Recycling Livestock Wastes

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Ecological Farm

LRRD (Livestock Research for Rural Development)
Recent developments in the recycling of livestock excreta; an essential feature of sustainable farming systems in the tropics

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Abstract

Loss of soil fertility and species biodiversity, and environmental pollution, are negative consequences of modern agricultural practices in the industrialized countries where, on most farms, intensive systems of production have resulted in the physical separation of livestock and crop production. One outcome of this policy is that the disposal of manure from livestock units concentrated in a small area, often with no land attachment, has become a major problem.

In SE Asia, the integration of crops and livestock, and the use of manure as fertilizer, are traditional practices and are the basis of the farming systems, especially at small-holder level. This manual describes ways in which these systems can be made more efficient, more productive and more environmentally friendly, by applying simple, low-cost technologies for recycling the manure through biodigesters, duckweed ponds and earthworms.

Introduction

The deterioration of soil fertility through loss of nutrients and organic matter, erosion and salinity, and the pollution of the environment - of air, soil and water - are negative consequences of modern agricultural practices in the industrialised countries where the divorce of livestock and crop production has become the norm (Haan et al 1997). Traditionally, livestock were a balanced - indeed an essential - component of farming systems but the development of the chemical industry in the 19th century, and the major impetus it received from the discovery of oil, created opportunities for the low-cost supply of plant nutrients in inorganic form and led to the rapid displacement of organic manures derived from livestock excreta.

The increasing global awareness that resources are finite, and that the livelihood of future generations depends upon the maintenance of renewable natural resources, is now a major stimulus for initiatives that will lead to the more efficient use of these same resources. In industry, recycling of processed goods at the end of their useful life is now seen as a means of lowering costs of production and reducing the pollution caused by accumulation of these materials in the environment.

This paper describes recent developments in the same recycling strategy as it can be applied to
livestock.

**Livestock excreta as livestock feed**

The accumulation of livestock excreta, chiefly from poultry kept in deep litter, was seen as an opportunity to recycle this material as a feed for ruminant livestock (Muller 1980), and there were even attempts to do likewise with the excreta from intensively-fed pigs (Buitrago J, personal communication) and cattle (Anthony 1971). However, in all these cases the nutritional value of the manure was mainly a reflection of the spillage of feed which is almost inevitable when intensive systems of self-feeding are practiced. The high risk of disease from recycling wastes through livestock, highlighted by the recent outbreaks of BSE (Taylor 1997), is now seen as a major deterrent to these practices. They will therefore not be considered further in this document.

**Potential benefits from the recycling of livestock excreta**

These can be summarised as follows:

- A source of nutrients for growth of plants
- Control of pollution
- A renewable source of energy (biogas)
- Added value to the end-product as being of "organic" origin

The relative contribution that livestock excreta can make to the achievement of the above goals is a function of:

- The processing applied to the excreta after it leaves the animal
- The species of livestock in view of the differences in the anatomy and physiological characteristics of their digestive system
- The chemical and physical characteristics of the feeds that are given to the livestock
- The management system (especially the housing) applied to the livestock
- The ecosystem in which the farming system must function (temperate or tropical; arid or humid)

Several of these features are determined by economic issues, such as the species and genotype of the livestock and the feeding and management systems that are applied. Most of them are inter-dependent (e.g. the most appropriate way of processing the excreta depends on its physical characteristics, which in turn is determined by the livestock species, and by the systems of housing). However, decisions in all of these areas are increasingly seen to be affected by the role of livestock within the immediate ecosystem. In other words, the advantages that may accrue from an appropriate system of recycling of the excreta become a stimulus for decision making in both the selection of the livestock species, and of the genotype within the species, and of the system of feeding and management. It follows that research on methods of recycling livestock excreta, and the development of appropriate technologies for this purpose, should be given high priority as these eventually become important determinants of the farming systems that are selected in a given ecosystem.

**Methods of processing (recycling) of livestock excreta**

In order of priority these are considered to be:

- Anaerobic biodigestion (biodigesters)
- Vermiculture
Irrespective of the processing method that is applied the concept of recycling implies an ecological and holistic approach to the use of natural resources in which livestock play an intrinsic role (Figure 1). It may not always be possible, or convenient, to incorporate all the sub-systems in the overall process. The biodigester sub-system, and the pond, are not essential for ensuring that plant nutrients are not lost as the essential cycle is between the crop and the livestock. Nevertheless, biodigesters and ponds are components in the system which:

- increase the efficiency of uptake of plant nutrients derived from livestock wastes,
- reduce the health hazards that might arise when livestock excreta is applied directly to the soil,
- reduce the release to the environment of greenhouse gases such as methane, nitrous oxides and carbon dioxide,
- give rise to products (biogas) and water plants which respectively contribute to family well-being (a clean fuel in the kitchen) and food security.

This manual describes a holistic approach to recycling of livestock excreta based on experiences gained in an ecological farm in the South East of Vietnam [http://www.hcm.fpt.vn/inet/~ecofarm](http://www.hcm.fpt.vn/inet/~ecofarm). The aim is to show the way to optimise the process, selecting the pathways that are most suitable for the different kinds of excreta likely to be produced in a small-scale family farm (Figure 2).
The biodigester is a closed medium in which livestock and human excreta (and / or other organic wastes) are fermented anaerobi cally giving rise to a gas (biogas) and a residue (the effluent). Biogas is a mixture of methane and carbon dioxide the volume ratio of which is about 65:35 (substrates rich in lipids produce biogas with higher proportions of methane). The effluent contains all the original mineral elements that give rise to nutrients needed for plant growth, but the reducing anaerobic medium improves the efficiency with which they can be assimilated (eg: the conversion of part of the organic nitrogenous compounds into ionic ammonia).

There are three main types of biodigester which originated respectively in India (floating canopy), in China (the fixed dome - dual compartment system) and in Taiwan (the plastic red mud tubular plug flow model). The Taiwan model was modified by Preston and coworkers (Botero and Preston 1986; Bui Xuan An et al 1998) into a simpler form using tubular polyethylene film, standard PVC sanitary fittings and discarded motor cycle inner tube. The Indian and Chinese models are undoubtedly the most robust and the most efficient. They are also the most expensive in terms of materials, the need for skilled artisans and time taken for construction. These models are described in detail in the book of Marchaim (1992). The materials required for the tubular plastic biodigester are low cost (from USD10.00 to USD50.00 for small scale farm family units), the required materials can usually be found in the markets of major cities throughout the developing world and they can be assembled and installed with unskilled labour. This manual is concerned only with the low-cost tubular polyethylene model in view of its cost-effectiveness as demonstrated by high rates of adoption by farmers without the need for subsidies (Bui Xuan An et al 1998; Lauridsen 1998). The companion article illustrates in detail the nature of the materials and how these are assembled,
and the biodigester installed, on the farm.

**Factors influencing the cost and performance of plastic biodigesters**

**Materials**

The plastic tube

Two types of plastic have been used for the tubular biodigester: poly-vinyl-chloride (PVC) and polyethylene. PVC film is manufactured by a rolling process which results in sheets that must be welded with heat into a tube. By contrast, polyethylene is produced by blowing air vertically (forming a large bubble) through the molten plastic encased in a mold the diameter of which fixes the diameter of the tube. The thickness of the plastic film is controlled by the rate at which the air is introduced into the process.

Making a tube by welding together PVC sheets is a skilled operation and not always successful. The facilities for the welding are rarely found other than in major cities. By contrast, tubular polyethylene needs no further processing and is ready to be used immediately it leaves the factory. The raw material is also cheaper than PVC.

Tubular polyethylene is therefore the material of choice. The cost is usually in the range of USD1.00 to USD1.50 / kg, depending on whether it is purchased direct from the factory or from re-sellers. A tube of 80cm diameter and thickness of film of 200 microns (the most common dimensions) weighs 500 g per metre of length. For a biodigester that is 6 m long the need is 15 m of tube (two tubes are used one inside the other) and 75 cm is required at each end for fixing the tube to the inlet and outlet pipes. This will weigh 7.5 kg and therefore cost between 7.00 and 11.00 USD.

The inlet and outlet pipes

Alternatives types of pipe are made from "fired" clay (ceramic), concrete and PVC. The relative advantages of each are indicated in Table 1.

<table>
<thead>
<tr>
<th>Material</th>
<th>Preference</th>
<th>Cost</th>
<th>Weight</th>
<th>Ease of use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceramic</td>
<td>1</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Concrete</td>
<td>2</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>PVC</td>
<td>3</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>

Connecting the tubular film with the inlet and outlet pipes

The tubular polyethylene is attached to the inlet and outlet pipes using rubber strips (5 cm diameter) made from rejected inner tubes from the wheels of vehicles. The relative advantages of the different sources are indicated in Table 2.

<table>
<thead>
<tr>
<th>Preference</th>
<th>Source</th>
<th>Strength</th>
<th>Ease of use</th>
</tr>
</thead>
</table>

**Table 1:** Relative advantages of different types of inlet and outlet pipes

**Table 2:** Relative advantages of different sources of rubber bands to secure the tubular polyethylene to the inlet and outlet pipes
<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Motor cycle</td>
<td>Good</td>
<td>High</td>
</tr>
<tr>
<td>2</td>
<td>Bicycle</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>3</td>
<td>Motor car</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>4</td>
<td>Truck</td>
<td>Very high</td>
<td>Low</td>
</tr>
</tbody>
</table>

The gas line

There are only two choices: rigid PVC tube (id: 13mm) or flexible garden hose. The latter is cheaper but the former is preferred as there will be fewer maintenance problems, especially blockages in the pipe.

The reservoir

The gas pressure in tubular plastic digestive is low: between 1 and 1.5 cm water column. If the cooking stove is situated more than 10 m away from the biodigester, the flow rate of the gas will be too low for efficient burning. The solution is to situate a reservoir as close as possible to the plastic biodigester.

The reservoir is made from the same tubular polyethylene as the biodigester and usually it is 2-3m long. It is closed at one end and the other is connected to the gas pipeline. A string is placed around the middle of the reservoir and can be tightened manually whenever a higher gas pressure is required.

Management factors that govern gas production

Size of biodigester

The amount of gas produced daily is a function of the:

- C total volume of liquid within the biodigester
- C amount of fermentable substrate (volatile solids) introduced daily.

Thus the gas produced (m³/day) = k1*L + k2*VS

where AL is liquid volume in m³; and VS the amount (kg) of volatile solids; k1 and k2 are constants.

In practice, the factors that determine biogas yield and efficiency of conversion of volatile solids into biogas are the:

- C liquid volume (which increases gas production)
- C daily input of volatile solids (which increases gas production)
- C residence (or hydraulic retention) time (longer time; higher efficiency)
- C concentration of volatile solids in the input suspension (increases the rate of production)

The ratio of volatile solids to total solids (VS/TS) is determined by the species of livestock and within the species by the feed (feeds of high digestibility produce excreta with a higher VS/TS. Within animal species, those with simple digestive systems (monogastric animals with poorly developed caecum and large intestine) will produce excreta of higher content of volatile solids.
The loading rate

The concentration of total solids in the input suspension can be varied within the range of 20 to 100 g/litre. For a fixed volume of input suspension, the gas production is a direct function of the concentration of total solids (Figure 3). In practice it is recommended to limit the total solids concentration to the range of 20 to 30 g/litre. Higher concentrations can lead to scum formation in the biodigester which can impede the flow of fermentable material and also reduces the surface area of particles accessible to fermenting bacteria.

Residence time

Residence time (or hydraulic retention time) is the average time it takes for the substrate to move from the input to the output pipes (ie: the time the substrate remains in the biodigester). It is determined by the liquid volume of the biodigester and the daily rate of input of the substrate. Residence time has little effect on daily gas production but a longer time increases the efficiency of conversion of volatile solids to biogas (Figure 4). The lower the concentration of volatile solids in the total solids (eg: the case of manure from buffaloes fed rice straw) the longer should be the residence time (20 to 40 days). For higher ratios of volatile solids to total solids (excreta from chickens and pigs fed concentrate diets with low fibre content) the residence time can be reduced to 10-15 days. The shorter the residence time the smaller can be the biodigester in relation to the daily entry rate of total solids.
Liquid volume

The required size of a biodigester (total liquid volume) is determined by the total amount of volatile solids available (the input) and the residence time. Indicative volumes are given in Table 3, according to residence time and total volatile solids available (depends on type of feed and the total liveweight of the animals and people providing the excreta).

The total volume of a tubular biodigester is a function of its diameter ($D$) and length ($L$).

$$\text{Volume} = \left(\frac{D}{2}\right)^2 \pi \times L$$

Thus a biodigester that is 6m long and 80cm diameter will have a total volume of:

$$0.4 \times 0.4 \times \pi \times 6 = 3\, \text{m}^3.$$

However, the liquid volume is less than the total volume because space must be left beneath the gas outlet for the gas to accumulate. The ratio of liquid to total volume depends on the configuration of the biodigester (Figure 5). If the floor of the trench is completely level then the ratio of liquid volume to total volume will depend on the level of liquid in the biodigester. In practice, when the floor of the biodigester is level, the liquid volume is likely to be from 70 to 80% of the total volume. A higher level of liquid carries the risk of blocking the gas outlet.

**Level or inclined biodigesters**

By having the floor of the trench sloping from input to output it is possible to concentrate the gas space in the region where the gas outlet is placed. This will make it possible to have a greater liquid capacity closer to 90% of total volume.
Where the required liquid volume is in the range of 2-4 cubic metres then it is convenient to use tubular polyethylene of 80 cm diameter with the length in the range of 6-10m. For larger biodigesters with required liquid volume in the range of 12 to 24 cubic metres then it is better to use tubular polyethylene of 1.25 m diameter, which for any given length will increase by a factor of 2.4 the volume compared with a diameter of 80cm. For a liquid volume greater than 24 cubic metres, the tubular polyethylene should be 2.5m diameter and have a length of between 20 and 30 m giving a range of liquid volumes of 70 to 110 cubic metres.

Animal species

In addition to the effects of the concentration of volatile solids in the total solids in the excreta, there are other physical factors which influence the suitability of excreta from some species compared with others. Thus the Apelleted® consistency of faeces from sheep, goats and rabbits makes this material unsuitable as substrate in plastic biodigesters. The Apellets® float on the surface of the liquid and rapidly cause the formation of scum on the surface. Excreta from these species is best processed through earthworms (see later section).

The most accurate way to estimate the required size of biodigester (liquid volume), and to predict the estimated gas production, is according to the total weight of animal / human population that will contribute excreta to the biodigester (Table 3). It is assumed that:

- the feed intakes are: 30, 50 and 100 g dry matter/kg liveweight for cattle, pigs (& people) and chickens, respectively
- that 1 kg of excreta dry matter produces 250 litres of biogas
- that the hydraulic retention times in the biodigester are: 40 days for excreta from cattle and 20 days for pigs, people and chickens.

Table 3: Estimates of required liquid volume and expected daily biogas production from excreta from different species of livestock according to category of feed and total liveweight of the animal / human population contributing to the biodigester
Commonly encountered problems

Life of tubular polyethylene biodigesters

If the biodigester is well protected against animals and against sunlight it can continue to function effectively for up to three years. It should then be replaced. Replacement involves only the renewal of the tubular polyethylene. The input and output pipes and the gas output line can all be used again. Sunlight was thought to be a major constraint to the life of the polyethylene. In practice, it has been found that this is not the case. Provided there is moisture on one side of the plastic film the sunlight appears to have little effect. In the absence of moisture the life is shortened considerably. Thus the outer layer of the polyethylene will deteriorate before the inner one.

It is wise to protect the biodigester with a fence that will keep out all farm livestock including chickens. Although there are isolated reports of rats making a hole in the plastic these have been isolated cases and this does not appear to be a major problem.

Accumulation of sludge and scum

Sludge is the accumulation of soil and other mineral matter on the floor of the biodigester. The scum is the accumulation of unfermented organic matter on the surface of the liquid. The latter can be dispersed by walking carefully on top of the biodigester. In the case of the sludge, the best solution is prevention by inserting a sand trap in the inlet sector (Figure 5). Once inside the biodigester, the sludge cannot be removed except by completely renovating the system.

In practice it is the accumulation of scum and sludge which is the major determinant of the effective life of the biodigester. The problem is exacerbated when high loading rates are used and when the input material has a high fibre content (e.g. contains straw residues from the feed or litter). As stated previously, it is recommended that a period of 2 - 3 years be considered as the working life of tubular polyethylene biodigesters. It is normal practice to expect to replace the plastic and remove the accumulated sludge and scum at this time.

Water in the pipeline

Biogas is fully saturated with water vapour. In the night-time, and on cooler days, some of this moisture will condense and will accumulate in the lowest points of the gas line. If there is a sudden drop in the volume of gas reaching the reservoir, water in the pipes may be the
problem (this assumes that there are no leakages in the gas line itself). The solution is to bore a small hole in the lowest points of the gas line, let the water drain out and then seal the hole with plastic tape or a strip of rubber inner-tube.

**Excreta as source of nutrients for water plants, terrestrial crops and earthworms**

Livestock excreta can be used directly as a source of nutrients for production of earthworms, aquatic and terrestrial plants and indirectly through the medium of algae for fish production. The excreta can also be mixed with other vegetative residues to make compost prior to its addition to soil or water as fertilizer. In all cases, with the exception of earthworms, performance (in yield and / or quality of the end-product) is improved when the excreta is passed first through a biodigester (Le Ha Chau 1998a,b; Hong Samnang 1996, unpublished data).

**Water plants**

A wide range of plant species grow luxuriously in water fertilized with livestock excreta, the most important ones being duckweed (*Lemnacacea*), water hyacinth (*Eichhornia crassipes*) and water spinach (*Ipomoea acuatica*). This manual is concerned only with the cultivation of duckweed in view of it's high nutritive value for livestock, high biomass yield, ease of harvesting and capacity to increase in protein content in response to nitrogen fertilization (Leng 1999; Rodriguez and Preston 1996a,b). The other water plants mentioned are efficient in removing nutrients from an aquatic medium and have high growth rates (Chara et al 1999), but their nutritive value is relatively low (with the exception of *Ipomoea acuatica*) and, in the case of water hyacinth, harvesting can be a problem. It appears there have been no attempts to cultivate water spinach, in the same way as has been done with duckweed.

**Cultivating duckweed**

Duckweed will grow in nutrient-rich water in a wide range of locations ranging from natural earth-lined ponds to plastic containers or ponds lined with polyethylene film (Haustein et al 1992; Rodriguez and Preston 1996a; Nguyen Duc Anh et al 1997). Assuming that the aim is to cultivate the duckweed as part of an integrated system based around the biodigester, then the following factors need to be considered,

**Construction of the ponds**

These should have ideally an area of about 20-30 m². Larger ponds can be used but should be separated into sections with floating bamboo poles as large surface areas are susceptible to the effect of the wind "blowing" the duckweed to the sides. The ponds should be 40cm deep. If the soil at this level has a high clay content, it may be sufficient to compact the base of the pond and to line the sides with clay-rich sub-soil. In general, however, it is quicker and more reliable to use a mixture of soil and cement (10 parts soil to one part cement) to line the floor and the sides. For a pond 40cm deep and with an area of 20 m², the required overall quantities are 25 kg of cement and 300 kg of soil. The way to line the ponds is shown in detail on the accompanying CDROM.

**Nutritive value of duckweed**

What gives a special value to duckweed as feed for livestock is that:

- It is rich in protein (can be as high as 40% in dry matter) of high biological value.
The protein content is directly proportional to the nitrogen concentration in the water.

The protein content can be estimated directly according to the length of the roots (Figure 6).

![Relationship between root length and crude protein content of duckweed](image)

**Figure 6**: Relationship between root length and crude protein content of duckweed (Source: Le Ha Chau 1998a)

Protein content is inversely and highly correlated with the length of the roots. It is very easy to measure root length and in this way the farmer can quickly estimate the probable protein content of the duckweed.

**Fertilizing the duckweed**

Appropriate fertilizing of the duckweed pond is a fundamental feature of the management in order to produce biomass of high nutritive value. The best fertilizer is the effluent from the biodigester. The dry matter of the duckweed can have up to 5 percentage units more protein when effluent rather than manure is used as fertilizer (Le Ha Chau 1998a). The aim should be to achieve a concentration of nitrogen in the pond water of between 20 and 30 mg/litre. The volumes of effluent to be added can be calculated from the table below. There are two factors to consider: in adding the effluent:

- At the beginning when the pond is prepared and filled with water the first time
- Every day (to compensate for the nitrogen removed in the duckweed assuming a daily harvest of 100 g/m² pond surface/day)

The calculations are based on a pond of 20m² area and 20 cm depth of water. For ponds with different dimensions the data should be adjusted accordingly.

**Table 4**: Amounts of effluent (litres) to be added daily according to dry matter content and N concentration in the dry matter of the effluent

<table>
<thead>
<tr>
<th>Pond area, m²</th>
<th>Pond depth, m</th>
<th>Dry matter content of effluent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.2</td>
<td></td>
</tr>
</tbody>
</table>
### Amounts of effluent (litres) to be added at beginning according to dry matter content and N concentration in the dry matter of the effluent

<table>
<thead>
<tr>
<th>N in effluent DM (%)</th>
<th>0.5</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>288</td>
<td>144</td>
<td>96</td>
<td>72</td>
<td>58</td>
<td>48</td>
</tr>
<tr>
<td>1</td>
<td>144</td>
<td>72</td>
<td>48</td>
<td>36</td>
<td>29</td>
<td>24</td>
</tr>
<tr>
<td>1.5</td>
<td>96</td>
<td>48</td>
<td>32</td>
<td>24</td>
<td>19</td>
<td>16</td>
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<td>2</td>
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<tr>
<td>2.5</td>
<td>58</td>
<td>29</td>
<td>19</td>
<td>14</td>
<td>11</td>
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</tr>
<tr>
<td>3</td>
<td>48</td>
<td>24</td>
<td>16</td>
<td>12</td>
<td>10</td>
<td>8</td>
</tr>
</tbody>
</table>

Problems and possible solutions

**Problem:** The yield declines and / or the protein content falls.<br>
**Explanation:** It may be due to buildup over time of some elements present in the effluent which have a deleterious effect on growth of the duckweed. The problem is more pronounced when the ponds are lined with polyethylene film rather than soil / cement.<br>
**Solution:** Take out the contents of the pond including the duckweed and replace with fresh water, effluent and duckweed acquired from another farmer. A long term solution is to set up the ponds so that there is continuous flow of water (and effluent) through the system (Nguyen Duc Anh and Preston 1998).

**Problem:** The duckweed is pale green to yellow in colour and has long roots (over 2 cm)<br>
**Explanation:** It is not obtaining sufficient nutrients from the medium<br>
**Solution:** Add more effluent. If it does not respond harvest all the duckweed and bring new seed from another farmer.

**Problem:** The water in the ponds overflows so the duckweed is lost.<br>
**Explanation:** Usually the result of very heavy rain falling in a short period.<br>
**Solution:** Bring new duckweed seed and start again. Cover the pipes that connect the ponds with a plastic net (fine mesh) and if possible also put net around the pond 10 cm high to avoid...
the overflow of the duckweed seed. Immediately the rain stops, harvest the duckweed that is left, redistribute it in the ponds and add more effluent. (In the rainy season the duckweed yield tends to decrease as there is a dilution of the nutrients and then the protein content decreases).

Problem: Yield declines, water becomes green.
Explanation: Another aquatic plants is competing with a negative effect on duckweed yield.
Solution: Change the water and apply new seed.

Earth worms

Background

The role of earthworms in improving soil fertility has long been appreciated by farmers but until the last two decades there had been no major attempt to cultivate them as a component in an organic recycling system. The potential value of the earthworm as a source of feed protein for poultry is often emphasized as justification for growing them, but their major role is in the recycling of animal excreta for the production of a high quality organic fertilizer in the form of the worm casts (humus).

Earthworms will grow on the faeces from all species of livestock. However, as indicated earlier they have a comparative advantage over other forms of recycling when the faeces are from goats, sheep or rabbits.

Species of earthworm

There are many species of earthworms but the one invariably used is the "California Red Worm" (Eisenia fetida). Its advantage is that it does not escape from captivity which is a major problem with other "wild" species.

Management

The following procedure has been developed in the Arizona farm (Pozo Verde) situated in the Cauca Valley, Colombia (Rodríguez 1997; Rodríguez et al 1995). Mounds of manure 25 cm high (370 kg of cow dung/m² approximately) are accumulated in beds the most convenient size of which is 1*5m. The manure is left to ferment aerobically for 30 days (using a stick to open holes to let in the air). The beds are irrigated to prevent loss of moisture.

500 g of earthworms or 1 kg of worms plus humus after partial harvest (see later) are introduced for each 1m² of bed. This should be done on day 30. Fresh manure is added as soon as it can be seen that the original manure has all been transformed into humus. Irrigation is applied as needed.

This process is continued for a further 60 days (in total 90 days) when the irrigation should be stopped and a mixture of water and manure put on the surface of the mounds. On the following day a layer of 10 cm can be harvested and it will contain 90% of the worms (partial harvest). The remainder of the bed is essentially humus with some worms.

Production coefficients

According to Beteta (1996), the rate of transformation of cattle manure by earthworms is relatively uniform with 100 kg of manure yielding between 0.9 and 2.6 kg of earthworms and 49 to 57 kg of humus. The composition of earthworms and humus derived from cow manure on a farm in Colombia is shown in Table 5. The concentration of plants nutrients is not high.
The value of the humus lies in its content of humic acids which give colloidal properties to the soil, improve the soil structure and form particles that encourage better development of plant root systems.

Table 5: Composition of worms and humus (dry matter basis)

<table>
<thead>
<tr>
<th></th>
<th>Worms</th>
<th>Humus</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>8.98</td>
<td>1.95</td>
</tr>
<tr>
<td>P</td>
<td>0.79</td>
<td>1.20</td>
</tr>
<tr>
<td>K</td>
<td>0.91</td>
<td>1.56</td>
</tr>
<tr>
<td>Ca</td>
<td>0.65</td>
<td>1.64</td>
</tr>
<tr>
<td>Mg</td>
<td>0.28</td>
<td>0.78</td>
</tr>
</tbody>
</table>

Source: Rodriguez and Salazar 1991

Researchers at the Goat and Rabbit Research Centre in North Vietnam (Nguyen Quang Suc et al 1999, unpublished data) have reported more precise data on growth and conversion rates of earthworms using manure from different animals species (Figures 7 and 8). For each species the initial substrate was 50 kg fresh manure to which were added 0.5 kg of California Red worms. Fresh manure was added every second day according to observed usage rates by the earthworms. The results show that worm growth and conversion rates were best with manure from goats and rabbits.

The fertilizer value of both the fresh manure and the worm casts (humus) was estimated by measuring the relative growth rates of maize planted in bags containing the different substrates and allowed to grow for 25 days. Growth on the humus was twice that on the fresh manure. The ranking (best to worst) for both manure and humus was: goats, rabbits, buffaloes and cows, the same order as for the growth and conversion rates of the worms (Figure 9).
These results confirm the validity of the propose strategy to recycle goat and rabbit manure through earthworms and that from cattle and buffaloes (and pigs) through biodigesters.

**Biodigester effluent and goat manure as fertilizer for cassava**

In humid tropical ecosystems, the staple foods for human consumption are invariably rich in energy (e.g., rice, maize, cassava, sweet potato) and the byproducts from the processing of these are all deficient in protein, either in quantity or in quality. Thus protein is the nutrient that is most limiting in livestock diets in these regions. In order to optimize the use of livestock excreta as fertilizer for terrestrial crops, the choice of plant species is therefore a decisive factor. The desired characteristics are:

- High yield of biomass rich in protein of high digestibility
- Capacity to extract nutrients, especially nitrogen, from a high application rate of manure
- Resistance to insect pests and other diseases
- Readily consumed by a wide range of livestock

Cassava (*Manihot esculenta*) has all the above characteristics with the additional advantage of being a multi-purpose crop that can be managed for production of protein (the leaves) or energy (the root).

**Goat manure as fertilizer**

Recent work in the Ecological Farm of the University of Tropical Agriculture in South Vietnam (Rodriguez Lylian, unpublished data), based on earlier experiences in the Dominican Republic (Ffoulkes and Preston 1978), has demonstrated that cassava can be managed as a semi-perennial forage crop with high yields of protein-rich foliage. Regular application of goat manure (20 tonnes/ha following each harvest) has been the means of achieving the high foliage yields which appear to increase with successive harvests (Figure 10). Translated into protein these yields are equivalent to more than 4 tonnes/ha/year.
Biodigester effluent

A relevant criticism of the use of biodigester effluent as fertilizer for terrestrial crops is its high degree of dilution and the labour cost of transport if the crop fields are some distance from the house plot where the biodigester is located. Raw or composted manure has comparative advantages in this scenario. By contrast, the effluent -- but not the raw manure -- is easily transported by low-power (0.2-0.3 KW) centrifugal pumps traditionally used for pumping water. Solar pumps which derive their power directly from a solar panel show high promise for this purpose, although presently their high costs precludes their use other than as demonstrations of future possibilities.

As in the case of aquatic plants, and specifically duckweed, biodigester effluent appears to be superior to raw manure when the target plant is a terrestrial plant. Small scale farmers in Cambodia (Thanh Soeur, personal communication) were quick to identify the superior growth of vegetables fertilized with biodigester effluent compared with the raw manure. This comparative advantage of the effluent has since been documented for cassava grown for forage (Le Ha Chau 1998b). The effluent from biodigesters charged with either cattle or pig manure supported higher yields of cassava foliage, which had a higher protein content, compared with the use of the raw manure (Figures 11a and 11b).

![Figure 10: Yield of cassava foliage at successive harvests](image)

\[ y = -0.018x^2 + 0.36x - 0.054 \]

\[ R^2 = 0.62 \]

**Figure 11a:** Biodigester effluent compared with raw manure in terms of fresh biomass yield for whole plant and leaf+petiole.

**Figure 11b:** Biodigester effluent compared with raw manure in terms of protein content for whole plant and leaf+petiole.
raw manure to fertilize cassava grown for forage (means of fresh biomass yields for two harvests) (Source: Le Ha Chau 1998b) raw manure to fertilize cassava grown for forage (means of protein in the foliage over two harvests) (Source: Le Ha Chau 1998b)

**Conclusions**

Much research remains to be done to document the comparative advantages of the respective pathways for recycling goat manure as crop fertilizer: through earthworms to produce humus or by direct application to the soil. The former is most suited to opportunities that emphasize the advantages of a medium for plant growth that is essentially odourless and easy to transport, store and use. House plants and garden vegetables are obvious targets for the humus derived from the action of the earthworms. By contrast, direct application of the manure to soil will probably be the more economical alternative when the end uses are as fertilizer for highly productive field crops such as cassava and fruit trees.

In the case of effluent versus raw manure, there is a need to characterize the properties of the effluent which give it an apparent superiority as a source of plant nutrients. From an environmental standpoint, prior anaerobic fermentation of manure in a biodigester ensures capture of the methane, part of which would be lost to the atmosphere when raw manure is applied direct to the soil as fertilizer. However, carbon dioxide emissions are likely to be similar for both processes. From the point of view of human and animal health, destruction of parasites and reduction in the population of pathogenic micro-organisms in the passage of manure through a biodigester is a major advantage of the process.

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Biodigester installation manual

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Introduction

Biodigesters can play a pivotal role in integrated farming systems by reducing health risks, facilitating control of pollution and at the same time adding value to livestock excreta through production of biogas and improved nutrient status of the effluent as fertilizer for ponds and crop land. Energy is also a fundamental factor for economic development, but normally the energetic models are based on "non-renewable" resources. In addition to energy sources from humans and work animals there are many kinds of renewable energy such as: hydraulic energy, wind energy, solar radiation or biomass (through pyrolysis and gasification). During the course of this century the world energy consumption per inhabitant has increased sixteen-fold. Today the industrial countries, with 32% of the world population, consume 82% of the planet’s energy. On average, a person from an industrialized country consumes 20 times more energy than a person in Africa. It is clear that the "economic development model" is what drives energy consumption.

In many developing countries there is a serious shortage of fuel and the energy crisis is a daily reality for most families. Cooking is one of the most energy-consuming activities, yet is often inefficient. The open fire is still very common. Today the devastation of forests in developing countries is frequently mentioned in the mass media. Deforestation has many causes. Poor people are migrating and inhabiting, cultivating and using new forest areas. In some cases they use "slash and burn" methods and this is another factor rapidly depleting the forests. War has been another important cause of deforestation. However, the daily consumption of fuel must not be underestimated when considering causes of deforestation. It is not unusual for a family to have to spend the greater part of their day gathering fuel for their home. At times dozens of kilometres need to be covered to find fuel (Nystrom 1988).

Many developing countries, such as Colombia, Ethiopia, Tanzania, Vietnam, Cambodia, have promoted the low-cost biodigester technology aiming at reducing the production cost by using local materials and simplifying installation and operation (Botero and Preston 1987; Solarte 1995; Chater 1986; Sarwatt et al 1995; Soeurn 1994; Khan 1996). The model used was a continuous-flow flexible tube biodigester based on the "red mud PVC" (Taiwan) bag design as described by Pound et al (1981) and later simplified by Preston and co-workers first in Ethiopia (Preston unpubl.), Colombia (Botero and Preston 1987) and later in Vietnam (Bui Xuan An et al 1994). More than 7000 polyethylene biodigesters have been installed in Vietnam, mainly paid for by farmers (Bui Xuan An and Preston 1995).

There are many designs of biogas plants which are available but the most common are the floating canopy (Indian) and fixed dome (Chinese) models. The poor acceptability of many of these digesters has been due mainly to: (a) high cost of the digesters; (b) difficulty in installing them; and (c) difficulty in procuring spare parts for replacement as these are not always locally available. The polyethylene tubular biodigester technology is a cheap and simple way to produce gas for small-scale farmers. It is appealing to rural people because of the low cost of the installation and therefore of the gas, and the improvement in the environment that the installation allows. It can be applied in rural or urban areas, both in low and hilly lands.

Pollution

The deterioration of soil fertility through loss of nutrients and organic matter, erosion and salinity, and the pollution of the environment - of air, soil and water - are negative consequences of modern agricultural practices in the industrialized countries where the divorce of livestock and crop production has become the norm. Traditionally, livestock were a balanced - indeed an essential - component of farming systems but the development of the chemical industry in the 19th century, and
the major impetus it received from the discovery of oil, created opportunities for the low-cost supply of plant nutrients in inorganic form and led to the rapid displacement of organic manures derived from livestock excreta.

The increasing global awareness that resources are finite, and that the livelihood of future generations depends upon the maintenance of renewable natural resources, is now a major stimulus for initiatives that will lead to the more efficient use of these same resources. In industry, recycling of processed raw materials at the end of their useful life is now seen as a means of lowering costs of production and reducing the pollution caused by accumulation of these materials in the environment.

The accumulation of livestock excreta, chiefly from poultry kept in deep litter, was seen as an opportunity to recycle this material as a feed for ruminant livestock (Muller 1980), and there were even attempts to do likewise with the excreta from intensively-fed pigs (Buitrago J, personal communication) and cattle (Anthony1971). However, in all these cases the nutritional value of the manure was mainly a reflection of the spillage of feed which is almost inevitable when intensive systems of self-feeding are practiced. The high risk of disease from recycling wastes through livestock, highlighted by the recent outbreaks of BSE, is now seen as a major deterrent to these practices.

The process of fermentation in biodigesters results in transformation of organically bound carbon into gaseous carbon dioxide and methane. The anaerobic environment and extended retention time also inhibit the growth of most pathogenic organisms and prevent the survival of intestinal parasites. It is therefore to be expected that both the chemical and biological parameters of livestock excreta will be improved by passage through biodigesters

Deciding on the location of the biodigester and excavating the soil to make the trench

The first step in installing the biodigester is to identify the most appropriate location. In general this
should be close to the source of the livestock pen where the waste is produced. It is a distinct advantage if the washings from the pen pass by gravity directly to the inlet of the biodigester. It is relatively easy to transport the gas by pipeline but difficult and tedious to do this with liquid wastes.

Once the site is selected the next step is to determine the size of the biodigester. As a general rule the excreta produced by 10 fattening pigs will require a biodigester of 4 m³ liquid capacity. The standard diameters of polyethylene tubular film are 80, 125 and 200 cm. For a small number of animals, it is advisable to use a diameter of 80 cm which gives a cross-section area of

$$0.4 \times 0.4 \times \pi = 0.50 \text{m}^2$$

On average 80% of the total volume in the tube corresponds to the liquid fraction, thus to provide a liquid volume of 4 m³ will require a biodigester with a length of:

$$\frac{4}{0.80/0.5} = 10 \text{m}$$

The recommended dimensions of the trench which will hold a biodigester of the above dimensions are:

- Width at the top 90 cm; depth 90 cm; width at the bottom 70 cm; length 10 m.

Having decided on the size of the biodigester the upper extremities of the trench should be defined by a string attached to four posts.

When digging the trench it is important to observe the following:

- The sides and the floor should be smooth with no protruding stones or roots which could damage the plastic film
- The floor should have a slope of about 2.5% from the inlet to the exit (this would be 25 cm for a biodigester of 10 m length)
- The soil that is excavated should be moved away from the edges of the trench so that movement around the biodigester during or after installation, or subsequent heavy rains, do not cause soil to fall onto the plastic

![Photo 5. Excavating the soil](http://www.fao.org/WAICENT/FAOINFO/AGRICULT/AGA/AGAP...)

### Preparing the plastic tube

The polyethylene comes from the factory in rolls which weigh about 50 kg. If the diameter is 80 cm then the length of the roll will be about 100 m (the weight of 1 m is about 0.5 kg). The rolls should be protected, especially the edges, and should be stored and manipulated in a horizontal position. Putting a steel rod (or bamboo pole) through the centre of the roll facilitates the extraction of the required length of tube. If the biodigester trench is 10 m long then an additional 75 cm should be added to each end of the plastic tube to allow for wrapping the ends over the inlet pipes. Thus the
length to be cut will be 11.5m.

Two lengths are required as one will be put inside the other to give added strength. When the second length of tube is inserted inside the first length, care should be taken to ensure that the two films fit snugly together and there are no folds or creases.

**Photo 6.** Putting a steel rod (or bamboo pole) through the centre of the roll facilitates the extraction of the required length of tube

**Photo 7.** Cutting the second piece of plastic

**Photo 8.** Bundling one plastic tube in preparation for putting it inside the other

**Photo 9.** Starting to put one plastic tube inside the other to give added strength

**Photo 10.** Putting one plastic inside the other to give added strength

**Materials required for the biodigester**

- Transparent polyethylene tubular film, the diameter of which varies according to the capacities
of the machines installed in the factories, but is usually in the range of 80 to 200cm (equivalent to a circumference of 2.5 to 6.3m). The calibre (thickness) should be in the range of 800 to 1,000 (200 to 250 microns). The length of the tube is determined by the size of the biodigester. The most appropriate material is that which is used for greenhouses as this usually contains an ultraviolet (UV) filter which helps to prolong the life of the plastic when fully exposed to the sun (see Photo 69).

- 2 ceramic tubes of 75 to 100cm length and 15cm internal diameter.
- Plastic (PVC) hosepipe of 12.5mm internal diameter (the length depends on the distance to the kitchen).
- 2 PVC adapters (male and female) of 12.5mm internal diameter.
- 2 rubber washers (from car inner tube) of 7cm diameter and 1mm thickness with a 12.5 mm diameter central hole.
- 2 rigid plastic (perspex) washers of 10 cm diameter and a central hole of 12.5mm. Although perspex is best, these washers can be cut from different sources such as old plastic buckets and other materials made from strong plastic.
- 2 m of PVC pipe of 12.5mm internal diameter.
- 4 used inner tubes (from bicycle, motor cycle or motor car) cut into bands 5 cm wide.
- 1 transparent plastic bottle.
- 1 PVC elbow of 12.5mm internal diameter.
- 3 PVC "T" pieces of 12.5mm internal diameter.
- 1 tube of PVC cement.

**Photo 11.** Materials for installing a plastic biodigester

**Fixing the gas outlet**

The components of the gas outlet and the order in which they are placed in the plastic tube are indicated below
The first step is to mark the place where the gas outlet will be placed. This should be 1.5m from the end of the plastic tube and in the centre of what will the top of the biodigester.

The size of the hole is determined by the external diameter of the PVC male adapter.

The rubber washer circles are cut from a length of "used" motor cycle or car inner tube, using the plastic (Perspex) circles as a guide.

The components are then assembled to ensure the male and female adapters fit together smoothly.

The male adapter, complete with plastic circle and above this the rubber circle, is inserted from within the plastic tube. The female adapter, with the rubber and plastic circles attached, is screwed tightly on the protruding male adapter.

The installation of the gas outlet is now complete.
Rubber bands 5cm wide are cut from "used" inner tubes (from bicycle, motor cycle or motor car). A polypropylene sack (or one of similar material) is placed on the ground below the work area to avoid damage to the plastic tube.

The ceramic pipe is inserted to one half of its length in the interior of the plastic tube and the plastic tube is folded around it. The join is secured by wrapping the rubber bands around the pipe beginning 25 cm from the edge of the plastic and working towards the exposed part of the ceramic pipe, each band overlapping the previous one, and finishing on the ceramic pipe so that the edges of the plastic tube are completely covered.
Photo 18. Placing the pipe  

Photo 19. Starting to fold up the plastic in the middle

Photo 20. Finishing one side

Photo 21. Ready to tie

Photo 22. Cutting the rubber bands

Photo 23. Wrapping the rubber bands around plastic tube where it overlaps the pipe

Photo 24. Completing the wrapping of the plastic over the inlet pipe

Filling the plastic tube with air

The inlet tube is closed with a square of plastic film (or a plastic bag) and a rubber band.
The exit of the female adapter is closed with a small square of plastic film and a rubber band.

The polyethylene tube is filled with air before being located in the trench. From the open end, air is forced into the tube in waves formed by flapping the end of the tube in a forward propelling movement of the arms. The tube is then tied with a rubber band about 3m from the end so that the air does not escape. This is to facilitate fitting the exit ceramic tube which is put in place using the same procedure as for the inlet pipe.

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**Photo 25.** Covering the entrance of the inlet pipe with a plastic bag

**Photo 26.** Covering the gas outlet with a plastic bag

**Photo 27.** Holding the plastic

**Photo 28.** Pumping air

**Photo 29.** Pumping air until the tube is full

**Photo 30.** Tying the tube but leaving enough plastic to insert the outlet pipe

---

**Final stages in preparing the plastic tube**

The second ceramic pipe is fitted to the exit of the plastic tube using the same procedure as for the inlet.

It is very important that the edges of the plastic are completely covered by the rubber bands which are applied each overlapping the previous one, and ending on the ceramic tube. When the ceramic
tube is fixed a square of plastic sheet, held in place with rubber bands, is used to seal the tube. The restraining rubber band, previously attached to prevent escape of air when the exit ceramic tube was inserted, is now removed. The bag will appear to deflate a little as air enters the final section previously closed by the rubber band. The final step in completely filling the bag with air is done by attaching a length (4m) of plastic tube (same material as used for the biodigester) to the ceramic exit pipe, filling this with air by the flapping procedure, and then removing the plastic sheet to allow this air to enter the main bag. The process can be repeated until the biodigester bag is completely full with air. The square of plastic, held in place with a rubber band, is again put in place to seal the exit pipe.

The inflated tube is then carried to the trench taking care that it does not come in contact with any object which might puncture it.

It is lowered into the trench in such a way that the gas outlet is at the top of the tube.

A support is prepared to hold the gas exit line.

The gas line (13mm internal diameter PVC tube) is secured using PVC cement.

The bag is filled with water until the inlet and outlet pipes are sealed (covered with water) from the inside. The air inside the bag is now trapped in the upper part. Filling with water is suspended and the plastic bags over the exit and entry pipes can be removed.

Photo 31. Placing the outlet pipe (following the same procedure as for the inlet pipe)  
Photo 32. Attaching a plastic tube of 3 m length

Photo 33. Tying the 3 m length of plastic tube to the exit pipe  
Photo 34. Pumping air (look at the position of the hands)
Photo 35. Untying the plastic bag

Photo 36. Forcing the air from the 3m tube to the main tube

Photo 37. Forcing the air into the main tube until it is full

Photo 38. The biodigester is full of air

Photo 39. Carrying the biodigester

Photo 40. Placing the digester in the trench

Photo 41. Connecting the PVC pipe to the gas outlet

Photo 42. A support is prepared to hold the gas exit line
Photo 43. Connecting a plastic hose (or rigid PVC tube) to the PVC gas outlet  

Photo 44. Adding water when a pump is available

The water trap (gas escape valve)

A "T" is prepared from three pieces of PVC pipe, two short pieces and a longer one which will fit into a "used" plastic bottle.

A 3*3cm hole is cut in the upper part of the bottle, just below the neck, through which water will be added to form the gas seal.

Small holes are made either side of the neck to take a length of thin wire which will be used to attach the bottle to some support structure.

The PVC "T" is inserted in the bottle and water is added to a depth of 4-5 cm above the lower point of the "T"

Small holes are punched into the sides of the bottle at a point 2 cm above the lower end of the "T". This ensures that if the gas pressure inside the system exceeds 2cm water column the gas can escape to relieve the pressure.

The "water trap" is now suspended in a convenient place so that the water level can be easily observed and replenished when necessary

A flexible plastic pipe is attached to the gas outlet and joined to one arm of the "T". The other arm links with another plastic pipe which goes to the kitchen.

Photo 45. Materials to prepare the trap (PVC "T" and PVC pipe, old plastic bottle, knife and water)  

Photo 46. Cutting a hole to add the water
Photo 47. The PVC pipe is inserted into the bottle and a little hole is made to fix the water level

Photo 48. Connecting a plastic hose to the PVC pipe of the gas outlet

Photo 49. Suspending the water trap

Photo 50. Joining the other end of the PVC "T" to the plastic hose that goes to the reservoir bag

The gas reservoir

This is a large plastic bag (4m length) of the same polyethylene tube used for the biodigester.

One end is closed using rubber bands from "used" car or motor cycle inner tubes.

A "T" made from rigid PVC pipe is fitted at the other end.

The reservoir is then located in a convenient place (for example, suspended in the roof space of the pig pen) close to the kitchen.

The arms of the "T" are connected to the gas line; the inlet to the biodigester and the outlet to the stove in the kitchen.

Photo 51. Closing one end of the 3m plastic tube

Photo 52. Fastening the closed end of the plastic tube with a rubber band
Photo 53. One end of the tube is closed

Photo 54. Placing the PVC "T" at the other end of the 3m plastic tube (one of the end of the "T" is joined to the hose coming from the digester and the other to the stove)

Photo 55. Tying with rubber band

Photo 56. Finishing wrapping the rubber band to ensure the connection is gas-tight

Photo 57. The finished reservoir bag

Photo 58. Suspending the reservoir bag in the roof space

Photo 59. The reservoir bag full of biogas

Taking the gas to the kitchen
With the reservoir in place, the gas line attached to the outlet arm of the "T" is fixed to the burners.

A strap is placed around the middle section of the reservoir. By pulling on the strap, and tying it to some fixed object or hanging a heavy stone or a brick, the pressure of the gas delivered to the burners can be increased. This is usually necessary when cooking proceeds over an extended period of time.

The time that elapses before gas is produced depends on the composition and quantity of the manure that is put into the biodigester. In certain farm households the washings from the pig pens may already be in an advanced state of fermentation when they are introduced into the biodigester. The farm family would thus be able to begin cooking with biogas only 5 days after the installation. With fresh unfermented manure the time lag is between 21 and 28 days.

**Photo 60.** Connecting the reservoir bag to the stove in the kitchen

**Photo 61.** Cooking with biogas

**Photo 62.** A string around the bag is used to increase the pressure

**Photo 63.** It is the women who benefit most from the installation of a biodigester

**Linking the waste outlets of the pig pens with the biodigester**

Channels are made with bricks and cement to link the waste outlets from the pig pens with the inlet of the biodigester.
Photo 64. A channel is made with bricks to lead the waste from the pig pen to the inlet of the biodigester

Photo 65. The channel is connected to the biodigester

The completed installation of the channels

With the channels in place the washing of the pens automatically forces the slurry into the biodigester

Photo 66. Channel completed

Photo 67. The finished installation

Protecting the digester

Photo 68. Fencing around the area where the biodigester is located

Photo 69. Roofing can protect the biodigester

The completed biodigester
What was once a polluted area is now dry soil.

There are no bad odours as twice daily the pig excreta is washed directly into the biodigester.

The farm family no longer need to buy liquid gas for cooking. The savings will help the cost of the biodigester in less than 12 months

![Photo 70. Before placing the biodigester](image1)

![Photo 71. After placing the biodigester](image2)

![Photo 72. Before placing the biodigester](image3)

![Photo 73. After placing the biodigester](image4)

![Photo 74. The complete system](image5)

**What to do if one day there is not gas to cook?**

The biodigester needs maintenance. It has to be fed every day with manure and water. But if one day there is not enough gas to cook, you should check:

<table>
<thead>
<tr>
<th>Check</th>
<th>No</th>
<th>Yes</th>
<th>Cause</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Are there enough animals to supply manure for the digester</td>
<td>X</td>
<td></td>
<td>The animals were sold</td>
<td>Join the toilet to your biodigester, the whole family can contribute to the gas production.</td>
</tr>
<tr>
<td>Question</td>
<td>Answer</td>
<td>Description</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is it the water enough for the biodigester?</td>
<td>X</td>
<td>Add water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is there a smell of gas?</td>
<td>X</td>
<td>A loose connection. A damaged tap in the kitchen. A hole in the plastic.</td>
<td>Check all the connections, starting with the taps in the kitchen up to the gas outlet from the biodigester. Repair with sticking plaster or tape.</td>
<td></td>
</tr>
<tr>
<td>Not enough gas is produced</td>
<td>X</td>
<td>A loose connection, a broken section of pipe or a pipe doubled over impeding the gas flow?</td>
<td>Cut a new piece of hose pipe to replace the damaged one.</td>
<td></td>
</tr>
<tr>
<td>Is there enough water in the trap bottle?</td>
<td>X</td>
<td>Evaporation caused the water level to fall below the tip of the gas tube.</td>
<td>Check it periodically and add water</td>
<td></td>
</tr>
<tr>
<td>Can you see a lot of gas in the biodigester but nothing or very little in the reservoir bag?</td>
<td>X</td>
<td>Water on the pipe gas line.</td>
<td>Check it frequently. There are two ways to solve the problem: 1. Open the joins and take out the water as it can be accumulated. 2. Make a hole in the PVC pipe, take the water out and stick it again with tape 3. Fit drain taps at the lowest points in the line.</td>
<td></td>
</tr>
<tr>
<td>Do you want to cook faster?</td>
<td>X</td>
<td>Not enough pressure inside the reservoir.</td>
<td>Tighten the string around the reservoir.</td>
<td></td>
</tr>
<tr>
<td>In the morning you find the reservoir bag with little gas?</td>
<td>X</td>
<td>You forgot to loosen the string around the reservoir after finishing cooking the night before.</td>
<td>Place the reservoir bag in the ceiling of the kitchen or in a place close by to facilitate the control of it. Check the reservoir bag after finishing the activities in the kitchen.</td>
<td></td>
</tr>
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<td></td>
<td></td>
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<td>---</td>
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<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>The biodigester has a hole through both layers?</td>
<td>X</td>
<td>An animal fell down</td>
<td></td>
</tr>
<tr>
<td></td>
<td>If the hole is not large it can be sealed by inserting another male and female adapter with washers big enough to cover the hole, and sealing the exit of the adapter. If the hole is large, replace the plastic tubes and reinstall the system. Protect the digester with a fence</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Can you see that the first layer of plastic is broken?</td>
<td>X</td>
<td>Crystallization of the plastic that does not have contact with water</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Try to set the digester in such was that most of the plastic surface is in contact with the water. It means that the inlet and outlet pipes are high enough to keep the bag almost full but of course leaving enough space for the gas to flow to the gas outlet. The solution is NOT to put 3 or 4 layers of plastic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Is there a lot of soil in the trench of the biodigester?</td>
<td>X</td>
<td>Usually it is more serious problem. It can happen when the biodigester is placed on very sandy soil or on low land so that the rain washes a lot of soil into the trench.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Avoid this by choosing a good place to set the digester. Make channels to lead away the rain water. Cover the upper walls of the trench with bricks or with a mixture of cement and soil. Make a wall in front of the biodigester inlet.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Is the slurry inside the biodigester very hard?</td>
<td>X</td>
<td>It can be caused by # 11 or by too high a content of manure in the input slurry. It is more of a problem when cattle manure is used. Experience with the plastic biodigesters indicates that the plastic has to be changed after about 2 to 4 years mainly because of this problem.</td>
<td></td>
</tr>
</tbody>
</table>
Photo 75. In Cambodia the latrine is always linked to the plastic biodigester.

Photo 76. Hose pipe bent down (#4) Cut the damaged hose and join it again.

Photo 77. Adding water to the trap (#5).

Photo 78. Accumulation of water. Open the joins and take out the water as it can be accumulated (#6-1).
Photo 79. Make a hole in the PVC pipe, take the water out and stick it again with tape or a rubber band (# 6-2)

Photo 80. Increasing the pressure in the reservoir bag. (# 7)

Photo 81. The outer plastic layer damaged (after 3 years...!). The inner one is still gas-tight.

Replacing the digester

Photo 82. Cutting the plastic to take out the contents

Photo 83. Hard layer of manure due to accumulation of soil in the trench and time (3 years). The plastic was in good condition
After removing all the content of the digester, pulling the plastic to one side of the trench, taking out the gas outlet to be reused, taking out the rubber bands and inlet and outlet pipes to be reused, and starting to fix the trench. And try to fix the previous mistakes.
**Uses of biogas in different systems**

At the family level the main use of the biogas is for cooking (#93-94). Because of the low pressure (less than 3 cm water column) it is not possible to use the gas for lighting.

In the ecological farm of UTA (many animals and ten biodigesters) there is enough biogas to supply the laboratory (#95-96).

The "Pozo Verde" farm in Jamundi, Cauca Valley, Colombia, there are 100 sows (1,000 pigs in total), 100 Crossbred (Holstein*Zebu) cattle and 20 buffaloes. The two biodigesters each have a liquid volume of 100 m³ (#97). There is enough gas to power a diesel generator in dual mode (#98) and to heat 20 "creep" areas of the piglets. The heater for the piglets is an inverted plough disc with a "U" tube underneath where the gas is burned (#99).
Photo 93. Reservoir bag placed vertically in the kitchen in Cambodia

Photo 94. In the small-holder farm the gas is enough to cook for the whole family and when there is a large population of livestock it will be enough to cook for the pigs also (Vietnamese tradition)

Photo 95. Reservoir bags storing biogas in the the laboratory of UTA

Photo 96. Using the biogas to digest samples for Nitrogen analysis

Photo 97. The use of plastic biodigesters to recycle the manure from a unit with 100 sows (1000 pigs in total) in Pozo Verde farm, Jamundi, Colombia

Photo 98. A large reservoir bag provides biogas for a diesel generator in the integrated farm of Pozo Verde, Colombia

Photo 99. The use of biogas to heat the piglets in Pozo Verde farm, Jamundi, Colombia

Photos by Lylian Rodríguez

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Follow the links

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The products of the biodigester

Using the effluent from the biodigester

Moving the effluent from the biodigester

Using a pump to manage the effluent

The duckweed ponds

Inoculating the pond with duckweed

Harvesting duckweed

Duckweed as a feed for chickens

Duckweed as a feed for "local" pigs

Related information

Introduction

The two products from the anaerobic biodigestion of livestock wastes are:

- Biogas which is rich in methane (55-65%) and used mainly for cooking
- Effluent which is the residue coming out of the biodigester and which contains all the plant nutrients present in the original manure

This section of the manual deals with the utilization of the effluent as a fertilizer for crop plants. Since the effluent is voluminous (about 98% water) it is an advantage if it is used as
close as possible to the site of production. For this purpose it is necessary to select crop plants which have a rapid growth rate (and therefore high capacity to extract nutrients from the medium in which they are growing) and good nutritive value.

For this purpose it has been found that duckweed (Lemnaceaea) is the most appropriate because it:

- Has a rapid rate of growth (doubles its biomass in 24 hours)
- Is palatable and has high digestibility for monogastric animals (dry matter digestibility over 65% in pigs according to Rodriguez and Preston 1996a)
- Its protein content is almost doubled (from 20-22% to 35-40%) when grown in nutrient-rich water (Leng et al 1995; Rodriguez and Preston 1996b; Nguyen Duc Anh et al 1997)

**The products of the biodigester**

These are:

- Biogas
- The effluent

The biogas flows by tube from the biodigester to the reservoir situated as close as possible to where it will be used, usually near the kitchen.

The effluent is produced daily in accordance with the schedule of charging the biodigester. The volume that comes out is equal to the volume that goes in. The residence time (time taken on average for the "digesta" to pass from the entrance to the exit) will vary usually within the range of 10 to 40 days depending on the **quantity of manure and water put into the biodigester**. The greater the input volume the shorter the residence time. It is desirable that the residence time is at least 20 days so as to secure inactivation of pathogenic organisms and parasites.

There should be a pit to receive the effluent large enough to hold at least the output of two days. Normally it is not necessary to line the pit as the floor and walls soon become impervious. If the topography permits a pipe should be laid to take the effluent from the receiving pit to the duckweed ponds.

**Photo 1. Methane for cooking**

**Photo 2. Effluent as source of nutrients**
Using the effluent from the biodigester

When manure and water enter the biodigester a similar volume of effluent is forced out of the exit pipe.

It is usually adequate to have an unlined pit as very quickly this becomes impervious to filtration.

A pipe from this pit then connects directly to ponds used to cultivate duckweed.

When duckweed is fertilized with biodigester effluent its crude protein content can be between 35 and 40% in the dry matter, making it a valuable supplement for pigs and poultry.

In order to maintain a nitrogen content in the pond water of about 20mg/litre, the volumes of effluent to be added can be calculated from the table below:

- At the beginning when the pond is prepared and filled with water the first time
- Every day (to compensate for the nitrogen removed in the duckweed assuming a daily harvest of 100 g/m² pond surface/day)

The calculations are based on a pond of 20m² area and 20 cm depth of water. For ponds with different dimensions the data should be adjusted accordingly.

<table>
<thead>
<tr>
<th>Effluent daily (litres)</th>
<th>0.5</th>
<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>area, m²m²</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>depth,m</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N in effluent DM (%)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>288</td>
<td>144</td>
<td>96</td>
<td>72</td>
<td>58</td>
<td>48</td>
</tr>
<tr>
<td>1</td>
<td>144</td>
<td>72</td>
<td>48</td>
<td>36</td>
<td>29</td>
<td>24</td>
</tr>
<tr>
<td>1.5</td>
<td>96</td>
<td>48</td>
<td>32</td>
<td>24</td>
<td>19</td>
<td>16</td>
</tr>
<tr>
<td>2</td>
<td>72</td>
<td>36</td>
<td>24</td>
<td>18</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>2.5</td>
<td>58</td>
<td>29</td>
<td>19</td>
<td>14</td>
<td>11</td>
<td>10</td>
</tr>
</tbody>
</table>
### Moving the effluent from the biodigester

The simplest way of moving the effluent is with buckets.

#### Photo 5. When manure and water enter the biodigester a similar volume of effluent is forced out of the exit pipe.

#### Photo 6. Taking the effluent with a bucket

#### Photo 7. Carrying the effluent to the duckweed ponds

#### Photo 8. Applying the effluent to the duckweed ponds

If the topography permits a more convenient method is to lay a pipe (5 cm id is enough)
connecting the effluent pit with the duckweed pond and in turn to have each duckweed pond connected in series to the next one.

![Photo 9](image1.jpg) ![Photo 10](image2.jpg)

**Photo 9.** A pipe linking the biodigester outlet with the ponds  
**Photo 10.** Pipe located between two ponds to allow the flow of the effluent

![Photo 11](image3.jpg)

**Photo 11.** Ponds linked in series

**Using a pump to manage the effluent**

In this example the duckweed ponds surrounding the biodigester are at a higher elevation than the outlet pit.

A 1/4 HP electric pump has the inlet pipe connected directly to the effluent pit and the outlet at the highest point of the slope. In a matter of minutes the effluent is pumped into the duckweed ponds.

![Photo 12](image4.jpg) ![Photo 13](image5.jpg)

**Photo 12.** The system: a pen with 24 hens, a pen with 4 pigs, a 6 m long biodigester and 6 duckweed ponds (each 6 m\(^2\)m), 3 ponds on each side of the biodigester and  
**Photo 13.** The pit full of effluent after washing the pen
cassava planted around the ponds and biodigester

Photo 14. A pump located next to the pit

Photo 15. Taking the cover off the pump

Photo 16. The pit holding the pump

Photo 17. The pump is located at a lower level than the effluent in the exit pit. This avoids the need to "prime" the pump

Photo 18. PVC pipes in the form of a "T" link the pump to the ponds on two sides of the biodigester

Photo 19. The PVC pipe connected to the pond on the left side of the biodigester

Photo 20. The PVC pipe connected to the pond on the right side of the biodigester
The duckweed ponds

If water is not a limiting resource the most appropriate way of using the effluent from the biodigester is for the cultivation of duckweed (Lemnaceae).

Where there is a high clay content in the soil the floor and wall of the pond soon become impervious to filtration of water. But in sandy soil it is necessary to line the ponds with a mixture of soil and cement. For a pond 40cm deep and with an area of 20 m², the required overall quantities are 25 kg of cement and 300 kg of soil.

Smaller mixes of 30 kg soil, 2.5 kg cement and 1.5 kg water are prepared and a thin layer of the mixture is applied to the floor of the ponds and to the walls.

After two days the ponds can be filled with water and seeded with duckweed

Inoculating the pond with duckweed

The duckweed pond is connected by a pipe with the exit of the biodigester.

The inoculum of duckweed is prepared and distributed on the pond surface at the rate of 400 g/m².
Harvesting duckweed

Each pond is harvested daily. It is a simple operation requiring a bamboo pole slightly shorter than the width of the pond and a plastic basket.

Beginning at the mid-point of the pond the duckweed is pushed steadily to the narrow end of the pond and then scooped out of the water with the basket. It is left to drain for few minutes before being weighed and taken to the animals.

These ponds are producing about 100 g fresh duckweed/m²/day which is equivalent to about 6 tonnes protein/ha/year.
Duckweed has a balance of essential amino acids slightly superior to soya bean meal (Rusoff et al 1980).

Rice bran and cassava root meal are dry, powdery materials. Duckweed by contrast is very wet (94-96% moisture...!!). Mixing fresh duckweed with either rice bran or cassava root meal, or with a combination of the two, produces a feed with a crumbly texture that is more readily accepted by chickens than any one of the ingredients given separately.

Proposed combinations (all on fresh basis) that will give at least 10% protein in dry matter (suitable for growing and laying chickens) are:

- one part rice bran; one part duckweed
- four parts duckweed: one part cassava root meal
- two parts duckweed: one part cassava root meal: one part rice bran
Duckweed as a feed for "local" pigs

The same principles apply as for chickens and the same mixtures of duckweed with cassava root meal and rice bran can be used.

Photo 36. Harvesting duckweed every day

Photo 37. Mixing duckweed with rice bran

Photo 38. The hens prefer the mixture rather than each feed given in separate containers

Photo 39. Fresh duckweed to supplement the diet of scavenging hens

Photo 40. Duckweed as protein supplement for chicks

Photo 41. Rice bran

Photo 42. Fresh duckweed
Photo 43. Mixing fresh duckweed with rice bran

Photo 44. Feeding the mixture to a pregnant Mong Cai sow

Photo 45. Fresh duckweed as a source of protein for Mong cai sows

**Duckweed also an alternative for landless farmers**

Photo 46. Small biodigester (3 m long) linked to the toilet and a pig pen (2 pigs) and connected to a duckweed pond

The pond has an area of 16 m² and the average daily yield over 3 months of observations was 91 g/m² (Figure 1), equivalent to 1.5 kg fresh duckweed daily. This is sufficient to provide the supplementary protein for 15 chickens.
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Productive use of livestock wastes; use of goat manure for earthworm production and fertilization of cassava

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Follow the links

Goats in the farming system

How to use the goat manure in the farming system?

Housing system

Earthworms

Goat manure as fertilizer for "forage" cassava

Cassava leaves as feed for poultry and goats

References

Goats in the farming system

Goats are often considered to be "enemies of the environment" as under free grazing systems they can rapidly destroy the vegetation. Some form of confinement, which can be combined with "supervised" grazing in the forest or on waste "scrub-infested" land, is a necessary prerequisite if the goats are to be part of a "sustainable" farming system.
How to use the goat manure in the farming system?

Housing system

Correct housing for goats implies a raised 'slatted' floor so they have always a dry 'bed'. Goats do not like a damp environment. The raised floor facilitates the recovery of the manure as can be seen in Photo 4.

Earthworms

When all livestock (especially pigs and poultry) are confined, the earthworms can be raised in heaps of manure on the surface of the ground (Rodriguez 1997). At family level, where scavenging chickens are the norm, the beds must be protected. A hole in the ground about 1*1 m area and 30 cm deep is one alternative. Once the manure and earthworms are introduced the hole is covered to keep out the chickens. When the process is completed the cover is removed so that the chickens themselves "harvest" the worms.

Photo 1. Goats are an important component of integrated farming systems

Photo 2. The housing system for goats makes it easy to collect the manure

Photo 3. Manure is one of the principal products of goat production

Photo 4. Digging the hole

Photo 5. A depth of 30 cm is appropriate
Photo 6. The hole ready

Photo 7. Placing a wooden frame (farmers can use whatever they have available, even the same mixture used for the duckweed ponds)

Photo 8. Collecting the manure from underneath the goat pen

Photo 9. Carrying the manure to the worm bed

Photo 10. Placing the manure in the bed

Photo 11. Leveling the manure
Photo 12. Inoculating with a mixture of humus and worms

Photo 13. The inoculum (normally 1 kg of worms +humus/m²)

Photo 14. Distributing the inoculum throughout the manure

Photo 15. The cover can be made from wood (as in this case) but other available resources can be used

Photo 16. The cover is necessary to protect the worms from the scavenging chickens and ducks and birds

Photo 17. It is very important to water the worms every day

Photo 18. The worms are already processing the goat manure

Photo 19. Humus and worms are the products from manure recycled through earthworms

Goat manure as fertilizer for "forage" cassava

Goat manure is a convenient "organic" fertilizer for highly productive crops such as cassava. In this case the cassava is grown as a perennial plant for production of foliage. The roots are not harvested. With applications of goat manure of 2 kg/m² (20 tonnes/ha) after each harvest, at intervals of 60-70 days, the annual yields of foliage are between 60 and 70 tonnes/ha equivalent to 3 - 4 tonnes of protein.

Cassava leaves as feed for poultry and goats
The cyanogenic glucosides in the leaves of cassava, which on ingestion give rise to toxic hydrocyanic acid (Tewe 1991), protect the plant against most predators. When the leaves are destined for use as a protein supplement for pigs and chickens the HCN can be neutralised by ensiling, a process which converts it to the non-toxic thiocyanate. The same occurs in the animal (goat) rumen and provided the rumen is fully functional (usually after 6-8 weeks of age), and the cassava leaves are introduced gradually into the diet, there need be no fear of toxicity. On the contrary, cassava foliage has been shown to be a complete substitute for soya bean meal in cattle fattened with molasses-urea (Ffoulkes and Preston 1978).

**Photo 20.** Collecting the goat manure to fertilize the cassava

**Photo 21.** Fresh goat manure to fertilize cassava

**Photo 22.** With frequent application of goat manure (20 tonnes/ha/harvest), cassava foliage can be harvested at 50-60 day intervals, producing 3-4 tonnes protein/ha/year

**Photo 23.** Separating cassava leaves from the stems. The leaves are chopped and ensiled for pigs and the stems (or the complete foliage) are fed to the goats.
Photo 24. Cassava foliage in the feed troughs of the goats

Photo 25. Stems and petioles are eaten with equal relish by this mature goat

Photo 26. Provided the kids have a functional rumen (usually by 6-8 weeks of age) they can also be fed fresh cassava foliage

Photo 27. The kids also enjoy the cassava foliage

Photos by Lylian Rodriguez

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