3. The Agricultural Setting

3.1 Natural Parameters for Biogas Plants of Simple Design

Climate zones

A minimum temperature of 15 °C is required for anaerobic fermentation of organic material (cf. chapter 5.1). Since simple biogas plants are unheated, they can only be used in climatic zones in which the minimum temperature is not fallen short of for any substantial length of time. In general, this is true of the area located between the two tropics, i.e. in the geographic region referred to as the "Tropics".

In the climatic sense, however, the Tropics are inhomogeneous, containing various climatic zones with their own typical forms of vegetation and agricultural practices. Proceeding on that basis, it may be said that a particular zone does or does not qualify as a "biogas zone" (cf. table 3.1).

With the exception of subtropical arid regions (deserts and semideserts), all tropical climates are characterized by:

– increasingly small diurnal and seasonal temperature variation in the direction of the equator,

– decreasing annual rainfall and number of humid months with increasing distance from the equator.

This basic zonal breakdown, though, is altered in several ways by other climatic factors such as wind, elevation and ocean currents. Consequently, the climatic zones serve only as a basis for rough orientation with regard to the climatic evaluation of potential sites for biogas plants. The locally

Fig. 3.1: Global 15 °C isotherms for January and July, indicating the biogas-conducive temperature zone (Source: OEKOTOP)

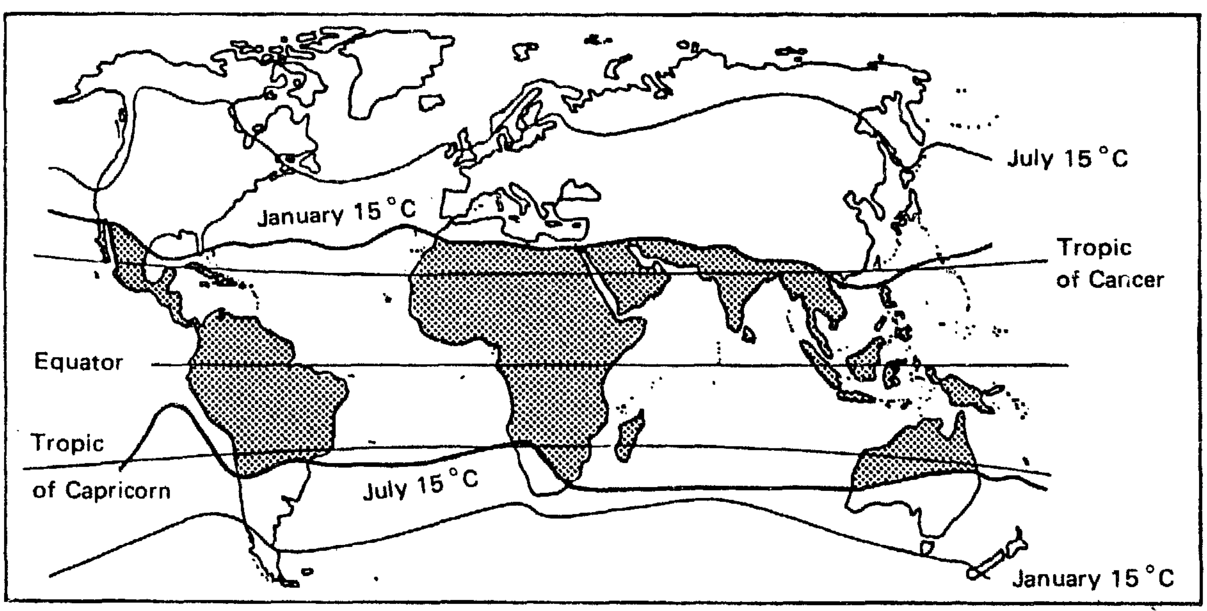


Table 3.1: Climatic zones and their suitability for biogas plants (Source: OEKOTOP)

Climatic zone	Factors of relevance for biogas generation	As biogas zone:
Tropical rain forest	Annual rainfall > 1500 mm; temperature fairly constant at 25–28 °C; little animal husbandry due to various diseases, i.e. scarcity of dung; vegetable waste from permacultures and gardening	unfavorable
Wet savanna	Water usually available all year (rainfall: 800–1500 mm), livestock farming on the increase, integral farms (crop farming + livestock)	favorable
Dry savanna	Short rainy season, long dry season; most livestock pastured, but some integral farming	possible
Thornbush steppe	Short rainy season (rainfall: 200-400 mm) extensive-type pasturing (nomads, cattle farmers), dung uncollectable; shortage of water	unsuitable
Dry hot desert	– – –	unsuitable

prevailing climatic conditions are decisive and must be ascertained on the spot.

Soil conditions

Since the digesters of simple biogas plants are situated underground, the temperature of the soil is of decisive importance. It depends on the surface structure, the type of soil and the water content. The soil temperature usually varies less than the air temperature, e.g. tropical soils show nearly constant temperature at a depth of 30–60 cm. Due to lower absorption, the temperature amplitude of light soils is smaller than of dark soils. Since moist soil appears darker than dry soil, the same applies with regard to temperature amplitude. As a rule of thumb, the region's mean annual temperature may be taken as the soil temperature in tropical areas.

For biogas plants with unlined digesters and/or underground masonry, it is important to know the stability of the soil structure. The stability of a given soil increases along with the bedding density. Natural soils are generally stable enough for biogas plants. Caution is called for, however, in the case of alluvial and wet, silty soils. Most of the laterite soil prevailing in the tropics shows high structural stability and is therefore quite suitable for biogas plants with unlined digesters. Unlined earth pits usually become more or less impermeable within a short time, but preparatory seepage trials should be conducted in exploratory holes, just to make sure. Previous experience has shown that seepage can drop to below 5% of the initial rate within a week. In the case of large-scale biogas plants, it is always advisable to have an expert check the soil stability.

Biogas plants should never be located in groundwater, areas subject to flooding, or near wells. On the other hand, an adequate supply of water must be available in the immediate vicinity of the biogas plant, because the substrate must be diluted. If the direction of groundwater flow is known, the biogas plant should be placed downstream of the well.

3.2 Suitable Types of Biomass and Their Characteristics

Practically any kind of watery organic substance is suitable for anaerobic digestion. The agricultural residues and waste materials that can be used as substrate for biogas plants consist chiefly of:

– waste from animal husbandry, e.g. dung, urine, fodder residue and manure,
– vegetable waste, e.g. straw, grass, garden residue, etc. (though such materials do not ferment well alone),
– household waste like night soil, garbage, wastewater, etc.

Solid and liquid agroindustrial waste materials, from slaughterhouses for example, and wastewater from sugar/starch processing are not gone into here, since small-scale biogas plants of simple design would not suffice in that connection (cf. chapter 6).

Waste from animal husbandry

Most simple biogas plants are "fueled" with manure (dung and urine), because such substrates usually ferment well and produce good biogas yields. Quantity and composition of manure are primarily dependent on:

– the amount of fodder eaten and its digestibility; on average, 40–80% of the organic content reappears as manure (cattle, for example, excrete approximately 1/3 of their fibrous fodder),
– quality of fodder utilization and the liveweight of the animals.

It is difficult to offer approximate excrement-yield values, because they are subject to wide variation. In the case of cattle, for example, the yield can amount to anywhere from 8 to 40 kg per head and day, depending on the strain in question and the housing intensity. Manure yields should therefore be either measured or calculated on a liveweight basis, since there is relatively good correlation between the two methods.

The quantities of manure listed in table 3.2 are only then fully available, if all of the animals are kept in stables all of the time and if the stables are designed for catching urine as well as dung (cf. chapter 3.3).
Thus, the stated values will be in need of correction in most cases. If cattle are only kept in night stables, only about 1/3 to 1/2 as much manure can be collected. For cattle stalls with litter, the total yields will include 2–3 kg litter per animal and day.

Table 3.2: Standard liveweight values of animal husbandry and average manure yields (dung and urine) as percentages of liveweight (Source: Kaltwasser 1980, Williamson and Payne 1980)

Species	Daily manure yield as % of liveweight		Fresh-manure solids[1]		Liveweight (kg)
	dung	*urine*	*TS* (%)	*VS* (%)	
Cattle	5	4–5	16	13	135–800
Buffalo	5	4–5	14	12	340–420
Pigs	2	3	16	12	30–75
Sheep/goats[2]	3	1–1.5	30	20	30–100
Chickens	4.5		25	17	1.5–2
Human	1	2	20	15	50–80

[1] The TS-content of urine is approx. 5% for all species
[2] Males are up to twice as heavy as females

Table 3.3: TS and VS-contents of green plants (Source: Memento de l'agronome 1984)

Material	TS (%)	VS (% of TS)
Rice straw	89	93
Wheat straw	82	94
Corn straw	80	91
Fresh grass	24	89
Water hyacinth	7	75
Bagasse	65	78
Vegetable residue	12	86

Vegetable waste

Crop residue and related waste such as straw, cornstalks, sugar-beet leaves, etc. are often used as fodder and sometimes processed into new products, e.g. straw mats. Consequently, only such agricultural "waste" that is not intended for some other use or for composting should be considered.

Most green plants are well-suited for anaerobic fermentation. Their gas yields are high, usually above that of manure (cf. table 3.5). Wood and woody parts of plants resist anaerobic fermentation and should therefore not be used in biogas plants. Due to the poor flow properties of plant material and its tendency to form floating scum, it can only be used alone in a batch-type plant. In practice, however, batch plants are unpopular because of the need for intermittent charging and emptying.

In continuous-type family-size biogas plants, crop residue therefore should only be used

Table 3.4: Digestion characteristics of animal-husbandry residues (Source: OEKOTOP)

Substrate	Scum formation/ sedimentation		Digestion	Recommended retention time[5] (days)	Gas yield compared to cattle manure
Cattle manure	none[1]	none	very stable	60– 80	100%
ditto, plus 10% straw	heavy	slight	very stable	60–100	120%
Pig manure	slight to heavy[2]	heavy to slight[2]	Danger of "tilting", i.e. acidification, at the beginning; slow run-up with cattle manure necessary	40– 60	200%
ditto, plus 10% straw	heavy	slight	ditto	60– 80	...
Chicken manure[3]	slight to heavy[4]	heavy	Slow run-up with cattle manure advisable; danger of "tilting"	80	200%
Sheep/goat manure manure	medium to heavy	none	stable	80–100	80%

[1] Dry manure and manure from cattle fed with fiber-rich fodder tends more toward scum formation.
[2] Heavily dependent on type of fodder used.
[3] Very little empirical data available.
[4] Pronounced scum formation, if feathers get into the digester.
[5] Practical experience shows that prolonged retention (up to 100 days) can preclude scum formation and sedimentation.

as an addition to animal excrements. Any fibrous material like straw has to be chopped up to 2–6 cm – and even that does not fully preclude scum formation.

Digestion characteristics and gas yields

As long as the total solids content of the substrate does not substantially exceed 10%, simple biogas plants can be expected to operate smoothly on a mixture of animal excrements and plant material (straw, fodder waste).

Manure from ruminants, particularly cattle, is very useful for starting the fermentation process, because it already contains the necessary methanogenic bacteria. On the other hand, the gas yield from cattle dung is lower than that obtained from chickens or pigs, since cattle draw a higher percentage of nutrients out of the fodder, and the leftover lignin complexes from high-fiber fodder are very resistant to anaerobic fermentation. Urine, with its low organic content, contributes little to the ultimate gas yield but substantially improves the fertilizing effect of the digested slurry and serves in diluting the substrate.

Table 3.5: Mean gas yields from various types of agricultural biomass (Source: OEKOTOP, compiled from various sources)

Substrate	Gas-yield range (1/kg VS[1])	Average gas yield (1/kg VS[1])
Pig manure	340–550	450
Cow manure	150–350	250
Poultry manure	310–620	460
Horse manure	200–350	250
Sheep manure	100–310	200
Stable manure	175–320	225
Grain straw	180–320	250
Corn straw	350–480	410
Rice straw	170–280	220
Grass	280–550	410
Elephant grass	330–560	445
Bagasse	140–190	160
Vegetable residue	300–400	350
Water hyacinth	300–350	325
Algae	380–550	460
Sewage sludge	310–640	450

[1] Fed volatile-solids

Table 3.6: C/N-ratios of varios substrates (Source: Barnett 1978)

Substrate	C/N
Urine	0.8
Cattle dung	10–20
Pig dung	9–13
Chicken manure	5–8
Sheep/goat dung	30
Human excrements	8
Grain straw	80–140
Corn straw	30–65
Fresh grass	12
Water hyacinth	20–30
Vegetable residue	35

The carbon(C)/nitrogen(N)-ratio of animal and human excrements is normally favorable for the purposes of anaerobic fermentation (9–25:1), while that of plant material usually indicates an excessive carbon content.

In many cases, various substrates should be mixed together in order to ensure a favorable gas yield while stabilizing the fermentation process and promoting gas production. The following formulae can be used to calculate the C/N-ratio and total-solids content of a given mixture:

$$MC/N = \frac{(C/N1 \times W1) + (C/N2 \times W2) + \ldots + (C/Nn \times Wn)}{W1 + W2 \times \ldots + Wn}$$

$$MTS = \frac{(TS1 \times W1) + (TS2 \times W2) + \ldots + (TSn \times Wn)}{W1 + W2 + \ldots + Wn}$$

MC/N = C/N-ratio of mixed substrate,
MTS = TS-content of mixed substrate,
C/N = C/N-ratio of individual substrate,
W = weight of individual substrate,
TS = TS-content of fresh material.

3.3 Agricultural/Operational Prerequisites and Stock-farming Requirements

In order to fulfill the prerequisites for successful installation and operation of a biogas plant, the small farm in question must meet three basic requirements regarding its agricultural production system:

– availability of sufficient biomass near the biogas plant,
– use for digested slurry as fertilizer,
– practical use(s) for the biogas yield.

Farms marked by a good balance between animal husbandry and crop farming offer good prerequisites for a biogas tie-in. Unfortunately, however, such farms are rare in tropical countries. In numerous Third World countries, animal husbandry and stock farming are kept separate by tradition.

As the world population continues to grow, and arable land becomes increasingly scarce as a result, the available acreage must be used more intensively. In wet savannas, for example, the fallow periods are being shortened, even though they are important for maintaining soil fertility. In order to effectively counter extractive agriculture, animal husbandry must be integrated into the crop farming system, not least for its fertilizing effect. On the other hand, systematic manuring is only possible as long as collectible dung is allowed to accumulate via part-time or full-time stabling.

The installation of a biogas plant can be regarded as worthwhile, if at least 20–40 kg manure per day is available as substrate. This requires keeping at least 3–5 head of cattle, 8–12 pigs or 16–20 sheep/goats in a round-the-clock stabling arrangement. The achievable gas yield suffices as cooking fuel for a family of 4–6 persons. That, in turn, means that the farm must be at least about 3 hectares in size, unless either freely accessible pastures are available or extra fodder is procured. Crop residue like rice straw, sorghum straw, cornstalks, banana stalks, etc. should be chopped up, partially com-

Fig. 3.2: Integration of a biogas plant into the agricultural production cycle (Source: OEKOTOP)

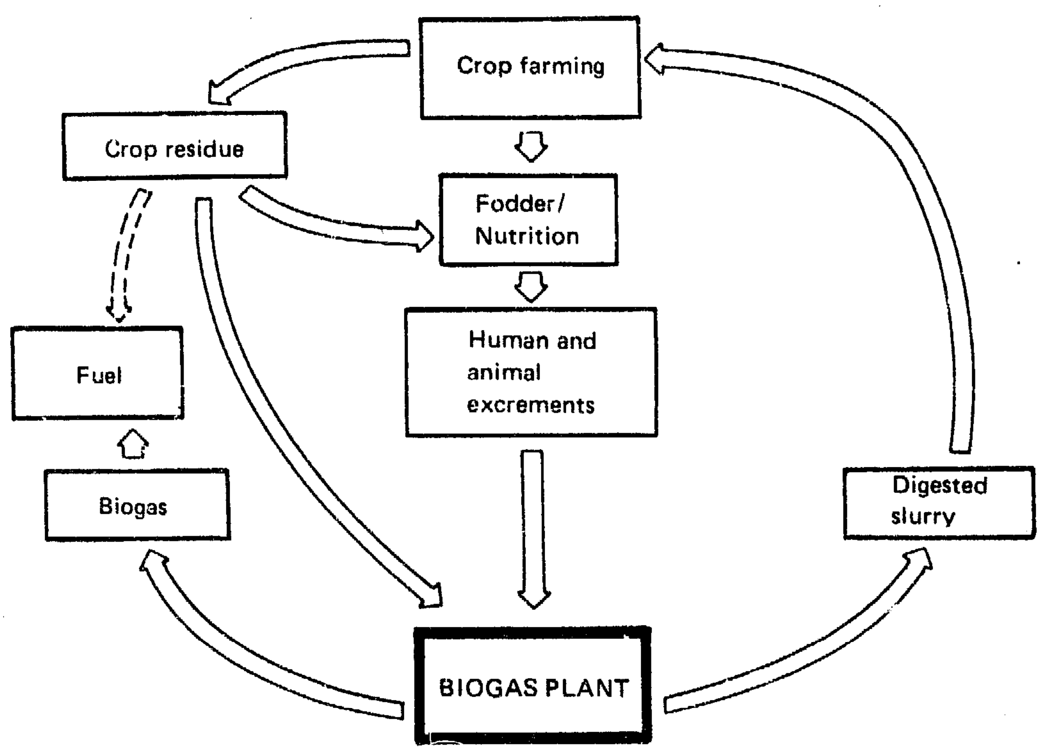


Table 3.7: Biogas compatibility of farm types (Source: OEKOTOP)

Type of farm	Characteristics of relevance to biogas generation	Rating as site for biogas plant
Stock farming only	Pasturing (nomadic, ranching, etc.) Intensive stationary fattening	unsuitable suitable
Crop farming only	Crop residue only; fermentation difficult	normally unsuitable
Mixed Agriculture		
Stock farming for:		
– animal power	Mostly nighttime stabling; only a few animals; 50% of dung collectible	possible
– meat production		
extensive	Pasturing; no stabling; dung wasted	unsuitable
intensive	Fattening in stables; dung directly usable	suitable
– milk production	Frequently permanent stabling; all dung and urine usable	suitable
Crop farming:		
– vegetables	Near house; crop residue and water available year-round	possible[1]
– field-tilling		
unirrigated	1 harvest per year, scarcity of fodder, long-distance hauling of water and manure	unsuitable
irrigated	2–3 harvests per year; water availabl:, small fields	possible[1]

[1] If vegetable waste is digested together with animal excr:ments.

posted and mixed with animal excrements for use in the fermentation process (cf. chapter 3.2).

Adding a biogas plant to an integrated agricultural production system not only helps save firewood and preserve forests, but also contributes toward sustained soil fertility through organic fertilization and ensures the long-term crop-bearing capacity of the soil. Work involving the dissemination of biogas technologies must account for and call attention to that complex relationship. If no organic fertilizing has been done before, a biogas plant will mean more work. Organic waste has to be collected and afterwards spread on the fields. Only if the owner is willing to invest the extra effort can the biogas plant be expected to serve well in the long term.

There are two central demands to be placed on the stock-farming system in relation to biogas utilization:

– permanent or part-time stabling or penning and

– proximity of the stables or pens to the place of gas utilization (usually the farmhouse).

If the distance between the stables/pens and the place of gas utilization is considerable, either the substrate must be hauled to the biogas plant (extra work) or the gas must be transferred to the place of use (cost of installing a supply pipe). Either of the two would probably doom the biogas plant to failure. The best set of circumstances is given, when

– the animal excrements can flow directly into the biogas plant by exploiting a natural gradient,

– the distance of flow is short, and
– the stables have a concrete floor to keep contamination like soil and sand from getting into the plant while allowing collection of urine.

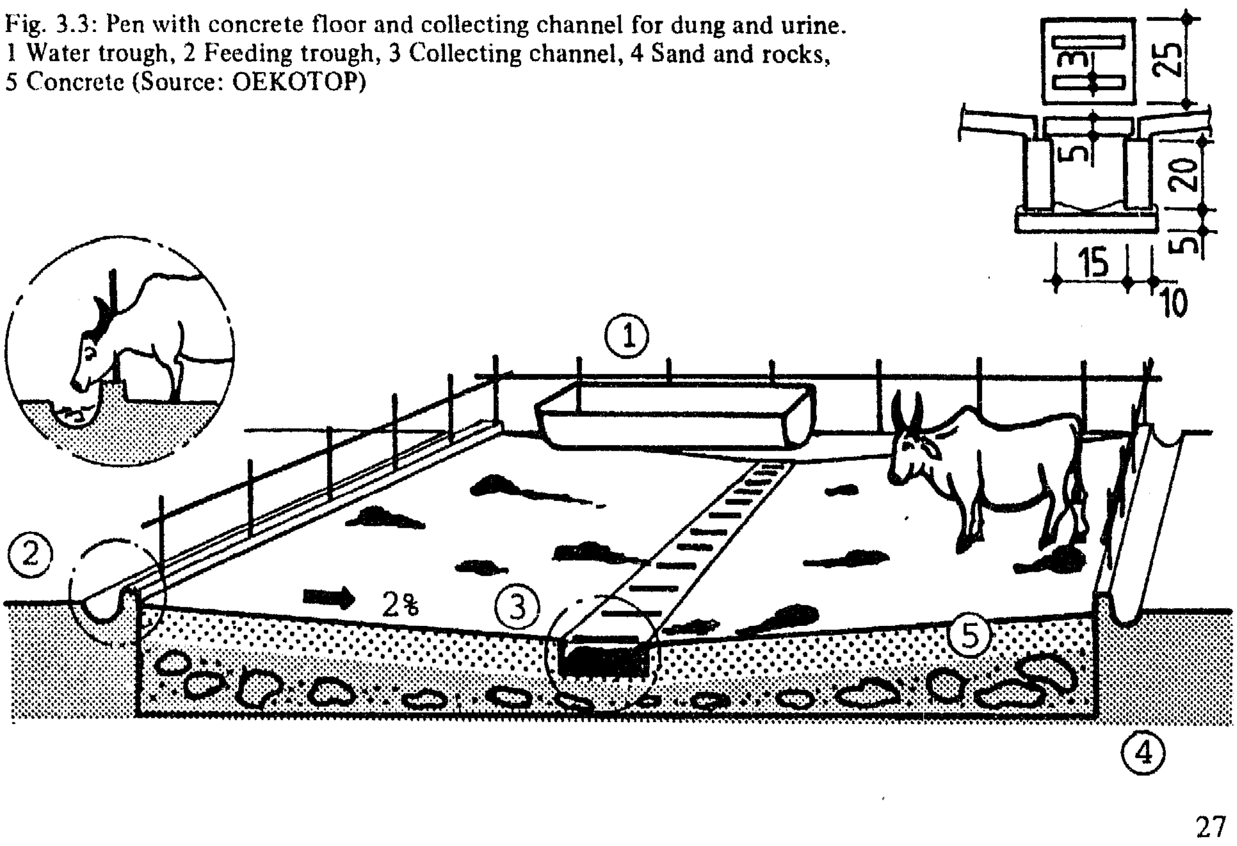
Cattle pens

Dung from earth-floor pens has a very high total-solids content (TS up to 60%), and the urine is lost. Daily collection is tedious and there is no way to prevent sand from getting into the digester. Consequently, at the same time a biogas plant is being installed, concrete floors should be installed in such pens and provided with a collecting channel. This increases the total cost of the biogas plant, but is usually justified, since it lowers the subsequent work input, helps ensure regular feeding of the plant, reduces the chance of hoof disease and keeps sand and stones out of the digester. The overall effect is to enhance acceptance of the biogas plant.

The collecting channels can be designed as open gutters or covered ducts. Concrete split tiles serve well as construction material for the second (more expensive) version. The slots should be about 2–3 cm wide, i.e. wide enough to let the dung pass through, but not wide enough to cause injury to the animals.

Cattle dung dries rapidly in a hot climate, particularly if the pen has no roof. The cleaning water also serves to liquefy the dung and reduce its TS content to 5–10% for the purposes of fermentation. The main advantage of this system is that the pens can be cleaned and the biogas plant filled in a single operation. The collecting channel should be designed to yield a floating-manure system with gates at the ends, so that a whole day's dung and cleaning water can collect at once. The advantages:
– easy visual control of the daily substrate input,
– prevention of collecting-channel blockage due to dung sticking to the walls and drying out,
– adding the substrate at the warmest time of day, which can be very important in areas with low nighttime temperatures.

Fig. 3.3: Pen with concrete floor and collecting channel for dung and urine.
1 Water trough, 2 Feeding trough, 3 Collecting channel, 4 Sand and rocks,
5 Concrete (Source: OEKOTOP)



Intensive forms of animal husbandry often involve the problem of excessive water consumption for cleaning, which leads to large quantities of wastewater, dilute substrate and unnecessarily large biogas plants (cf. chapter 6). In areas where water is scarce, the digester drain-water can be used for scrubbing down the pens and diluting the fresh substrate, thus reducing the water requirement by 30–40%.

Stables

Differentiation is generally made between:
– stabling systems with litter and
– stabling systems without litter,
with the design details of the stalls appropriate to the type of animal kept.
For use in a biogas plant, any straw used as litter must be reduced in size to 2–6 cm. Sawdust has poor fermenting properties and should therefore not be used.

Cattle shelter

Variants suitable for connection to a biogas plant include:
– Stanchion barns with a slurry-flush or floating removal system (no litter) or dung collecting (with litter),
– Cow-cubicle barns with collecting channel (no litter).

Piggeries

The following options are well-suited for combination with a biogas plant:
– barns with fully or partially slotted floors (no litter),
– lying bays with manure gutter (no litter),
– group bays (with or without litter).
Liquid manure from swine normally has better flow properties than liquid manure from cattle, the main reason being that swine eat less fibrous material. Additionally, though, swine drop more urine than dung.

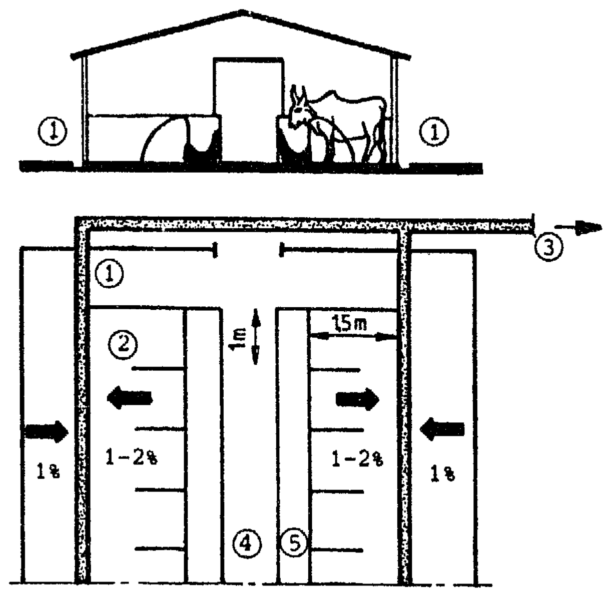
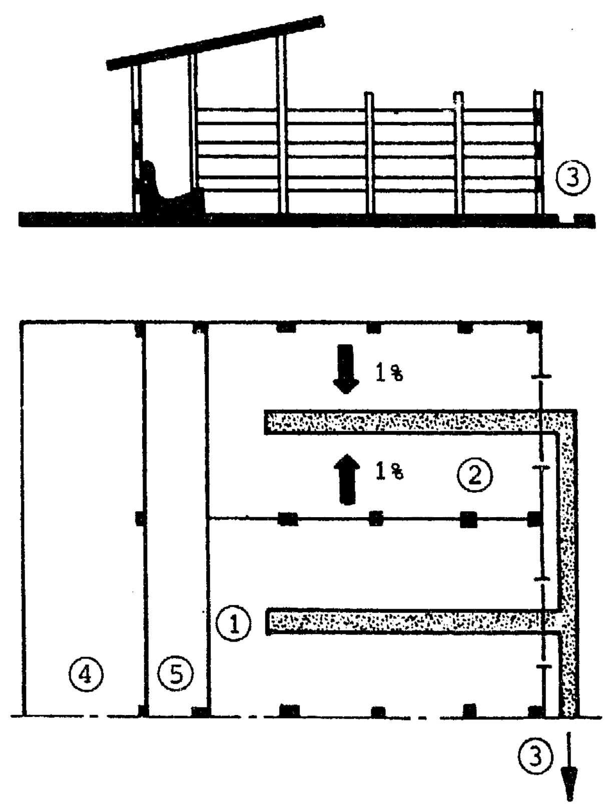


Fig. 3.4: Stanchion barn with floating gutter. 1 Collecting channel, 2 Stable, 3 Floating gutter leading to the biogas plant, 4 Feeding aisle, 5 Feeding trough (Source: OEKOTOP)

Fig. 3.5: Cow-cubicle barn with floating gutter. 1 Collecting channel, 2 Cubicle, 3 Floating gutter leading to the biogas plant, 4 Feeding aisle, 5 Feeding trough (Source: OEKOTOP)



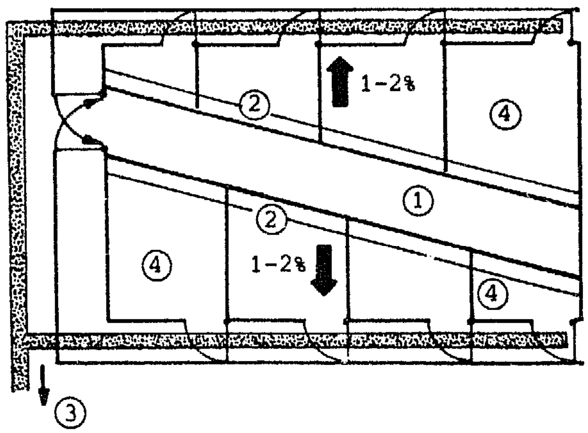


Fig. 3.6: Piggery with group bays (no litter). 1 Feeding aisle, 2 Feeding trough, 3 Floating gutter leading to the biogas plant, 4 Bay (pigpen) (Source: Manuel et Preas D'Elevage No. 3, 1977)

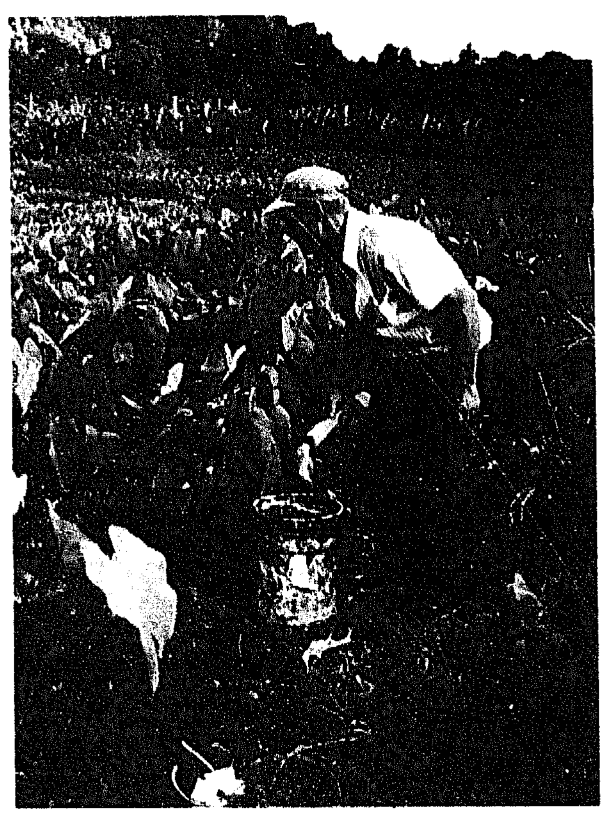
In tropical countries, few pigsties have fully or partially slotted floors. Most pigs are kept in group bays. Figure 3.6 shows a schematic representation of a piggery with bays of different size to accommodate animals of various weight categories. The animals are moved in groups from one bay to the next as they grow.

Chicken coops

Hens kept in battery-brooding cages never have litter. Despite the name, straw yards can be managed with or without litter.
In either system, the dry droppings are collected, transferred to the biogas plant and diluted to make them flowable. Feathers and sand are always problematic, since they successfully resist removal from the substrate. In many cases, the coop is only cleaned and disinfected once after the entire population is slaughtered. As a rule such systems are not suitable as a source of substrate for biogas plants.

Photo 3: Feeding the plant and mixing the substrate (Source: OEKOTOP, BEP Burundi)

Photo 4: Fertilizing with digested slurry (Source: BEP Caribbean)



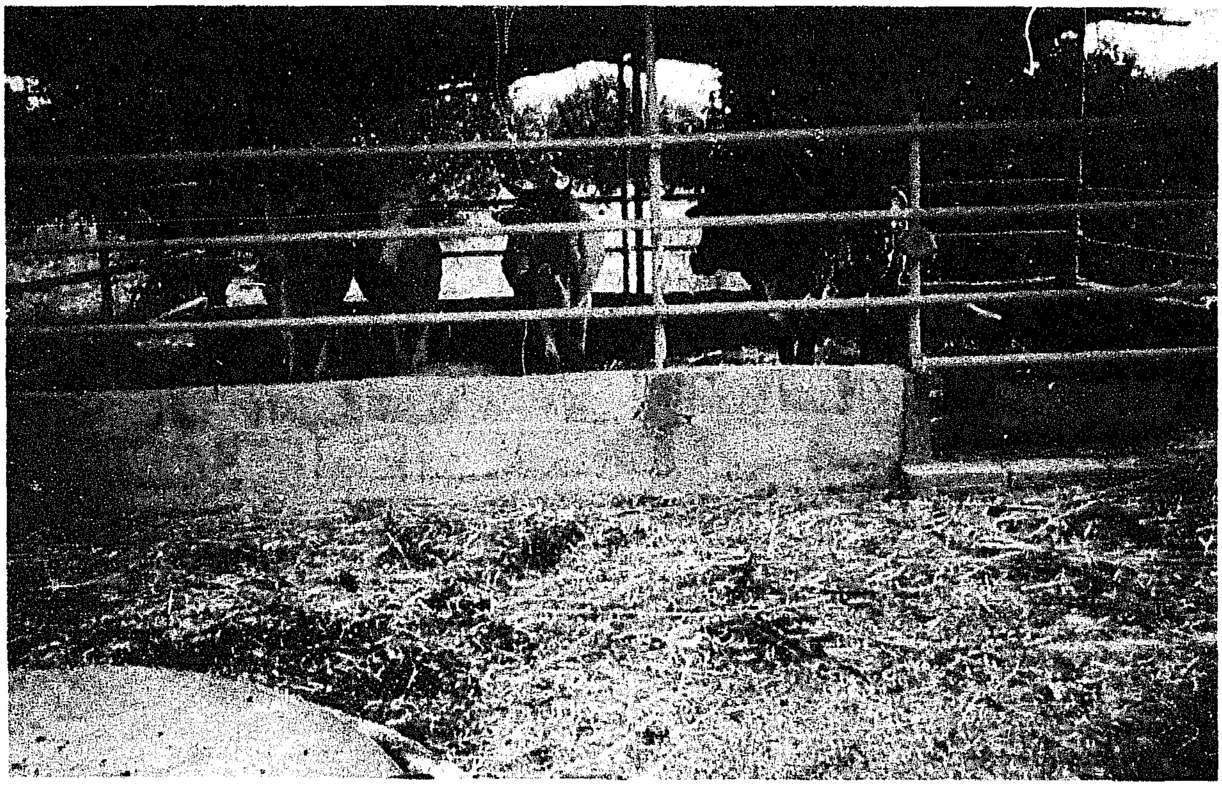


Photo 5: Cattle shelter feeding into a biogas plant (foreground) (Source: BEP Burkina Faso)

3.4 Fertilizing with Digested Slurry

The practice of regular organic fertilizing is still extensively unknown in most tropical and subtropical countries. Due, however, to steady intensification of agricultural methods, e.g. abbreviated fallow intervals, some form of purposeful organic fertilizing, naturally including the use of digested slurry as fertilizer, would be particularly useful as a means of maintaining tropical soil fertility. Since Third World farmers have little knowledge of or experience in organic fertilizing methods, particularly with regard to the use of digested slurry, the scope of the following discussion is limited to the general plant-growth efficiency factors of digested slurry.

Fermentation-induced modification of substrate

– Anaerobic digestion draws carbon, hydrogen and oxygen out of the substrate. The essential plant nutrients (N, P, K) remain, at least in principle, in place. The composition of fertilizing agents in digested slurry depends on the source material and therefore can be manipulated within certain limits.

– For all practical purposes, the volume of the source material remains unchanged, since only some 35–50% of the organic substances (corresponding to 5–10% of the total volume) is converted to gas.

– Fermentation reduces the C/N-ratio by removing some of the carbon, which has the advantage of increasing the fertilizing effect. Another favorable effect is that organically fixed nitrogen and other plant nutrients become mineralized and, hence, more readily available to the plants.

– Well-digested slurry is practically oderless and does not attract flies.

– Anaerobic digestion kills off or at least deactivates pathogens and worm ova, though the effect cannot necessarily be referred to as hygienization (cf. Table 3.8). Ninety-five

Table 3.8: Survival time of pathogens in biogas plants (Source: Anaerobic Digestion 1985)

Bacteria	Thermophilic fermentation 53–55 °C		Mesophilic fermentation 35–37 °C		Psycrophilic fermentation 8–25 °C	
	Fatality Days	Rate (%)	Fatality Days	Rate (%)	Fatality Days	Rate (%)
Salmonella	1–2	100.0	7	100.0	44	100.0
Shigella	1	100.0	5	100.0	30	100.0
Poliviruses			9	100.0		
Schistosoma ova	hours	100.0	7	100.0	7–22	100.0
Hookworm ova	1	100.0	10	100.0	30	90.0
Ascaris ova	2	100.0	36	98.8	100	53.0
Colititre	2	10^{-1}–10^{-2}	21	10^{-4}	40–60	10^{-5}–10^{-4}

percent of the ova and pathogens accumulate in the scum and sediment. Plant seeds normally remain more or less unaffected.

– Compared to the source material, digested slurry has a finer, more homogeneous structure, which makes it easier to spread.

Fertilizing properties

The fertilizing properties of digested slurry are determined by how much mineral substances and trace elements it contains; in tropical soil, the nitrogen content is not necessarily of prime importance – lateritic soils, for example, are more likely to suffer from a lack of phosphorus. The organic content of digested slurry improves the soil's texture, stabilizes its humic content, intensifies its rate of nutrient-depot formation and increases its water-holding capacity. It should be noted that a good water balance is very important in organically fertilized soil, i.e. a shortage of water can wipe out the fertilizing effect.

Very few data on yields and doses are presently available with regard to fertilizing with digested slurry, mainly because sound scientific knowledge and information on practical experience are lacking in this very broad domain. Table 3.10 lists some yield data on digested-slurry fertilizing in the People's Republic of China.

For a practician faced with the task of putting digested slurry to good use, the following tendential observations may be helpful:

– While the nitrogen content of digested slurry is made more readily available to the

Table 3.9: Concentration of nutrients in the digested slurry of various substrates[1] (Source: OEKOTOP, compiled from various sources)

Type of substrate	N	P_2O_5	K_2O	CaO	MgO
			– % TS –		
Cattle dung	2.3–4.7	0.9–2.1	4.2–7.6	1.0–4.2	0.6–1.1
Pig dung	4.1–8.4	2.6–6.9	1.6–5.1	2.5–5.7	0.8–1.1
Chicken manure	4.3–9.5	2.8–8.1	2.1–5.3	7.3–13.2	1.1–1.6

[1] without litter

Table 3.10: Effects of digested slurry on crop yields (Source: Chengdu 1980)

Plants tested	Quantity of digested slurry (m³/ha)	Yield with digested slurry (kg/ha)	Yield with liquid manure (kg/ha)	Increase (kg/ha)	Increase (%)
Sweet potatoes	17	24000	21500	2500	12
Rice	15	6500	6000	500	8
Corn (maize)	22.5	5000	4600	400	9
Cotton	22.5	1300	1200	100	8

plants through the mineralization process, the yield effect of digested slurry differs only slightly from that of fresh substrate (liquid manure). This is chiefly attributable to nitrogen losses occurring at the time of distribution.

– Digested slurry is most effective when it is spread on the fields just prior to the beginning of the vegetation period. Additional doses can be given periodically during the growth phase, with the amounts and timing depending on the crop in question. For reasons of hygiene, however, lettuce and vegetables should not be top-dressed.

– The recommended quantities of application are roughly equal for digested slurry and stored liquid manure.

– The requisite amount of digested-slurry fertilizer per unit area can be determined as a mineral equivalent, e.g. N-equivalent fertilization. The N, P and K doses depend on specific crop requirements as listed in the appropriate regional fertilizing tables.

With a view to improving the overall effect of slurry fertilizer under the prevailing local boundary conditions, the implementation of a biogas project should include demonstration trials aimed at developing a regionally appropriate mode of digested-slurry application. For information on experimental systems, please refer to chapter 10.6 – Selected Literature.

Proceeding on the assumption that the soil should receive as much fertilizer as needed to replace the nutrients that were extracted at harvesting time, each hectare will require an average dose of about 33 kg N, 11 kg P_2O_5 and 48 kg K_2O to compensate for an annual yield of 1–1.2 tons of, say, sorghum or peanuts. Depending on the nutritive content of the digested slurry, 3–6 t of solid substance per hectare will be required to cover the deficit. For slurry with a moisture content of 90%, the required quantity comes to 30–60 t per hectare and year. That roughly corresponds to the annual capacity of a 6–8 m³ biogas plant.

Like all other forms of organic fertilizing, digested slurry increases the humic content of the soil, and that is especially important in low-humus tropical soils. Humus improves the soil's physical properties, e.g. its aeration, water retention capacity, permeability, cation-exchange capacity, etc. Moreover, digested slurry is a source of energy and nutrients for soil-inhabiting microorganisms, which in turn make essential nutrients more available to the plants. Organic fertilizers are indispensable for maintaining soil fertility, most particularly in tropical areas.

The importance of digested slurry as a fertilizer is underlined by the answers to the following questions:

– How much chemical fertilizer can be saved with no drop in yield?

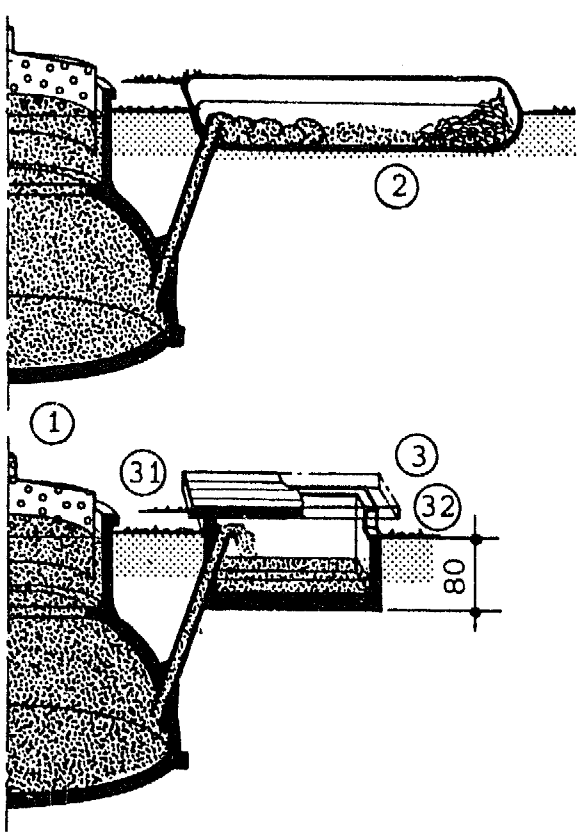
– Which yield levels can be achieved by fertilizing with digested slurry, as compared

to the same amount of undigested material, e.g. stored or fermented liquid manure?
– By how much can yields be increased over those from previously unfertilized soil?
Depending on those answers, a certain monetary value can be attached to digested slurry, whereas the labor involved in preparing and applying the fertilizer must be given due consideration.

Storing and application of digested slurry

With a view to retaining the fertilizing quality of digested slurry, it should be stored only briefly in liquid form in a closed pit or tank and then applied to the fields. Liquid storage involves a certain loss of nitrogen due to the evaporation of ammonia. For that reason, and in order to limit the size of the required storage vessels (a 30-day supply corresponds to about 50% of the biogas plant volume), the storage period should be limited to 2–4 weeks. The resultant quasi-continuous mode of field fertilization (each 2–4 weeks), however, is in opposition to the standing criteria of optimum application, according to which fertilizer should only be applied 2–4 times per year, and then only during the plants' growth phase, when they are able to best exploit the additional nutrient supply.
The practice of spreading liquid digested slurry also presents problems in that not only storage tanks are needed, but transport vessels as well, and the amount of work involved depends in part on how far the digested slurry has to be transported. For example, transporting 1 ton of dung a distance of 500 m in an oxcart takes about 5 hours (200 kg per trip). Distributing the dung over the fields requires another 3 hours or so.
If, for reasons of economy and efficiency, liquid fertilizing should appear impractical, the digested slurry can be mixed with green material and composted. This would involve nitrogen losses amounting to 30–70%. On the other hand, the finished compost would be soil-moist, compact (spade able) and much easier to transport.
If irrigated fields are located nearby, the digested slurry could be introduced into the irrigating system so that it is distributed periodically along with the irrigating water.

Fig. 3.7: Slurry storage and composting. 1 Biogas plant, 2 Slurry composting pit with green cover, 3 Masonry storage pit (V = 10 Sd), 31 Sturdy wooden cover, 32 Overflow (Source: OEKOTOP)



3.5 Integral Agriculture

Integral agriculture, also referred to as biological or ecological farming, aims to achieve effective, low-cost production within a system of integrated cycles. Here, biogas technology can provide the link between animal husbandry and crop farming.

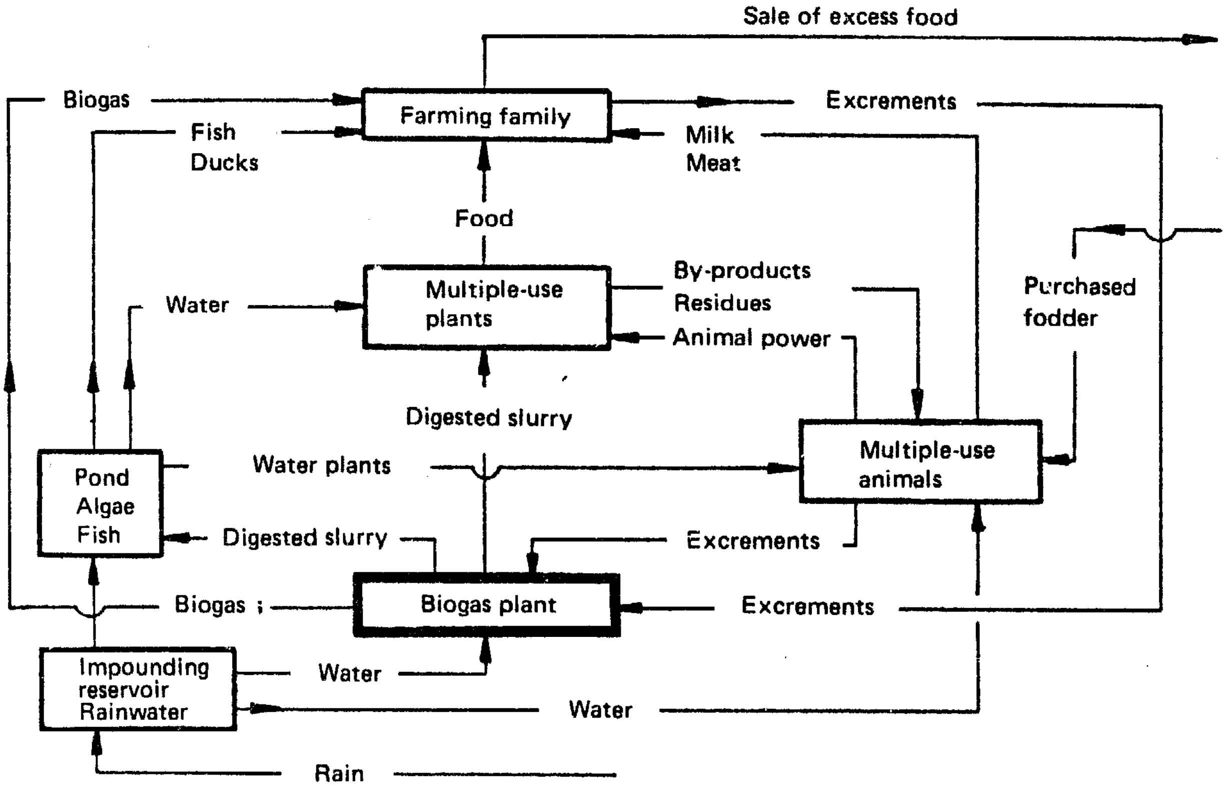


Fig. 3.8: Flow diagram for integral farming with a biogas plant
(Source: GTZ 1985)

Consider, for example, the planning of a GTZ project in Côte d'Ivoire. The project included the development of a model farm intended to exploit as efficiently as possible the natural resources soil, water, solar energy and airborne nitrogen.

The integral agricultural system "Eco-ferme" (ecofarm) comprises the production elements gardening, crop farming (for food and animal fodder), stock farming (for meat and milk) and a fishpond. A central component of such closed-loop agricultural production is the biogas plant, which produces both household energy and digested slurry for use in the fishpond and as a fertilizer.

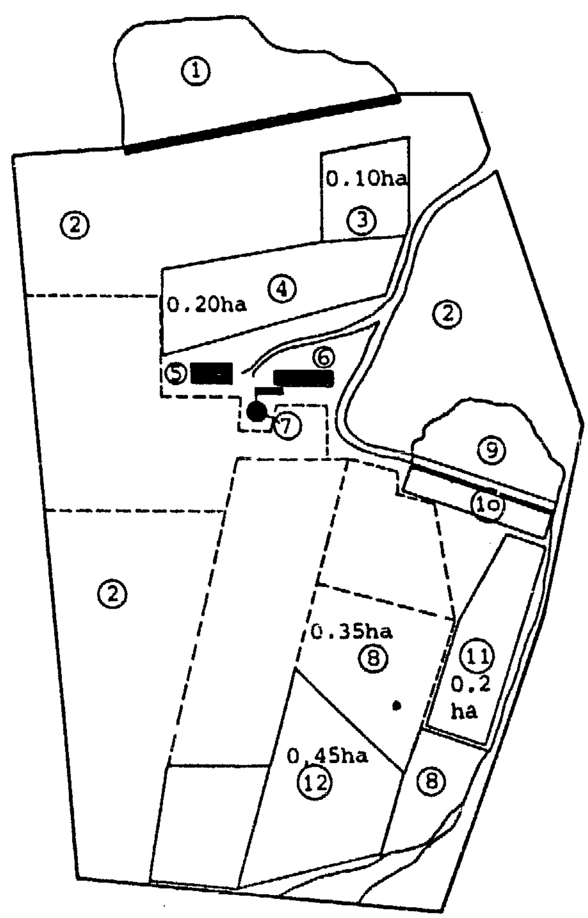


Fig. 3.9: Site plan of the Bouaké Ecofarm in Côte d'Ivoire. 1 Impounding reservoir for rainwater, 2 Fallow land, 3 Manioc (1st year), 4 Yams and Manioc (2nd year), 5 Farmhouse, 6 Stables, 7 Biogas plant, 8 Sugar cane, 9 Water reservoir, 10 Fishpond, 11 Vegetable garden, 12 Various food plants (Source: GTZ 1985)

The average family-size "eco-ferme" has 3 ha of farmland with the following crops:

Fodder plants	
Panicum (for the rainy season)	0.15 ha
Sugar cane (for the dry season)	0.50 ha
Leucaena and brachiaria (mixed culture	0.50 ha
Panicum, brachiaria and centrosema (mixed culture)	0.50 ha
Food plants	
Manioc	0.20 ha
Corn	0.40 ha
Yams	0.10 ha
Potatoes – beans	0.10 ha
Vegetables	0.20 ha
Rice and miscellaneous crops	0.17 ha

Four milk cows and three calves are kept year-round in stables. The cattle dung flows via collecting channels directly into a 13 m^3 biogas plant. The biogas plant produces 3.5–4 m^3 biogas daily for cooking and lighting. Part of the digested slurry is allowed to flow down the natural gradient into an 800 m^2 fishpond in order to promote the growth of algae, which serves as fish food. The remaining digested slurry is used as crop fertilizer.