of SCP on ligno-cellulose, the world's largest reserve supply of renewable carbohydrate, could become an efficient alternative.

Ruminant Production of Protein

Cellulose cannot be digested by man, but, as a major component of fibre, it does play a role in the motility of the gastro-intestinal tract. At present, the major practical converters of cellulose to useful products such as milk and meat are the ruminants - sheep, goats, and cattle. They have micro-organisms in their rumens that can hydrolyze cellulose to glucose which, in turn, is used by the microorganisms for energy to synthesize proteins from inorganic nitrogen that can be supplied in forms such as urea. Minerals supply the other growth requirements for these micro-organisms. The animal subsequently digests the microorganisms and synthesizes milk and meat proteins, which serve as major foods in the Western world. Thus, the ruminants themselves are SCP fermenters.

Hydrolysis of cellulose outside the ruminant is, at present, too slow to be a practical method of producing SCP.

However, many laboratories are working on the problem and it is likely that cellulose hydrolysis may become rapid enough to permit cellulose to be utilized as a major energy source for SCP production in the future.

Processes have already been developed to raise the protein content of straw to as high as 30 per cent by growing a cellulolytic mould on it. This improves the straw as an animal feed (12)

Mushroom Production on Ligno-Cellulose

It is possible, also, to use cellulose or ligno-cellulosic wastes such as waste paper, cotton waste, straw, wheat, or rice bran and go directly to a food. This idea has already been developed to a high degree in Asia in the production of mushrooms such as Volvariella volvacea, the padi mushroom, and Pleurotus ostreatus, the oyster mushroom, on cellulosic and ligno-cellulosic wastes (13-15). Mushroom contain 2 to 5 per cent protein on a fresh weight basis, but from 30 to 47 per cent on a dry weight basis (16)

As much as 1.25 kg of fresh mushrooms can be produced on 1 kg of straw. In Hong Kong there is an estimated 30,000 tons of cotton waste per year. This could serve as a substrate for producing approximately an equal weight of fresh mushrooms.

The padi mushroom is grown by many farmers in Asia, using rice straw as a substrate. Thus, the Asians have demonstrated to the world a practical way to transform ligno-cellulosic wastes directly into highly acceptable food for man. They are literally growing a type of microbial protein (SCP) directly on cellulosic waste as a nutritious, delicious food.

The padi and oyster mushrooms can be grown under rather simple conditions. Paper or cotton substrates are shredded. Straw can be trimmed, coarse ground, or used directly. Five per cent wheat or rice bran and 5 per cent CaCO3 are added, along with sufficient water to raise the moisture content to about 60 per cent. This requires that approximately 1,500 ml of water be added per kg of ligno-cellulosic waste. The substrate should then be steamed for 30 minutes.

Alternatively, the substrate can be composted in heaps where microbial activity results when the temperature rises to about 55C. The substrate is then cooled and inoculated with the mushroom spawn. The spawn is the desired mushroom species grown on soaked, sterilized wheat, corn, or rice straw, Approximately 160 9. of spawn are added to each kg of starting (dry weight) substrate. Within a few weeks, under tropical temperatures and humidities, several flushes of fresh mushrooms are produced (15).

The developing countries in Asia are already expanding their own use of mushrooms in the diet. Taiwan is producing canned mushrooms for export. Last year Americans consumed 163,000 metric tons of mushrooms, 22 per cent of which were imported (17)

I have discussed the production of SCP on inedible substrates such as hydrocarbons and cellulose and the production of mushrooms on ligno-cellulosic wastes. What remains to be discussed is the growth of microbial protein on edible substrates and the conversion of byproducts, such as oilseed press-cakes, to food by means of fermentation.

Again, it was Asia that taught the world how to convert vegetable protein to meat-like flavours in the form of soy sauce (shoyu) and Japanese soybean paste (miso) (18, 19).

Production of Indonesian Tempeh

Asians, particularly the Indonesians, have introduced meat-like textures into vegetable substrates. A prime example is Indonesian tempeh in which soybeans are soaked, dehulled, briefly cooked, cooled, inoculated with the mould Rhizopus oligosporus, wrapped in wilted banana or other large leaves, and fermented from 36 to 48 hours. During this time the white mould-mycelium knits the soybean cotyledons into a tight cake that can be sliced thin and deep-fat fried or cut into chunks and used in soups (20 - 22). Tempeh is a major meat substitute in Indonesia, and it is produced daily by small factories in the villages.

Containing nearly 47 per cent protein, it is very nutritious and, in fact, kept thousands of Westerners alive in Japanese prisoner-of-war camps during World War I I. The mould not only introduces texture, but it also solubilizes the proteins and lipids, making them more digestible. It releases a peppery flavour that adds to the nutty flavour of the soybean substrate. The mould doubles the riboflavin content, increases the niacin level by almost seven times, decreases pantothenate slightly, and, unfortunately, decreases thiamine content, but surprisingly vitamin B12 is found in nutritionally significant amounts (23).

One of the problems of vegetarian diets is that vegetable foods generally do not contain significant vitamin B12. It was found that a bacterium sometimes present in the mould is responsible for the vitamin B12 in tempeh (24). If the fermentation is carried out with pure mould, the tempeh does not contain B12. If the bacterium is present, the tempeh will contain as much as 150 mg B12 per g. Thus, this single food provides both protein and vitamin B12 for vegetarians.

There are at least five vegetarian communes in the United States today (for example, The Farm, Summertown, Tennessee) where tempeh has been adopted as the major protein source, replacing meat in the diet. In California, Nebraska, and Canada (Toronto), there are at least six small factories producing tempeh commercially. The acceptance of this Indonesian food technology in the United States and Canada suggests that the technology could also be extended to developing countries, thus improving the diversity and nutritive value of the diets of the poor.

It has already been demonstrated that the tempeh process can be used to introduce texture into other substrates made, not only from soybeans, but from wheat and other cereals as well (25). A bacterium has also been used to raise the content of vitamin B12 in Indian idli, which is made by fermenting a batter of ground soaked rice and black gram dahl with Leuconostoc mesenteroides (26).

There is a similarity between the Miller, Rank, Hovis, MacDougall meat analogue process discussed above and tempeh production In both cases, the texture is derived from mould mycelium, but the former process is sophisticated and relatively costly, while the latter is low-cost technology.

Fast-Cooking Foods

Fast-cooking foods are appreciated world-wide because fuel is costly. Tempeh fermentation reduces the cooking time for soybeans from six hours of boiling to ten minutes, or four to five minutes of deep-fat frying at 190 C.

Increasing the Protein Content of High-Starch Substrates SCP can easily be produced by growing suitable organisms on a starch substrate to which minerals and inorganic nitrogen are added. This is the basic process used by Miller, Rank, Hovis, and MacDougall to produce mould-mycelium for their meat analogues.

Indonesians successfully grow edible microbes on starch substrates to produce tape ketan and tape ketella, grown on rice and cassava, respectively. The major fermenting organisms are Amylomyces rouxii, a mould, and at least one yeast, such as Endomycopsis burtonii. They grow compatibly in the substrate and not only increase the protein content but triple the thiamine level and synthesize lysine, the first limiting amino acid in the starchy substrate. The acids, alcohols, and esters produced during fermentation add a flavour highly acceptable to the consumer (27). The protein content of tape ketan may be as high as 16 per cent; in tape ketella it is from 4 to 8 per cent. Unfermented cassava contains only 1 or 2 per cent protein, not an adequate amount to meet human protein requirements, yet millions of the world's very poor use cassava as a major staple food. In the form of tape ketella, the protein quantity and quality of cassava are both improved. This process could usefully be expanded and extended to other countries.

Utilization of Food Processing and Agricultural Wastes to Produce High-Quality Foods

Indonesian ontjom and bongkrek

The Indonesians have also developed methods to convert food processing by-products, such as peanut and coconut press-cakes, which the Western world has traditionally fed to animals, to high-quality foods called ontjom and bongkrek. They have done this by using the basic tempeh process. The press-cakes are hydrated, coarse ground, steamed, cooled, and inoculated with either the tempeh mould or Neurospora intermedia. The mould grows over the particles, knitting them into tight cakes that can be sliced or cut into chunks and used in soups (28). These products are low-cost, protein-rich meat analogues. The basic changes are similar to those that occur during tempeh fermentation. In addition, it has been found that the content of aflatoxin, always present in peanut press-cake, is reduced (29). The strains of Neurospora intermedia also contain cellulases that reduce the natural fibre content of the peanut or coconut press-cake.

These indigenous fermented food processes offer a unique opportunity for increasing the quantity and quality of protein in areas of the world where the staple food is largely comprised of starch. They not only contribute to Western food science, but are also suitable, at the village level, for low-cost production of foods with acceptable flavours, textures, and nutritive values.

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Discussion summary

With regard to the fermented foods produced in Indonesia, it was pointed out that, while the fungi used may be fairly rich in lysine, they are likely to be poor in methionine. Nevertheless, as cereal diets tend to be lysine deficient, an improvement in nutritional value may be produced by fungal lysine.

Successful fungal fermentation of cassava requires the addition of inorganic nitrogen. Because Neurospora, the organism used to ferment a cassava/groundnut mixture, provides virtually no protein, the protein value of the mixture depends entirely on the amount of groundnut present.

The question of mycotoxin contamination of Indonesian fermented foods was raised, Although this problem had not been reported before, recent evidence suggests that it may have occurred. Contamination can happen if a pseudomonad, which produces highly toxic metabolites, intrudes during fermentation of tempeh.

This dangerous possibility should be prevented by standardized procedures for traditional fermentation methods, using high" quality inocula from recognized, competent centres.