17 Poultry

Section 17 provides information on small-scale poultry breed selection criteria and breed performance, diverse options for housing, and how to feed the animals.

17.1 The role of poultry in smallholder farms

Small-scale poultry is a widespread practice among smallholder farms. Intensive poultry is only feasible if the market situation can justify the high monetary need to build a system that is productive and accounts for animal welfare (special heat control and feeding requirements). Therefore, this section concentrates on optimising small-scale poultry in accordance to organic guidelines.

17.2 Breed selection

When choosing the breed of chicken best suited for the farm, several factors have to be considered (Table 75). For most situations the keeping of local breeds, which are of hardy constitution and well adapted to local climatic conditions (breed comparison see Table 76), is advised.

Table 75. Factors for poultry breed selection

Factor	Local breeds	Commercial breeds	Hybrid breeds
Price	Low	High	High
Adaptability	Adapted to local conditions	Not adapted to tropical climate	Not adapted to tropical climate
Scale	Suited for small-scale keeping	Suited for larger scale operations	Suited for larger scale operations
Breeding	Continuation of own flock possible	Continuation of own flock possible	New animals have to be bought regularly
Market situation	Less relevant	*Layers* should only be considered if there is a specific demand for eggs *Dual-purpose* breeds should be preferred otherwise	Hybrids should only be chosen if there is a good market situation, as well as a good availability of feedstuff and animals
Experience	Less experience needed	More experience needed	More experience needed
Farm management	Can easily be integrated in the farm	Specialized management for *layers*, *broilers* or *dual-purpose* raising necessary	Specialized management necessary for profitability
Productivity (eggs year^{-1})	Approx. 50	*Dual-purpose* < 250 *Layers* < 300	250-270
Availability	Widely available	Can be poor	Can be poor, long-term availability has to be guaranteed for success

Sources: Own compilation; Eekeren, Maas, Saatkamp & Verschuur (1995)

Table 76. Comparison of widespread local chicken breeds in Ethiopia

Traits	Unit	Tukur	Melata	Kei	Gebsima	Netch
24-week body weight	g	960	1.000	940	950	1.180
Age at 1st egg	days	173	204	166	230	217
Eggs	No.*	64	82	54	58	64
Egg weight	g	44	49	45	44	47
Fertility	%	56	60	57	53	56
Hatchability	%	42	42	44	39	39

Source: Sonaiya & Swan (2007)
*bird per year

17.3 Housing

Traditionally, poultry is kept in a free-range housing system. The birds are allowed to roam free under a scavenging system, with minimal inputs for housing, feeding, or health care. The free-range system is a viable option if there is enough space of sufficient quality available (preferably pasture). But in most smallholder farms, high chick mortality rates and flock devastation by disease are common problems in free-range systems which are avoidable by implementing suitable housing structures.

17.3.1 Mobile chicken house

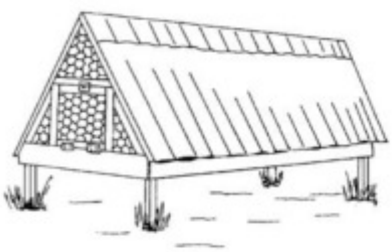
The construction of a mobile chicken house (Figure 21) is advised as a minimum housing structure for free-range chicken, which has to follow some guidelines (Table 77).

Table 77. Specifics of a mobile chicken house

Subject	Description
Size	At most 3 – 4 birds per m^2.
Mobility	Mobile houses allow for pasture regeneration and better hygiene.
Orientation	Place in shade and sheltered from the wind.
Roof	As high as possible to allow for good ventilation.
Walls	Can be made from wood or mesh wire; the house has to be dark but with good ventilation.
Flooring	Has to be raised of the ground to allow for good hygienic conditions. Floor should allow for ventilation and can be made of a combination of wooden slats and mesh wire or sticks (e.g. bamboo, 5 cm apart).
Nest boxes	One nesting box for every 3 - 4 hens (30 cm x 30 cm x 40 cm). Can be made from wood, baskets, cardboard boxes. Keep nests clean and inviting (straw litter, etc.).
Perches	Chickens prefer to roost on perches overnight. Allow for 20 -25 cm perching space per bird. The construction of a removable “droppings board” 20 cm below the perch allows for manure collection and facilitates hygiene.
Water access	Fresh drinking water should be provided at all times.
Possible problems	**Solutions**
Nest boxes are not used	Keep chickens confined in home until mid-morning (until 10 am), as most egg laying will occur in the early morning. Keep nest boxes clean and inviting (straw litter). Sometimes the placement of a fake egg (e.g. golf ball, ceramic egg) in the nest box can convince hens to start using it.
Nest boxes used for sleeping	Provide more roosting space/spots. Block nesting boxes with an obstacle in the early evening and remove it after the birds have settled to roost.

Sources: Eekeren et al. (1995), Sonaiya & Swan (2007)

Figure 21. Simple, mobile chicken house with raised floor, corrugated sheet roofing and mesh wire walls

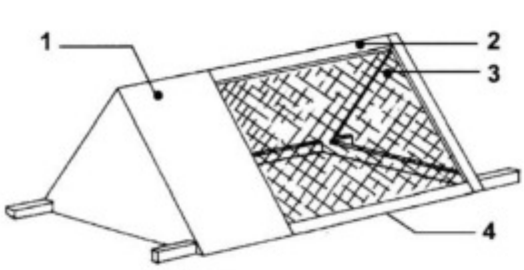


Source: Eekeren et al. (1995)

17.3.2 Fold units for chick protection

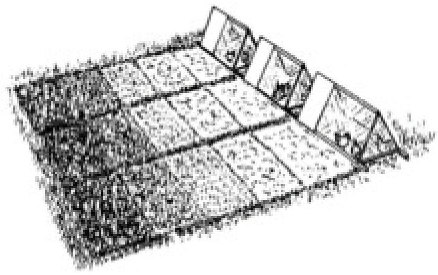
Foldable mobile housings can provide a simple shelter (0.5 m^2 space needed for each bird) for chicks and mother hens (Figure 22). As chicks are especially prone to drought and cold during the first days of their life, the area underneath the boarded section of the folding unit has to be provided with nesting material as well as sufficient feed and water access. These portable units have to be moved every day over an area of grassland (Figure 23).

Figure 22. Simple fold unit for chick raising



Source: Eekeren et al. (1995); 1: Boarded section for shelter, 2: Wooden frame, 3: Mesh wire wall, 4: mesh wire floor

Figure 23. Daily movement pattern of mobile fold units



Source: Eekeren et al. (1995)

17.3.3 Permanent housing with run

A permanent coop with run offers an alternative to the free-range system mentioned above, although investment and maintenance costs are higher in this system (dimensions and construction see Table 77). It is advised to construct more than one run, so that access to the runs can be changed every two weeks. This allows the vegetation to recover and reduces parasitic infection risks (runs have to be roofed or kept dry otherwise).

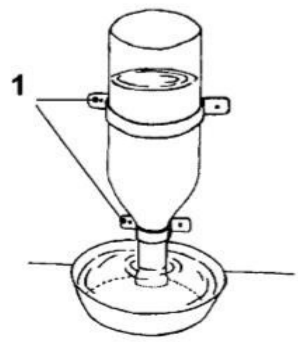
Table 78. Comparison of free-range and permanent poultry housing systems

Subject	Free-range system	Permanent housing
Feeding	Low input, birds can mostly feed themselves.	Feedstuff has to be provided.
Hygiene	Mobile homes reduce risk of disease and parasitic infections.	To maintain proper hygiene, more labour is required.
Labour input	Generally lower, moving and cleaning of housing units.	More labour for construction and cleaning required.
Cost	Construction costs lower.	Construction costs higher.
Control	Free-range birds are difficult to control.	Birds are easy to control.
Mortality rates	Higher predation and accident rates.	Usually lower, higher risk of diseases.
Egg production	A large percentage of eggs can be lost if hens are not used to laying nests.	Egg production is controlled. Egg eating by hens can occur if there is a calcium-deficiency in the diet.
Animal welfare	If free-range conditions are good, higher animal welfare.	Lower animal welfare and higher stress levels due to confined space.
Breeding	Separate fold units for hens with chicks are advised.	If own stock is bred, separate houses for chicks of different age groups have to be constructed.
Heat control	Heat has to be managed for night-time in mobile homes.	Consider orientation and wind direction when constructing the house (east-west direction, sheltered from wind), limit direct sunlight (e.g. tree next to house, shading structures, etc.).

Sources: Eekeren et al. (1995), Sonaiya & Swan (2007)

17.4 Nutrition

Figure 24: Upside-down bottle drinker



Depending on the housing system, different approaches have to be taken when formulation poultry feed rations. In the tropics, access to enough fresh water is often a limited factor and care should be taken to ensure adequate water intake by the birds in free-range as well as permanent housing systems. An upside-down bottle drinker as shown in Figure 24 is easy to construct and to maintain. A bottle is filled with water and then inverted into an open container. Ensure that there is 3 cm of drinking space per bird.

1: Tin or leather straps for fixation.
Source: Eekeren et al. (1995)

17.4.1 Feed intake in free-range housing

If poultry is kept in a traditional free-range scavenging system, the farmer has little influence on the feed intake of the birds, but some management options can be taken to ensure proper nutrition (

Table 79).

Table 79. Optimisation of free-range chicken nutrition

Topic	Optimisation
Water	Ensure unlimited water access for birds, installation of additional drinkers.
Quality of land	Ensure access to enough good pasturing land. High chick mortality rates without signs of predation can be a sign for severe food competition and insufficient food resources.
Energy	Supplemental feeding of 35 g of grains per bird per day (except during harvest time) is advised for ensuring that energy requirements are met.
Protein	Often insufficient, allow access to a compost and offer fodder legumes.
Vitamins	Especially during the dry season, add ashes and dried greens to the diet.
Flock size	Should be adapted to season (cull during dry season).

Sources: Own compilation, Eekeren et al. (1995)

One possibility to supplement scavenging is the use of a “free-choice cafeteria system”. Here, poultry has free access to three containers comprising a protein concentrate (e.g. soya meal, forage legumes), a carbohydrate source (e.g. wheat bran, maize germ), and a mineral source (e.g. limestone) for two to three hours in the evening. Supplements are recommended in the range of 30 – 80 g per day, depending on the season.

17.4.2 Feeding in permanent housing with run

In case poultry is kept in a permanent housing system, greater care is necessary to ensure that the nutritional needs of the animals are fulfilled. In permanent housing systems it is required to separate the animals by age groups because nutritional requirements differ (Table 80).

Table 80. Composition of poultry feed formulation

Feedstuff part of diet (%)	Starters <21 days	Growers >21 days	Layers after first egg	Feed examples
Energy rich	45	50	60	Maize bran
Protein rich	40	35	25	Grain legumes
High fat content	8	8	4-8	Copra meal
Vitamins	2	2	2	Fermented fruit juice
Minerals	4	4	4-8	Limestone, bone meal
Salt	1	1	1	

Sources: Own compilation, Ravindran (2013)

The most important aspect when feeding poultry is to calculate if the diet meets the protein needs of the animals (at least 18% crude protein) (Table 81). The formulated feed mixture reaches a protein level of 22%. To minimise the risk of malnutrition, diets should be as versatile as possible and should also include any animal protein (snails, worms, etc.).

Table 81: Exemplary diet formulation for layer hens (excluding minerals and vitamin additions)

Feedstuff	Quantity kg	Protein % CP	In mixture kg x %CP
Whole maize	20	9	1.8
Wheat bran	15	14	2.1
Maize germ	10	13	1.3
Sunflower seeds	15	26	3.9
Flax seeds	10	23	2.3
Cowpeas	10	25	2.5
Groundnut cake	15	49	7.35
Sesame seeds	5	20	1
Sum	**100**		**22.25**

Sources: Own compilation, Ravindran (2013)

A wide variety of feedstuff can be used as poultry fodder. Fodder can be grown on-farm or purchased on market (organic). Table 82 shows an overview of widely available feedstuff and their approximate inclusion rates into the diet.

Table 82. Feedstuff inclusion rates for poultry

Feedstuff	Alternative/ remark	Proportion in diet (up to) %
	Energy sources	
Animal fat		5-8
Banana / plantain meal	Remove peels.	10-20
Breadfruit meal		<30
Cassava peel meal	Must be combined with high protein foods.	5
Citrus pulp		2
Coffee pulp	Has to be dried.	3-5
Maize	Wheat Sorghum – low tannin variant Millets – can replace >65% of maize	
Mango seed kernel meal	High tannin levels!	5-10
Molasses		2-5

Rice bran		20
Sweet potato tuber meal		20
Taro	Needs processing.	10
	Protein sources	
Cottonseed meal		10-15 for broilers
Canola meal		30
Coconut meal	Combine with high energy source (e.g. cassava meal).	50
Grain legumes	Lupins, field peas, chickpeas, cowpeas, pigeon peas, faba beans, etc.	20–30% when processed (boiling, drying) and supplemented with methionine.
Groundnut cake		8-24
Leaf meals, aquatic plant meals	Rich in minerals.	5
Leucaena leaf meal		2-5
Sesame seeds	Raw and un-hulled.	20-35
Sesame meal		15
Sunflower meal		10-15
Sunflower seeds	Can replace grains.	25
	Animal protein sources	
Blood meal		<5
Insects, fly larvae, earthworms, termites, bees, snails, etc.		Can replace 50% of fishmeal in formulations.

Sources: Diverse sources, fao.org, Ravindran (2013)

17.5 Further information

- http://www.fao.org/ag/AGAInfo/themes/en/poultry/home.html

18 Animal manure management

Section 18 presents important aspects of animal manure and slurry management, as optimal handling is crucial for the quality and thus effects soil fertility and plant nutrition. The section provides some figures for the calculation of manure and slurry amounts, and nutrient contents.

In many Ethiopian smallholder farms animals provide manure and/or slurry. Both are highly relevant for soil fertility and crop growth, as well as for closing nutrient cycles. However, much of the manure produced by the animals never reaches the crops. The manure is often lost when animals roam freely, or used for cooking, and/or for house construction. Slurry that is collected in open holes in the ground loses much of the nitrogen through leaching or via the formation of ammonia. The yield loss of crops through animal manure mismanagement is estimated at 50 to 200%. A challenge for a proper calculation of manure is the lack of nutrient data of animal manures under tropical low input conditions. As a consequence, nutrient contents can currently only roughly be estimated, based on live weight of animals and feed material.

18.1 Manure production and distribution

Similar to forage, the production of manure has to be estimated with farm specific data. Manure and urine production closely relate to the forage and water intake. With Table 83, the amount of excretions of some common farm animals, under tropical extensive management conditions, can be estimated.

Table 83. Amount of excretions as percentage of body weight

Animal	Amount of excretions as % of average body weight		Amount of fresh dung
	Dung	Urine	kg day-1
Cow	5	4-5	15-20
Pig	2	3	1.2-4.0
Goat/sheep	3	1-1.5	0.9-3.0
Chicken	4.5	-	0.02-0.15

Source: Teenstra, de Buisonjé, Ndambi & Pelster (2015)

Table 84 provides an example for calculating the amount of dry manure that is provided by different types of animals per day and over the year. Additionally, the different amounts of manure that certain crops need is presented.

Table 84. Estimated dry manure supply per animal and crop demand

Manure production Animal	Amount DM kg day^{-1}	Animals No.	Days No.	Total amount kg
Cow	4	1	365	1,460
Calf	0.3	1	365	110
Cattle	2	1	365	730
Oxen	3	1	365	1,095
Sheep	0.3	1	365	110
Goat	0.2	1	365	73
Donkey	2	1	365	730
Rabbit	0.15	10	365	548
Chicken	0.05	10	365	183
Total manure production				**5,037**
Crops	**Demand manure DM kg ha^{-1}**	**Area ha^{-1}**	**Margin DM t ha^{-1}**	**Total demand DM kg ha^{-1}**
Mucuna	0			0
Napier grass	5,000	0.1	3-10	500
Alley branches	0			0
Pasture	2,500	0.1	1-10	250
Maize	5,000	0.1	2.5-10	500
Potato	5,000	0.1	2.5-10	500
Teff	2,500	0.1	2.5-10	250
Vegetables	5,000	0.01	2.5-10	50
Herbs	2,500	0.01		25
Fruit trees	2,500	0.1		250
Coffee	5,000	0.5		2,500
Total manure demand		**1.12**		**4,825**
Manure balance				**+212**

Sources: Own data, various sources (see Excel – manure calculations)
Remark: See Excel sheet “Manure calculation”; animal manure is calculated as dry manure; losses in weight after composting over 2-4 month can reach up to 50% of the input quantity; all numbers are averages that can vary with local conditions.

Keep in mind:

- Manure production and quality is usually the result of farm own biomass, i.e. amount of forage per animal. Therefore, the nutrients in the manure are not an addition from outside, but from the farm's soil stock! With the manure, the nutrients of the farm will only be redistributed.
- This is true except for nitrogen, if legumes are cultivated and fed to the animals. Here, approx. 50 to 75% of the nitrogen is fixed by bacteria from the air and thus a real contribution from outside the farm.
- Only cereals and protein crops from outside (mostly for chicken production), brewery, or oil press cake residues for dairy production can be calculated as a plus for the farms nutrient balance.
- Nutrients from hedge and alley cuttings are used in the same way. Normally, these biotopes are not manured. They serve as a nutrient source for the farm. Their site-specific nutrient balance is always negative.
- Manure is mostly distributed directly to the crop or the crop row.
- Most crops prefer mature manure. Fresh manure can increase pest and disease occurrence.

If manure is not collected and redistributed to the soils, the soil nutrient stock is permanently decreasing.

18.2 Slurry production and distribution

The main parts of animal manure and specifically that of cows, if partly kept in a stable or a small fenced area in a farm, is in a liquid form (called slurry). Specifically in the rainy season, when the ground is often wet and muddy and there is no straw or any other material to absorb the liquid, the slurry is running uncontrolled into the yard. A fixed floor with clay and a channel for collection of liquids is a must. Better is a concrete / cement structure with channels and a pipe that flows into a tank or small pond secured for example with plastic (or heavy clay / concrete if affordable). The pond should be covered to reduce ammonium losses and to secure against people falling into it. Picture 5 shows a manure pile (on the right) and a channel leading to a small pond. However, nitrogen losses are high as the pond and the manure pile are not covered.

Picture 5. Slurry drainage and pond

Source: Lekasi, Tanner, Kimani & Harris (2001)

If water and an appropriately voluminous tank is available, the addition of water is of advantage. After complete depletion of the slurry, the residues can be used as manure. When biogas plants are established, farmers are more aware of collecting liquid. But, as in this case, soluble and gaseous losses must be avoided through adapted systems (see section 20).

The slurry can be applied to cereals, maize, potato, Napier grass and other grasses in small amounts, but not to legumes. The liquid should be distributed directly to the plants. If the liquid is too thick, water can be added up to a relation of 1:1. Little amounts can be used to push the composting process on composting heaps. Table 85 shows an exemplary calculation of the amount of slurry that can be provided by different types of animals and the amount needed by certain crops. For herbs and vegetables slurry is only given at the very beginning of plant growth, in small amounts and mixed with water. High supply as for Napier grass is to split in amounts of max. 20,000 l ha^{-1}.

Table 85. Estimated slurry supply per animal and crop demand

Slurry supply Animal	Amount l day^{-1}	Animals No.	Days No.	Total amount l ha^{-1}
Cow	10	1	365	3,650
Calf	5	1	365	1,825
Cattle	10	1	365	3,650
Oxen	10	1	365	3,650
Sheep	2.5	1	365	913
Goat	3.5	1	365	1,278
Donkey	5	1	365	1,825
Rabbit	-	10	365	
Chicken	0.08	10	365	29
Total slurry supply				**16,819**
Slurry demand Crops	**Demand l ha^{-1}**	**Area ha^{-1}**	**Range l ha^{-1}**	**Total demand l ha^{-1}**
Mucuna	0			0
Napier grass	50,000	0.1	10,000-60,000	5,000
Alley branches	0			0
Pasture	4,000	0.1	3,000-10,000	400
Maize	30,000	0.1	10,000-40,000	3,000
Potato	20,000	0.1	10,000-30,000	2,000
Teff	6,000	0.1	5,000-10,000	600
Vegetables	800	0.01	-2,000	8
Herbs	400	0.01	-2,000	4
Fruit trees	3,000	0.1	-5,000	300
Coffee	6,000	0.5	-5,000	3,000
Total slurry demand		**1.12**		**14,312**
Slurry balance				**+2,507**

Sources: Own data, various sources (see Excel – manure calculations)
Remark: The slurry demand shows estimates. Slurry should not be applied to fruits and vegetables that are meant for fresh consumption due to possible transmission of harmful pathogens to humans.

18.3 Nutrient content of manure and slurry

Feed type, amount, and quality lead to different manure and slurry amounts and nutrient contents. Therefore, data from any catalogue might not fit for the specific farm situation (Table 86). Forage legumes, leaves of legume trees and hybrid grasses, as well as residues from industrial processing and concentrates from cereals lead to higher nutrient concentrations than fallow plants, straw, stubbles, or wooden parts of branches. The lower range numbers can be attributed to current practices among smallholder farmers, while the higher nutrient contents rather depict better management and fodder qualities.

Table 86. Nutrient value of fresh solid and liquid manures

Manure type	DM %		kg t^{-1} FM (= g kg^{-1}) N total		NH_4-N		P_2O_5		K_2O		Mg	
Solid	**Range**	**Ø**	**Range**	**Ø**	**Range**	**Ø**	**Range**	**Ø**	**Range**	**Ø**	**Range**	**Ø**
Cattle	16-43	22	2-8	5	0.5-2.5	1	1-4	3	1-9	6	0.5-2	1
Sheep & goat	25-48	31	6-9	8	1-3	2	2-5	4	6-16	10	1-4	2
Horse	25-40	32	20-35	28			8-16	12	30-50	40	1-3	1.9
Pig	20-30	24	4-9	7	1-6	3	2-9	6	2-7	5	0.5-3	1
Broiler	45-85	60	18-40	30	2-15	8	7-25	19	7-23	17	2.5-6.5	4
Layer	22-55	41	13-45	24	5-25	11	8-27	17	6-15	11	1-6	3
Liquid												
Cattle slurry (without water)	3-20	10	2-8	5	0.2-4	2	0.6-8	2	1-9	6	0.6-3	1
Sheep & goat	25-48	31	3-10	7			2-6	3	6-18	12		

Source: Teenstra et al. (2015) (see Excel - manure calculations)

Human faeces can be rich in nutrients, depending on food habits. Hence, collecting and applying the manure to crops means returning the nutrients to the soil. However, human manure should only be applied to trees due to possible contaminations with pathogens. Table 87 presents the average amount of nutrients human faeces contain, in comparison with the average nutrient demand of wheat.

Table 87. Human manure nutrient content and nutrient demand of wheat

Human manure (pure nutrient)	**N**	**P**	**K**
kg $year^{-1}$	2.1	3.5	5.1
Human manure (oxide form)	**NO_3**	**P_2O_5**	**K_2O**
kg $year^{-1}$	9.2	8.0	6.1
Nutrient demand of wheat	**N**	**P_2O_5**	**K_2O**
Expected yield 2 t ha^{-1}	43	17	31

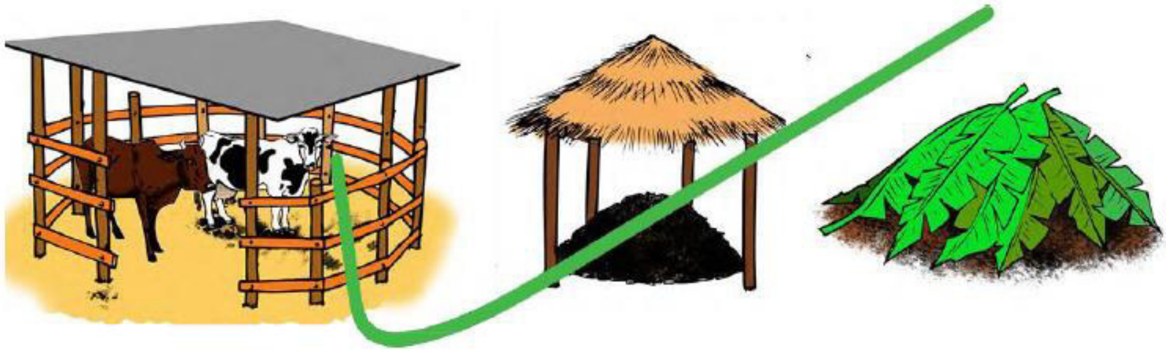
Sources: Various sources (see Excel – manure calculations)

18.4 Storing facilities

Handling and storing of manure and slurry is important as it heavily affects its quality. If manure is exposed to rain, many nutrients will be washed out and lost through the air in form of ammonium (10% to 90%). The nitrogen losses can be reduced if manure is stored in a more compact and anaerobic storage system.

Slurry should be collected in small ponds using plastic or a tank. The less straw, forage residues, alley branches, or saw dust is used in the stable, the higher is the amount of slurry. If slurry is not properly collected, specifically potassium loss is high. Figure 25 introduces some simple methods to reduce the loss of nitrogen through coverage methods.

Figure 25. Best practice examples of manure storage



Source: Teenstra et al. (2015)

Manure can be improved through high-quality feed, e.g. a feed ratio of straw, Napier grass and added leaves from *Sesbania, Calliandra, Gliricidia* or *Leucaena*.

In order to minimise nutrient losses, the farmyard manure should be protected from sun, wind, and rain. This can be done by covering the manure heap with polythene film, or better available enset and banana leaves. Manure should be stored for at least three months before use, as fresh manure can increases pest and disease occurrence.

18.5 Manure application

In most cases, manure should be directly applied to the crop or the crop row. Little amounts of slurry can be used to support the composting process. Application techniques and quantities are recommended as follows:

- Manure should only be applied to crops when they need the nutrients.
- The amount of manure depends on the crop requirements, the soil fertility status, and the share of short-term availability of manure nutrients.
- Manure/compost should be spread in the field when the soil is moist, optimally just before the planting starts to avoid nitrogen losses.
- Manure/compost should be spread in a uniform way (e.g. with a spade or fork).
- The manure should be covered on the same day to avoid heavy nitrogen losses.
- Under dry conditions and in light soil, the manure/compost should be incorporated into the soil to 15 cm, while under humid climatic conditions and in heavy soils to about 10 cm.

18.6 Further information

- https://edepot.wur.nl/362491
- https://edepot.wur.nl/383683

19 Compost management

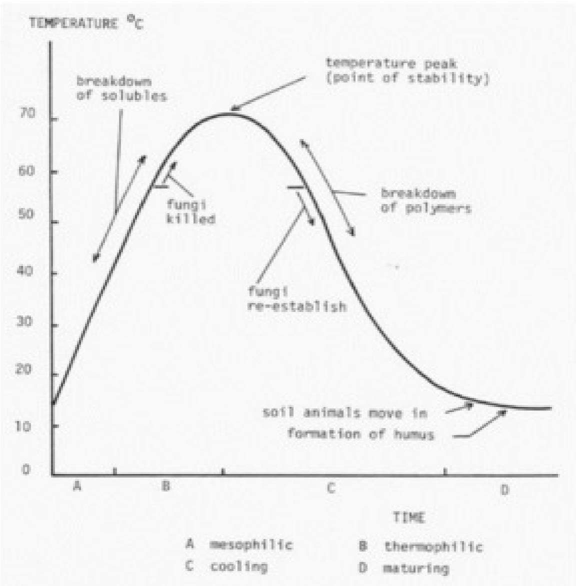
Section 1 introduces diverse composting techniques, their multiple values and applications.

Composting is a method for turning farm and household waste into a valuable fertiliser resource. The method of composting describes the natural fermentation or decomposition process of organic matter (OM) by microorganisms and under aerobic conditions. The main compost materials are residues from feeding, from the kitchen, leaves from trees (hedges and alleys), processing residues, and any kind of cutting material, which should have max. 1 cm diameter and cut in little pieces (< 15 cm).

Similar to animal manure, the nutrient source of compost is the soil and is therefore not an addition, with the exception of nitrogen from legumes. Composting is a labour-demanding activity. But their impact on reducing soil erosion, increasing soil fertility and thus crop yield on the other hand positively influences the income.

19.1 Compost production

Figure 26. Temperature curve in good composting practice



Source: Dalzell, Dalzell, Biddlestone, Gray & Thurairajan (1987)

During the composting process it is crucial to reach and hold for a few days a core temperature of around 60 °C (Figure 26). This helps to guarantee that pathogens and unwanted seeds are destroyed. To reach this temperature, a compost pile should always encompass at least 1 m^3 in size.

There are two methods of compost making that are most commonly used, the heap or pile method and the pit method.

19.1.1 Compost heap method

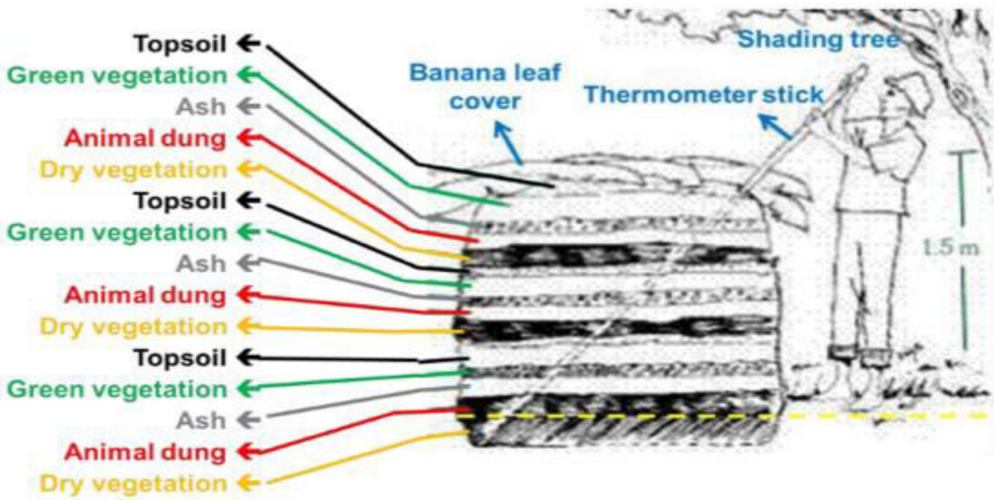
A compost heap is suitable for larger scale operations as well as small-scale systems in areas with high rainfall (Table 88 and Figure 27).

Table 88. Construction of a compost heap

Step	Description
1: Base preparation	The compost base should be 30 – 45 cm deep and 2 m wide and as long as it is convenient; the ground should be loosened and covered with coarse plant material (larger twigs, branches) to ensure good air circulation and drainage. The compost heap should ideally be placed under some kind of cover, like a big tree. To allow for the right temperature to build up, compost heaps should min. encompass $1m^3$.
2: First layer	30 cm layer of dry vegetative matter, chopped into small pieces, as they have a faster decay rate.
3: Second layer	10 cm layer of old compost, animal manure, or slurry; decomposition will be sped up with this extra bacteria and fungi.
4: Third layer	10 cm layer of green materials like kitchen waste, fruit peelings, fresh vegetation, etc. (maintain a ratio of one part of green material to three parts of dry matter in the compost).
5: Repeat layering	Repeat this layering until the heap reaches a height of 1 – 1.5 m.
6: Ash and soil sprinklings	Ash and topsoil of cropped land can be sprinkled onto the layers.
7: Watering	Water the whole pile well before covering; water the heap 1- 2 times per week (depending on rainfall); material should remain moist but not wet.
8: Covering	Cover the heap to protect it against heavy rains. A 10 cm layer of topsoil may be applied before additional covering with enset/ banana leaves/ foil; this should reduce nitrogen loss from the compost.
9: Thermometer stick	A long hollow (bamboo) stick is then driven into the pile at an angle, to check the heap from time to time and ensure additional air-circulation. If removed after a few days, the stick should feel slightly hot, as indicator that the composting process is working: • Stick very hot – decomposition process works too fast, compact heap and add water. • Stick not hot at all – more air or water needed. • Stick white - too much fungi activity (“fire fang”), add water.
10: Turning	The heap should be turned (switching of inner and outer layers) after 1-3 weeks, to allow for even aeration and decomposition; a second and even a third turning should follow after 3 weeks each. Cover heap again after every turning event.
11: Distribution	Depending on the conditions, the compost should be mature and ready to distribute (crumbly, humus-rich structure) after 6 – 12 weeks.

Source: Modified after Teenstra et al. (2015)

Figure 27. Schemata of a layered compost heap



Source: Teenstra et al. (2015)

19.1.2 Compost pit method

In case that liquid manure is available, it can be used in a pit for composting (Table 89). The pit should be shade-covered to prevent excess evaporation losses.

Table 89. Compost pit for liquid manure

Steps	Description
1: Pit preparation	1.2 m wide and 0.6 m deep, length according to the amount of materials available (min. 1m^3); in case of slurry composting: combined volume equal to the total digester volume, next to the biogas plant but at least 1 m away.
2: First layer	20 cm layer of dry materials (forest litter, waste grasses, straw) to absorb moisture and reduce nutrient leeching into the groundwater.
3: Slurry addition	Now let the slurry flow into the pit until the dry materials are well soaked.
4: Covering	Cover the slurry with a thin layer of dry material (straw, stable waste).
5: Repeat	Repeat steps 3 and 4 every day until the pit is full, then cover with dry straw/materials or a thin layer of soil and leave it for one month.
6: Turning	After a month, the compost in the pit should be turned and again covered with additional dry materials or a thin layer of soil; turn again after 15 days.
7: Distribution	Depending on the conditions, the compost should be mature and ready to be distributed (crumbly, humus-rich structure) after 6 – 12 weeks.

Source: Modified after Teenstra et al. (2015)

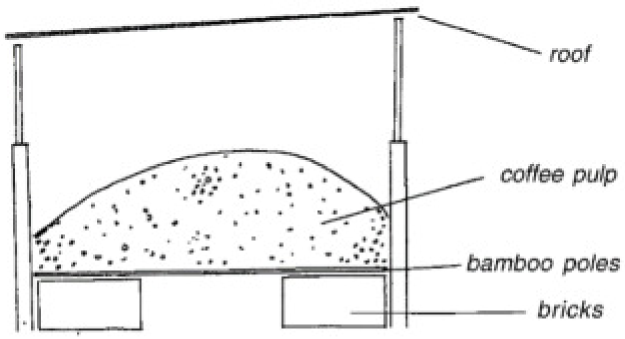
Figure 28. Slurry flowing into compost pit

Source: International Livestock Research Institute

19.1.3 Composting coffee pulp

In coffee producing areas, the pulp can be used effectively as compost, but high moisture levels pose a problem. Coffee pulp is a very dense material, therefore good aeration is key. Heaps of pulp need to be piled on an elevated floor (e.g. bamboo poles mounted on bricks) and roofed or covered to keep excess moisture out (Figure 29). The pulp should be well drained and mixed with vegetable waste, soil and, if available, some mature compost to obtain the right microorganisms. The heap should be turned every four to six weeks and mature in four to six months. Mixing coffee pulp with small pieces of volcanic stones or sand (8:1, pulp:pumice) accelerates the rate of decomposition.

Figure 29. Composting coffee pulp



Source: Inckel, de Smet, Tersmette & Veldkamp (2005)

19.2 Nutrients

For the composting process to function properly (in other words, to feed the right microorganisms), the carbon to nitrogen (C/N) ratio is to be adjusted via a specific combination of biomass. The ideal ratio should be somewhere between 20/1 - 30/1. Animal manure and legumes are high in N, dry vegetative parts like straw or sawdust are high in C. If too much N in form of green materials is included, the heap / pit will rot, and much N will be lost as gas. If the share of nitrogen is too low, the decomposition process will slow down and not enough heat is produced to break down materials such as weed seeds and pathogens. The approximate ratios of common composting materials show a wide variety in their C/N ratio (Table 90). As a rule of thumb, plant materials can be grouped by their colour into nitrogen rich “green waste” and carbon rich “brown waste”. The right mixture for composting is usually 25 – 50% green waste and 50 – 75% brown waste.

Table 90. C/N ratios of materials commonly used for composting

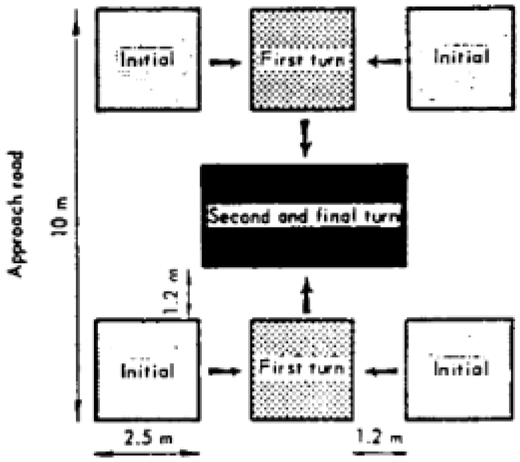
Material	C/N ratio
Ashes (wood)	25 / 1
Alfalfa	12/ 1
Cardboard, shredded	350 / 1
Cattle manure	20 / 1
Chicken manure	10 / 1
Coffee grounds	20 / 1
Food waste	30 / 1
Fruit waste	35 / 1
Grasses and weeds	20 / 1
Goat/sheep manure	14 / 1
Legume hay	25 / 1
Leafs	20-60 / 1
Maize stalks	60 / 1
Paper	800 / 1
Sawdust	200 / 1
Straw and hay	50-90 / 1
Vegetable waste	12 / 1

Sources: Various sources

19.3 Storing and moisture test

Compost should be kept covered, out of direct sunlight and rain. If the compost is not used soon after maturation, nutrients will be lost. To produce a regular supply of compost, the piling of three heaps/ digging of three pits side by side is advisable. With every turning (generally after two to three weeks), compost should be moved from one pit to the next and a new compost pile needs to be set up with fresh biomass (Figure 30).

Figure 30. Exemplary layout of a compost unit using several heaps



Source: Gotaas (1956)

The correct moisture in a compost heap/pit is crucial for decomposition to work properly. In order to test the compost for the right moisture, a bundle of straw can be added into the heap/pit. When taken out again after about five minutes, and the bundle is clammy, the heap contains the correct moisture level. If it is still dry, water needs to be added. Water droplets on the straw indicate that it is too wet, and the compost should be opened up and aerated immediately.

19.4 Distribution

On average, 15 to 25 % of compost can be gained from the total volume of raw material used for a heap/pit. To obtain a significant response by crops, it is advisable to apply compost at a minimum rate of 2.5 t ha^{-1} directly to the crops, with ideal dosage levels of 10 to 20 t ha^{-1} evenly spread over the whole field.

The chosen application rate depends obviously on the amount of available compost. If there is sufficient compost to achieve the minimum rate, the compost should be spread directly to the crops. In case available quantities are smaller, compost application should be focused on seedlings, freshly planted crops, plant nurseries, and vegetable gardens (Table 91).

The application of compost should be as close to the time of crop establishment as possible, to enable young plants to take advantage of the surplus of mineralised nitrogen and phosphorus in the soil.

Table 91. Guidelines for compost application

Place of application	Compost layer/ mixture with soil	Remark
Vegetables	5 cm	If used as mulch around plants, top dress around the base of the plants to the drip line. It is advisable to cover compost mulch with straw. For new plants, fill the planting hole with compost, then add the plant.
New garden bed preparation	2-10 cm	Use a rototiller, apply 2-10 cm of compost on top of the soil and till it to a depth of 10-15 cm into the soil.
Liquid fertiliser	1 part compost, 3 parts water	Mix water and compost, then leave it for three days before application.
Potting mix	1 part compost, 1 part soil	A high compost percentage prevents potted plants from drying out.
New trees and shrubbery	1 part compost, 9 parts soil	Soil-compost mixtures help in establishing new trees and shrubs.
Established trees and shrubbery	1 – 2 cm	Use as mulch around the base of the tree out to the drip line.

Source: Own compilation

19.5 Further information

- "The Preparation and Use of Compost; Agrodok 8" (1990) by Inckel, M. et al.; AGROMISA, PMB 41, 6700 AA, Wageningen, The Netherlands
- "Soil Management: Compost Production and Use in Tropical and Subtropical Environments" (1987) Food and Agriculture Organization of the United Nations (FAO) Soils bulletin 56. FAO, Via delle Terme di Caracalla,00100 Rome, Italy
- "Field Notes on Organic Farming" (1992) Njoroge, J. Kenya Institute of Organic Farming, PO Box 34972 Nairobi, Kenya

20 Biogas production

Section 20 introduces biodigester types, biodigester management, suitable substrates, biogas and bio-slurry production.

Smallholder farmers remove organic matter (OM) like livestock manure and crop residues from fields for fuel, construction, and feed purposes. OM can no longer be used to fertilize crops, removing nutrients from the farm that could otherwise be recycled. This competition between the two applications can be reduced by a biodigester, in which OM is transformed to biogas, a source of energy, and bio-slurry, which is a nutritious organic fertiliser. Utilising bio-slurry allows to recycle nutrients and use scarce resources efficiently and fits well in the organic farming (OF) approach, where all efforts should be conducted to optimise the nutrient cycling and fertilization of crops while protecting the forest (reduction of fuel wood use). Biogas can replace the traditionally used wood for fuel, which is particularly important as there is an increasing pressure on forests and its resources. Overall, a biodigester has a variety of benefits for the household:

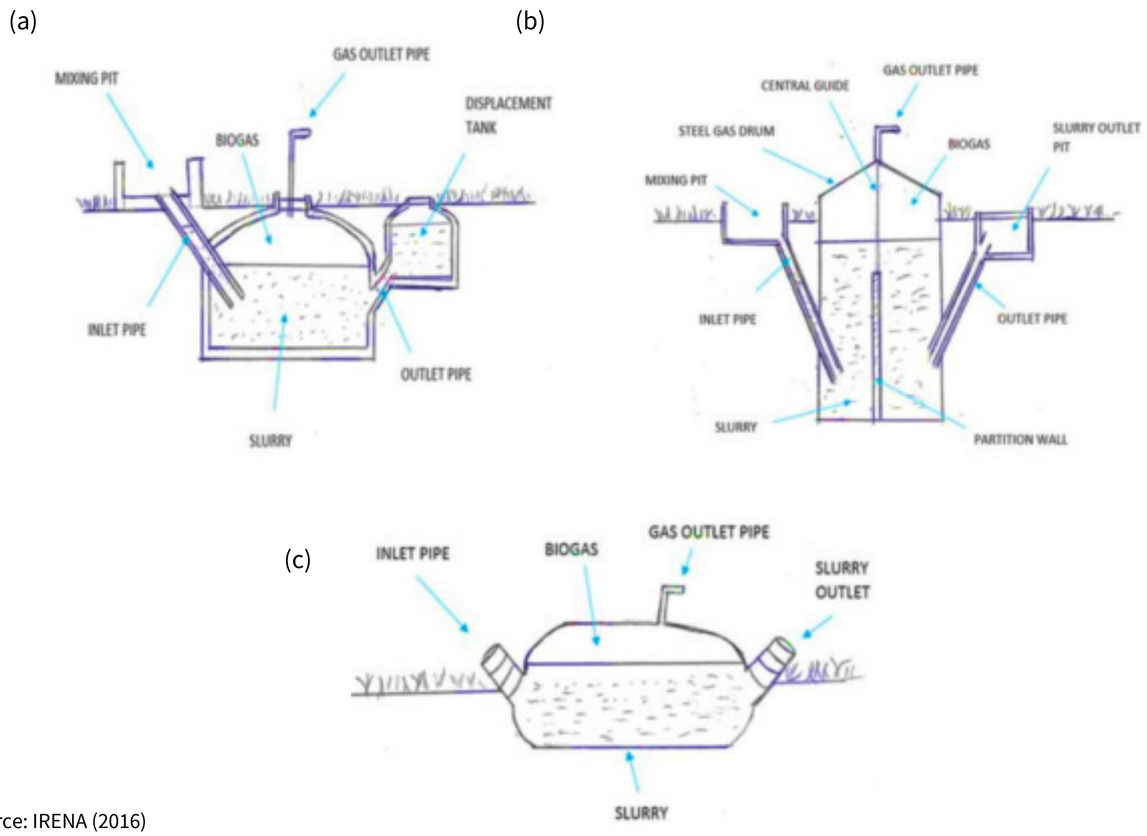
- Producing energy for light and cooking.
- Producing a nutritious organic fertiliser.
- Reduction in workload for women, as less firewood is required.
- Fewer greenhouse gases.
- Protects the unique rainforest of the Kafa Zone through replacing firewood by biogas for fuel.
- Enhances on-farm nutrient recycling.
- Economic benefits through fewer expenditure on chemical inputs, or when no fertiliser was previously used, higher profits through higher yields; fewer expenditure on traditional energy sources such as charcoal.

However, a biodigester requires an investment to start with, maintenance, and a good management throughout the year to function well. Different types of biodigesters in different sizes allow customized installations. However, costs and benefits must be weighted to make correct decisions.

20.1 Types of biodigesters and requirements

Three common biodigester designs exist. The fixed dome (Figure 31a), the floating drum (Figure 31b), and the tubular digester (Figure 31c). They are mostly different in their shape, while their functioning is similar. Generally, the substrate enters the biodigester through the inlet pipe or mixing pit and undergoes anaerobic decomposition in the chamber. During the decomposition phase, the gas rises and leaves the digester through the gas outlet, whereas the bio-slurry leaves the digester through an overflow into the bio-slurry pit. From this pit, the farmer can further handle the bio-slurry.

Figure 31. (a) Floating drum biodigester, (b) Fixed dome biodigester, (c) Balloon biodigester



Source: IRENA (2016)

The type of biodigester to be installed depends on the availability of finances, technical skills, space, and local materials available. A comparison between each design is presented in

Table 92, which can be used as a guideline for finding the most appropriate type of digester. Prior discussions with the farmer will provide information on their preference and help in the decision-making process. To ensure good quality and a leakage proof digester, all designs require a trained worker for installation. In addition, farmers need to be trained on how to manage the digester and carry out small repairs.

Table 92. Comparison of digester designs

Criteria	Fixed dome digester	Floating drum digester	Balloon digester
Type	Below ground	Below or above ground.	Below ground.
Lifespan	15-20 years.	8-12 years in a dry climate if gas holder is from metal.	2-5 years depending on plastic material.
Costs	Excavation and materials can be expensive.	Metal holders are more expensive than gas tight plastic holders.	The cheapest option.
Insulation	Installed below ground, well insulated.	When installed below ground it is well insulated; when installed above ground badly insulated.	Building a greenhouse around the biodigester will increase temperatures.
Mobility after construction	Requires exact planning, fixed construction.	Mobility depends on which materials are used.	Mobile and can be moved after installation.
Visibility of gas production	Not visible.	Yes, the drum floats up and down depending on gas availability.	Yes, the digester fills up like a balloon when gas is produced.
Easiness of cleaning the biodigester	As fixed in the ground and made from stones or cement, difficult but not impossible to clean.	Depends on the construction material.	Easy and uncomplicated.

Sources: Kossmann et al. (n.d.); Voegeli (2014)

There are some general requirements to consider before installing a biodigester:

- Temperatures above 15 °C. However, gas production increases with rising temperatures, as microorganisms become more active in warmer environments. In colder areas like the Kafa Zone, a below-ground biodigester is more suitable, as the soil reduces fluctuations in day and night temperature. To install an above-ground digester like the balloon digester, a greenhouse can be built to increase temperature and spurge biogas production.
- Constant inflow of substrates. Depending on the dry matter content water must be added.
- Site conditions:
    - For a below-ground biodigester: the soil should not be too loose and not fully saturated with water to reduce energy and time on digging.
    - For an above-ground biodigester: a small and levelled piece of land.
    - A digester should be close to the area where substrate is collected and to the area where the gas is utilised.

20.2 Substrate management

There are a variety of organic materials that can be used to feed a biodigester. However, each substrate yields a different quantity of biogas and bio-slurry, as the production largely depends on the organic share, the fraction of carbohydrates, proteins and lipids of a substrate. The higher the OM content, the more biogas will be produced. Substrates high in lignin like woody parts are unsuitable for a biodigester, as they cannot be digested by anaerobic bacteria. The diverse substrates need to be prepared before loading them into a biodigester:

- **Cow dung:** Cow dung is the most suitable for a digester, as it already contains the right bacteria and is grinded into small particles due to previous fermentation in the rumen. To transform cow dung into a homogeneous consistency, it should be mixed with water at a ratio of 1:1. Straw has to be removed to avoid clogging of the gas and slurry outlets. If the management system allows, urine can be added to increase gas production considerably.
- **Chicken droppings:** Chicken droppings can only be used if there is a collecting area, as the sand fraction is otherwise too high. If collected droppings are dry, they need to be pulverized and mixed with water before feeding the digester.
- **Human waste:** It is also possible to connect a latrine to the digester, which is particularly interesting for households who otherwise do not have access to a toilet. However, in some cultures, applying bio-slurry originating from human excrements is a taboo. Another challenge are remaining pathogens that survive the anaerobic digestion process. Bio-slurry from human excrement would thus require further handling before application to the fields, preferably to trees.
- **Horse manure:** Horse manure is less suitable as it contains a high amount of indigestible matter. Feeding it to the digester will therefore require prior chopping so that bacteria can better access the nutrients.
- **Goat and sheep manure:** Goat and sheep manure are valuable due to their high nutrient contents but must be chopped prior to mixing it with water and feeding the digester, due to the high fibre content. On the downside, its collection is time intensive and straw must be removed.
- **Kitchen waste:** To allow easier breakdown and avoid pipe blockage, vegetable matter has to be chopped into smaller pieces. Another option is to compost vegetable waste about a week before feeding the digester, as aerobic bacteria are better at breaking stronger organic structures.
- **Plant residues:** Plant cells are often strengthened with lignin and cellulose, making it difficult for bacteria to break down. As plant residues can also clog digester pipes, plant material should be used for composting the bio-slurry once it leaves the digester (see section on management of bio-slurry).
- **Coffee residues:** Wet coffee processing generates pulp, mucilage, and wastewater with a high organic load and sugar content, potentially producing high amounts of biogas. The husk from both wet and dry processing is not suitable due to its high fibre content and should be used to compost the bio-slurry.

The optimal consistency of a substrate to feed a digester is a homogeneous fluid. This can be reached by mixing the substrate with water at a ratio of 1:1. A variety of substrates are ideally mixed, as this will have an optimal C/N ratio for anaerobic bacteria to strive. Always, when starting a biodigester, cow manure or bio-slurry from another digester has to be used to inoculate the digester with suitable microbes.

20.3 Biogas yield

Biogas in Ethiopia is typically utilised for light and cooking purposes. The OM in a substrate is broken up by microbes and released as biogas. The typical composition of biogas is 55-70% methane, 35-40% carbon dioxide, and 2.7% water. Nutrients released through the fermentation leave the digester through the bio-slurry and are directly plant available. The biogas yield (l/kg FM) of selected substrates is presented in Table 93, while the average consumption of appliances used in Ethiopia is presented in Table 94. As the biogas yield originating from animal manure is largely dependent on the feed quality, it can be assumed that in the dry season biogas production falls by 20% due to lower feed quality and availability.

To ensure a required environment by anaerobic microbes, a biodigester needs to be well maintained. Some processes will help to ensure a steady gas flow:

- Add fresh material every day.
- Avoid adding too rich material.
- Do not add manure that is too old.
- Avoid adding manure from cows that received antibiotic treatment.
- Do not add water with soaps.
- Ensure that all gas pipes and valves are closed.

Table 93. Manure and biogas production per day of selected animals

Type of animal	Manure production	Biogas production	
	FM kg day^{-1}	l1 kg^{-1} FM	l day^{-1} animal^{-1}
Cattle	10	40	400
Chicken	0.075	70	5.25
Buffalo	12	30	360
Sheep/ Goat	2	44	88
Horse	10	56	560

Sources: Calculations based on Kossmann et al. (n.d.); IRENA (2016)
Remark: Exact values depend on feed quality and weather. If feed quality is high and outside temperature is higher than 25°C, biogas yields increase.

Table 94. Biogas consumption rate of selected appliances

Biogas appliance	Average biogas consumption l hrs^{-1}
Lamp	135
Household stove	325
Generation of 1 kWh of electricity with biogas/diesel mixture	700

Source: Kossmann et al. (n.d.)

Table 93, Table 94 and Table 95 offer some guideline data, assuming, that all manure is used as a substrate for the biodigester (per day):

- With 1 cow, 400 l of biogas is produced, enough to cook for about 1 hour.
- 1 cow provides about 3 hours of light.
- 1 cow can replace 2 kg of wood.
- 1 cow can replace 800 g of charcoal.

Table 95. Amount of l biogas that can replace 1 kg of wood and charcoal

Fuel source	Amount of biogas (l) corresponding to 1 kg of selected fuel source
Wood	200
Charcoal	500

Source: Kossmann et al. (n.d.)

The main disadvantage of a traditional biogas system, such as the ones presented above, is the absence of a biogas storage facility. This is particularly a problem for households that produce more biogas than is needed. Under any circumstances, the release of excess biogas into the atmosphere should be avoided, as valuable resources are wasted, and the emitted methane and carbon dioxide contribute to climate change.

20.4 Determining the biodigester size

To determine the size of a digester, the hydraulic retention time (HRT) and the daily waste production must be known. The HRT is a measure of the average duration in days that a substrate remains in the biodigester, largely dependent on the temperature. At an outside temperature below 20°C, the HRT is on average 75 days, while the HRT between 20-25°C is around 50 days, and from 26°C- 30°C around 40 days. Table 96 shows an overview of biodigester size, their input requirements and the biogas output.

How to calculate the size of a biodigester can best be shown using a practical example: A farming household with 4 cows would like to install a biodigester and use the manure to produce biogas and bio-slurry. The household decides for a balloon biodigester, as they are cheap and easy to construct by using local materials. In the area there is a prevailing temperature of 25°C.

The daily waste production will be: If 1 cow produces 10 kg of fresh matter (FM) per day, 4 cows produce 40 kg of FM (see Table 93). As manure is diluted at a ratio of 1:1 with water, the total weight is 80 kg. One method to determine the exact daily waste used to load the biodigester is to let the farmer collect the organic material for two weeks and record the daily production.

HRT: The ideal HRT at a temperature of 25°C is recommended to be around 40 days.

Calculating the biodigester volume (Formula 1)**:**

$$Biodigester\ volume\ (cm^3) = HRT\ (days)\ \times\ Daily\ waste\ production\ (kg)$$

$$Biodigester\ volume\ (l) = 50\ days \times\ 80\ kg = 4000\ l$$

The size of the biodigester should therefore be 4 m^3.

Table 96. Biodigester sizes, their input and biogas output per day

Biodigester size m^3	Daily cattle dung feedstock kg	Water to mix l*	Use of biogas stove hrs	Use of biogas lamp hrs
4	20-40	20-40	3.5-4	8-10
6	40-60	40-60	5.5-6	12-15
8	60-80	60-80	7.5-8	16-20
10	80-100	80-100	9.5-10	21-25

Source: Teenstra et al. (2015)
* depends on substrate liquidity

20.5 Bio-slurry

20.5.1 Characteristics and benefits

Bio-slurry is a nutritious organic fertiliser, containing the macronutrients nitrogen, phosphorus and potassium, and the micronutrients calcium, magnesium, iron and amino acids required for crop growth. A typical bio-slurry consists of 93% water and 7% dry matter (DM), of which 4.5% is organic and 2.5% inorganic matter. As unstable compounds are removed during anaerobic digestion and released as biogas, left over organic carbon in the bio-slurry is stable. This stable OM can strengthen the physical, chemical and biological soil properties. The OM is arranged in a lignin matrix, which forms the consistency of humus when added to the soil. This matrix is able to absorb and retain moisture and nutrients, increasing the soil water and nutrient holding capacity. This has a positive impact on root and plant growth, especially on largely depleted soils. Due to these characteristics, bio-slurry has a high potential to replenish soil nutrients and OM.

The breakdown of organic compounds during anaerobic digestion furthermore release nutrients that are directly plant available. As a result, bio-slurry has a higher ammonium to total nitrogen ratio than its substrate, as between 45-80 % of organic nitrogen is transformed to ammonium. Consequently, bio-slurry has a higher fertiliser value than other organic fertilisers. Also, as stable OM continues to mineralise during the growing season, nutrients are released and plant available steadily. Although the impact of bio-slurry compared to other fertilisers on crop yield is disputed, it will have a positive impact when access and availability to fertilisers is limited.

While nutrient loss is low during the anaerobic digestion process, the nutrient content of bio-slurry largely depends on the substrate quality. The rule of thumb is that nutrients fed to the digester equal the quantity of nutrients that leave the digester through bio-slurry. The nitrogen, phosphorus and potassium content of common animal manure used as a substrate is presented in Table 97. Nutrient values however can change, depending on feed quality. Nutrient requirements by specific crops in the Kafa Zone are presented in Table 98. These values may also differ, depending on soil quality, crop variety, and expected yields.

Table 97. Nutrient values of different types of solid manure

Manure type	FM kg day-1	Nutrient content kg / kg fresh matter			Yearly nutrient production kg / animal		
		N total	P_2O_5	K_2O	N total	P_2O_5	K_2O
Cattle	10	0.0048	0.003	0.0057	17.5	11	20.8
Sheep/ goat	2	0.0078	0.004	0.0099	5.7	2.92	7.2
Chicken	0.075	0.03	0.0166	0.0107	0.8	0.5	0.3

Sources: Calculations based on Teenstra et al. (2015), IRENA (2016)

To calculate the required quantity of bio-slurry to cover crop nutrient demand, data from Table 97 and Table 98 can be used. From this, some guideline data can be derived:

- To cover nutrient demand of 1 ha of wheat with a yield of 2.8 t ha^{-1}, bio-slurry from manure from 3-4 cows is required.
- To cover nutrient demand of 1 ha of maize with a yield of 3.7 t ha^{-1}, bio-slurry from manure from 5 cows is required.

However, these values assume that all manure is collected and used for the biodigester. If manure is only collected in the stable, and not all manure is used for the biodigester, these values will decrease accordingly.

Table 98. Nutrient uptake of selected crops

Crop	Average yield in Ethiopia t ha^{-1}	N uptake	P_2O_5 uptake kg $unit^{-1}$	K_2O uptake
Wheat	2.8	64.4	30.8	56.0
Maize	3.7	88.8	37.0	92.5
Faba bean	2.0	90.0	30.0	80.0
Coffea arabica	0.67	75.0	12.0	83.8

Sources: FAO (2020), Raiffeisen Ware (2020), Winston, Op de Laak, Marsh, Lempke & Chapman (2005)

20.5.2 Management and storage

The most appropriate way to store bio-slurry once it leaves the biodigester is through a bio-slurry pit (Figure 32). From this pit, the bio-slurry can be directly applied in its liquid form to crops or be further handled and transformed to its solid state through composting. The pit is connected through a slurry flow canal of 1 m length to the biodigester, with a slope to allow easy flow of the bio-slurry into the pit (Figure 32). Normally there are two pits, which alternate the collection of bio-slurry: while one pit is filled with bio-slurry, the other pit is used to compost bio-slurry. Generally, the combined pit size should be the size of the digester and min. 1 m long, 1 m wide and 0.8 m deep, an average size adapted to small farms. To avoid nutrient losses through leaching, the pit should be stabilized with bricks, concrete, or a plastic sheet, depending on the porosity of the soil. Furthermore, a roof above the pit will protect the bio-slurry from rain and sun, and reduce nutrient losses through volatilization (Figure 33).

In a well-functioning biodigester, bio-slurry is produced continuously, however bio-slurry crops only require nutrients at a specific time during the growing season. As bio-slurry contains a high water content when it leaves the biodigester, there is a high risk of nutrient losses through volatilization if not applied directly. One option is to install farm storage facilities for a certain time period. However, these require high investments and have a high-quality demand for the construction. Other possibilities related to handling or storing bio-slurry with available farm resources are:

1. Transport bio-slurry to other farms that apply bio-slurry directly.
2. Direct application as liquid bio-slurry: in rows, around a standing crop during the growing season, or as foliar application.
3. Bio-slurry transformation to solid bio-slurry through composting: application before planting or around the standing crop.

Figure 32. Bio-slurry pit

Source: Mia Schoeber

Figure 33. Bio-slurry pit with a roof

Source: Mia Schoeber

20.5.3 Application

20.5.3.1 Liquid

Liquid bio-slurry can be directly applicated after leaving the biodigester by using a row system, around the standing crop, or as foliar application. Application in rows uses gravity through a network of slurry furrows with a small slope (Figure 34). A furrow system can be directly connected to the biodigester or filled using buckets. Typical crops grown using this method are maize and vegetables. When applying liquid bio-slurry to growing plants like coffee or enset, first dig out a canal around the plant roots, about 0.5-1 m from the stem, then fill the canal with the bio-slurry and cover it with soil or mulch (Figure 35).

Foliar application is applied to the standing crop throughout the growing season. It can be applied to protect the plant against pests, but also as a fertiliser, as leaves can absorb required nutrients. For the application, the bio-slurry should be diluted with water at a ratio of 1:1 to reduce toxic effects due to a high ammonia concentration in the bio-slurry. The solution is then transferred to the crop using a watering can or any other suitable method (Figure 36).

Figure 34. Farrow system for bio-slurry application

Source: Mia Schoeber

Figure 35. Application of solid or liquid manure to a coffee plant

Source: Kenya Biogas Program (2016)

Figure 36. Foliar application of liquid bio-slurry

Source: Mia Schoeber

20.5.3.2 Compost

Composting can be a good alternative compared to the preservation of bio-slurry in its liquid state, as solid bio-slurry is easier to transport and to store. Suitable material for composting is any dry organic material such as straw, coffee husks, or dry grasses (like grasses from the coffee ceremony). An overview of a description of how to compost bio-slurry in a pit is presented in Table 89. The organic material absorbs the liquid and transforms the nutrients to its biological form, preventing water from evaporating and nutrient losses through volatilization. Mixing bio-slurry with OM like straw also speeds up its decomposition process as microorganisms can use nutrients present in the bio-slurry.

Composted bio-slurry can be applied on the whole field or directly around the crop throughout the growing season. It is best applied during soil preparation, as it should be mixed with the soil as early as possible to avoid excessive nutrient losses. When applying to crops around a standing crop like a coffee tree, a canal should be dug around the crop, about 0.5-1 m from the stem. The canal should be filled with composted bio-slurry and covered with soil or mulch to prevent nutrient losses.

To apply composted bio-slurry before planting trees, holes should be dug, depending on the crop (root) size. Composted bio-slurry should be mixed with the soil at a ratio of 1:1 and the seedling should be planted at 3/4 pit depth. Finally, the seedling can be watered and covered with mulch.

20.6 Further Reading

- Bonten, L. T. C. et al. (2014). Bio-slurry as fertiliser: Is bio-slurry from household digesters a better fertiliser than manure? A literature review. No. 2519. Alterra, Wageningen-UR.
- Kossmann, W. et al. (n.a.). Biogas Digest Volume I–IV. German Agency for Technical Cooperation (GTZ). Eschborn, Germany.
- Fulford, D. (2015). Small-scale rural biogas programmes: A handbook. Practical Action Publishing.
- Voegeli, Y., Lohri, C. R., Gallardo, A., Diener, S., Zurbruegg, C. (2014). Anaerobic Digestion of Biowaste in Developing Countries: Practical Information and Case Studies. Swiss Federal Institute of Aquatic Science and Technology (Eawag), Duebendorf, Switzerland.

21 Nutrient balances and consequences for fertiliser management

Section 21 introduces the calculation of farm specific nutrient balances and the consequences for fertiliser management. A valid calculation ensures sufficient nutrient supply for crop growth in an environmental-friendly manner. Hence, nutrient balance calculation is an important tool for the economic and environmental sustainability of a farm.

21.1 Aim of nutrient balances, data sources and general interpretation

Nutrient balances provide information for optimising the nutrient management at a farm. They serve for analysing and planning the nutrient status of a farm or field over the whole period of a crop rotation, support an economically viable application of fertilisers, and adjustments in the crop rotation to ensure the provision of nitrogen via legume crops. Nutrient deficits which limit crop growth, or an oversupply of nutrients damaging the environment can be avoided. As nutrient balances integrate all biomass, they also provide first information about the carbon cycle of a farm.

Each soil and climate indicate a certain yield potential, which informs about the nutrient demand of a crop. Under conditions of healthy and active soils, the crop nutrient demand is equal to the above-ground crop nutrient content, i.e. the harvested share taken from the field.

The data used for calculating nutrient balances are the quantities of products and the nutrient content of harvested products, organic and mineral fertilisers. Nutrient content and nitrogen fixation are usually derived from data catalogues. These data represent an average (see Table 99, Table 100), however, the presented values might differ to some extent to the real farm situation. Factors influencing the nutrient concentration of harvested products depend on the input level i.e. intensity of the nutrient input and soil characteristics of the farm. As a consequence, the presented values need to be adjusted to farm specific circumstances.

Table 99. Nutrient content of crops

Crop	Biomass products	N			P_2O_5			K_2O		
		kg nutrients per 1.000 kg of harvested product								
		from	to	∅	from	to	∅	from	to	∅
Wheat	Grain	11	18	14	5.6	10.4	8.0	4.2	7.8	6.0
	Grain+Straw	14	23	18	8.6	14.3	11.0	15.6	26.0	20.0
Barley	Grain	10	17	14	6.2	10.4	8.0	4.7	7.8	6.0
	Grain+Straw	13	22	18	8.6	14.3	11.0	17.9	29.9	23.0
Teff	Grain	14	24	19	6.2	10.4	8.0	4.7	7.8	6.0
	Grain+Straw	12	20	16	8.6	14.3	11.0	7.8	13.0	10.0
Maize	Grain	9	15	12	6.2	10.4	8.0	3.9	6.5	5.0
	Grain+Straw	14	24	19	7.8	13.0	10.0	19.5	32.5	25.0
Faba beans	Grain	25	41	33	9.4	15.6	12.0	10.9	18.2	14.0
	Grain+Straw	34	56	45	11.7	19.5	15.0	31.2	52.0	40.0
Peas	Grain	22	36	29	8.6	14.3	11.0	10.9	18.2	14.0
	Grain+Straw	31	51	41	10.9	18.2	14.0	31.2	52.0	40.0
Potatoes	Tubers	2.1	3.5	2.8	10.9	18.2	14.0	46.8	78.0	60.0
	Whole plant	2.5	4.2	3.4	13.3	22.1	17.0	54.6	91.0	70.0
Vegetables	Whole plant	2	6	4	0.8	1.3	1.0	0.4	0.7	0.5
Herbs	Whole plant	3	5	4	0.4	0.7	0.5	3.9	6.5	5
Alfalfa (DM)	Whole plant	18	30	24	5.5	9.1	7.0	2.3	3.9	3.0
Clover (DM)	Whole plant	22	27	24	4.7	7.8	6.0	2.3	3.9	3.0
Sorghum / Sudangrass	Whole plant	18	30	24	12.5	20.8	16.0	42.1	70.2	54.0
Napier grass	Whole plant	13	22	18	5	9	7	37	62	48
Pasture	Whole use	8	13	10	2	3	2.5	9	16	12
Coffee	Green bean	24	40	32	3	5	4	38	64	51
Mango	Fruit	0.7	1.2	1	0.26	0.44	0.35	1.6	2.6	2.1
Avocado	Fruit	11	41	26	4.4	22	13	24	73	48

Sources: Various sources (see Excel sheet – nutrient balances)

Due to their broad range of nitrogen content (Table 100), data for forage and grain legumes need to be estimated according to the farm specific conditions.

Table 100. Nitrogen provided by forage and grain legumes

Crop	N – amounts in roots and stubbles		N provided to the following crop	
	kg N ha^{-1}		kg N ha^{-1}	
	Range	Average	1st year 75%	2nd year 25%
Forage legume	70-180	120	90	30
Grain legume	20-100	60	45	15

Source: Estimated from Freyer (2003)

Generally, nutrient balances inform about nutrient quantities, the input-output of nutrients (farm, field, stable) and their distribution in the farm, and provide first information for the fertiliser management (see section 21.3). Annual positive and negative balances are acceptable if they follow the thresholds (Table 101). Beyond these data which serve as an orientation, positive balances are acceptable over a certain period if the soil indicates deficits, while negative balances are acceptable if the soil indicates a surplus.

Table 101. Acceptable annual nutrient balances

Nutrient	Accepted negative balance kg ha^{-1} a^{-1}	Accepted positive balance kg ha^{-1} a^{-1}	Remarks
Nitrogen	-25	+25	With up to +25, the risk of ground water pollution can be excluded, while -25 does not lead to an immediate negative impact on the crop yield.
Phosphorous	-5	+5	Annual negative balances with up to -5/-25 do not restrict the crop yield, but deficits in the long-term.
Potassium	-25	+25	

Source: Own compilation

The accumulated results (sum of several years) of nutrient balances over a crop rotation cycle inform about the long-term demand of nutrients from outside the farm and the need for the provision of nitrogen via legume crops (see the example in Table 102).

Table 102. Example of an accumulated farmgate nutrient balance for phosphorous (P) over 5 years

	kg ha^{-1}	%
Total soil nutrient stock ha^{-1} 30 cm^{-1} (soil depth) year 2015	**2,000**	**100**
Year 2015	-25	
Year 2016	-10	
Year 2017	-3	
Year 2018	-10	
Year 2019	-2	
Total 2015-2019	**-50**	
Total soil nutrient stock kg ha^{-1} 30 cm^{-1} (soil depth) year 2019	**1,950**	**97.5**

Source: Own compilation

21.2 Nutrient balance types

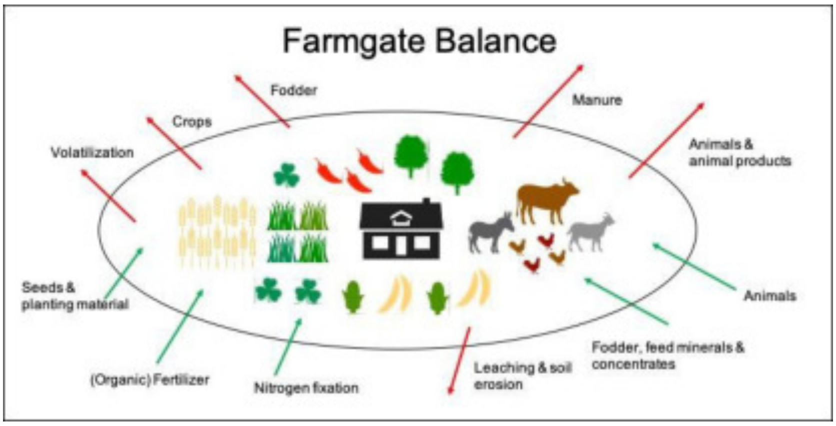
For optimising the nutrient management of a farm, two nutrient balance types can be distinguished:

1. Farmgate nutrient balance: overview about the general maintenance of nutrients.
2. Field nutrient balance:
    - Field-stable balance: nutrient balance including feed and animal manure.
    - Field balance: nutrient balance including the whole in- and output to a field.

21.2.1 Farmgate nutrient balance

The farmgate nutrient balance describes the nutrient flow in and out of a farm. The outflow comprises all crops, fodder, manure, compost, living animals or animal products (e.g. eggs, milk, cheese), etc., which are exported from the farm, while the inflow comprises the same products. Seeds and planting material, feed minerals and concentrates, as well as nitrogen from leguminous crops count as inflows as well (Figure 37).

Figure 37. Farmgate nutrient balance



Source: Own illustration

The long-term nutrient trend of the farming system must be calculated by summing up the results over the whole crop rotation period (see Table 103). It is sufficient to calculate a farmgate nutrient balance once a year, if the production, yields, and inputs are more or less the same over the years.

Table 103. Template for a farmgate nutrient balance calculation sheet

Product input	kg N	kg P	kg K	kg ha-1 N	kg ha-1 P	kg ha-1 K	% N	% P	% K
Fertiliser									
….									
….									
….									
Total fertiliser									
Feed									
….									
….									
Total feed									
Product output									
Crops									
…									
…									
…									
Total crops									

Animal products	
...	
...	
...	
Total animal products	
Total all	

Source: Own illustration (see Excel calculation sheet for own calculations)

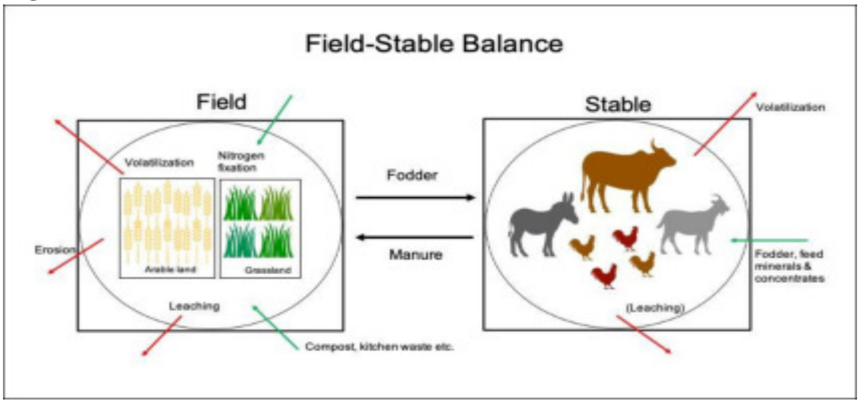
21.2.2 Field nutrient balance

Field i.e. plot specific balances are of relevance, as they inform about the (un-)equal distribution of manure and fertilisers in the farm. The results provide an orientation for the short-term and, if accumulated over years, the long-term development of the field nutrient status. The field nutrient balance includes two sub-types (Figure 38):

- Field-stable balance: nutrient balance including feed and animal manure.
- Field balance: nutrient balance including the whole in- and output on a field/plot.

The field-stable balance informs about the livestock specific organic fertiliser distribution. The stable also includes fodder and feed addition inputs from outside the farm, and all fodder that is transferred from the fields to the stable.

Figure 38. Field-stable nutrient balance



Source: Own illustration

The field balance includes all farm internal and external organic fertilisers, indirectly the external feed additions through the amount of animal manure and mineral fertilisers from outside the farm, and all crop biomass leaving the field. If the farm comprises grassland and animals only, both balances are equal. The field nutrient balances can be calculated for a single field or as an average of all fields.

The field-stable balance informs about the potential animal manure amount and nutrient content available for the crops. The more fodder and feed mineral supplements are imported from outside the farm, the higher is the nutrient content of the animal manure. The same accounts for the farm internal forage production if hybrid grasses and forage legumes are integrated into the farm's production. Therefore, nutrient contents of animal manure are farm specific and thus usually need farm specific adaptation by using literature-based data.

21.3 Consequences for the fertiliser management

Fertiliser management in organic farming (OF) refers to:

- Soil and (micro) climate conditions i.e. characteristics (see Table 104).
- Amount of pre-crop residues and their mineralisation characteristics (e.g. C/N).
- Results of nutrient balances.

Orientations for balancing nutrient deficits, i.e. the consequences for fertiliser management, are:

- **General:** Fertilisers should be given to those crops that have a specific need or are deficient of specific minerals. For example, legumes react positive to P application as it will support the fixation of nitrogen, while potassium supports the potato quality.
- **Nitrogen:** Increase of forage legumes and leguminous alley crops using branches as compost or mulch material.
- **Minerals:**
  - At farm level: additional organic or mineral fertilisers from outside the farm.
  - At field level: fertiliser distribution in the farm.
  - At plot level: fertiliser distribution in the whole plot, along crop rows, or directly to the single crop.

Fields close to the homestead are mostly over or well-fertilized, while those more distanced receive less fertiliser, also mirrored in the crop yields (Zingore, Murwira, Delve & Giller, 2007). Reasons might encompass limited transportation facilities or fear of theft.

Table 104. Soil and climate characteristics for the planification of nutrient demand

Soil / climate characteristics	Description	Evaluation**
Climate	Hot	+
	Warm	++
	Cold	-
Soil nutrient stock	Low	-
	Medium	+
	High	++
pH / soil nutrient availability	3-5	--
	5-7	++
Humus content (%)	>4%	++
	2-4%	+
	1-2%	-
Soil water conditions	Very dry	-
	Dry to moist	++
	Moist to wet	-
Proportion of coarse soil particles*	None	++
	Medium	-
	High	--
Soil depth	Low	-
	Medium	+
	High	++
Soil type	Light (sand)	***
	Medium	+
	Heavy (clay)	-

Source: www.duengerplan.at
*bigger sized soil particles (size of visible stones)
**effect of characteristics on nutrient delivery: -- = negative; - = slightly negative; + = positive; ++ = very positive
***dependent on: nutrient availability (P+N) generally increases as soils warm up, but nutrients also leach more easily in sandy soils

For fertiliser management, there are several aspects to keep in mind:

- The elder the plant the wider the C/N ratio, influencing mineralisation and availability of the nitrogen to the following crop (Table 104).
- While leaves mineralise in a short time, elder material with a wide C/N ratio mineralises slowly. As a consequence, fresh plant material should be applied. However, the more lignified plant parts additionally mitigate erosion control.
- The more humid the climate, the faster the mineralisation process.
- An estimated share of 75% of nitrogen will be provided to the following crop by forage legumes and 40% by grain legumes, based on their N-fixation rate. The rest is stored in the soil stock as part of the humus complex, and available for the crops in the following years.
- Further orientation for the fertiliser management of P and K is given by the estimated mineralisation rate of crops (Table 105).
- Deficits need to be covered with mineral fertilisers of phosphorous and potassium (certified organic fertilisers if the farm is certified organic).

Table 105. Estimation of nitrogen availability from different legume crops plant parts

Crop	Plant parts	C/N	Short-term nitrogen availability	Time
Peas, beans	Stem, leaves, pods, roots	< 10	+++++	Days
Sweet potato, irish potato	Wines, roots	< 10	+++++	Days
Teff/ wheat/ barley/ oat/ millet/ maize/ sorghum	Straw	20-200	+++ - +	Weeks – several months
Tree lucerne, crotalaria	Leaves	< 10	+++++	Days
	Young branches	15	++++	Weeks
	Older branches	50-300	++ to (+)	Weeks – several months
Forage legumes	Leaves	< 10	+++++	Days
Cabbage	Stem	10-30	+++++ to +++	Weeks
	Young thin roots	10	+++++	Days
	Old roots	20-200	+++ to +	Weeks – several months
	Leaves	10-20	+++++ to ++++	Days
Grass	Roots, stubble	10-30	+++++ to +++	Weeks

Source: Own compilation
+++++ = very high; + = very low

21.4 Example for a nutrient balance

The example represents a smallholder farm with total 1.6 ha, where 1.08 ha are arable land, 0.37 ha pasture, and 0.15 ha Napier grass, which is used over 3-5 years. The balance is a field-balance, where only organic manure from the stable is applied (Table 106, Table 107, Table 108, Table 109).

The results indicate a plus for N, a plus for P, and a deficit for K. Following the assessment rules introduced in Table 101, there is a need for adapting the fertiliser strategy as follows:

- N: The resulting balance can be considered acceptable.
- P: The resulting balance with a plus of 14 kg can be considered a little too high. The stocking rate of the farm might need to be reduced.
- K: The deficit for K_2O amounts to 84 kg and needs to be compensated with mineral fertiliser.

While nitrogen can be balanced via legume crops, deficits of phosphorous and potassium need to be covered with organic matter (OM) (e.g. feed, compost, processing residues) and/or mineral fertiliser from outside the farm (certified organic fertilisers if the farm is certified organic).

Table 106. Nutrient export from fields

		Area		Crop yield		Nutrient content of harvested products			
Two seasons	**Crop rotation**	**Acres**	**ha^{-1}**	**kg ha^{-1}**	**kg**	**kg N**	**% N-Fix**	**kg P_2O_5**	**kg K_2O**
1	Alfalfa	1.07	0.27	6,000	1,620	39	75	11	5
2a	Maize	0.28	0.07	5,000	350	7		4	9
	Maize	0.8	0.2	5,000	1,000	19		10	25
2b	Grain legumes	1.08	0.27	800	216	10	40	3.2	9
3a	Teff	0.97	0.24	2,000	480	8		5.3	5
	Teff	0.12	0.03	1,500	45	0.7		0.5	0.5
3b	Potato	1.08	0.27	15,000	4,050	14		5	28
4a	Vegetables	0.8	0.2	10,000	2,000	8		2	1
b	Herbs	0.28	0.07	1,000	70	0.3		0.04	0.4
	Napier grass	0.58	0.15	15,000	2,250	40		16	108
	Pasture	1.46	0.37	2,000	740	8		2	9
Total			**1.6**			**152**		**58**	**199**

Source: Own data (with values from Table 99) (see Excel sheet – nutrient balances)

Table 107. Nutrient input from stable to fields

Nutrients provided by fresh manure	Animals	Amount of fresh manure	Days	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	No.	**kg day^{-1}**	**No.**	**kg kg-1 manure**			**kg total**		
Cattle	2	17.5	365	0.005	0.003	0.006	64	38	77
Sheep & Goat	3	2	365	0.007	0.004	0.01	15	9	22
Poultry	5	0.8	365	0.024	0.017	0.011	35	25	16
Liquid manures									
Cattle slurry (no added water)	0	18	365	0.005	0.002	0.006	0	0	0
Sheep & Goat	0	3	365	0.007	0.003	0.012	0	0	0
Total							**114**	**72**	**115**

Source: Own data (with values from Table 86) (see Excel sheet – nutrient balances)

Table 108. Nutrient input from N-fixation by grain and forage legumes

	N-Fixation kg N ha^{-1}	Cultivated area ha^{-1}	N kg total
Forage legumes	120	0,27	32
Grain legumes	60	0,27	16
Total			**48**

Source: Own data (with values from Table 100) (see Excel sheet – nutrient balances)

Table 109. Nutrient balance

	N	P_2O_5	K_2O
Nutrient content of harvest products	152	58	199
Nutrient input from stable and legumes	163	72	115
Balance	**11**	**14**	**-84**

Source: Own data (see Excel sheet – nutrient balances)

21.5 Further information

Nutrient balances:

- http://www.fao.org/3/y5066e/y5066e00.htm#Contents

Crop residues:

- https://tspace.library.utoronto.ca/html/1807/23005/cs00043.html
- https://www.sciencedirect.com/science/article/pii/S0167198702000624
- https://www.sciencedirect.com/science/article/abs/pii/S0308521X14000316
- https://www.sciencedirect.com/science/article/abs/pii/S0167880903001506
- https://www.tandfonline.com/doi/abs/10.1080/01904160500474082

22 Farm and household

Section 22 provides a brief overview of the linkage between farm and household, and goods that can be produced and used beyond food and forage, which should be kept in mind when planning the production, labour, and farm economy.

22.1 Farm-household linkages

Farm and household are closely interwoven (Table 110). Labour, economic, and social units are dependent on each other.

Table 110. Interactions between farm and household

Delivery of crop-based material by the farm for the household	Delivery of material by the household for the farm
Crops for consumption and for sale	Kitchen waste as animal feed or compost.
Wood for construction and burning	Ash for crop fertilization.
Straw/grass and clay for construction	Wastewater for irrigation.
Seeds for storage	Seeds from storage for planting.

Source: Own compilation

22.2 Crops as a source for diverse household and farm purposes

Smallholders have the potential to produce a broad range of plant-based products beyond food and forage that are of high value for the farm household and maintenance of the farm. They can reduce expenses for products from outside of the farm and deliver further products for the market/to make an income. We differentiate the following crop groups and uses (Table 111).

Table 111. Crop groups and their functions for the household and maintenance of the farm

Crop group name	Usage	Examples
Food crops	Food for home and markets.	Cereals, root crops, grain legumes, vegetables, herbs and spices.
Stimulant crops	Alcohol, stimulants.	Hops, tobacco, khat, coffee, betelnut.
Medicinal crops	Human and animal health.	Kosso, lotus sweet juice.
Forage crops	Meat, milk, eggs, soil fertility.	Napier grass, *Sesbania*, rhodes grass, alfalfa, clover, desmodium, mucuna, crotalaria.
Alley crops	Forage, mulching, fencing, construction wood, energy.	Tree lucerne, pigeon pea, *Leucanea.*
Tree crops	Energy (cooking, heating, lighting) and construction material (fencing, housing, storing).	Acacia decumbens, african cherry, grevillea, (eucalyptus).
Soil fertility crops	Fertilizing, mulching.	Alfalfa, clover, desmodium.

Source: Own compilation

22.3 Planning food demand

Consequently, a farmer tries to implement a diverse cropping plan in a systematic way through planning the annual, medium, and long-term demand of certain crops for both the diverse home use and for the market. Therefore, a farm plan is needed for each field/plot over several years, for the household demands, costs, labour, and expected/ necessary income.

For a six-person household, the demand can be estimated over one year (Table 112). Obviously, the result of this calculation based on Ethiopian data leads to a demand which is beyond the current productivity of a 1 ha farm. Therefore, a specification according the food culture and food provision in the Kafa Zone is needed.

Table 112. Six-person household food demand per year

Product	Per person g day^{-1}	Per person kg a^{-1}	Per household (6) kg a^{-1}	Demand area ha^{-1}
Wheat	55.07	20.1	120.6	0.1
Maize	85.48	31.2	187.2	0.1
Sorghum	88.22	32.2	193.2	0.1
Barley	35.07	12.8	76.8	0.1
Teff	70.96	25.9	155.4	0.1
Other cereals (incl. processed)	31.23	11.4	68.4	0.1
Enset, kocho, bulla	112.33	41	246	0.04
Pulses	123.29	45	270	0.1
Oilseeds	41.10	15	90	0.1
Oils & fats	13.70	5	30	

Vegetables & fruit	2.74	1	6	0.001
Root crops	82.19	30	180	0.02
Sugar & salt	12.33	4.5	27	*
Beef	8.77	3.2	19.2	0.04
Mutton & goat	3.56	1.3	7.8	0.02
Chicken	1.37	0.5	3	0.01
Fish products	0.55	0.2	1.2	
Dairy products	40.27	14.7	88.2	0.18
Eggs	0.82	0.3	1.8	0.004
Honey	1.37	0.5	3	
Other foods	32.33	11.8	70.8	
Sum	**842.74**	**307.6**	**1,845.6**	**1.10**
Timber	**Per person kg day^{-1}**	**Per person kg a^{-1}**	**Per household (6) kg a^{-1}**	**Demand area ha^{-1}**
Fuel woods, construction, charcoal	5.00	370.00	2,220	0.222
		Total area needed (ha) 1,3		

Sources: National Food Consumption Survey Report Ethiopia, FAO, Seyoum (2013), and many others
Excel calculation (see additional material); * products bought

22.4 Further information

- https://www.ephi.gov.et/images/pictures/National%20Food%20Consumption%20Survey%20Report_Ethiopia.pdf
- https://livestocklab.ifas.ufl.edu/media/livestocklabifasufledu/pdf-/pdfs-by-country-pre2019/Minten-ESSP_WP113.pdf
- http://www.fao.org/3/t0207e/T0207E03.htm
- https://www.icarda.org/annual-report-2015/01-turning-the-tide-on-pulse-production-in-ethiopia.html
- http://www.fao.org/3/a-ab582e.pdf

23 Farm system planning

After learning about the different parts of a farm and how to organise and manage them, section 23 shows how to use the provided information in this handbook for the planning of a conversion towards organic farming. It guides through the organisation of the planning steps, starting by explaining the general characteristics of planning, the identification of targets, the planning process itself, planning schemes and reporting, and closes with a suggestion on how to generally organise such planning processes with farmers.

23.1 Planning characteristics

The conversion from non-organic farming toward an organic farm is always a process of planning the whole farm, including three main phases:

1. Analysis of the current farm situation.
2. Description on how the future farm should look like.
3. The pathway from the current farm to the future.

All sub-systems (see the sections and sub-sections of this handbook), such as soil, crop production, fertilization, forage for animals, or investments of a farm need to be analysed for all three phases in order to make visible:

(a) What must not be changed i.e. maintained?
(b) What can be adapted?
(c) What is completely new?

How detailed the single planning steps should be done depends on the farm situation itself and the targets of the planning process. The time calculated for establishing the changes depend on these targets as well. It can be some weeks, months, a year or even several years. Very often the decision to change towards organic farming (OF) includes a reset or re-organisation of the farm as a whole, due to e.g. the handover of the farm to the next generation. There are also restrictions i.e. limitations for the planning process, including:

(1) Ecological preconditions: Soil type, relief, climate
(2) Economic potentials: Financial resources, labour resources
(3) Limited knowledge: Knowledge about OF

Some of these restrictions, such as knowledge, can be overcome, others, like soil type, financial resources, or labour are often unchangeable.

23.2 Target identification

The initiation of change in a farm always starts with clear targets (Table 113). We distinguish between those with an obligatory character, describing in general what should be achieved after the farm completed the transition and new practices are established, and more specific targets, which in our case is the transformation of the farm towards organic agriculture (OA). Detailed targets can be added and then be used to monitor the implementation process.

Table 113. Farm planning targets (example)

Obligatory targets	Specific targets	Detailed targets
1 To secure food for the family over the whole year in quantity and quality	1 To establish an organic certified farm	1.1 To optimise the stable 1.2 To diversify the crop production 1.3 To optimise water harvesting
2 To avoid adverse effects on human health and polluting the environment	2 To increase income	2.1 To diversify the market channels for organic coffee
3 To secure income for health care and school fee payment	3 …	
4 To be prepared against climate change	4 …	
5…		

Source: Own compilation

Targeted planning provides an orientation for all the next steps. These targets are not set in stone. In general, planning is guiding a learning process. Often this learning process leads to new insights and ideas and ends up in a change of the plan.

23.3 Planning process

After these clarifications, the most relevant planning steps must be identified (Table 114) and integrated into a planning scheme. How to plan, structure, and develop the different parts of the farm can be studied in the preceding sections of the handbook. Market, specific labour, economic and investment aspects are only partly introduced above. Therefore, some further information is necessary.

Under "Status quo" the result of a measurement and the assessment is to be documented. Under "Future situation" the content of the target is to be formulated for each sector. "Activities for change" inform about what must be done to reach a targeted future situation. The column "Start…end" informs about the follow-up of the diverse activities, when to start and when the result should be achieved.

Table 114. Planning scheme

Farm sector	Section	Status quo	Future situation	Activities for change	Start … end
Site characteristics					
Soil and climate	5, 6, [illegible], 24				
Relief	5, [illegible]				
Crop production					
Crop rotation	[illegible]				
Soil tillage	8				
Organic fertiliser	20, 21, 22, 23				
Weeds	9				
Pests and diseases	1				
Alleys and hedges					
Soil erosion	6				
Planting trees	11				
Specific crops					
Coffee	1				
Fruit trees	-				
Pastures					
Management	13				
Animal husbandry					
Livestock	14				
Dairy cattle	15				
Sheep and goats	16				
Poultry	17				
Household					
Management	22				
Markets and marketing					
Labour					
Economy					

Source: Own compilation

Changing the market approach (providing organic products, etc.) creates a need for information about and an analysis of the local, regional, national, and international market for the specific products. This is mainly not conducted by the smallholder farmer, but a service that should be provided by private and public institutions. However, to identify individual market niches it is also the responsibility of the farmer to identify specific options. In general, diversified market channels are recommended, as far as the number of products allow such a strategy. Otherwise, it should always be studied if a collaboration with other farmers is an option for optimising the marketing of products.

The planning of labour demand is based on former experiences. If new working steps are established, estimations, information from literature, or experiences from other farmers should be used. Any planning process also needs to optimise the farm internal organisation and household activities. Changing or optimising parts of the farm always comes with additional labour for the learning process (trial and error), as well as the organisation and implementation of the innovation. Collaborative activities with neighbours and relatives are common and recommended.

Through new procedures, crops, animals, and markets, significant changes in the farm and household economy as a whole can be achieved. An economic analysis is a must and the foundation of any change in a farm. Often economic data can only be estimated. Therefore, calculations should include average, worst, and best case scenarios. When it comes to investments, it should be analysed if a shared investment with other farmers, or the use of a service provider is feasible.

23.4 Planning sheets and reporting

There are several Excel sheets for each thematic field prepared that can be used to calculate the farm specific situation. Where not available, advisors can develop own planning sheets adapted to the planning topic and farmers demand.

Furthermore, a map of the whole farm, inclusive household and some information about the neighbourhood, is obligatory for drawing in the diverse activities. Two plans, including the status quo and the targeted future situation, are helpful, as farmers often prefer a visual presentation of their farm.

The planning process is documented with the plans and additional calculations and a written text with the most relevant information. The implementation of the identified activities follows a schedule (see Table 114). Ongoing monitoring and evaluation serve as the foundation for optimising the planning process, the assessment of the usefulness of every activity, and the need for revision, optimisation, or extension of a certain activity.

23.5 Organisation of the planning process

We recommend a combination of group and farm individual approaches for guiding and planning the change toward OF as follows:

(a) Building gender balanced farmer groups for change (max. 20 farmer families).
(b) General introduction into training a group of farmers.
(c) Developing individual plans with the farmers.
(d) Evaluation and monitoring of continuous change with the farmer groups by organised farm visits around the year.

The specific situation in a Woreda or Kebele, as well as the financial background, must be considered when organising such activities. At least the whole process should be coordinated with a certification body and the specific formalities prepared according to the OF guidelines (see section 2.4).

23.6 Further information

- Prowse (2007)
- Fan, Brzeska, Keyzer & Halsema (2013)
- Walaga, Hauser, Delve & Nagawa (2005)
- Netting (1993)
- Ayuya et al. (2015)
- Sempore, Andrieu, Nacro, Sedogo & Le Gal (2015)
- Kamau, Stellmacher, Biber-Freudenberger & Borgemeister (2018)
- Nalubwama et al. (2014)

24 Annex

24.1 Animal feed

Table 115. Livestock feedstuffs

Name	Description	Limitations / Remarks
Alfalfa	Can be fed green to rabbits or cut, sun dried, and stored for hay to be fed to ruminants; can be ground into a meal for use in rations for monogastric animals.	Limit of 20% in swine and chicken rations.
Bananas	Meet 50 to 75% of energy requirements in all animals.	Fill problem. Can be unpalatable and toxic if green.
Barley (grain)	Can replace corn for swine and chickens with a slight drop (10 to 30%) in weight gain; produces eggs with a very light-colored yolk.	Poor protein quality. Should be ground or crushed except for sheep/poultry.
Beans	Field beans only to pigs and chickens, entire pod to goats and rabbits.	Sundry, limit to 40% of protein requirement.
Beet pulp	Rich in carbohydrates, low in protein, poor in fat, and high in fiber.	Palatable to cattle, goats, and sheep Not a feed for monogastrics.
Bermuda grass	Important pasture grass for cattle, sheep, and goats.	Can be used for hay.
Blood meal	Boil for 30 minutes or until it coagulates, then sundry for two to three days.	High in excellent quality protein Unpalatable to poultry, limit to 5% of ration.
Bone meal	Phosphorus supplement, but difficult to prepare - must be cooked under steam pressure or for longer periods in open kettles and then sun dried.	Use only 1 or 2% in rations.
Brewers dried grain	Dry in the sun for two to three days. Use for swine and poultry.	Fill problems; if of good quality can be used, exclusive protein source for poultry/swine!
Buckwheat	Should form only 1/3 of the grains in the ration. Ground for all livestock except poultry.	Produces soft pork meat.
Cassava meal (maniac, yuca & tapioca)	Can be fed (cooked or raw) to pigs, cattle, sheep, and goats Leaves are richer in protein and minerals than root; boil roots for 30 minutes and sundry for two to three days.	Must be mixed with water or molasses for poultry. Storage is difficult.
Chick peas	Can be fed raw to swine, for chickens boil 30 minutes and then sundry. Can be used up to 50% as protein source.	Harvesting and supply problems.
Clover hay	Good for cattle, sheep, goats, and rabbits; can be fed green.	Watch for bloat.
Copra meal	For chickens and pigs.	Use only 20% in rations.
Corn (yellow dent corn)	Excellent energy source for all animals. Should be shelled and cracked before being fed.	Poor protein quality. Should be ground for poultry.
Corn and cob meal	Used for cattle, less common for goats and sheep. Can form 20% of the meal.	Not preferred for swine, rabbits, or poultry.

Cottonseed meal	Excellent protein sources for ruminants. Must be industrially processed.	Limit to 50% of protein source for pigs Limit to 10% of ration for pigs and 5% for chickens.
Field peas	Palatable for all livestock. Feed to swine and rabbits raw, for chicken boil 30 minutes and sundry for two to three days.	Can be used as sole protein source, but do not feed pods to pigs and chickens. Harvest and supply problems.
Hominy	A milling by-product of corn.	Fed to all livestock.
Leucaena	Up to 30% for cattle and 20% for goats.	5% limit in ration for chickens and pigs due to toxicity.
Meat and bone meal	Excellent amino acid balance. Used as protein supplements for swine and poultry.	Must be boiled (30 min) and sun dried.
Millet	Should always be ground or rolled except for poultry.	Not equal to corn.
Molasses (beet and cane)	Used commonly for cattle.	Limit to 10% in growing chickens and pigs, 20% to adult chickens and pigs. Can cause scours in pigs.
Oats	Palatable to all livestock; bulky, can reduce cannibalism in poultry; popular dairy feed; palatable to rabbits.	Fill problem with swine due to bulk and fiber content; for swine it equals 80% of the value of corn pound for pound; limit to 10 to 15% of poultry ration.
Peanuts	Can feed entire plant during early bloom to rabbits. Good as forage. Use only the nut for pigs and chicken.	Must be dry, humidity forms toxic molds; medium quality protein; use for up to 50% of protein requirements.
Peanut meal	Excellent protein supplement for all animals. Highly palatable to swine.	Becomes rancid quickly in warm, humid climates.
Peas	Highly palatable to all livestock, can be substituted for grains; can be fed raw to swine, cattle, and rabbits, for chicken boil 30 minutes and sundry for 48 hours. Can be used as a sole protein source.	Do not feed pod to chickens and pigs Harvest and storage problems.
Pineapple bran	Feed only to cattle.	
Plantains	See Bananas.	
Potatoes	Boil 30 minutes and sundry for two days for swine and poultry. Good energy source; chicks and piglets must have them peeled; feed raw to cattle.	Fill problem; basis for survival diets; 4:1 ratio in energy values with grains.
Sorghum	Sundry the fodder, excellent energy source for all animals Feed fodder only to cattle; should be ground except for sheep, palatable to rabbits; feed value equal to corn; some varieties grown for silage; dry well to eliminate prussic acid.	Limited in amino acids, palatability may be a problem. Green grain sorghum plants are poisonous due to the presence of prussic acid.
Soybeans and soybean meal	Boil for 30 minutes and sundry for two to three days for chickens and pigs; can be fed raw to ruminants; excellent protein supplement for all animals; high in lysine and can produce soft pork.	Should be ground before feeding; SBM is a better feedstuff than whole soybeans for monogastric animals.
Sugar	Excellent energy source for all animals except piglets and chicks.	Normally not an animal feed due to expenses.

Sunflower seeds	High in fiber and low in amino acids; remove hull by soaking, used in ruminant feeds and as meal in non-ruminant feeds. Good to combine with a high lysine supplement.	Require industrial proceeding for pigs and chickens and should be limited to 25% of protein requirement for monogastrics.
Taro	Boil 30 minutes and sundry; cooked tubers good for all livestock; leaves are relished by cattle and sheep.	Unknown inhibitors for chickens and pigs.
Wheat bran	Formed by the coarse outer coatings of the wheat kernel.	Very bulky; can work as a laxative; palatable to all livestock.
Wheat grain	Should be cracked and coarsely ground for all animals Wheat powder is not very palatable. Can be used as "finisher" for cattle and sheep, preferred by poultry to all other grains.	Limit to 50% of concentrate mix Expense limits its use as an animal feed. Poor protein quality and low in calcium.
Whey	A by-product of the making of cheese; very low in protein; one pound of whey (dried) is equal to 13 to 14 pounds of liquid whey in nutrients; high in riboflavin.	Fed primarily to swine.
Wing beans	The root tuber is high in energy; boil 30 minutes and sundry for two to three days; pod with seeds may be fed whole to pigs, chickens, goats, rabbits, and cattle.	Can be used for at least 50% of protein requirements in all animals.
Yeast (Brewer's yeast)	Excellent source of highly digestible good quality protein Contains B vitamins and growth factors.	It can replace up to 80% of the animal protein portion of swine and poultry rations when supplemented with calcium.

Source: Bacon (1982)

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