Organic and Climate Change Adapted Agriculture at the Kafa Biosphere Reserve, Ethiopia

Guidebook for Supervisors

Imprint

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List of abbreviations

Al	Aluminium
C	Carbon
CEC	Cation exchange capacity
comp.	compare (with)
CP	Crude protein
DM	Dry matter
EOA	Ecological Organic Agriculture Initiative
FM	Fresh matter
GMO	Genetically modified organism
hrs	Hours
ha	Hectare
HRT	Hydraulic retention time
ICS	Internal Control System
K	Potassium
K_2O	Potassium oxide
kg	Kilogram
l	Liter
IFOAM	International Federation of Organic Agriculture Movements – Organics International
M.a.s.l.	Meters above sea level
m	Metre
N	Nitrogen
NABU	The Nature and Biodiversity Conservation Union
OA	Organic agriculture
OF	Organic farming
OM	Organic matter
P	Phosphorus
P_2O_5	Phosphate
PGS	Participatory guarantee system
t	Tons
ToT	Training of Trainers

1 Introduction

Section 1 introduces the reader to the idea and background of the handbook and how it is structured and used.

1.1 Why a handbook on organic farming?

In Kafa Zone, partially protected as Kafa Biosphere Reserve within UNESCO's worldwide biosphere reserve network, agriculture constitutes the most important economic sector and guarantor for income and food security for local communities. At the same time agriculture has significant impact on natural ecosystems and may disturb ecosystems' resilience. This calls for organic forms of agriculture, balancing the demands of communities with the smallest possible impact on biodiversity and ecosystems while addressing long-term soil fertility and the effects of climate change. Organic farming (OF)

- is based on increasing crop diversity - the backbone of healthy nutrition for humans and animals. Crop diversity is reducing pest, disease and weed pressure and helps to balance extreme weather events;
- aims at enriching biodiversity in order to increase root biomass and reduce evapotranspiration for increased natural soil fertility;
- increases economic well-being by adapting to climate change, maintaining and increasing agro-biodiversity and often productivity of farms and households;
- offers premium prices through certification and source marketing e.g. the label of the Kafa Biosphere Reserve.

NABU therefore promotes OF for Kafa Zone and in particular for Kafa Biosphere Reserve and elaborated this guide and reference book together with experts from University of Natural Resources and Life Sciences, Vienna (Austria). The goal of this handbook is to provide solid knowledge for advisors to guide farmers in the process of converting to OF or simply to optimise their current organic practices in the Kafa Zone. The book offers training material and can also serve teachers, students and scientists. Enjoy reading and support organic farming!

Your NABU team

To enable the right application of this handbook by advisors, we highly recommend ToT sessions to propagate the use of this handbook in combination with the ***additionally provided excel and poster material (also see www.kafa-biosphere.com). For planning steps of OF and climate adaptive measurements see section 23****.*

1.2 Challenges of smallholder farmers in the Kafa Zone

The population in the Kafa Zone is growing and thus the average farm sizes are decreasing. Today the majority of farm families own less than 1 ha on average while approximately 60% own less than 0.5 ha. Farmers' demand for agricultural land pressures the natural forest resources. The ongoing cutting of trees and mismanagement of agricultural activities lead to soil erosion and humus losses far beyond 50 t ha^{-1} a^{-1}, thus contributing to an increase of (regional) temperatures and changes in the regional moisture regime.

All these activities might additionally hamper the cultivation of the most relevant cash crop coffee. A further cutting of trees will increase the risk of intensifying the impacts of climate change and therefore reducing agricultural productivity and life quality of the whole zone.

Smallholder farming is at a critical stage due to these various challenges. Environmental degradation leads to a decrease of productivity and finally lower income. The internal causes affecting the production level and thereby related consequences are manifold and can only be understood if we look at the farm and household as a whole (Figure 1).

Picture 1. Tree cuttings lead to erosion

Source: Pierre Ellssel

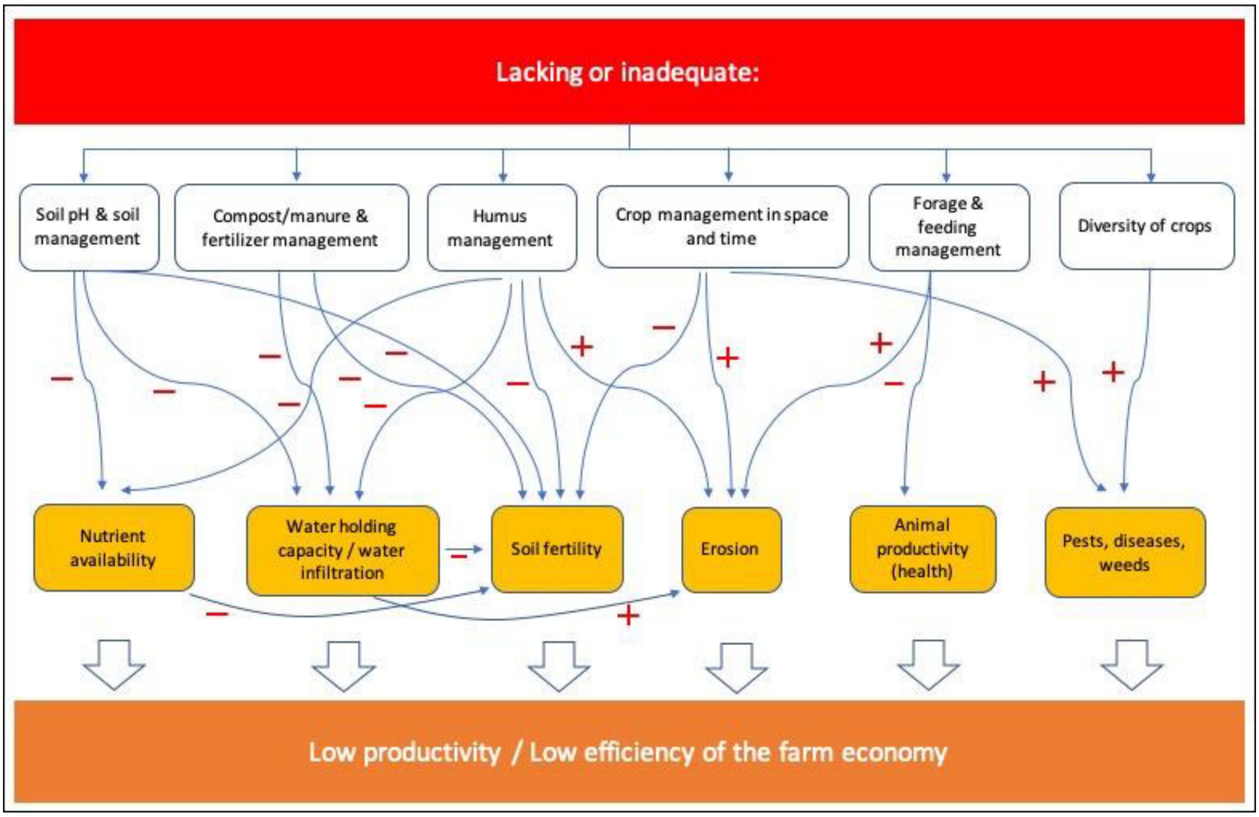
Picture 2. Semi-forest and garden coffee cultivation combined with trees and banana

Source: Pierre Ellssel

Knowing the underlying factors / reasons and how different deficits in farming are interconnected, farmers are enabled to critically analyse their farms and make a change. Advisors can support farmers with specific recommendations, trainings and best practices. In other words, knowledge of reasons as well as specific tools and techniques are the entry point for farmers to optimise the whole farm and household.

Yet, especially if farmer families depend on very small farm holdings, the more important is a sustainable use of available resources while at the same time adapting to a changing climate.

Figure 1. Influence diagram – Farm internal factors with negative impact on environment and smallholder farmers productivity (lack of/inadequate management procedure (white box), decreases = minus (-), increases = plus (+), environmental factor (yellow box))



Source: Own illustration

Finally, there are not only farm management deficits, but also external factors negatively impacting the overall performance of smallholder farms. Specifically, climate change is challenging the survival of smallholder farms. Low prices, lack of financial support, availability of technology and limitations in adequate trainings accompany the situation.

1.3 Content and structure of the handbook

This handbook is primarily prepared to support advisors, i.e. development agents, teachers, students and scientists, to acquire an overview about OF practices in general and specifically related to the Kafa Zone, to support farmers toward changing to OF or optimising already existing organic farms. It can be used not only as an information or learning material for advice, training, and education, but also for different planning purposes, monitoring and evaluation processes.

The content of the handbook entails many relevant sub-systems of an organic farm. At the beginning of each section there is a box with a brief summary what the reader can expect. For several sections we additionally list under “Further information” internet sources and literature that can be used for further exploration of a topic.

Several organic farms are already established in the Kafa Zone - mainly for coffee production. For those farms the guide might offer information on how to optimise their current farming system. For others, who are still not organic and intend to transform their farm, the guide offers overall background information about OF and provides necessary planning data with regards to production, labour and parts of the farm economy.

The guide introduces to the diverse parts of the farm. Each section and its sub-sections can be studied independently from others, although linkages to other sections always exist. The guide offers diverse tables with data for calculating e.g. forage or nutrient balances. Market aspects are excluded, as costs for farm inputs as well as prices at the market are continuously changing.

As far as data are available for calculations, they are prepared in an excel sheet which you can use for adaptation to your specific planning case. The majority of planning data presented in this handbook was not available in a comprehensive manner but was assembled from many different sources. Therefore, you might need to adapt data and calculations to the specific farm case. A planning process is briefly introduced in section 23.

2 The overall approach of Organic Farming

Section 2 explains what organic farming means, distinctions to other farming methods, their ethical foundations described in the IFOAM Principles, and an introduction into the guidelines.

2.1 What is organic farming?

Organic farming (OF) was established in 1972. Today it is practiced in more than 120 countries all around the world. The International Federation of Organic Agriculture Movements (IFOAM) defines Organic Agriculture (OA) as "a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. OA combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved."

Organic production is therefore not simply the avoidance of chemical inputs, as applied in conventional agriculture, or the substitution of these inputs by natural components. It is a practice which emphasizes the system's overall health by implementing a wide range of strategies and management practices in order to develop and maintain biological diversity, soil fertility and the overall agro-ecosystem stability. OA as an agricultural method is mainly based on its own resources and it can only be successful if the following practices are established/implemented (Table 1).

Table 1. Comparison of traditional, conventional and organic farming practices

Practices	Traditional*	Conventional	Organic	Aim of Organic
Crop rotation	By default, 3-4 crops.	Narrow to none.	Crop rotation with more than 8 crops following rules.	Promoting soil fertility, breaking of disease cycles, fostering diversity and resilience.
Animal dung and slurry	Rarely systematic handling and application.	More reliance on synthetic fertilisers.	Mainly organic fertiliser.	Promoting soil fertility.
Synthetic fertiliser	A few farmers use it, but not systematically according to crop demand.	High application rates.	Not allowed, except rock-phosphate, K_2SO_4 and carbonic lime.	Synthetic fertilization does not align with the systemic thinking of OF.
Crop residue	Burned or used for animal feed (pasturing of arable fields).	Removed/ burned or mixed into soil.	Crop residues left on field, planting of cover crops.	Crop residues improve soil structure and add nutrients.
Tillage	Mainly the traditional plow.	Mainly the traditional plow, disc plow in larger farms.	Shallower tillage, diverse approaches.	Ploughing can lead to long-term destruction of soil structure and declines in soil fertility and organic matter (OM) levels.
Weed control	Chemical or non-chemical.	Mainly chemical.	Crop rotation, tillage, cover crops, mechanical weeding.	Chemical herbicides harm non-target species; avoid tolerance build-up of weeds against herbicides, avoid dependence of farmers on companies.
Pesticides	Sometimes application of chemical pesticides.	Chemical pesticides.	Crop rotation, tillage, no chemical pesticides, biological control (e.g. neem oil, pheromone traps).	See above → weed control (chemical herbicides).
Seeds	Own and purchased seeds, partly with a chemical protection.	Focus on high yielding varieties, (sometimes) seed saving restrictions by companies.	Focus on resistant varieties, own and purchased seeds, partly with a non-chemical protection, OF focus on input optimisation instead of output maximization.	Seed saving makes farmers independent, allows for regionally adapted varieties.

Chosen cultivars	Locally available.	Yield maximisation.	Resistance to stress.	
Intercropping	Sometimes applied.	Often mono-cropping.	Intercropping as integral part of the farming system.	Intercropping: Additional income, resilience, synergetic plant-plant relations.
Soil fertility	No specific strategy.	Usually no specific strategy.	Soil fertility is a key focus and investments are made in every season.	The maintenance / improvement of soil fertility is a central focus of OA.
Compost	Sometimes applied.	Reliance on synthetic fertilisers.	Systematic use of compost as fertiliser or humus provider.	High quality fertiliser, cycling of nutrients at farm level.
GMOs (Genetically modified organisms)	Sometimes applied.	Used in conventional farming.	Excluded in OF due to ecological, ethical and social reasons.	
Additives in animal husbandry	Sometimes applied.	Usage of growth hormones, antibiotics.	Growth hormones are excluded, use of antibiotics restricted.	Growth hormones & antibiotic residues remain in animal products, careless use of antibiotics leads to long-term resistance build up by microorganisms.
Animal welfare	Not a specific concern.	Of lesser concern.	Guidelines to guarantee animal welfare.	Ethical treatment of animals as a principle of OA.
Workload	Labour intense.	Under certain circumstances less workload.	Often more labour, however, with positive impact on farm sustainability and increase of yields.	
Regulations	No regulations.	Contract based (with companies).	Legislative guidelines, certification and inspections.	

Source: IFOAM Norms for organic production and processing 2014
* the current most dominating approach

2.2 The organic farming principles

The IFOAM formulated four general principles, on which OA is based on (IFOAM, 2005). These principles are the roots from which OA grows and develops. Although facultative, they guide your practices. In which way you may act, you should question if the practices applied follow the four principles (see also Figure 2):

1. **The principle of health**

This principle states that the health of individuals and communities cannot be separated from the health of ecosystems. Healthy soils produce healthy crops, which in turn are the base for healthy people and animals. Health is defined not only as an absence of illness but of continued well-being. Immunity, resistance and resilience are its key characteristics. The role of OA, whether in farming, processing, distribution, or consumption, is to sustain and enhance the health of ecosystems and organisms.

2. **The principle of ecology**

This principle emphasizes the interconnection of agriculture with its ecological environment. OF, pastoral and wild harvest systems should fit the cycles and ecological balances in nature. These cycles are universal, but their operation is site-specific. OF operations have to be adapted to local conditions, culture and scale. Ecological thinking works in cycles, and in order to maintain and improve environmental conditions, methods of recycling and efficient management of energy and materials are central. OA should attain an ecological balance through the design of farming systems, establishment of habitats and maintenance of genetic and agricultural diversity.

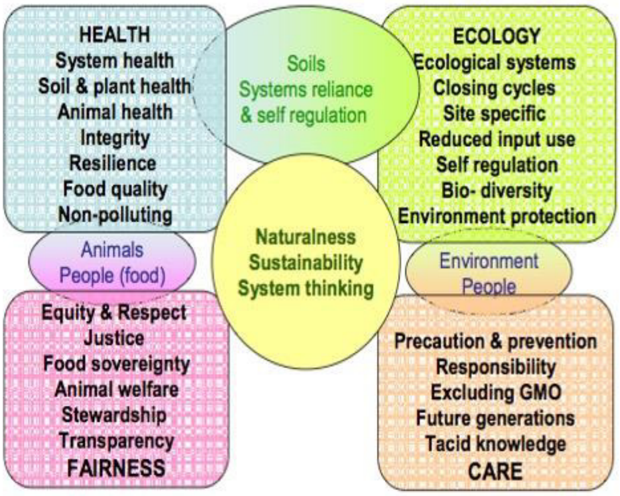
3. **The principle of fairness**

Following this principle, those involved in OA should conduct human relationships in a manner that ensures fairness at all levels and to all parties – farmers, workers, processors, distributors, traders and consumers. OA should contribute to a good quality of life, promoting food sovereignty and a reduction of poverty by producing a sufficient supply of high-quality foods and other products. This principle also encompasses the fair treatment of animals, which should be provided with living conditions that accord with their physiology, natural behaviour and well-being.

4. **The principle of care**

OA is a dynamic system, responsive to internal and external demands and conditions. In a changing world, new technologies need to be assessed and existing methods constantly reviewed. Given our incomplete understanding of ecosystems and agriculture, this principle emphasises precaution and responsibility as key concerns in management, development and technology choices in OA. Scientific knowledge, practical experience, as well as traditional and indigenous knowledge should all be combined to take the necessary care when adopting appropriate technologies and rejecting unpredictable ones, such as genetic engineering. A transparent and participatory decision-making process should be used to reflect the values and needs of all parties involved.

Figure 2. IFOAM Principles for Organic Agriculture



Source: Padel, Jespersen & Schmid (2007)

The following Table 2 summarises the IFOAM principles and provides practical examples of the principles' meaning for the farmer and the respective strategies and actions.

Table 2. IFOAM principles summarised

IFOAM Principles	What does this mean for the farmer (examples)?
Principle of health	Resistant crop varieties, soil health via cover crops, extended crop rotations and shallow tillage, no chemical pesticides and fertilisers.
Principle of ecology	Crop rotations, intercropping, preserving/creating natural elements for predators of pests, adapted grazing, integration of manure and compost, use of site adapted crops.
Principle of fairness	Organic products are more expensive and secure fair prices for farmers, business relationships with long-term purchase contracts.
Principle of care	No GMOs, long-term strategies that secure environmental sustainability, no untested technologies.

Source: IFOAM

2.3 The organic farming guidelines

OF follows guidelines that must be fulfilled along the whole value chain. Farmers have to follow all rules if they wish to be certified organic. The guidelines precisely describe what is allowed and what is not, e.g. with regard to inputs such as fertilisers, feed material, substances for pest and disease management, medicine etc. Some aspects in the guidelines are only recommended, but their application will support a sustainable and resilient production. The guidelines sometimes appear to be very rigid, but clear guidelines are necessary for the consumer communication and trust. This might seem less important for the (local) Ethiopian market due to a lack of awareness and demand, but it is of high importance for the international market. However, exclusion of practices as recommended in the guidelines would lead to a less efficient production. In case farmers are not complying with guidelines they might lose their organic certification and thus their access to the export market and premium prices.

The following Table 3 presents an overview of obligatory and additional recommended practices for OF operations. The complete list of norms and practices can be found at https://eoai-africa.org/.

Table 3. Most relevant obligatory and recommended practices of the organic agriculture guidelines

Themes	Obligatory or recommended practices	Remark
Documentation	The operation should keep records appropriate to the scale and ability of the farmer.	A system for traceability of organic products has to be maintained.
Contamination	Chemical products that endanger human health or the environment, as well as contamination through such products, has to be avoided.	
GMOs	GMOs or their derivatives, as well as ingredients, additives or processing aids derived from GMOs, shall not be used in OF and processing.	
Social justice	The fair treatment of employees and workers has to be guaranteed in OA.	
Biodiversity	In OA, biodiversity is to be maintained and promoted wherever possible (e.g. hedges as boundaries, trees in fields).	
Farming system diversity	Diversity in plant production, OM, soil fertility, microbial activity and soil and plant health shall be stimulated by crop rotation, intercropping, agro-forestry and other appropriate measures.	
Soil and water conservation	Soil conservation forms an integral part of OA and a variety of methods are available to guarantee sustainable soil conditions (e.g. windbreaks, soil cover, cover crops, minimum tillage, fallowing (with vegetation cover), mulching, terraces and contour planting). Burning of vegetation is to be restricted and water saving promoted.	
Soil fertility management	Material of microbial, plant or animal origin shall form the basis of the soil fertility programme, fertilisers of mineral origin shall be applied in the form which they are naturally composed and extracted. They shall not be rendered more soluble by chemical treatment, other than the addition of water. Mineral fertilisers may only be used for long-term fertility needs, along with other techniques such as OM additions, green manures, crop rotations and nitrogen fixation by plants.	Fertilisers and soil conditioners approved for use in OA according to the IFOAM Basic Standards or CAC GL32 may be used.
Pest, disease and weed management	Physical, cultural and biological methods for pest, disease and weed management, including the application of heat, may be used.	Inputs for pest, disease, weed or growth management approved for use in OA according to the IFOAM Basic Standards and CAC/ GL 32 may be used.
Seeds, seedlings and planting materials	Seeds, seedlings and planting materials from organic production shall be used. If organic seeds, seedlings and planting materials are not commercially available, then conventional, chemically untreated seed, seedlings and planting material may be used.	Chemically treated seeds & materials: only if nothing else is available (docu-menttation required!).
Animal production		
Conversion and brought-in animals	The animal husbandry and individual animals brought into a herd shall undergo a conversion period.	
Parallel production	Products from the same type of animal and the same type of production, which are both organic and non-organic (conventional or in-conversion) on the same farm, shall not be sold as organic unless the production is done in a way that allows for the clear and continuous separation of the organic and non-organic productions.	

Animal management	Animals shall be kept in accordance with good animal husbandry practices, i.e. access to sufficient fresh air, water and feed, sufficient protection from the elements and adequate housing conditions that allow for natural behaviour.	
Breeding	Artificial insemination is allowed in OA, embryo transfer and cloning techniques are forbidden.	
Mutilations	Animal mutilation may not be practiced, except for ringing, castration and dehorning of young animals.	The suffering of animals should be minimised (appropriate use of anaesthetics).
Animal feeds	Animal feedstuff should be as organic as possible, animals should be given access to as much fresh fodder as possible and the farmer should supply as much own fodder as possible.	
Parasite and disease management	OA promotes methods of disease prevention; if animals get sick, phyto-therapeutic methods should be preferred to synthetic veterinary drugs or antibiotics.	
Transport and slaughter	Handling, including transport and slaughter, shall be carried out calmly and gently and involve the minimum of physical and mental strain or stress for the animals.	
Bee-keeping	Organic materials for hive disinfection, no synthetic bee repellents, only natural smoking materials.	
Recommended practices		
Agroforestry	Inclusion of trees into the farming system.	
Wide crop rotations	Diversified and wide crop rotations are preferable.	
Ground cover	Avoid bare soil as much as possible.	
Inclusion of legumes	Legumes fixate nitrogen.	
Tethering of animals	OA allows for the tethering of animals, but in accordance with animal welfare, this practice should be minimised as much as possible.	

Sources: IFOAM & EAOPS

Table 4 provides information about some practices that are specifically not allowed in certified OA. If a farmer intends to become organic certified, it is crucial for farmers and advisors to be well aware of the rules and regulations in order to avoid incompliance.

Table 4. Practices that are explicitly not allowed in organic farming (OF)

Theme	Description of practices prohibited in OF
Synthetically produced substances	Synthetic fertilisers, herbicides and pesticides are prohibited in OA; some exceptions are, for example, copper sulphate, elemental sulphur, ivermectin.
Biological interventions	Plant and animal growth regulators, hormones, antibiotics (restricted use!), embryo-transfer.
Technologies	Nanomaterials, GMOs.
Methods	Agricultural residue burning, sewage sludge use, irradiation.

Sources: IFOAM& EAOPS

2.4 Certification

In case a farmer intends to sell his produce under an organic label, the guidelines must be fulfilled. To become certified organic, a certification process, which is defined by law, has to be followed. Farmers can also follow the organic guidelines without a certification process. However, in this case you can neither sell the products to retailers nor export them to other countries under the label 'organic'. Due to the efficient farming practices and premium prices, in many cases OF is promising better income than the traditional, and also often than the conventional method.

2.4.1 Certification procedure

A certification system is usually built upon the following components:

- Standards
- Contracts
- Inspection
- Approval
- Management
- Labelling
- Information

To certify the production / products, a farmer is required to follow a series of steps (Table 5).

Table 5. Follow-up of the certification process of an individual farm

Step	Description	Remark
1: Contact & research	Choosing and contacting a certification body, studying of organic standards, preparation (e.g. seed origin).	
2: Application	Contract with certification body, preparation of field histories and field maps, fees, start of conversion period.	
3: Pre-inspection review	Examination of problem areas, preparation for inspection.	Saves time and money on inspections.
4: Inspection	Annually, documents and farming practices will be reviewed, access to all parts (organic & non-organic) of the operation must be granted to inspectors.	Can be a learning tool for the farmer.
5: Final review and decision	Inspection report and other documents are sent for review, certificate(s) are issued.	

Source: Weidmann and Kilcher (2011)

2.4.2 Certification approaches

Three certification approaches exist which can be of relevance, dependent on the products of the farm, certification costs and other aspects:

1. The farm is certified individually.
2. The farm is part of a group certification process, as it is practiced for coffee farmers.
3. The farm is part of a participatory guarantee system (PGS).

2.4.2.1 Third party certifiers for organic farming in Ethiopia

Currently, three internationally recognised certification bodies (Table 6) carry out certification in Ethiopia through locally-based representatives.

Table 6. Organic food system certifiers in Ethiopia

Certifier	Description
Ecocert IMO	Certifier founded in Switzerland, based in Addis Ababa. Specialises in ICS-certifications for smallholders.
Ceres	International certifier, based in Addis Ababa. For individual farmers as well as groups, traders, wild collection companies, beekeepers.
BCS	The first German certification body registered under the Organic Regulation of the EU, based in Addis Ababa.

Sources: Certifier websites

2.4.2.2 Group certification

Individual certification is often too expensive and too administratively complex for many smallholder farmers. If this is the case, group certification offers an affordable alternative.

While PGS may be suitable for local markets, a group certification system allows for access to export-oriented markets.

In a group certification system, a group of farmers implements an Internal Control System (ICS) and becomes collectively certified by a third-party certification body. This third party assesses the performance of the ICS and performs a representative number of spot-check inspections of group members.

When is a group certification system feasible?

Group certification can be considered where there are many farmers producing similar crops using similar production practices. There is the need for some organisational structure as well as a common marketing strategy. The system thereby is useful for smallholder farms which, on an individual level, would not produce enough products to cover the cost of individual external inspections.

What is an ICS?

An ICS functions as an internal audit (ISO53) and is managed by a project operator (e.g. an exporter or a group of farmers). All participating actors (smallholders as well as their extension officer/internal inspector) have to be identified, instructed, contracted and, if necessary, sanctioned by the project operator. The third-party certification body evaluates the ICS and can carry out re-inspections. A functioning ICS needs good documentation (e.g. member list, area map, contracts, inspection forms, a certifier approved grower's list) carried out by the ICS manager or a documentation officer.

The ICS is ideally combined with farm research, extension work or other quality management functions of agricultural professionals.

2.4.2.3 Participatory guarantee systems (PGS)

IFOAM defines Participatory Guarantee Systems (PGS) as "locally focused quality assurance systems. They certify producers based on active participation of stakeholders and are built on a foundation of trust, social networks and knowledge exchange." They were developed as a reaction to the high costs of third-party certification. PGS set a high priority on knowledge and capacity building of producers and consumers. It involves the sharing of ideas and local capacity building. The producers have the power and responsibilities to make the PGS work. However, it is seldom accepted for export.

A well-functioning PGS requires the identification/definition of the group (farmers and consumers) that will work together. Paperwork can be less exhaustive than with third party certification, but there is a need for recognised standards, contracts, etc., and some kind of documentation of the production processes.

Decision making by the group has to be clear, sometimes the delegation of oversight to an external certification body is recommended. Clearly defined and implementable consequences for farmers, who are not fulfilling the standards, are necessary. Seals and labels also need to be recognized.

2.5 Further information

- https://www.ifoam.bio/sites/default/files/poa_english_web.pdf
- https://www.ifoam.bio/sites/default/files/ifoam_norms_july_2014_t.pdf
- https://www.organic-africa.net/
- https://www.oecd.org/aidfortrade/47719232.pdf
- https://orgprints.org/35159/7/fibl-2019-ics.pdf
- https://www.organic-africa.net/fileadmin/organic-africa/documents/training-manual/chapter-08/Africa_Manual_M08.pdf

3 Organic farming in Ethiopia and in the Kafa Zone specifically

Section 3 informs about specific activities on organic farming (OF) in Ethiopia.

3.1 Organic farming in Ethiopia

As of 2015, about 200,000 farms have been certified as organic in Ethiopia (Table 7). Most of them are small-holders with an average farm size of 1 ha. The largest share of exported organic products are coffee, followed by sesame and honey.

Table 7. Organic agriculture in Ethiopia

Year	Organically managed land [ha]	Share of total agricultural land	Number of producers
2015	186,155	0.5%	203,602

Sources: IFOAM (2019), Ethiopian Institute of Agricultural Research

3.2 The Ecological Organic Agriculture Initiative (EOA)

The Ecological Organic Agriculture Initiative (EOA) is led by the African Union and started in 2013. It aims to establish an African OF platform based on available best practices and develop sustainable OF systems. Its mission is to promote ecologically sound strategies and practices among diverse stakeholders in production, processing, marketing and policy making to safeguard the environment, improve livelihoods, alleviate poverty and guarantee food security. The project is currently being implemented in eight African countries: Benin, Ethiopia, Kenya, Mali, Nigeria, Senegal, Tanzania and Uganda.

The EOA project is funded mainly by the Swiss Development Corporation (SDC) and the Swedish Society for Nature Conservation (SSNC). In-country activities are driven by six strategic pillars:

- Research, training and extension
- Information and communication
- Value chain and market development
- Networking and partnership
- Supportive policies and program
- Institutional capacity development

Further activities exist, e.g. for organic coffee marketing, supported by GIZ and others.

3.3 Implementation of organic farming

The history of organic agriculture (OA) in Ethiopia follows five leverage points (Table 8). Today, OA is fully established in Ethiopia. First certified OF operations in Kafa were established with the export of coffee, especially wild coffee.

Table 8. Organic farming development in Ethiopia

Year	Event
2003	Establishment of the organic taskforce.
2004	Adoption of the Cartagena Protocol on Biosafety by the government.
2006	Issuing of Federal Negarit Gazeta: Proclamation No. 488/2006 to establish “The Ethiopian Organic Agriculture System”.
2006	Inclusion of environmental issues in Ethiopia’s Poverty Reduction Strategy Programme (PRSP).
2013	Start of the EOA initiative.

Sources: Diverse sources

Table 9. Organic farming development in the Kafa Zone

Year	Event
Since approx. 2010	Increasing share of smallholder coffee farmers converting to organic farmers, and a smaller group with herbs and spices.

Sources: Feedback from experts

Picture 3: Micro-demo farm training in Bonga

Source: Bernhard Freyer

3.4 Further information

- www.ifoam.bio
- https://www.giz.de/en/worldwide/39619.html

4 Natural conditions of the Kafa Zone

Section 1 introduces three main agroecological zones, climate data, climate change, and topography, which are relevant for the selection of crops and the planning of cropping systems as well as strategies to avoid soil erosion.

4.1 Agroecological zones

An agroecological zone is defined by the climatic conditions, the characteristics of the soils, the landform[1] and/or the land cover. From these characteristics the potentials, constraints and ecological requirements for land use can be determined. The Kafa Zone has three major agroecological zones (Table 10).

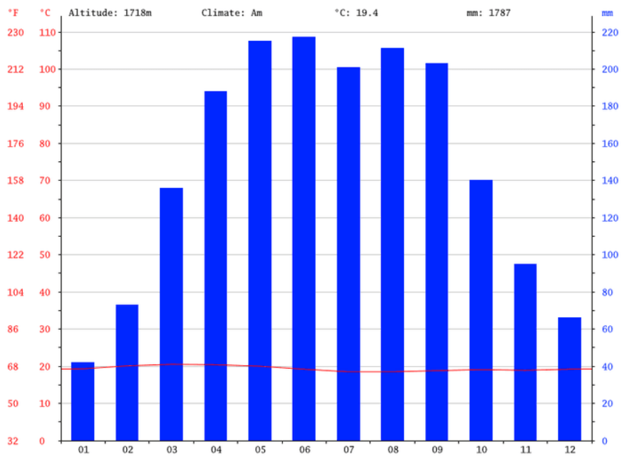
Table 10. Agroecological zones of the Kafa Zone

Zone	%	m.a.s.l.	NN mm	T C°
Highlands (Dega)	9	2,300 – 3,200	900 – >1,400	11 – 16
Midlands* (wet/moist Weyna Dega)	70	1,500 – 2,300	900 – 2,300	16 – 20
Lowlands (wet/moist Kolla)	21	500 – 1,500	900 – 1,400	20 – 27

Source: Hurni (1998)
* Area of Bonga Town

4.2 Climate

Figure 3. Climate diagram for Bonga (midland)



Source: https://en.climate-data.org

The climatic factors temperature, rainfall, evaporation, global radiation, hours of sunshine, and their distribution over the year are determining factors for plant growth. The temperature influences plant growth and thus biomass production. For example: Biochemical reactions double between 0°C and 30°C with every 10°C increase. High temperatures limit the yield if water is not sufficiently available.

4.3 The mean temperatures in the Kafa Zone range between 11 and 27°C across the three agroecological zones (Table 10). Therefore, the possible growing season spans across the year, when not limited by rainfall or other water supply sources. Climate

Figure 3 exemplary shows the rainfall distribution and average temperature over the year of the town of Bonga (midland).

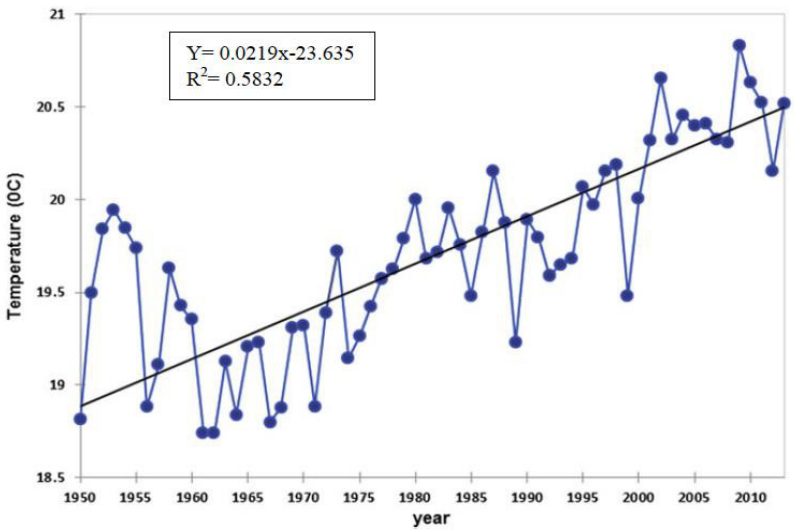
[1] Major landforms are mountains, hills, plateaus, and plains, while minor landforms comprise buttes, canyons, valleys, and basins.

4.4 Climate change

The trends, as indicated in Figure 4 and Figure 5, display a change in climate patterns over the last decades which will probably further accelerate. Therefore, an adaptation of the agricultural systems, specifically with trees, is recommendable. The increase of temperature implies an increase of evapotranspiration, higher humidity and thus an increasing risk of crop diseases and reduced human welfare. The decrease of rainfall over the years is reducing the water availability for crops and thus a higher risk of crop losses.

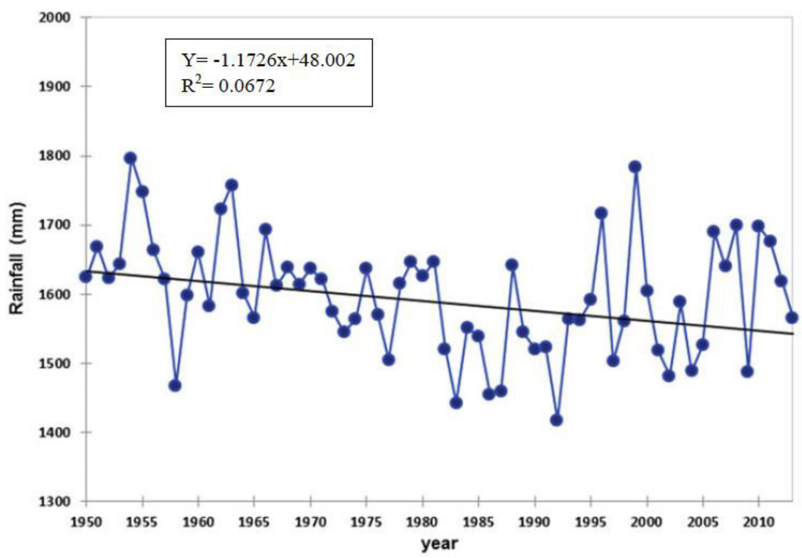
Organic farming (OF) methods, combined with an intensified tree management, provide practices for adaptation to and mitigation of climate change.

Figure 4. Mean temperature development in the Kafa Zone



Source: Kassahun & Bender (2020)

Figure 5. Mean rainfall over time in the Kafa Zone

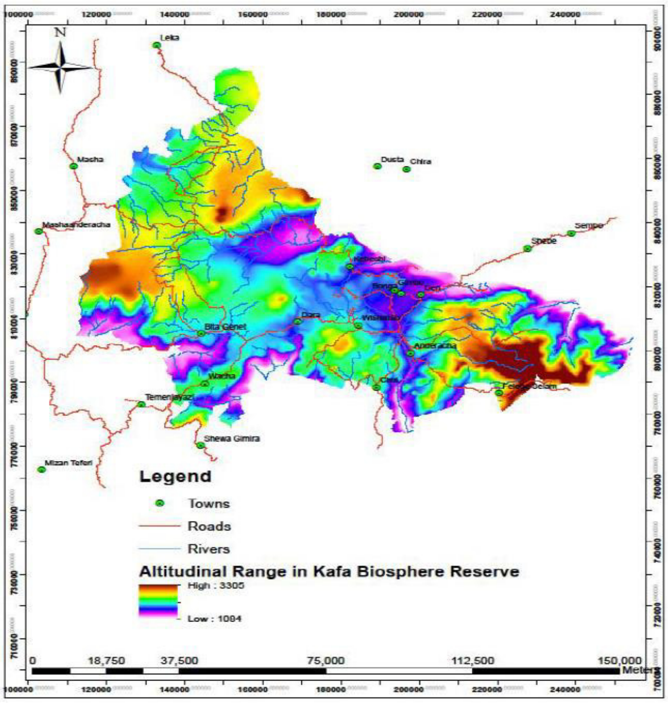


Source: Kassahun & Bender (2020)

4.5 Topography

The land surface in Kafa is characterised by a highly diverse topography, with elevations ranging from about 1,000 to 3,200 m.a.s.l. (Figure 6) and slopes with inclinations ranging from 0 to > 60%. Much of the land indicates a slope class between 2 and 15% inclination. With rainfall ranging from 900 to 2,400 mm, cultivated land can easily be affected by soil erosion if no counter measures are implemented (e.g. continuous soil cover, contour bunds, terracing).

Figure 6. Altitudinal range in Kafa Biosphere Reserve



Source: NABU (2015) (DEM 90 m)

4.6 Further information

- https://en.climate-data.org/

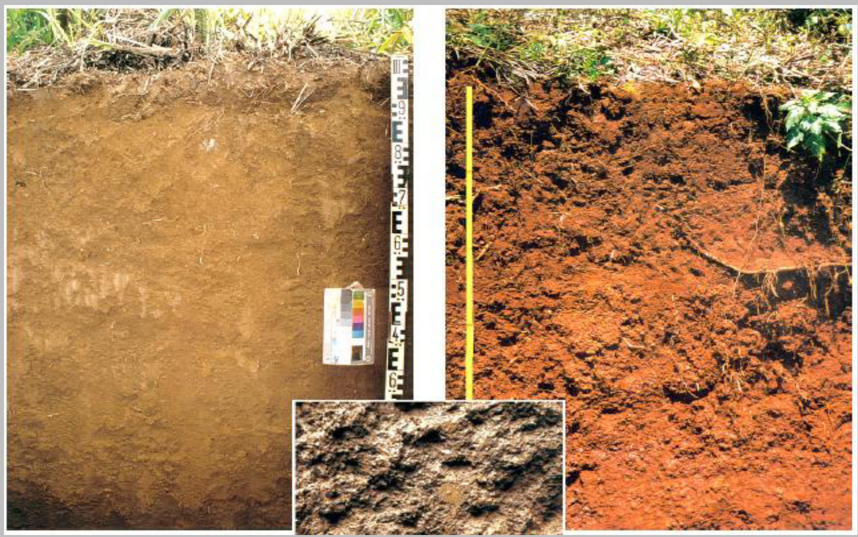
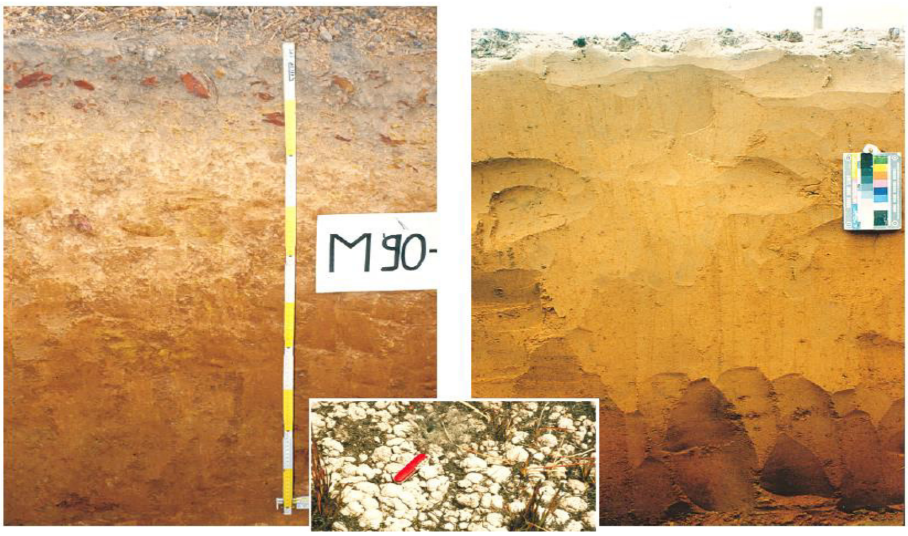
5 Soils and soil fertility

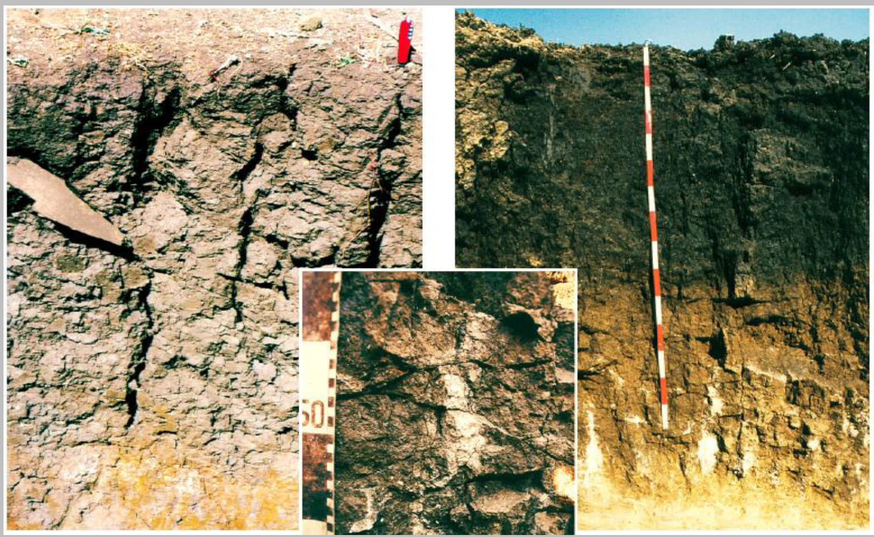
Section 5 provides information about the main soil types and their characteristics in the Kafa Zone. The meaning of soil fertility is explained, and the diverse methods for measuring soil features are introduced. A brief introduction is given to spade diagnosis. Specifically, methods for pH measuring and how to influence the pH are explained, and the role of humus is introduced.

5.1 Soil types

The dominant soil types in the Kafa Zone are Nitisols, Acrisols and Vertisols (Table 11). The most dominant soil types are Dystric Nitisols and Orthic Acrisols.

Table 11. Soil types in the Kafa Zone

Soil type	Characteristics
(Dystric) **Nitisols**	• Well-drained with good physical properties. • High water-storage capacity, a deep rooting zone, and stable soil aggregate structures. • pH 4-7, good nutrient supply; high P sorption (but no acute lack of P). • Often high humus and N stocks. • During rainy season high C and N mineralisation rates.  **Guiding crops:** E.g. maize, banana, coffee, tea, pineapple, etc. **Yield level:** One of the highest yielding soils in the tropics.
Acrisols	• Strongly weathered soils, with accumulation of clay minerals in the subsoil; tend to water logging during long rains; tend to harden in dry periods which hinders rooting. • Topsoil with low humus content. • pH around 5; high contents of Al, high P fixation. • Low nutrient stocks, low CEC; low biological activity; after deforestation low soil fertility, prone to erosion.  **Guiding crops:** E.g. perennials (coffee, pineapple, tea, etc.). **Yield level:** Low productivity.

Vertisols	• Deep soils and rich in clay. • Good water infiltration at the beginning of the rainy season, but with increasing time prone to water logging (insufficient drainage). • pH 6,5 – 8; CEC usually high. • Even though dark coloured, humus content ususally <3%; high nutrient stocks, but ususally insufficiently available; low turnover rate of organic substances due to stable organo-mineral bonding,  **Guiding crops:** E.g. maize and wheat. **Yield level:** High yield potential (especially with technologies such as mechanized field operations).

Source: Zech, Schad & Hintermaier-Erhard (2014)

5.2 Definition and methods for measuring and interpreting soil fertility

Soil fertility is defined as „the capacity of soil to provide physical, chemical and biological requirements for growth of plants for productivity, reproduction and quality (considered in terms of human and animal wellbeing for plants used as either food or fodder) relevant to plant type, soil type, land use and climatic conditions" (Abbott and Murphy, 2003).

In organic farming (OF) we interpret soil fertility as the result of biological processes rather than the result of the application of chemical fertilisers. Therefore, the principal task is to support these biological processes in the soil to an optimum extent.

A cultivated fertile soil can constantly produce agricultural crop yields. In case that yields are not reaching the site specific optimum or are even declining, soil fertility indicators, as depicted in Table 12, may help to identify leverage points. The soil fertility status can be measured in different ways, using literature, desktop calculations, field methods, or laboratory analyses. Each way is relevant and should be applied as a package. Most of them are low cost, knowledge based, and can be applied directly in the field. In total, a sum of 12 methods to assess the soil fertility status exist. The methods provide different information about a soil's fertility. Methods are complementary and inform with different methodological approaches about the same aspect.

Table 12. 12 direct and indirect analytical methods for analysing and describing the soil fertility status

No.	Method	Description	Classification
1	**Soil classification**	Official maps on soil classification: in general, their characteristics inform about the crop potential and provide first information about the general status of nutrients in soils.	Literature; desktop
2	**pH-value**	pH can be measured in the field directly; it informs about the nutrient availability of soils and the general crop growth conditions	Field method
3	**Spade diagnosis**	Spade diagnosis can be applied to analyse soil physical characteristics, organic matter (OM) management, soil organisms, soil physical data, impact of technology on soil quality, and information on nutrient availability.	Field method
4	**Humus balance**	Estimated current biomass and organic manure production can be used to approximate the humus status of the soil.	Literature; desktop
5	**Nutrient balance**	Estimated nutrient cycle can be used to gain an overview and an approximation to the current nutrient status of the farm or a field.	Literature; desktop
6	**Crop rotation**	Crop rotations inform about the nutrient and humus balance.	Field method; desktop
7	**Alley cropping, hedges**	Alleys inform about potential additional biomass, nitrogen and erosion risk reduction.	Field method; desktop
8	**Biotopes**	Biotopes inform about potential additional biomass, nitrogen and erosion risk reduction.	Field method; desktop
9	**Manure management**	Manure management informs about the recirculation of OM and the nutrient content of the animal manure.	Literature; desktop; field method
10	**Compost management**	Compost management informs about the recirculation of OM and nutrients from crop and household residues.	Literature; desktop; field method
11	**Chemical analysis**	Chemical analysis informs about the total sum of nutrients, their availability, and the organic carbon content.	Laboratory
12	**Biological analysis**	Biological analysis informs about soil organism diversity and quantity.	Laboratory

Source: Own compilation

5.3 pH and its measurement in the field

The pH-value has an influence on many soil characteristics and thus on the conditions for the existence and performance of soil organisms and plant growth.

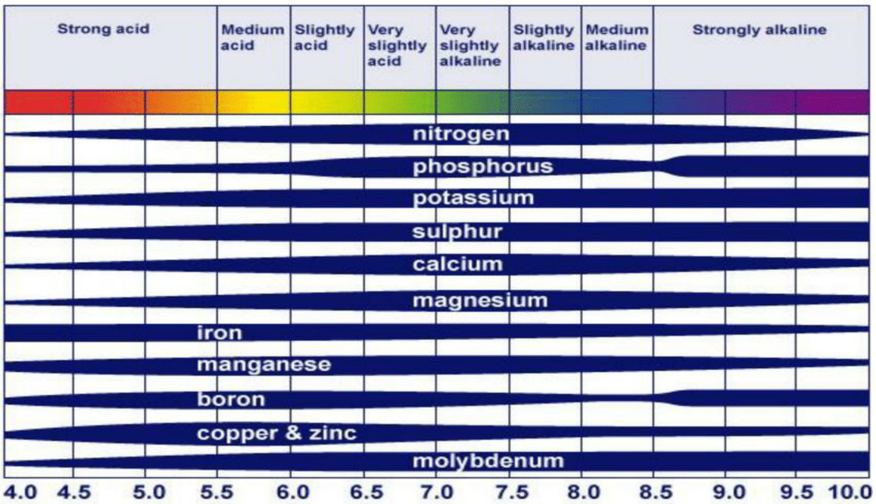
5.3.1 Significance of pH for crop growth

The pH-value indicates which crop types can be cultivated or which adjustments need to be considered to influence the soil pH in the wished direction.

The pH determines to a large extent how many of the soil's nutrients are bound and thus available for plant nutrition. Most of the nutrients show highest availability at a pH range between 5.5 and 8 (Figure 7). The pH of most soils in the Kafa Zone is between 5.2 and 5.8.

The pH of a soil can be negatively affected by different external factors such as acidic rain (due to air pollution), or chemical fertilisers (e.g. ammonium sulphate, super phosphate). However, the extent of the effect depends on the buffering capacity of the soil. Otherwise, organic animal manure, and specifically slurry, are fertilisers with neutral and even higher pH.

Figure 7. pH and nutrient availability



Source: Roques, Kendall, Smith, Newell Price & Berry (2013)

The optimum pH ranges for different crop and tree species are depicted in Table 13. Some species have a much wider range of acceptance than the depicted pH range but might not grow optimally.

Table 13. Optimum pH ranges of selected crops and trees

Crop group	pH	Crop group	pH	Crop group	pH	Crop group	pH
Cereals		**Forage legumes**		**Vegetables**		**Hedge/Alley crops**	
Teff	5-7	Mucuna	<5-8	Cabbage	6.5-6.8	*Sesbania sesban*	5-7
Maize	5.8-6.8	Alfalfa	6.5-7.5	Lattice		Tree lucerne	4.8-6.5
Wheat	6-7	Desmodium	4-7	Carrot	6-6.8	Tephrosia	5-6.5
Barley	6-7.5	Clover	6-8	Broccoli	6-7	Pigeon pea	5-7
Sorghum	6-7.5	**Grain legumes**		Beetroot	6.5-7	Calliandra	4.5-8
Millet	5.5-7.5	French beans	6-6.5	Garlic	6-7.5	Crotalaria	6-7
Root crops		Peas	5.8-7	Onion	5.5-6.5	Grevillea	5.5-6.5
Potato	4.8-5.5	Lupin	6.8-7.2	**Fruit crops**		**Tree crops**	
Sweet potato	5.6-6.5	Garden pea	5.5-7	Coffee	6-6.5	*Prunus africana*	5.5-6.5
Taro	5.5-6.5	**Herbs**		Tea	4.5-5.6	*Croton macrostachyus*	n/a
Yam	n/a	Rosemary	6-7.5	Enset	5.6-7.3	*Albizia* spp.	5-7
Spices		Verbena	5.8-6.2	Banana	5.5-6.5	*Ficus* spp.	6-7
Cardamom	4.5-7	*Lippia adonsensis*	n/a	Pineapple	4.7-6.5	*Erythrina* spp.	4.5-8
Red pepper	6-6.8	*Ocimum basilicum*	5.5-6.5	Apple	5-6.5	*Cordia africana*	4.5-7
Black Pepper	5.5-6.5			Avocado	6-6.5	*Millettia* spp.	6-9
Chili	5-6			Passion fruit	6.5-7.5		
Turmeric	6-6.5			Guava	5.5-7.5		
Ginger	4.5-6						

Sources: Own compilation, various sources

5.3.2 pH measurement

The pH can be measured by different means with differing accuracy.

5.3.2.1 pH paper

The simplest and cheapest measurement can be conducted by using pH paper. A small amount of soil is mixed with ionised (distilled) water and left for about 10 minutes. Subsequently, the pH paper is being immersed with the water solution and compared to a coloured scale. The test is cheap and simple, but only provides an approximate of the soil pH.

The pH testing can certainly be conducted for different substrates such as topsoil (0-30 cm), below ground (about 50 cm), slurry, compost etc. In case no ionised (distilled) water is available you can test the water first and, in the following, compare the deviation with the other fluids as in Picture 4.

Picture 4. Testing of pH of different substrates during a training in Kafa 2019

Source: Bernhard Freyer

5.4 Spade diagnosis

The spade diagnosis is a simple and easy to use method to judge the soil's structure with regard to the size and structure of soil fragments and soil aggregates[2], soil compaction, root penetration, and soil moisture. In combination with knowledge on the current crop rotation and a field test for the soil pH, you gain key information about a soil's status.

For the spade diagnosis you dug a square hole of about 30 cm depth as depicted in Figure 8. When pricking the spade into the ground you will already get an idea of the density of the soil according to how easy it is to move the spade into the ground. For the parameters of the diagnoses see Table 14.

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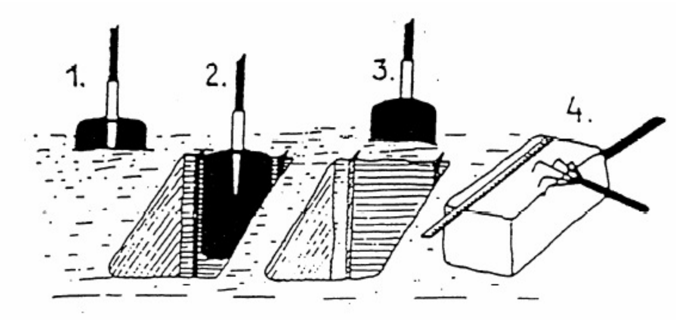
[2] The term "soil aggregate" describes microstructural elements which are formed by the aggregation of individual soil components (e.g. clay minerals, silt, sand grains, and OM) to form larger units (aggregations), and which stand out clearly from the surrounding area. Soil aggregates are formed by a) high biological activity and intensive rooting (crumbs, worming aggregates), b) shrinking processes (polyhedra, prisms, columns) and c) mechanical stress on the Ap-horizon during soil cultivation (crumbling, clods).

Figure 8. Spade diagnosis



Source: Beste (2003)

Table 14. Spade diagnosis and soil parameters

Parameter	Desired soil properties	Undesired soil properties
Structure on the soil surface	- stable aggregates - organic materials - earthworm activity (hollows)	- silting of the soil - wind/water erosion - soil incrustation
Root penetration	- throughout the soil horizon - even distribution of roots - intensive, crop specific rooting	- buckled or bent roots - roots are not penetrating due to compaction
Macro- and Bio-pores	- earthworm droppings on the surface and in the soil profile - new earthworm hollows in the cultivated layer and hollows across upper and lower soil layers	- on the soil surface no open bio-pores - in the cultivated layer few vertical earthworm hollow - no connection of hollows between upper and lower soil layers
Structure and hardening	- structure: porous, loose, finely aggregated - when putting pressure on the soil between two fingers, the soil falls apart easily - when throwing the soil down from the spade, the soil falls apart easily into crumbles - you can easily stick a knife into the soil profile (without resistance) - the lower crumb should be more compact than the upper crumb	- structure: tightly connected and mounted, strongly solidified, sharp-edged - big, sharp-edged aggregates after throwing a big cluster from the spade - difficulties sticking the knife into the soil profile - root felt on the surface of the aggregates
Organic materials	- after seeding, evenly spread on the surface - evenly incorporated across the soil crumb (first 20-30 cm) - organic material from the pre-crop well rotten - even root development	- after seeding, uneven distribution of straw - concentration of organic material from the pre-crop on the surface - non-rotten materials from the previous years (can lower pH in those areas) - roots not penetrating layers of undecayed materials
Colour and smell	- colour can provide evidence of the air and water household, as well as humus content - even colour with soil horizons - soil smells earthy, in the upper soil layers this smell is more pronounced than in the lower soil layers	- grey and blue zones in the soil horizon are signs of chemical reduction processes (due to soil compaction, lacking oxygen for the decay of organic materials) - signs of rust also indicate temporarily lacking oxygen - bad, foully smell

Source: Own Compilation, LWK (2020)

5.5 Humus, roots, C/N and mineralisation

Today, the reproduction of carbon, i.e. humus, is a key factor for climate robust farming systems. Soil humus is becoming more and more the key factor of cropping systems to balance droughts through higher water holding capacity and better water infiltration capacity, specifically during heavy rain events.

In most of the farmland in Ethiopia, the humus balance is negative for decades. As a consequence, the rebuilding of soil fertility is even more necessary. Current humus reproduction in smallholder farms is far below 5 t ha^{-1} a^{-1}.

Under tropical climate conditions approx. 10 t DM ha^{-1} a-^{1} biomass production is necessary to sustain the humus content in soils. In this context it is of high importance that the whole farm surface is used for the production of biomass, with crops that produce a high root biomass playing a key role (Table 15).

Again, forage legumes, but also alley crops take over a key function in producing biomass, due to its high above and specifically below ground productivity. Animal manure, including parts of the straw that are not fed to the animals, and compost need to be maintained in the carbon cycle of the farm to preserve the humus content of the soil.

Humus quality can be expressed through the C/N ratio, besides other indicators. C/N ratios of about 10-25 indicate a high availability of soil nitrogen. The number of soil organisms increases through a positive humus balance, together with the mineralisation rate of soils.

5.6 Further information

- Okalebo, Gathua & Woomer (2002)
- Mamo & Haque (1991)
- Critter, Freitas & Airoldi (2002)

Table 15. Crop rotation-based characteristics for humus production

Year (two seasons)	Crop rotation	Acres	ha	Root biomass kg DM ha^{-1}	Root biomass kg DM a^{-1}	Humus balance	C/N	Mineralisation
1	Alfalfa	1.07	0.27	5,000	1,338	+++	10/1 -30/1	+ to +++
2a	Maize	0.28	0.07	500	35	0	30-50/1	(+)
	Maize	0.80	0.20	500	100	0	30-50/1	(+)
2b	Grain legumes	1.08	0.27	750	203	+	15/1	+++
3a	Teff	0.97	0.24	500	122	+	25-35/1	+
	Teff	0.12	0.03	500	15	+	25-35/1	+
3b	Potato	1.08	0.27	300	81	-	10/1	+++
4a	Vegetables	0.80	0.20	500	100	-	10-30/1	+++
4b	Herbs	0.28	0.07	300	21	-	10-30/1	+ to +++
	Napier grass	0.58	0.15	1,000	146	+ to ++	25/1	+
	Pasture	1.46	0.37	1,500	548	(+)	15-30/1	+ to ++
	Alley branches	0.49	0.12	3,000				
Total		**6.85**	**1.71**	**2,838**	**677**			

Source: Own data (for own calculations see Excel)
a, b: first and second growing season of the year; humus balance and mineralisation rates: negative (-) to neutral (0) to positive (+) to very positive (+++)

6 Soil erosion management

Section 6 describes techniques to avoid soil erosion. Mainly plant based techniques are introduced that can be adapted to site and farm specific conditions.

6.1 Characteristics

In the past, the Kafa Zone was nearly covered to 100% by rainforest. At such a high forest density, soil erosion was not a problem as the soil was protected against rain and sunrays due to soil coverage by plants, branches and litterfall. Nowadays, resources in forests are increasingly (over-) harvested for fuel, timber and construction purposes, and finally used for agricultural production. Otherwise, the replantation of trees is lacking. The left-over bare soil is prone to mainly water induced erosion, especially in climates with 2.000 mm of rainfall or more per year and with heavy rains occurring in short time periods.

Specifically, in areas under arable use, where soils are not or only partly covered over a longer period throughout the year, approximately 20 to 200 t ha^{-1} a^{-1} soil can be lost. Also overgrazed grasslands lose high amounts of soil.

Consequences of soil erosion are the loss of nutrients, humus, and water holding capacity. In many cases, the loss of soil is irreversible, e.g. through gully erosion. This can lead to an estimated financial loss of around 2.000 and 20.000 Birr per ha and year. While the humus layer can easily be lost in one year, it needs decades to rebuild the fertile topsoil layer to the same level/amount as before.

6.2 Technologies for soil erosion control

To offset soil erosion with just one measure is normally not sufficient. Erosion measures require the combination of technical and cropping strategies, combined with a particular arrangement of measures. Organic farming (OF) methods are of high relevance, as their basic practices are already including a combination of methods that effectively reduce soil erosion.

There is an ongoing debate how to avoid soil erosion. Two groups of techniques in arable or fruit tree / coffee areas are to be differentiated. We would specifically highlight the first group of techniques, which currently receives less attention, although we would advise to focus on these measures at the beginning when transforming a farm. The main difference between the measures is where they take place – directly where the erosion starts, or at the edge, more or less outside the field.

Group 1 focusses on direct measures in the field where erosion normally starts. Here point 1 is the most relevant. Group 2 deals with the management of already eroded soil at the edge of fields.

Group 1: Techniques to be applied where erosion starts – nearly permanent soil cover with crops and in addition mulch material.

1. Crop rotation with a high share of forage legumes (25%; every fourth year) (see section Crop rotation 7.4).
2. In crops with a distance of 50 cm in the rows, or in between the rows, or more need to be cultivated with an intercrop, or with under-sown forage legumes (Table 21) (e.g. maize with beans, potato with beans, etc.).
3. Leguminous alley crops and banana/enset integrated in the cropping/fruit/coffee system provide the mulch material.
4. Mulch material from the surrounding of the field, or from hedges, can be added.
5. Animal manure is limited and, due to its importance for crop productivity, only used for directly manuring single crops / crop rows.

The need for alley mulch material becomes obvious when knowing the average quantity of biomass that a field requires. To sustain the humus balance on 1 ha of land, a farmer needs to produce 10 t dry matter (DM) per year.

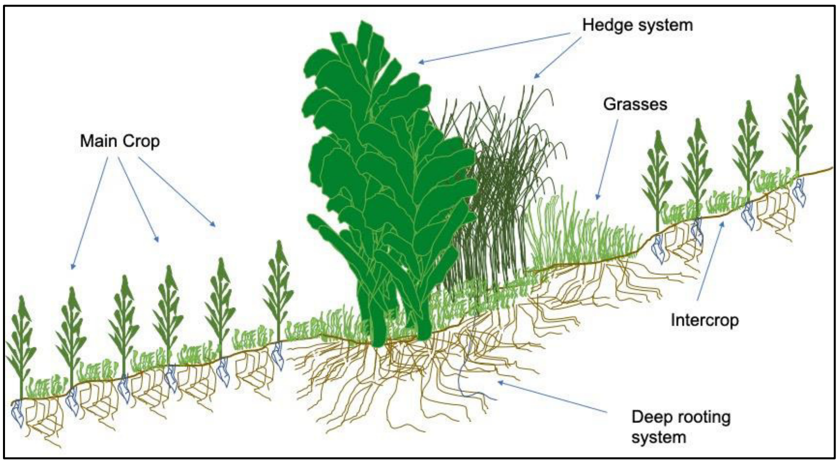
Group 2: Techniques to collect eroded soil – a combination of technical & crop specific measures (**Figure 9**).

1. Digging trenches with 30-60 cm width and 50-70 cm depth, which serve for transporting surplus water while eroded material should be already minimised via the other technologies. The distance between the trenches should be between 10 and 20 m, depending on the landscape, surface structure of the land, efficiency of measures introduced from group 1, and amount and intensity of rainfall (as an example see Figure 9).
2. The trenches need to be stabilised with diverse crops, combining deep rooting trees (alley shrubs and trees) with grass types (vetiver, lemon grass, sorghum, Napier grass). These crops can be used for farm and household purposes (food, feed, beverages, fuel for cooking, medicine).
3. If soil accumulates along the trenches, it needs to be reallocated to higher areas where the soil was eroded from; otherwise there is also a risk that rodents will destroy the trenches.

The digging of trenches needs to be discussed controversially. If activities from group 1 are not implemented, there is a risk to induce landslides.

Once these techniques are applied, erosion can be reduced to less than 5 t ha^{-1} a^{-1}, while soil fertility and yields are increasing.

Figure 9. Example of a field with trench system



Source: Own illustration

6.3 Soil water management

Diverse techniques for rainwater harvesting are introduced, but in many cases labour demand and costs (e.g. roof rainwater harvesting, irrigation, etc.) are the hindering factors for establishment of such measures. Nevertheless, there are cost effective and easy to establish rainwater conserving practices which can be established by most farmers. We differentiate between crop based and agronomic based techniques, partly analogue to the two groups introduced in section 6.2.

6.3.1 Crop based practices

To increase water infiltration during the rainy season the soils have to be completely covered with crops. As a result, water is used more efficiently and runoff (erosion) is hindered. Crops with > 50 cm distance between the rows – maize, cassava, sorghum, etc. – are always to be combined with under-sown legumes.

- Grain legumes, such as beans, peas or groundnut, are partly taking over this function. Their above ground biomass production varies between 0.5 and 1.5 t ha^{-1} a^{-1}, while the root biomass is approx. between 0.2 and 1 t ha^{-1} a^{-1} DM.
- Due to their dense soil cover and extensive rooting system, under-sown forage legumes like desmodium, clover, or alfalfa are the most efficient crops to preserve an optimum soil water household. Above ground biomass in the half-shade of the main crop is between 1 and 3 t ha^{-1} a^{-1}. The root biomass is nearly the same. After the harvest of the main crop the biomass increases. Under water-limited conditions the forage legumes are sown later, and the growing period is to be reduced in order to reduce competition with the main crop.

For more information on catch crops and intercropping see also section 7.3.

6.3.2 Agronomic / technical based practices

Agronomic and technical based practices offer further options to enhance soil water conservation. However, the combination of these practices with crop-based practices is key to be efficient, while a single technical intervention is insufficient. Table 16 summarises the diverse practices that need to be adjusted to the site-specific conditions.

Table 16. Agronomic / technical based practices to soil water management

Agronomic / technical based practices	Characteristics
Hedge and alley systems in the surroundings of the fields	• Retain water around them as they slightly decrease the temperature and evaporation. • Cuttings spread over the fields increase the organic matter (OM) content of the soil and thus increase water holding capacity. • For further insights see section 11.
Mulching	• Achieved by leaving crop residues on the field or by transferring plant residues from trees and hedges or from other fields or pastures (transfer mulch). • The goal is to produce enough fodder for livestock to reduce stubble grazing, which leads to soil compaction and humus loss. • For further insights see section 8.

Manure and/or compost, alley branches	• Application of manure/compost is key to building and sustaining soil fertility and thus water holding and infiltration capacity of the soil. • OM and nutrient delivery by manure/compost is underestimated by many farmers.
Biochar	• Mixing biochar in planting holes of e.g. coffee. • Incorporating biochar across the whole field.
Tillage reduction	• Shallow tillage. • For further information see section 8.
Contour tillage and graded furrows contour tillage	• Effective water conservation practice. • Avoids water erosion, but also conserves water as the ridges formed by tillage hold water on the land, which increases the time for infiltration.
Basin tillage (tied ridging)	• Formation of small earthen dams in furrows to trap rainfall, thereby preventing runoff and providing more time for infiltration.
Land smoothing	• Uneven land hinders mechanisation, increases weed development and leads to lower plant growth. • Land smoothing serves to move soil from high to low points in a field. • When low points are eliminated, water is prevented from concentrating at them; this creates more uniform storage of water in the field for the next crop. • Land smoothing should not eliminate small-scale surface depressions if these allow water to be stored temporarily rather than running off.
Terracing	• Various types of terracing have been developed that provide soil and/or water conservation benefits.
Improving irrigation efficiency	• Optimised management of irrigation water would increase yields up to 100-200%, but care and emphasis must be given as to when and where to construct irrigation infrastructures, and how the activity avoids also land degradation. • Irrigation efficiency can be enhanced by: appropriate conveyance systems (using water-tight materials, proper canal gradients, etc.), as well as appropriate water application systems (such as drip irrigation or furrowing), improved irrigation calendars (such as managing deficit irrigation and selecting proper cropping patterns, such as double-row planting). • Water collection from roofs, regulation of runoff water, and water storage for household needs or nearby vegetable gardens, are techniques with low investment and labour costs; adapted solutions are household specific. • Many farmers can, with little effort, increase vegetable and fruit tree yields at about 50-200%; furthermore, the vegetation period towards the dry season can be extended for approx. 1-2 months.

Source: Own compilation

6.4 Further information

- Nair, Kang & Kass (1995)
- Islam, Nasrin, Islam & Moury (2013)
- Maass, Jordan & Sarukhan (1988)
- Lal (2019)
- Frankl, Guyassa, Poesen & Nyssen (2019)
- Vancampenhout et al. (2019)
- Ramos- Scharrón & Thomaz (2017)
- Abdulkareem, Pradhan, Sulaiman & Jamil (2019)
- Lee et al. (2018)

7 Crop profiles and crop combinations over space and time

Section 7 introduces the diversity of crops that can be cultivated in the Kafa Zone, their specific demands and characteristics, the specific role of forage legumes, how to integrate the crops into a crop rotation, and how to combine two or more crops in the same place at the same time (intercropping). Information is provided on the vegetation period, the pre-crop value of selected crops, specifically that of forage and grain legumes, and crop rotation and intercropping examples.

7.1 Crop groups and vegetation periods

There is a high diversity of crops that can be cultivated in the Kafa Zone. Diverse cropping systems enrich biodiversity, reduce pest and disease as well as weed pressure, and contribute to lower the erosion risk. Currently, the implementation of diverse cropping systems (intercropping, crop rotation) is missing in the majority of smallholder farms.

Crops can be grouped according to similar characteristics (Table 17). Sometimes it is the same botanical family, in other cases crops from different families, but with similar characteristics, are summarised in one crop group (e.g. root crops).

Table 17. Sowing periods, vegetation periods, harvest periods

Arable crops	Vegetation period				**Variations / Remarks**
	Sowing periods	**Harvesting periods**	**Days**	**m.a.s.l.**	
Cereals					
Teff *(Eragrostis tef)*	Jul/Aug	Dec	90-180	Up to 3,400	Wide range due to variety differences.
Maize (*Zea mays*)	Nov; Apr	Sep/Oct		Up to 4,000	Highlands sown in Nov, lowlands sown in Apr.
Wheat *(Triticum aestivum)*	Jul/Aug	Oct-Dez	90-180	1,600 -3,200	Favours higher altitudes.
Barley *(Hordeum vulgare)*	Mar - Jul	Jun-Dez	90-170	Best > 2,500	Direct sowing.
Finger millet *(Eleusine coracana)*	May/Jun	Nov-Jan	120-160	1,000- 2,000	
Sorghum (*Sorghum bicolor)*	Mar-Jun	Aug-Dez	120-220	Up to 2,500	
Rice *(Oryza glaberrima)*	Jun	Oct-Nov	65-115	Up to 2,000	Planting after the onset of rain.
Root crops					
Potato *(Solanum tuberosum)*	Apr/May	Oct/Nov	150/180	Up to 3,200	
Sweet potato *(Ipomoea batatas)*	Jun	Nov/Dec	150/180	Up to 2,100	
Taro *(Colocasia esculenta)*	May/Jun	Jan/Feb	120/180	Up to 1,800	
Yams *(Dioscorea spp.)*	Jan/Feb	Oct	210-365	Up to 2,700	
Cassava *(Manihot esculenta)*	Mar-May	Oct-Jan	550-730	Up to 1,500	
Forage legumes					
Mucuna *(Mucuna spp.)*	Apr	Jul-Dec	240	Up to 2,100	Annual.

Alfalfa *(Medicago sativa)*	Apr	Jul-Dec	240	Up to 2,400	
Desmodium *(Desmodium spp.)*	Apr	Jul-Dec	240	Up to 2,500	
White clover *(Trifolium repens)*	Apr	Jul-Dec	240	> 1,800	
Vetch *(Vicia spp.)*	Apr	Jul-Aug	90-120	> 1,800	
Berseem (*Trifolium alexandrinum*)	Apr	Jul-Dec	240	Up to 750	Annual.
Grain legumes					
Common beans *(Phaseolus vulgaris)*	Jul/Aug	Nov/Dec	120/160	Up to 3,000	
Peas *(Pisum sativum)*	Jul/Aug	Nov/Dec	120/160	Up to 1,000	
Lupin *(Lupinus albus)*	Jul	Dec/Jan	150/210	Up to 4,000	
Lablab *(Lablab purpureus)*	Apr-May	Sep-Dec	150-210	Up to 2,400	IC with maize: plant when maize is > 15 cm.
Oil crops					
Mutto/Flax *(Linum usitatissimum)*	Apr/May	Aug/Sep	110	1,800-2,100	No more than one in six years on the same plot.
Noug* *(Guizotia abyssinica)*	Mar	Jul/Aug	120-170	Up to 2,500	*First season.
Noug* *(Guizotia abyssinica)*	Jun	Jul/Aug	120-170	Up to 2,500	*Second season.
Rapeseed cabbage (*Brassica carinata*)	Apr/May	Oct/Nov	180	2,200 – 2,800	
Sesame *(Sesamum indicum)*	May/Jun	Aug/Dec	90-150	Up to 1,700	Planting after onset of rains, strip cropping with maize and sorghum possible.
Safflower* *(Carthamus tinctorius)*	Mar	Jun/Jul	110 - 150	Up to 1,400	*First season.
Safflower* (*Carthamus tinctorius*)	May/Jul	Sep/Nov	110 - 150	Up to 1,400	*Second season.
Vegetables					
Cabbage *(Brassica oleracea)*	Oct/Nov	Dec/Jan	120 - 140	800-2,200	
Lettuce *(Lactuca sativa)*	Oct/Nov	Dec/Jan	120 - 140	> 500	
Carrot (*Daucus carota* subsp. *Sativus)*	Oct/Nov	Dec/Jan	120 - 140	> 500	
Broccoli *(Brassica oleracea)*	Oct/Nov	Dec/Jan	120 - 140		Temperature needs to be below 30°C!
Beetroot *(Beta vulgaris)*	Oct/Nov	Dec/Jan	120 - 140	Up to 2,100	
Garlic *(Allium sativum)*	Mar/Apr	Jun/Jul	120 - 150	> 500	First season.
Garlic *(Allium sativum)*	Aug-Nov	Dec-Mar	120 - 150	> 500	Second season.
Onion *(Allium cepa)*	Mar/Apr	Jun/Jul	100 - 140	Up to 1,900	Manure and compost applied before and after planting.
Tomato *(Solanum lycopersicum)*	Oct/Nov	Jan/Feb	75 - 130	> 500	Planting time usually after fasting period.

Sweet pepper *(Capsicum annuum)*	Mar/Apr	Jun/Aug	100 - 150		Manure and compost applied before and after planting.
Hedge/ alley crops					
Calliandra *(Calliandra calothyrsus)*	May	Apr	>700*	Up to 2,200	* It takes 2 years for good biomass production.
Crotalaria juncea	May/Jun	Jul-Sep		Up to 1,500	
Grevillea *(Grevillea spp.)*	Dec/Jan	Jun	>700*	130 – 2,300	* It takes 2 years for good biomass production.
Pigeon pea *(Cajanus cajan)*	Dec/Jan	Jun	>700*	Up to 2,000	* It takes 2 years for good biomass production.
Sesbania sesban	Dec/Jan	Jun	>700*	Up to 2,300	* It takes 2 years for good biomass production.
Stylosanthes spp.	May-Jul	Aug-Dez	120 - 150	Up to 1,500	
Tree lucerne / Tagasaste *(Cytisus proliferus)*	Dec/Jan	Jun	>700*	Up to 3,000	* It takes 2 years for good biomass production.
Leucaena *(Leucaena leucocephala)*	Dec/Jan	Jun	>365	200 – 2,500	May be lightly grazed after first year, heavily after second.
Tree crops					
Prunus africana	Dec/Jan	Sep/Oct	20	900 – 3,400	
Bambusa vulgaris	Dec/Jan	Aug/Sep	20	Up to 1,200	Harvesting starts after third year.
Croton macrostachyus	Dec/Jan	Jun/Jul	10	200 – 2,000	
Albizia spp.	Dec/Jan		15 - 20	400 – 1,500	Can be intercropped with maize, cassava, mango.
Ficus spp.	Dec/Jan	Irregular	25	Up to 2,000	
Erythrina spp.	Dec/Jan		10	Up to 1,500	Can be used as “living fence”.
Cordia africana	Dec/Jan	Jan-Sep	10 - 20	550 – 2,700	One of the best multi-purpose trees.
Leuceanea *(Leucaena leucocephala)*	Dec/Jan		10	Up to 1,000	Use as forage, shade tree, fuelwood.
Millettia spp.	Dec/Jan		Up to 35	Up to 1,800	
Fruit crops					
Coffee *(Coffea arabica)*	May-Sept	Nov-Feb/ Jun-Sep		1,300 – 2,800	
Tea *(Camellia sinensis)*		Year round		Up to 2,100	
Enset *(Ensete ventricosum)*	Apr	Year round		1,100 - > 3,000	Cropping cycle 3-4 years.
Banana *(Musa spp.)*	Apr	Year round	523	Up to 1,200	
Pineapple *(Ananas comosus)*	Apr	Aug/Oct	730	Up to 1,800	
Apple *(Malus domestica)*	Nov/Dec	Sep/Oct		> 500	Fruits after 2-10 years.
Avocado *(Persea americana)*	Nov/Dec	Sep/Oct		Up to 2,800	It can be available year-round.
Passion fruit *(Passiflora edulis)*	Mar/Apr	Sep/Oct	180-365	> 350	Purple variety for fruit yield, yellow for disease resistance.
Guava *(Psidium guajava)*	Feb/Mar Jul/Aug	Aug/Sep Jan/Feb		Up to 2,000	IC with short legumes possible Fruits after 3 years.
Herbs					
Rosemary *(Salvia rosmarinus)*	Dec/Jan	Jul/Aug	365		
Verbena *(Verbena spp.)*	Dec/Jan	Jul/Aug	365	Up to 2,000	

Lippia adonsensis	Dec/Jan	Jul/Aug	365		
Basil *(Ocimum basilicum)*	Dec/Jan	Year round	50-75	Up to 1,000	
Spices					
Black cumin (*Nigella sativa*)	Dec/Jan	May/Jun	150	1500 – 2,500	
Black pepper, Turfo (*Piper capense*)	Dec/Jan	Nov-Jan	700 – 1,000	Up to 1,500	
Cardamom, Hail (*Elettaria cardamomum)* **Green Cardamom or Hail-Arabic/ Ogiyo**	Dec/Jan	Sep/oct	700	600 – 1,200	
Chadramo *(Ruta chalepensis)*	Dec/Jan	Year round		1,500 – 2,000	
Chili (Capsicum *frutescens*)	Mar/Apr	Jun-Aug	100-150	Up to 2,000	
Colocasia esculenta	Mar/Apr	Dec/Jan	270-330	Up to 2,500	
Doko (re-introduction)					No data.
Gesho/Hops (*Rhamnus prinoides*)				Up to 2,000	No data.
Ginger *(Zingiber officinale)*	Apr/May	Dec/Jan	160-240	Up to 1,500	
Korerima (*Aframomum cororima*)	Apr/May	Sep/Oct		1,350 – 2,000	
Kundo berbere/Pepper *(Piper nigrum)*				Up to 1,250	
Gala Dinich *(Plectrantus edulis)*				1,800 – 2,100	
Red pepper *(Capsicum annum)*	Dec/Jan	Sep/Oct		Up to 2,000	Fruit production starts after 3 years.
Sudan Kido /Faranje Kido/Oloso *(Xanthosoma sagittifolium)*					No data.
Timiz (*Piper longum*)	Apr/May	Dec/Jan		Up to 800	Bear fruits after 3-4 years.
Turmeric (*Curcuma longa*)	Apr/May	Feb/Mar	300	Up to 2,000	Lift and divide every 5 years.

Sources: Own compilation; NABU Bonga oral communication; www.feedipedia.org; www.plantnet-project.org; www.pfaf.org; www.tropical.theferns.info; www.tropicalforages.info; Dorosh & Rashid (2013); Watson (2002)

Table 18 provides an orientation about the seeds and seedling demand for the main leguminous crops that need to be established in an organic farm, calculated for a smallholder farm and a community. The data underline the need for seed and seedling supply and the multiplication at farm and community level to cover the demand. Furthermore, some crops are added that can be integrated into hedges and woodlots to increase food and forage supply and raw material for farm specific purposes, as well as for the market.

Table 18. Crop seeds and tree seedling demand

		Smallholder farm		Community	
	Share	Seeds		Share	
	%	kg ha^{-1}	kg 0.1 ha^{-1}	kg 0.1 ha^{-1}	kg 1,000 ha^{-1}
Forage crops					
Alfalfa	30	10	1	0.3	300
Clover	20	15	1.5	0.3	300
Desmodium	50	10	1	0.5	500
Total	**100**			**1.1**	**1,100**
Green manure crops with multiple use options					
Mucuna	50	40	4	2	2,000
Lablab	25	20	2	0.5	500
Cow pea	25	30	3	0.75	750
Total	**100**			**3.25**	**3,250**
Trees	**%****	**No ha^{-1}*****	**No 0.1 ha^{-1}********	**No 0.1 ha^{-1} (10%)**********	**No 1.000 ha^{-1}************
Alley crops					
Leucaena l.	10	2,500	250	25	25,000
Faidherbia a.	20	2,500	250	50	50,000
Tree lucerne	30	2,500	250	75	75,000
Calliandra	5	2,500	250	12,5	12,500
Tephrosia	5	2,500	250	12,5	12,500
Crotalaria	10	2,500	250	25	25,000
Pigeon pea	10	2,500	250	25	25,000
Sesbania s.	10	2,500	250	25	25,000
Total	**100**			**250**	**250,000**
Hedge crops					
Grevillea	20	2,700	270	54	54,000
Papaya	10	2,700	270	27	27,000
Enset	10	2,700	270	27	27,000
Banana	20	2,700	270	54	54,000
…	10	2,700	270	27	27,000
…	10	2,700	270	27	27,000
…	10	2,700	270	27	27,000
…	10	2,700	270	27	27,000
Total	**100**			**270**	**270,000**
Woodlots					
Eucalyptus globulus	5	2,500	250	13	12,500
Eucalyptus camaldulensis	5	2,500	250	13	12,500
Acacia decurrens	50	2,500	250	125	125,000
Cupressus lusitanica	15	2,500	250	38	37,500
Pinus patula	5	2,500	250	13	12,500
Juniperus spp.	10	2,500	250	25	25,000

Podocarpus spp.	5	2,500	250	13	12,500
…	5	2,500	250	13	12,500
Total	**100**			**250**	**250,000**
Total tree seedlings*				**770**	**770,000**

Source: Own data
* alley, hedge and woodlots
Reading: example trees: ** share of trees per area and of all trees: e.g. 10% of all tress should be Leucena; *** Number of trees per ha if 100%; **** Number of trees per ha if 10%; ***** Number per 0.1 ha if share is 10%; ****** calculation for a community with 1,000 ha

7.2 Pre-crop values with a specific focus on legume crops

Crops influence the following crop differently as described in their pre-crop values (Table 19). The best pre-crop values are delivered by forage legumes (large rooting system, weed suppression, N-fixation) and to a lesser extent by grain legumes. Forage legumes have small seeds and thus shallow sowing is required. In the first weeks of development, the risk of weed competition by annual weeds and their sensitivity to drought is high. The spacing of grain and fodder legumes is approx. 30-50 cm between the rows. Denser sowing is an option to reduce weed pressure in early stages, however this is also a cost factor. Grain legumes often serve as intercrops under-sown in main crops, such as potato, maize or sorghum (two weeks before harvest), or catch/ relay crops at the end of the rainy season or in the short rain season.

Table 19. Pre-crop values of arable crops

Crop group/ family	Below ground biomass*	Above ground biomass*	Nitrogen fixation *	Weed suppres-sion*	Pre-crop value*	Possible following crops**
Forage legumes						
Alfalfa	+++	+++	+++	+++	+++	Maize, wheat, potato, sweet potato
Clover (red)	+++	+++	+++	+++	+++	Maize, wheat, potato, sweet potato
Clover (white)	+++	+++	+++	+++	+++	Maize, wheat, potato, sweet potato
Desmodium	+++	+++	+++	+++	+++	Maize, wheat, potato, sweet potato
Forage/ grain legumes						
Cow pea	++	+ to ++	++	++	++	Potato, sweet potato, teff, cereals
Lablab	++	++	++	++	++ to +++	Maize, wheat, potato, sweet potato
Mucuna	+++	+++	+++	+++	+++	Maize, wheat, potato, sweet potato
Grain legumes						
Beans spp.	+	+	+	+	++	All cereals
Faba bean	++	++	++	++	++	All cereals with higher N-demand
French bean	+	+	+	+	++	All cereals
Garden peas	+	+	+	+	++	All cereals
Lupin	++	+ to ++	++	++	++	All cereals with higher N-demand
Peas	+	+	+	+	++	All cereals
Cereals						
Barley	+	+	-	+	+	
Maize	+	++	-	+	+	Teff, oat, millet, all legumes
Millet	+	+	-	+	+	All legumes
Oat	+	+	-	+ to ++	+	All legumes
Sorghum	+	+++	-	+ to ++	+ to ++	All legumes
Teff	+	+	-	+	+	All legumes
Wheat	+	+	-	+ to ++	+	Barley, teff, all legumes
Root crops						
Potato	+	+	-	+ to ++	+	Wheat, barley, teff, millet, oat
Sweet potato	+	++	-	++	+ to ++	Wheat, barley, teff, millet, oat

Cassava	+	+ to ++	-	+ to ++	+	Wheat, barley, teff, millet, oat
Taro	+	+ to ++	-	+ to ++	+	Wheat, barley, teff, millet, oat
			Grasses			
Napier grass	++	+++	-	++	++	All legumes

Source: Own data
*+ = low; ++ = medium; +++ = high; - no nitrogen fixation; ** Ranking: the first crop can best use the pre-crop value

The high pre-crop value of forage legumes could be demonstrated in several trials (Table 20). Using *Vicia spp.* and clover accessions as an example, trials show that different genetic sources differentiate species characteristics and performance and thus its pre-crop value.

Table 20. Pre- and pre-pre-crop value of forage legumes in two years

1984	1985			1986			1985/1986	
Forage legume pre-crop	**Sorghum**	**Stat.**	**rel.[2]**	**Maize**	**Stat.**	**rel.[2]**	**Total add. yield**	
	kg ha^{-1}			**kg ha^{-1}**			**kg ha^{-1}**	**%**
Trifolium steudneri	2,632.0	a[1]	1.9	2,730.7	ab[1]	1.7	2,405	181
Vicia dasycarpa	2,130.3	ab	1.5	3,273.7	a	2.1	2,447	183
Lablab purpureus	1,549.7	b	1.1	2,461.7	b	1.6	1,054	136
Trifolium tembense	1,842.0	ab	1.3	2,170.7	b	1.4	1,055	136
Avena sativa	1,386.0	b	1.0	1,571.3	c	1.0		

Source: I. Haque (ILCA, Addis Ababa, Ethiopia, unpublished data)
[1] Within columns, values followed by the same letter are not significantly different at the 5% level (Duncan's Multiple Range Test)
[2] Relative to *Avena sativa* (oat); add. = additional

7.3 Intercropping

Intercropping describes the practice of growing two or more crops on the same patch at the same time. Intercropping has several advantages:

- Optimised use of resources
- Higher yield
- Synergistic plant behaviour
- Weed suppression (see section 9)
- Pest control (see section 10.3)

Plant competition over space, water, nutrients and sunlight need to be regulated according to the specific species characteristics, planting density and sowing time! Therefore, it is recommended to combine species with complementary properties, such as the planting of deep rooting plants together with shallow rooting ones, or the planting of a tall crop in combination with a shorter and shade-tolerant crop, and length of species and variety specific growth period. In general, we distinguish between a few different intercropping systems, according to crop individual characteristics and the time-space arrangement.

7.3.1 Spatial / temporal intercropping

The most basic form of intercropping uses the different morphologies (roots and vegetative parts) or different durance of growth of a crop, i.e. their varieties. Well known in arable production is e.g. oat or barley with peas. Intercropping is especially applied in vegetable gardening with limited space (Table 21).

Table 21. Examples of spatial / temporal intercropping schemes

Used plants	Description
Lettuce + onions + carrots	These three plants have different leaf forms, light requirements, and rooting depths, which makes them compatible both physically and in terms of their resource needs.
Parsley + spinach + onions	Spinach and onions are ready to be harvested before the sprouts mature, parsley can tolerate some shade; also, their nutrient needs diverge.
Radishes + lettuce + peppers	Radishes grow fast, the lettuce tolerates the shade of the young peppers; by the time the peppers are full-grown, the other plants have been harvested.
Lettuce/spinach + potatoes	Lettuce/spinach planted between rows of potatoes saves room in the garden and they do not compete for nutrients.

Sources: Various sources

In all these examples, nitrogen fixing trees (e.g. *Calliandra, Gliricidia, Leucaena, Desmodium, Tephrosia*) are an important additional element for providing biomass and nitrogen that can be used for fertilizing, compost production, and mulch material or feedstuff.

7.3.2 Multi-storey cropping

Multi-storey cropping describes a planting system in which different strata of vegetation/plants with different growth heights are implemented at the same time. In south-western Ethiopia, traditional homegardens widely employ this kind of intercropping (Table 22).

Table 22. Examples for multi-storey intercropping

Crop combinations	Description
Papaya + banana/ enset + coffee + sweet potato/ ginger/ pineapple	The uppermost storey is comprised of papayas, which are branchless and do not shade too much. Enset provides shade in between, serves well as mulching material for coffee plants growing underneath. The lowest layer consists of different root crops/ tubers, like sweet potato or ginger, fruits, or forage legumes.
Maize + beans + squash	The beans fixate nitrogen, the cornstalks form a trellis for the bean vines to climb, maize roots exudates feed rhizobia; the broad squash leaves inhibit weed growth and shade the soil.
Tapioca + butterfly pea	The tapioca tree works well as a trellis for the pea, which in turn provides nitrogen for the tree.
Leucaena + chives	Leucaena provides nitrogen and shade for chives.
Eucalyptus + papaya + berseem	Berseem acts as forage/ pasture and fixes nitrogen.
Pigeon pea + sesame + ground nut	Pigeon pea provides shade, both legumes provide nitrogen, sesame serves as the cash crop, can be intercropped with ground nut.
Mango + guava + cowpea	Two fruit trees of different height serve as trellis, cowpea fixates nitrogen.

Sources: Own compilation, Abebe et al. (2010)

7.3.3 Trap cropping

Trap cropping is a method of pest/disease control that involves the combination of a main cash crop and an additional trap crop. Trap crops are intercropped or planted around the cash crop (border cropping) and they either attract pests away from the cash crop (trap cropping), repel them (repellent intercropping) or provide both functions (see push-pull intercropping) (Table 23).

Table 23. Examples of trap cropping

Trap crop	Main crop	Planting method	Used against
Napier grass, sudan grass, desmodium (push crop + N fixation)	Maize, sorghum	Intercrop/border crop, push-pull intercropping.	Stem borer.
Onions and garlic	Carrot	Border crop/as barrier between crops.	Carrot root fly, thrips.
Tomato	Cabbage	Border crop (tomato should be planted two weeks ahead).	Diamond black moth.
Lupin	Hot pepper	Strip intercropping.	African Bollworm (prefers lupin as egg depository).

Sources: Various sources

7.4 Crop rotation

Crop rotation is defined as the systematic follow-up of crops with different functions and characteristics for optimal crop growth over a certain period of years.

7.4.1 General rules

Per season one or two crops are planted in a follow-up. In some cases, a crop can be under-sown after a short time of establishing the main crop or at the end of the rainy season (relay cropping), using the remaining water in the soil.

Crop groups, i.e. families, represent different strengths and weaknesses. Therefore, the follow-up of crops has to take care of these characteristics. The change of crops follows specific rules that fulfil the functions in an organic farm (e.g. weed control, pest and disease control, nitrogen supply) (Table 24). Functions which are fulfilled in conventional systems via external inputs.

Table 24. Guidelines for crop rotations

Subject	Rules
Nitrogen fixation (legumes)	Alternate between N-fixing and non-fixing crops.
Crops of the same family	Change families from season to season.
Intercropping	Integrate where possible.
Relay cropping	Integrate where possible.
Soil cover	High share of soil covering crops or mulching material.
Humus	Alternate between humus-demanding and humus-promoting crops.
Weeds	Alternate between weed-sensitive and weed-suppressing crops.
Nutrients	Alternate between crops with high and low nutrient demand.
Pests and diseases	Avoid the follow-up of crops with the same / similar pests and diseases.
Distances in time (years)	Keep the distances between crops with the same soil borne diseases.
Catch crops	Integrate where possible.

Source: Own compilation

Crop rotation length is minimum two years, if there are two seasons per year, and five to six years, if there is only one rainy season per year.

7.4.2 Share of crop families and crops in rotation

To secure humus production and nitrogen availability and to avoid soil-borne diseases (insects, fungi, nematodes), the following shares of crop families are recommended (Table 25). A single crop should not cover more than 25% in a rotation, as the majority of soil-borne diseases survive for three years in the soil and most of the crops are affected by such diseases. The share of intercropping is also limited because integrated crops, even with a minor share in the field, are “transporters” of pests and diseases.

Table 25. Share of different crop groups in the crop rotation

Crop families	% of the rotation	Crop examples
Forage legumes	15-25	Alfalfa, desmodium, mucuna, lablab, cow pea, *Vicia spp.*
Grain legumes	10-20	Beans, peas, chickpea, cowpea
Cereals	up to 60	Maize, wheat, barley, teff
Oil crops	up to 20	Rape, sunflower, nug
Root crops	up to 20	Irish potato, potato
Intercropping	10-30	Cereals with grain legumes

Source: Own compilation

Crops are a host for soil-borne diseases and, therefore, an interruption of their cultivation should be planned to avoid the transfer of these diseases (Table 26).

Table 26. Cropping distances in organic crop rotations in number of years

Crop	Years
Rye	0-1
Millet, hemp	1-2
Maize, soybeans	2-3
Barley, triticale, wheat	2-4
Yellow, persian and egyptian clover, crowtoes (*Lotus corniculatus*)	3-4
Sugar beets, forage beets, cabbages, potato	3-6
Oat, rape seed	4-5
Lucerne, red-, swedish- (*Trifolium hybridum*), italian clover (*Trifolium incarnatum*)	4-8
Field bean (*Vicia faba*), peas, lupines	4-14*
Sainfoin (*Onobrychis vicifolia*)	5-6
Sunflower, flax	7-8

Source: Freyer (2018)
* crop rotations with a high share of peas should be avoided

7.4.3 Crop rotation example

Crop rotations should be designed based on the introduced rules (Table 24, Table 25, Table 26). High annual rainfall and longer rainy seasons or the access to irrigation allow two to three crops per year (Table 27). Crops growing for more than one year (bi-annuals, perennials) can be implemented in crop rotations (Table 28).

Table 27. Crop rotation examples for annual and bi-annual rainfall patterns

Year	Season	Annual rainfall/ one season	Bi-annual rainfall/ two seasons, ex. 1	Bi-annual rainfall / two seasons, ex. 2
1	Short		Forage legumes (e.g. Alfalfa)	Alfalfa
	Long	Forage legumes/ CC	Maize-IC, RC (grain legumes)	Alfalfa
2	Short		Grain legumes	Maize
	Long	Maize-IC, RC (grain legumes)	Wheat	Beans (RC)
3	Short		CC (mixture of grain legumes mainly)	Teff
	Long	Grain legumes (2 times, e.g. chickpea and lentil)	Potato	Potato
4	Short		Forage legumes	Vegetables/Herbs
	Long	Wheat / CC	Teff / oil crop	
5	Short			
	Long	Grain legumes (2 times)		
6	Short			
	Long	Potato / oil crops /CC		

Source: Own compilation (AT)
CC = Catch Crop; IC = Intercropping; RC = Relay cropping; / = alternatively

Table 28. Example for a crop rotation with crops cultivated over more than one year

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1	Forage legumes											
2	Forage legumes			Cassava + under-sown desmodium						Maize + beans		
3				Yams								
4							Wheat				Grain legumes	
5	Teff						Vegetables / Herbs / Spices*				Forage legumes	

Source: Own representation, modified after Dillon & Hardaker (1980)
* Herbs and spices mostly stay in the field for a longer period, with a low share of an area, or are planted in between coffee where shading is low.

7.5 Further information

- Abebe, T., Wiersum, K. & Bongers, F. (2010). Spatial and temporal variation in crop diversity in agroforestry homegardens of southern Ethiopia. *Agroforestry systems, 78*(3), 309-322.
- Freyer, B. (2019): The role of the crop rotation in organic farming, in: Köpke, U. (2019). *Improving organic crop cultivation*: Burleigh Dodds Science Publishing Limited.

8 Soil tillage

Section 8 introduces the role and functions of tillage approaches, links the different machineries with crop demands and informs about the management of mulching systems and related tillage practices.

8.1 The role and functions of soil tillage

Tillage systems are defined by the combination of technical operations applied in a given situation to reach certain targets in the crop production system. Tillage involves modifying, usually mechanically, the conditions of the upper soil layer, while, from time to time, also deeper layers.

Mechanical interventions in the soil are always interwoven with the cropping system. Loosening the soil is a combination of technical and biological interventions, where the latter is a combination of the root system capacities (type, quality, quantity, depth, root type), the above ground biomass production of the crop, and any additional organic matter (OM) in form of compost, farmyard manure of different qualities (fresh or aged manure) and slurry. OM can be used as a surface cover, mixed into the first 10 or 15-25 cm.

Soil tillage has a far-reaching influence on soil fertility, soil water household and crop growth. Soil tillage provides general, and in some cases also crop specific functions (see Table 29). Introduced machinery might be adapted in different ways to the specific soil and rainfall patterns.

Table 29. Soil tillage functions and used machinery

Functions	Machinery
Loosening the upper soil layer - 10cm	Stubble cultivator + skimmer plow
Loosening the below ground soil layer - 30cm	Wing share cultivator
Seed bed preparation	Circular harrow; rotary harrow; harrow
Transferring weed seeds into deeper soil layer	Plow
Stimulating weed germination	Currycomb + harrow
Ripping out and burying weed residues	Currycomb + harrow

To transfer weed roots from below to surface	Stubble cultivator
Combing weed roots out of the field	Horse harrow (with long prongs)
Transferring diseases towards below ground	Plow
Cutting OM; mixing into above ground soil layer	Stubble cultivator + skimmer plow
Mixing stubbles/ straw into the soil (straw length < 10 cm)	Mulcher + stubble cultivator; skimmer plow + wing share cultivator
Ridging for water harvesting	Plow
Mineralisation of humus	Several machineries with different intensities

Source: Own compilation
Plus (+) = combination, semicolon (;) = alternative approach

8.2 Implementing soil tillage practices

Soil tillage needs to be adapted according to soil characteristics, soil status, pre-crop residues and following crops' specific seedbed needs. In general, the smaller the seeds the higher is the demand for the fineness and evenness of the seedbed and the shallower seeds must be placed in the soil. However, the drier the soil conditions and the more insecure the expected rainfall will be, the deeper the seeds need to be placed. Table 30 describes different tillage approaches adapted to pre-crop residues and the demand of the following crop.

Table 30. Pre-crop following crop specific tillage approaches

Pre-crop	Tillage tool	Following crop
Forage legumes	Skimmer plow / wing share cultivator / stubble cultivator / harrow	Maize; wheat, other cereals
Cereals	Mulcher or removal of straw / stubble cultivator / harrow	Grain legumes
Grain legumes	Stubble cultivator / harrow	Maize
Maize	Plow / stubble cultivator / harrow	Grain legumes
Potato	Plow or circular harrow	Wheat
Teff	Skimmer plow / stubble cultivator / harrow	Forage legumes

Source: Own compilation

The diversity of tillage systems is in general very high, due to all kind of tillage tool specifications and combinations of functions. We distinguish three types:

1. **Clean tillage** in a broader sense comprises the process of ploughing and cultivating to incorporate all crop residues or the "cleaning" of residues via burning or using as forage. This kind of residue management risks that the soil becomes crusted and the surface closed by immediate rainfall, runoff water transporting soil with the consequence of a reduced infiltration rate of water. Also, frequent tillage pulverizes the soil and increases the potential for erosion and crusted soils.
2. Forms of **conservation tillage** are characterised by a shallow technical intervention. Concentrating crop residues on or near to the soil surface is most effective for conserving soil and water resources.
3. **No-tillage** is defined as the sowing / planting of crops without preparatory tillage, with or without biomass residues.

The current tillage technologies in most parts of Ethiopia cannot be characterised as a classical plow, but rather a mixture of thorn/chisel, cultivator and plow. This is not really turning the soil, although turning the soil (approx. 110-130°) is the main purpose of plowing. In general, soil tillage should, on average, affect the soil to a maximum depth of 10-15 cm. The turning of the soil needs specific plow shares, according to the soil type (share of sand, silt). Consequently, current smallholder farmers practice "plowing" with up to seven crossings of a field, thus a fundamental change of current soil tillage management is necessary due to the adverse effects on soil properties.

Forms of reduced soil tillage (conservation tillage) improve the rainfall use efficiency through increased water infiltration and decreased evaporation from the soil surface, with associated decreases in runoff and soil erosion. At least the tillage-crop combination determines the efficiency of this process. Reduced soil tillage has a less negative impact on mycorrhiza growth and distribution, it has a positive impact on the diversity of soil organisms and their quantity, specifically when crop rotations are established. An increase of microorganisms and mycorrhiza contributes to the uptake of minerals and water.

Zero tillage can be applied by hand if respective machinery is not feasible or available. Seeds can be placed in the soil, in between the stubbles from the pre-crop (shadowing by pre-crops), by using a stick when the soil contains sufficient humidity. When using zero tillage in cereal production, the cereal crops need to be cut close to the ground when harvested. Thus, insect larvae, which are in the straw, will be transferred out of the field. After several years with zero tillage, the soil naturally becomes compacted due to rainfall, machinery and/or pasturing of animals. Hence, loosening of deeper soil layers will be necessary.

A tillage-induced surface roughness and crop residues, possible for seeding wheat, maize or grain legumes, can reduce runoff velocity, wind erosion and create depressions for temporary water storage on the soil surface, thereby providing more time for water infiltration and reducing the potential of soil erosion by water. In contrast, an uneven soil surface complicates mechanical weed control. Loosening the soil surface via mechanical weed control, e.g. via harrowing, increases water and oxygen infiltration and thus belowground water reserves.

8.3 Mulching systems

The mulching of crop residues limits soil water evaporation and soil crusting, thereby increasing soil water infiltration and soil water availability for the crop. Biomass residues provide physical soil protection and thus minimising water runoff and the risks of water and wind erosion. Decomposition of retained crop residues also influences nutrient cycling in the soil and the availability of nutrients to the crop. Additionally, a minimum soil disturbance and the presence of a biomass residue cover may enhance soil carbon storage, reduce weed infestation and increase soil biological activity. Several types of mulching systems can be distinguished with specific advantages and challenges (

Table 31).

Table 31. Mulching systems

Mulching type	Description	Tillage system	Advantages	Challenges and risks
Mulching of crop residues in no-tillage systems	Organic matter of the former crop stays on the surface.	No tillage.	Low workload; increase of soil moisture.	Loss of a feed resource; accumulation of pests and diseases.
Mulch material from outside the field	Transfer of mulch material.	All kind of tillage systems.	Increase of soil moisture; addition of a specific biomass quality and quantity.	Higher workload; often biomass is not available; attracting pests and diseases.

Source: Own compilation

Approximately 8 t ha^{-1} of residues are needed to decrease soil water evaporation by about 30% compared to no-till bare soil, which is a high amount of biomass usually not available directly in the field. For increasing soil water infiltration, reducing water runoff and decreasing soil loss, a minimum of residue of at least 2 t ha^{-1} is required. The effect of increasing amounts of surface crop residues on soil nutrient supply (N, P and K) is relatively low, however depends on the type of mulch material (C/N ratio), quantity applied, and climatic conditions. An increase of annual soil OM can be expected, which can be estimated at about 0.4 t C ha^{-1} $year^{-1}$ as a result of leaving residues of 4 to 5 t ha^{-1} on average. Furthermore, weeds can be suppressed even with small amounts of residues, starting at about 1 t ha^{-1} DM mulch material.

8.4 Crop residue functions and management implications

The decision on the selection of a tillage system is closely linked to the way of the crop residue management. The residue management is connected to the soil-water nexus, demanding technical and crop specific adaptations. Crop cultivation residues (stover) can be stubbles, straw, and weed residues. While straw is mainly collected and mostly used as animal fodder, or sometimes clay briquettes, and partly for roofing, the use of stubbles and weeds, and their functions are diverse. On the other hand, they have many positive effects on the soil, if they stay in the field, such as:

- Reduction of soil erosion.
- Building of the humus content of the soil.
- Provision nutrients for the following crops.

The multi-functionality of crop residues demands a balance between supporting feed ratios of animals and building/maintaining soil fertility. The farmer's decision is between:

- Removal of all stubbles from the field.
- Maintenance of all stubbles in the field.
- Removal of parts of the residues from the field only.

The more root biomass and biomass from alley crops, farmyard manure and/or slurry a farm produces, the less impact has the decision which sub-system of a farm is appropriate.

8.5 Further information

Currently, there is no specific literature on organic farming (OF) tillage available. Be aware, that in some of the trials non-organic methods are applied. But there are several trials that might also inform about the organic system, with the exception of those where herbicides are applied, and thus a direct application is excluded in OF.

- Abidela Hussein et al. (2019)
- Adimassu, Alemu & Tamene (2019)
- Bayabil, Tebebu, Stoof & Steenhuis (2016)
- Erkossa, Stahr & Gaiser (2006)
- Gebregziabher et al. (2006)
- Gebretsadik, Haile & Yamoah (2009)
- Oicha et al. (2010)
- Subhatu et al. (2018)
- Tebebu et al. (2017)

9 Weed control

Section 9 describes the weeds' critical and positive characteristics. It introduces the pre-cautionary crop rotation and tillage approaches to reduce the risk of weed competition, as well as mechanical weed control options after the crops are established in the field.

9.1 Weeds from different perspectives

Weed is a main factor limiting crop yield. The delay of weed control leads to tremendous losses of crop yields (Table 32). Currently, the main technique for weed control is the hand hoe. Non-chemical mechanical management techniques are limited. Even if herbicides are applied (which are not allowed in organic farming (OF) systems), practices of weed control are weak, inefficient, and endangering for human health and the environment. That is because handling is often not compliant with safety rules, the spraying is not adapted to the growing stage of weeds, weed resistance, diaspores have accumulated in soils, etc.

Table 32. Estimated yield reductions due to delayed weeding

Crop	% yield reduction	Crop	% yield reduction
Maize	40	Sorghum	30
Wheat	35	Barley	18
Teff	30	Lentils	50
Chickpeas	30	Faba beans	20
Haricot beans	36	Field peas	15
Soya beans	50	Cotton	73
Peppers	30	Coffee	62

Source: Desta (2000)

Weeds compete with crops for water, nutrients, and light. In the early development stages crops are specifically vulnerable against weed competition. Competition for water is generally considered the most important factor under dry conditions, while with high rainfall weeds can completely cover the main crop if not regulated properly. Under high rainfall conditions weeds are growing fast and the risk of reducing the main crop yield is high. Weed yield can reach more than 1 t ha^{-1}, which is significant compared to crop yields with often less than 2 t ha^{-1}.

Weeds, or in this context herbs and grasses, also provide multiple positive functions in a cropping system, with positive impacts on soil fertility and crop yield, e.g.:

- Soil coverage, reducing risk of soil erosion.
- Mineral transfer from belowground and uptake of micro-nutrients.
- Host for mycorrhiza (increases the mineral and water uptake under dry conditions) as a source for the main crops.
- Host for beneficial insects, e.g. wild bees that are responsible for the efficient pollination of main crops.
- Feed source for bees.
- Feed source for animals.

Weeds can be tolerated to a certain amount, mostly when the main crop covers the soil approximately six weeks after sowing, without having a negative impact on the main crops' performance. Optimised weed management can lead to a yield increase of the main crop of up to 50-200%.

9.2 Crop characteristics and crop rotation-based weed control

Crop sensitivity to weeds starts with the size of crop seeds. Small seeds are sensitive (e.g. teff, forage legumes), due to the longer time period they need to reach a certain crop size, in comparison to large seeds. This fact can be explained by their faster germination and seed induced nutrient and water reserves (e.g. peas, beans) (Table 33). Furthermore, the dormancy of seeds can vary within different varieties and increase the risk of competition with weeds, as well as the germination rate of seeds, if not regarded in the seed density. Higher distances in and between crop rows can lead to an increase of weed competition. On the other hand, it allows for better mechanical weed control, specifically between the crop rows. Cereals with a short straw type (e.g. finger millet) are more vulnerable against weed, as well as pea varieties with half-leaves, or lentils and chickpeas. Generally, after approx. six weeks, crops cover the soil sufficiently to compete successfully with weeds. Before, an efficient weed control is of high priority.

Based on crop specific vulnerabilities and their capacity to suppress weeds, defined rules exist for the follow-up of crops in crop rotations to limit weed development and competition with the main crops (see also section 7.4). The main rule for controlling weeds via a crop rotation is to alternate between weed-sensitive and weed-suppressing crops, and to integrate forage crops with more than one cut per year.

Table 33. Crop characteristics and mechanical weed control

Crop	Vulnerability in the early stage	Weed suppressing capacity	Potential for mechanical/ mechanised control	Potential techniques
Wheat	+ to ++	++	++	Hand hoe / mechanical weed control*
Barley, oat	++	+	++	Hand hoe / mechanical weed control*
Maize	+	++	+++	Hand hoe / mechanical weed control*
Finger millet, teff	+++	+	+	Hand hoe / mechanical weed control*
Faba bean	+	++	++	Hand hoe / mechanical weed control*
Peas	+++	+	+	Highly sensitive and mechanical weed control limited; mainly hand hoe
Lablab	+	+++	+++	Hand hoe / mechanical weed control*
Cowpea	+	+++	+++	Hand hoe / mechanical weed control*
Forage legumes	+ to ++	+++	+++	Cutting/mulching the crop after growth of approx. 10 cm to kill the annual weeds in between
Vegetables	+ to +++	+	+++	Hand hoe / mechanical weed control*
Potato	+	++	+++	Hand hoe / mechanical weed control*
Sweet potato	+	+++	+++	Hand hoe / mechanical weed control*
Tuber crops	+	+++	+++	To add e.g. clover in between the crops

Source: Own compilation
* curry comb and weeding cultivator

9.3 Tillage based weed control

As chemical herbicides are prohibited in OF, tilling plays an important role in mechanical weed control.

9.3.1 Tillage techniques for weed control

We distinguish eight main tillage systems for weed regulation (see also section 8). They are used in practice, partly combined with a crop rotation sequence, and often with diverse instruments, different sizes, working depth, driving speed of tractors, or drawn by animals. The tillage systems differ in their impact on soil, water, weed, pests and diseases. This diversity poses limits to offering general recommendations. Following procedures are always to be adapted to the field specific circumstances:

- Deep plow (up to 35 cm): burrowing of weeds to a deeper soil depth can hinder their germination, but on the other hand conserve the seeds with possible germination during the following season(s).
- Inter-row cultivation with oxen-plow (*Shilshaloat*): Breaking the soil crust in between the crop rows, such as maize or sorghum.
- Shallow plow (up to 15 cm): loosening of weeds and covering them with soil.
- Wing share cultivator (up to 30 cm): loosening specifically deep rooting weeds.
- Double-heart coulter cultivator (up to 15 cm): shallow mixing the soils, de-rooting weeds and transferring them to the surface.
- Chissel plow (up to 10 cm): cutting weeds via rotating discs.
- Rotavator (up to 8 cm): rotating knives, loosening of weeds, mixing with soil.
- No-tillage: no intervention in the soil; seeding via a stick, or if mechanized via slit drill seeding.

Under OF conditions, where herbicides are excluded, reduced tillage as a stand-alone measure can be critical and mostly leads to stronger weed growth. This approach can be established only if combined with regulative strategies in the cropping system with 20-25 % of forage legumes, mulching, and additional technical interventions.

9.3.2 Times of tillage interventions for weed control

To reduce weed pressure effectively, timely weed control before planting is essential. Technical measures, following specific time windows, are:

- After harvesting the pre-crop: Soil should be loosened and weed seed germination facilitated via harrowing to induce seed germination – this can be conducted twice or more times.
- In between harvest and establishment of the following crop: In case perennial weeds dominate, they can be reduced by using catch crops and their cuttings (see above), and / or mouldboard ploughing to bury the weeds; disking perennial root weeds can lead to weed multiplication via parts of roots.
- Before sowing: High seed bed quality is of high importance in order to provide best germination conditions and growing advantages for the main crop.

The weed control can be significantly improved by applying such interventions properly and in time. The specific actions depend on several aspects such as the pre- and following crop, soil conditions (soil type, water), crop residues, or the availability of a certain technique.

9.4 Mechanical weed control after establishing the crops

Mechanical weed control provides multiple functions. Besides reducing weed pressure, loosening the soil to increase water and oxygen infiltration serve for optimising the overall growth conditions for the crops, the micro-fauna and microorganism activity of the soil, while increasing the mineralisation of (soil) nutrients.

Equal to tillage techniques, several options for weeding, such as horse and currycomb harrow, wheel hoe, or finger harrow exist. Five degrees of technological intensities can be differentiated:

1. Hand hoes in different versions and instruments.
2. Instruments with or without wheels that can be moved via oxen or horses.
3. Instruments with wheels, but without motorisation.
4. Instruments that are moving by a rotovator (walking tractor).
5. Instruments for tractors.

The selection of technologies depends on the soil, soil structure, size of the land, rainfall, crop, and financial capacities. Currently, most of these technologies are not available in Ethiopia or not affordable for the single farmer, which is a challenge for the weed control management.

Hand hoe / mechanical weed control should be applied according to three phases:

- Phase 1 – Before germination of crops: loosening the soil and disturbing weeds in the germination phase.
- Phase 2 – Early stage of crops: 4-6 or 6-8 leave stadium of crops; loosening the soil and disturbing weeds in the germination phase, as well as small already rooting weeds.
- Phase 3 – Before the crop is closing its canopy: disturbing bigger weeds.

Mulching is also an efficient strategy for suppressing weeds. Furthermore, mulching reduces evapotranspiration, provides nutrients, and hinders erosion processes. However, the challenge is to produce sufficient mulching material. Weeds can serve as mulching material, but mulching with weed biomass containing weed seeds should be avoided.

An appropriate amount for the suppression of weeds are approx. 5 t DM ha^{-1} a^{-1}. To produce this amount, alleys in between the field crops, or in the surrounding of the fields, can provide the needed biomass. In some cases, compost can also be used for covering the surface around single crops or crop rows.

9.5 Further information

Limited research on weeds in OF systems in the tropics exists. Some of the existing literature includes the use of herbicides which is prohibited in certified OF. Such research needs a reflection on how the recommendations beyond the herbicide use can be relevant for OF systems.

- Iyagba (2010)
- Marambe & Sangakkara (1996)
- A. K. Watson (1992)
- Liebman & Davis (2009)

10 Crop pest and disease control

Section 1 introduces to why the conventional pest and disease management does not provide a sustainable solution for smallholder farmers. Instead, a series of alternative technical and crop production methods for regulating pests and diseases are introduced, including nature-based products.

10.1 The critical situation of pest and disease control

The Ethiopian climate in the highlands provides both, humid conditions that are predestined for the development of crop fungi, and more dry periods that are favoured by insects. The latest developments in cropping systems indicate less crop diversity, which provokes an increase of soil-borne diseases, i.e. crop rotation pests and diseases.

Crop production strategies to reduce pest and disease pressure via crop rotations with more than six crops are rarely implemented in farms. As a result of one-sided crop rotations, the humus content of soils is low, which is often an additional indicator for low microbial biomass and diversity, as well as low mycorrhiza growth. This is weakening the soil's potential to reduce diseases, but also reducing the uptake of available nutrients.

Technical measures, such as the low cutting of maize stubbles, are often missing and hence allowing for the survival of e.g. stemborer larvae, if not pastured by animals. Strategies to increase the anti-phytopathogenic potential of soils, via the addition of compost or farmyard manure, are often lacking, too.

A strategy to implement pest and disease resistant varieties is not established. In general, a broader spectrum of varieties with specific characteristics is missing in the market. Biotopes in the farms and overall biodiversity decreased over time and today living spaces for beneficial organisms are limited or absent.

In summary, at most farms relevant cropping systems and natural based mechanisms for pest and disease control are excluded or lost their functionality. Current doses and application techniques of pesticides are critical, spraying is often not timed correctly and can lead to environmental pollution and human health problems. Integrated pest management systems are weakly developed and information thereof is rare.

The following section focusses mainly on the farms' internal potential and natural based interventions to regulate pests and diseases, as it is the strategy in organic farming (OF) systems. This introduction informs about a range of innovations for reducing the risk of pest and disease infections, with an estimated yield potential of 50 to 100 %.

10.2 Alternative pest management

Alternative pest management strategies can be classified into agronomic, plant production and biotope specific measures in the farm, and technical strategies offered by industries. Table 34 provides an overview of the general strategies which are only in some cases crop specific. The strategies help to increase the resilience of farming systems against pests and diseases. Obviously, many strategies need to be optimised for crop protection against pests and diseases.

Table 34. Alternative pest management

Approaches	Description
	Farm internal
	Agronomic
Sowing technique	To offer best growing conditions through optimal spacing and deposition of seeds in a well-prepared seedbed.
Sowing date	To sow early or late to avoid pest and disease damages in certain plant growth periods.
Seed protection	To protect seeds through application of liquids or specific soils; pre-germination of seeds in (warm/hot) water.
Seed development	To initiate fast development of plants through pre-germination in water.
Soil tillage	To disturb the living space of pests; to transfer pests into deeper layers where they are not able to survive or develop and finally die off.
Harvest	To cut and transfer parts of plants that host pests and diseases.
Irrigation	To establish water saving methods in order to regulate climatic conditions to avoid fungi.
Manure, compost	Well prepared compost with temperatures above 60°C.
Slurry	To control pests.
Plant based liquids	To control pests and to strengthen plant health.
	Plant production
Crop rotation	To reduce the survival of soil borne diseases.
Catch crops	Pest distraction.
Intercropping	To offer beneficial living space and to reduce pest pressure.
Crop spacing in an area	To optimise general plant growth conditions.
Companion planting	To integrate "enemy" plants to keep pests in distance or to hinder their development.
Cover cropping	To reduce the spreading of diseases.
Guard crops	Strong smelling plants to discourage pests.
Push and pull	To regulate pests, diseases and weeds through the combination of maize, desmodium, Napier, and other grasses.
Alley cropping	To regulate micro-climatic conditions; to provide living space for beneficial organisms.
	Biotopes
Single trees	To provide living space for beneficial organisms.
Hedges	To provide living space for beneficial organisms.
Woodlots	To provide living space for beneficial organisms.
	Farm external
	Seeds
Varieties	To provide resistant or tolerant varieties against pests and diseases.
Seed protection	To protect seeds against pests and diseases through the application of industrial produced liquids.
	Products
Natural based pesticides	To protect / reduce pests and diseases through the application of industrial produced liquids.
Pheromones	To hinder the multiplication of pests.
Yellow tables / Glue	To collect pests.
Lime	To block pest pathways.

Source: Own compilation

10.3 Crop combinations to reduce risk of pest and disease development

Many different allelopathic interactions between plants or plant families are known (see also section 7.3). The principle of companion planting is a strategy in gardening to use these positive physical or chemical interactions between plants for more effective planting schemes (Table 35).

Table 35. List of useful plant combinations / companion planting to reduce pest and disease pressure

Crops	Companion plants	Remark
Allium		Allium species may inhibit nitrogen fixation of legumes, but assist with pest control.
Chives	Leaf crops	Repels aphids, disease resistant.
Garlic	Leaf crops	Pest control reduces potato and tomato blight.
Leek	Celery, carrots, onion	
Onion	Beet, lettuce, carrots	
	Asteraceae	
Lettuce	Strawberry, carrots, legumes	
	Brassicaceae	
Broccoli, cauliflower, brussel sprouts, cabbage, savoy, chinese cabbage	Beet, tomatoes, herbs (celery, mint, parsley, rosemary, sage, thyme, wormwood)	
Choumoellier, covo, rape, kohlrabi, turnip	Beet, lettuce, peas, herbs (chervil, celery, mint, parsley, rosemary, sage, thyme, wormwood)	
	Cereals	
Maize, corn	Legumes, cucurbita, rice	
Sorghum, millet, rapoko	Legumes, bushy plants, ground creepers	
	Cucurbita	
Butternut, courgette, cucumber, pumpkin, gem squash, melon, gherkin	Maize, sorghum, millet, peas, runner beans	In general: combine with tall, shade providing crops.
	Fruits	
Apple	Herbs (lavender, rosemary, hyssop, rue)	
Citrus	Nasturtium, guava	
Gooseberry	Tomatoes	
Grapevine	Mulberry, legumes	
Strawberry	Bush beans, lettuce, spinach	
	Herbs Often contain strong smelling essential oils	
Celery	Leeks, bush beans, runner beans, tomatoes	
Dill, caraway	Maize, cabbage, onion, lettuce	Flowers help to attract predatory wasps.
Fennel	Do not combine with tomatoes, beans, caraway	Fennel is a poor companion plant, works moderately with dill.
Hyssop	Grapevine	Can be a decoy plant for cabbage butterfly.
Lemon balm	Tomatoes, cabbage family, fruits, onions	Can help to prevent bees from swarming.
Lemon grass	Herbs	Repels mosquitoes and flies.
Mint	Kale, cabbage, radish	Mint repels moths.
Parsley	Tomatoes	
Wormwood	Carrots	
	Legumes Fix nitrogen for subsequent seasons	
Broad beans	Dill	
Groundnut	Maize, soybean	
Kidney beans, dwarf beans, runner beans	Carrots, beet, cauliflower, maize, celery	

Pea	Beet, radish, carrots, cucurbita, potatoes	
Pigeon pea	Sunflower, millet, other legumes	
Soybean	Groundnut	
	Diverse	
Spinach	Strawberries	
Chard	Legumes	
Chicory	Radish, carrots, beet, turnips	
Sunflower	Lettuce, legumes, herbs	Do not combine with potatoes.
	Root crops	
Beet	Lettuce, cabbage, onion, dwarf beans	
Carrots	Lettuce, radish, chives, onions, leek	Leek repels carrot fly.
Cassava	Tapioca	
Parsnip	Onions, legumes	
Radish	Legumes, onions, lettuce	Radish is a good companion plant to most plants.
	Solanaceae	
Eggplant	Green beans, potatoes	
Potato	Legumes, sweet corn, cabbage, eggplant, flax, parsley, garlic	Flax repels potato bug.
Tomato	Parsley, garlic	
Tobacco	Tomatoes	Compost made with tobacco roots is rich in potassium.
Capsicum, pepper (sweet and hot)	Parsley, garlic, legumes	

Sources: Own compilation; Vukasin, Roos, Spicer & Davies (1995)

The maintenance of an ecological diversity via the before-mentioned agronomic methods should be the main focus in preventing pests and diseases. Besides these measures, herb teas, oils and other liquids, and household remedies can be applied for combatting pests, especially as they are cheap to produce (Table 36).

Table 36. Plant based liquids and household materials for pest control

Ingredients	Description	Method
Basil *(Ocimum sp.)*	Treatment of seedbeds against soil borne diseases and pests.	Crush leaves and soak for 24 h, drench soil with infusion before planting.
Blackjack *(Bidens pilosa)*	Insecticidal and antifungal properties.	Collect and crush seeds, boil for 10 minutes to make a tee before spraying.
Garlic / Onions *(Allium sp.)*	Natural pesticide against insects and slugs.	Soak 1-3 crushed bulbs in 1 l of water before spraying; bit of soap can be added.
Khakibush /Marigold *(Tagetes sp.)*	Can be used against aphids, soft bodied insects, and nematodes.	Soak 10-15 mature, chopped plants in 20 l boiled water; add some sieved wood ash and spray affected plants. The remaining course material from the solution can be used as good mulch.
Chili *(Capsicum sp.)*	Used against insects. Best in a mixture with garlic/onion and marigold.	Crush 1 garlic bulb, 1 onion and 1 tablespoon of chili, mix with 1 l of water, add 1 tablespoon of soap after 1 h, then spray.
Tephrosia *(Tephrosia vogelii)*	Powerful repellent and insecticide. Contains rotenone which kills fish, should not be used near streams or water!	Crush 50 fresh leaflets and soak in 1 l water for 24h; train and spray, do not add soap.

Tobacco	Nicotine contained in tobacco is very poisonous, should only be used with extreme caution and as a last resort! Never harvest plants treated with tobacco within 3 days after spraying. Do not use tobacco on the potato family.	Soak 1 kg of bruised tobacco leaves in 15 l water for 24 hours, then spray. Addition of slaked lime will increase the effectiveness of the spray.
Mineral oils	Light mineral oils may be used against pests and eggs. Do not spray often and not on hot days since the oil affects plant growth.	Mix 20 ml of oil in 1 l water, then apply.
Pyrethrum	An effective insecticide derived from the *Chrysanthemum* family or *Tanacetum parthenium.* Spray can be used against many insect pests, it is non-toxic to mammals.	Pour 1 l of boiling water over 50 g pyrethrum powder / 250 g *Tanacetum* flowers, let it soak for several hours, then filter and add 1 l soapy water, then spray.
Flour	Household flour can be used to control mites, aphids, and caterpillars.	Dilute 1 tablespoon of flour in 1 l water, splash or wipe on infested leaves; the solution should be put on the plants in the morning on a sunny day. Flour can also be dusted on caterpillar-infested plants.
Milk	Milk can be used against many fungal diseases and some viral diseases, as well as spider mites and the eggs of several caterpillar species. Sour milk mixed with water and wood ashes can be effective in controlling mildew.	Dilute 1 l of milk in 10-10 l water, then spray. Spraying has to be repeated after 10 days for diseases and after 3 weeks for insects.
Insects	Remedies made from a pest species itself often discourages others from eating.	Crush 10-20 grasshoppers and mix with 5 l water; sprinkle over crops affected by this specific pest.
Compost	A tea made from well decayed, fermented compost can be used as a tonic to strengthen plants and treat a variety of fungal and bacterial diseases.	Mix a shovel full of compost with 10 l water and let it stand for 3-11 days, then apply on plants directly, using a watering can. After sieving, it can be used to spray on diseased leaves.

Source: Vukasin et al. (1995)

10.4 Further information

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11 Hedge and alley systems

Section 11 introduces the role and function of hedge and alley systems and their integration into smallholder farms. An example is given that explains the economic relevance of alley trees.

11.1 Role and functions of hedge and alley systems

From an ecological point of view, there is no stability of the Kafa Zones ecosystems without trees. As a result, strategies are necessary that integrate elements of forestry into the farming system. Hedges and alleys are elements of agroforestry systems and are important contributors for farm productivity increases and sustainability. When hedgerows and alleys are systematically implemented, farm productivity can be raised by about 50 to 200%.

Advantages of hedge and alley systems:

- Provide fuel wood, timber, shade, fruit, medicine, fodder for livestock, and green manure for improving soil fertility.
- Benefits for crops through improved soil fertility, soil structure, soil moisture and micro-climatic conditions, transfer of nutrients to crop field from hedges/alleys, possibly habitat generation for pest predators (increased farm biodiversity), soil erosion protection from wind and water.
- Extended cropping period and higher intensity of land use possible.
- Trees and shrubs deliver highly demanded fuel wood and construction material, and can thus be used to generate additional value and income (as well as additional fodder for animals).
- A farmer can produce a higher yield per unit of land compared to monoculture cropping.

Challenges for the establishment of hedge and alley systems:

- Establishment needs some time, thus benefits will come with a time gap.
- Capital for investment in trees is necessary.
- Higher demand for labour and management – planting, watering, and pruning schedules need to be carried out in time, otherwise the result will be poor; however, the labour demand can be reduced by proper planning.
- Alley crops can compete with crops for water and nutrients; therefore, you need to plant trees/shrubs with deeper rooting systems than the crop plants.

11.2 Species characteristics

The diversity of alley and hedge crop species is enormous. Species perform differently in terms of biomass production, nitrogen fixation, phenotype, root biomass, wood quality, drought and frost resistance, forage quality, contour planting potential, pH demand, and yield (Table 37).

Table 37. Alley and hedge crop characteristics

Species	Site conditions pH; T°C; NN; M.a.s.l.	Drought resistance	Biomass production* t ha^{-1} a^{-1}	Nitrogen fixation kg N ha-1 a^{-1}	Feeding cha-racteristics	Source
Acacia spp. (*Acacia nilotica*)	5-9 pH 18-28 °C (tolerates 4-47°C) 300-2,200 mm 0-1,340 m	+++	n/a	n/a	++ (leaves: 14-20% crude protein, leaves and pods generally well accepted by animals)	www.tropicalforages.info http://apps.worldagroforestry.org/treedb/index.php
Crotalaria spp. (*Crotalaria juncea*)	6-7 pH (tolerating 5 – 8) 20-30 °C (tolerates 4-40) 500-1,500 mm (tolerates 200-4,300 mm) up to 1,500 m	+++ (when est.)	Total green matter yields 18-27 t/ha, forage yield 5-19 t/ha	10-90 kg/ha	+ (some compounds cause unpalatability)	www.pfaf.org Samba et al. (2002)
Calliandra spp. (*Calliandra calothyrsus*)	5-6.5 pH 22-28 °C 700-4,000 mm 250-1,800 m	++ (can tolerate drought)	++ 7-10 t DM/ha/a	n/a	++ Leaves and pods rich in protein (22% DM), non-toxic, but contain tannins (can reduce protein digestibility)	www.pfaf.org http://apps.worldagroforestry.org/treedb/index.php
Faidherbia spp. (*Faidherbia albida*)	5,5-7 pH (tolerating 5-7.5) 18-30 °C 250-1,200 mm 270-2,700 m	+++	n/a	n/a	Pod and leaves high quality feed forage	www.infonet-biovision.org http://tropical.theferns.info
Gliricidia (*Gliricidia sepium*)	4.5-6.2 pH >15 °C 900-1,500 mm 0 - 1600 m	+++	++ 9 to 16 t/ha of DM in fodder plots	+	+++ High nutritive value. CP content 18-30% and in vitro digestibility of 60-65%	www.tropicalforages.info
Grevillea spp. (*Grevillea robusta*)	5-7 pH 15-20 °C (tolerates down to -8) 0-3,000 m 700-2,000 mm	+++	n/a	n/a		www.infonet-biovision.org http://apps.worldagroforestry.org/treedb/index.php
Leucaena leucocephala	5-8 pH 25-30 °C 500-2,000 mm 0-1,000 m	+++	++	n/a	+++	http://www.newforestsproject.org/ www.pfaf.org

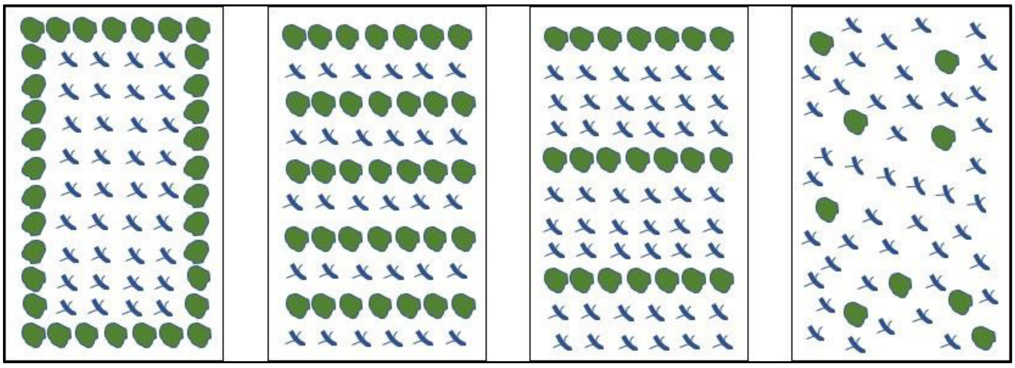
Pigeon pea (*Cajanus cajan*)	5.5-6.5 pH 18-38 °C 500-1,000 mm Up to 1,500 m	+++ (when established)	+++ 1-5 t/ha/a green matter	n/a	+++ Leaves up to 9% protein	www.pfaf.org www.infonet-biovision.org
Sesbania sesban	5-7,5 18-24 °C 100-2,300 m 500-2,000 mm	+++	+ Average 4-12 t DM/ha/a, but up to 20 t/ha DM	n/a	+++ Protein rich (20-30% of DM), good digestibility	www.infonet-biovision.org www.feedipedia.org
Stylosantes spp. (*Stylosantes fruticosa*)	4-8 pH 25-30 °C 350-1,500 mm Up to 2,000 m	+++	+ 3-6 t DM/ha/a	n/a	++ About 8% protein in DM	www.feedipedia.org
Tree lucerne (*Chamaecytisus palmensis*)	5-7 pH -15-40°C (tolerates a wide range) 350-1,600 mm 0-1,000 m (but survives up to 3,000 m)	+++	+++	+++	+++ (foliage 17-22% protein (DM))	http://apps.worldagroforestry.org/treedb/index.php

Sources: Own compilation, various sources
* Depends on the size/age of the bush or tree
+ (lower) to +++ (high) = Level of drought resistance / ability to fixate nitrogen/ fodder quality

11.1 Integration of hedges and alleys into farming systems

There are different ways of adopting hedge and alley systems (Figure 10). In the first three examples (from left to right), trees and shrubs are grown in alleys or hedgerows. In the example on the right, where trees are dispersed, they should be grown in a distance of 8 to 10 m. The alleys need to get pruned regularly to avoid shading of crops, with the biomass providing a valuable resource.

Figure 10. Alley system designs



Source: Own illustration, according to Kang (1996)

11.2 Economy of alley crops

The economy of alley crops needs a site-specific calculation, as many factors influence the performance. Table 38 provides an exemplary calculation of labour input, investment costs, and profit based on a case study on *Grevillea robusta*, which is suitable for the midlands and highlands of Kafa. *Grevillea robusta* has high potential as it is a hardwood with a high market demand, low water needs, beneficial to the soil, and yields significant returns if kept for at least six years. It can be planted as a barrier crop around the fields and hence, having a high adoption potential for limited land sizes. However, seedling supply, investment costs, and difficult germination of *Grevillea robusta* are challenges to face.

Table 38. Exemplary economic calculation *of Grevillea robusta* cultivation with 200 trees using a space of 10 x 5 m on 1 ha

Indicator	Unit	Planting Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Total
Labour	Days	40	30	20	15	15	15	15	**150**
Seed and material costs	Birr	1,000	400	0	0	0	0	0	**1,400**
Labour costs	Birr	2,350	1,700	1,200	900	900	900	900	**8,850**
Costs	Birr	3,350	2,100	1,200	900	900	900	900	**10,250**
Sale value per tree	Birr tree $^{-1}$	-	14	60	140	300	440	600	**600**
Sale value 200 trees	Birr*	-	2,800	12,000	28,000	60,000	88,000	120,000	**120,000**
Net primary value	Birr								**109,750**

Source: Adapted from OneAcreFund (2014)
*The trees do not provide a cash flow per year, but rather provide income when the trees are harvested. The sale values are conservative estimates.

11.3 Further information

- Bishaw (2001)
- B. Kang & Mulongoy (1992)
- B. Kang, Van der Kruijs & Atta-Krah (1989)
- Jabbar, Reynolds, Larbi & Smith (1997)
- Sumberg, McIntire, Okali & Atta-Krah (1987)

12 Coffee

Section 1 describes the diverse coffee systems, seedlings, planting, and coffee plant education, planting schemes, organic manure, and fertiliser demands that are relevant for an optimal coffee yield, and specifically to adapt to and mitigate to climate change.

12.1 Coffee systems

As the origin of wild coffee, *Coffea arabica*, Ethiopia produces premium quality coffee, as the highland area is suitable for Arabica production. Ethiopia has the potential to be a leading producer in both, quality and quantity. Ethiopian coffees are traded worldwide as conventional or speciality products. Speciality coffee is certified by organic (Ndambi, Pelster, Owino, De Buisonje & Vellinga, 2019) standards, Rainforest Alliance, Fairtrade, or combinations of programs.

Arabica coffee grows over a wide range of agroecological zones and geographical regions. A high share of coffee produced in Ethiopia is shade grown (40-60% canopy cover), except for some homegarden systems in the east.

Ethiopian coffee regions can be classified into four production systems, of which the first three can be considered as traditional (Table 39). Coffee production systems differ according to accompanying vegetation, structural complexity, management, and agronomic practices.

Table 39. Coffee production systems in Ethiopia

Production system	Data	Description	Propagation
Forest coffee (FC)	5% of total production Yield: 200-250 kg/ha	Close to natural forest condition, almost no intervention.	Natural regeneration.
Semi-forest coffee (SFC)	50-55% of total production Yield: 300-400 kg/ha	Forest is manipulated mainly for coffee production, low management intensity.	Natural regeneration, planting of local coffee varieties.
Garden coffee (GC)	40% of total production Yield: 400-500 kg/ha	A lot of variations within the coffee system, intensive management needed, hoeing and fertilization; planted shade trees, mainly intercropping with enset.	Planting of selected coffee varieties; seedling selection and raising in nurseries.
Plantation coffee (PC)	<5% of total production Yield: 1,000-1,200 kg/ha	Coffee grown by the state enterprise or private companies, under planted shade trees.	Planting of selected coffee varieties; seedling selection and raising in nurseries.

Sources: Gole, Itana, Tsegaye & Senbeta (2015); Hirons et al. (2018)

Forest coffee production displays the highest biodiversity of all coffee production systems (Table 40) and, therefore, fits naturally well for an organic approach.

Table 40. Vegetation characteristics of different production systems (Yayu area)

Coffee systems	Canopy cover %	Trees ha^{-1}	Canopy tree species n	Coffee plants ha^{-1}
Forest	84	460	32	3,600
Semi-forest	40-60	155	19	5,800
Garden	30-40	75	5-10	1,000-3,500
Plantation	30-40	75	5-10	3,300

Source: Gole et al. (2015)

In the following we focus on the garden coffee system, which asks for several organic farming (OF) practices that can also be applied in the plantation system.

12.2 Garden coffee management

While in forest and semi-forest coffee systems the intervention via management is limited, garden coffee needs several activities to make the coffee productive and capable to cope with climate change, i.e. increasing temperatures. To maintain and increase biodiversity is of high relevance in terms of climate regulation, wood use for different purposes, apiculture, and other options for second income generation.

Garden coffee is a combination of coffee plants, crops that deliver humus and nitrogen or other nutrients (fertiliser trees), shadow and cooling function, eventually other fruit crops, green manure, and value trees for diverse purposes. In the early stage of planting, also food crops, e.g. maize with beans, can be integrated without competing the coffee shrubs (Table 41, Table 42).

Coffee seedlings are prepared in shaded nurseries. Seedlings are to be raised 6-12 months before the planting season. For that, a seedling bed needs to be prepared, with best compost quality from cow dung. Under reduced rainfall patterns seedlings are dependent on a water supply.

The young coffee plants need to establish under shade trees (see section 12.2.1). Most of the certifiers of organic coffee ask for more than 12 different tree species. For planting coffee, compost must be added to the planting hole (see Table 41) and mulch to the surrounding of the coffee plant. After planting the seedlings, it takes 2.5-3 years before the first coffee is produced.

Weed control should be done continuously around the coffee plants. The main reduction of weeds under Kafa rainfall conditions is through under-sown legumes. Whenever possible, mulch material is to add to the coffee plants directly from banana/enset (leaves), or branches from the shadow trees.

Pruning is an essential management practice in coffee production. It helps to achieve the desired plant shape and leads to sustainable higher yields, while contributing to disease and pest control. Current practice involves capping the main branches at 1.8 m toward a stumping at 30 cm above ground (Gole et al., 2015). The cutting should be done with an angle, allowing the water to drop down, so the cutting can dry fast to avoid the development of fungi. As important is the cleaning of the shrub in the inner part of the coffee plant, which supports air circulation and thereby reduces the risk of increased humidity and thus favourable conditions for fungi. Complete stumping is recommended at an 8-12 years interval.

Not only under the organic label, but also in traditional coffee farming, plant health is regulated by shading and pruning. Pest and disease pressure are higher in the more intensively managed systems, like plantations and home gardens. The major coffee diseases in Ethiopia are coffee berry disease (CBD) and coffee wilt disease (CWD). Coffee leaf rust (CLR) is regulated by high genetic diversity and the existence of tolerant genes, disinfected cutter for pruning, and the burning of infected material. The major coffee pests are nematodes, the coffee berry borer, leaf minor, stem borer, and scale insects.

Table 41. Steps to set up a garden coffee system

Steps	Activity	Remarks
		Year 1
1	**Selecting the site**	There are no specific limitations.
2	**Assessing soil quality**	Min. pH measurement.
3	**Tillage**	Keep the fertile soil on top.
4	**Measuring the field**	See figure below; keep the distances in the rows and in between the rows.
5	**Planting coffee**	See section 12.2.1.
6	**Planting shadow trees**	Shadow trees: mix of *Sesbania* and other legume trees; high value trees; trees for apiculture.
7	**Planting banana or enset**	For humus production and soil erosion control.*
8	**Apply manure**	One bin per coffee plant mixed with surface soil.
9	**Apply water**	One bin per coffee plant.
10	**Mulch the coffee**	Approx. a layer of 50 cm green manure around the plants.
11	**Sowing green manure**	Desmodium, alfalfa, clover, or mucuna.
12	**Pruning coffee and trees (ongoing)**	Use a clean cutter, protect the cut stem with wax or other substances; keep the inside of trees free of branches.
13	**Mulching prunings**	Cover the soil in between the crops with the prunings; infected material must be sorted out from the coffee site and used as mulch in other fields.
		Year 2-3
1	**Sowing green manure and mulching**	Keep soil around coffee crops free. Weed control only very shallow, to avoid damage of the shallow coffee root system.
2	**Sowing maize and beans**	Avoid narrow planting to the coffee reducing competition.
3	**Green manure seeds**	Harvest the seeds, dry and store for the next year, or let them fall down to the soil directly.
		Year 4-ongoing
1	**Composting coffee husks**	Recycle the compost to the crops.
2	**Animal manure and slurry**	Small amounts directly to the coffee plants.
3	**Green manure**	Use the seeds from the former years.
4	**Pruning coffee and trees (ongoing)**	See above; balance the shadow effect of trees.
5	**Banana / enset leaves**	Use the leaves for mulching directly around the coffee plants.

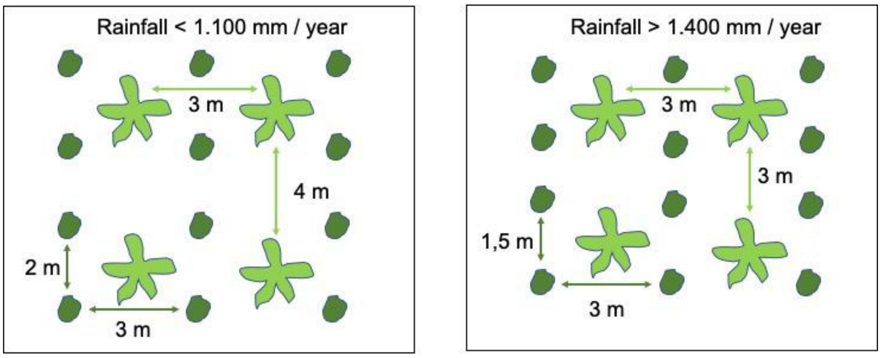
Source: Own compilation
* after harvest of fruits stems can be positioned in the field as soil erosion barriers above the single coffee plant

12.2.1 Coffee planting schemes

Coffee crop density, the implementation of banana or enset, of leguminous or shadow trees, and other plants like herbs (see the example) is a site-specific decision, based on experience, the soil quality, the rainfall pattern, and the amount and characteristics of the chosen coffee varieties. With decreasing rainfall, the density of all crops has to be reduced as well (Figure 11).

Due to an ongoing increase in temperature, professional shading to reduce the temperature is becoming more and more relevant for organising healthy coffee systems. Temperatures of 30°C and more lead to stress and challenge the survival of the plant itself. Shade trees can moderate extreme temperatures by at least 5°C.

Figure 11. Structure of banana-coffee intercropping under different rainfall regimes



Source: Own illustration, according to CIALCA (2010)

The planting scheme in Table 42 provides an example for a rainfall regime higher than 1,400 mm a^{-1}, added by Table 43 summarising the number of plants.

Table 42. Planting scheme for coffee with trees, cash crops, herbs and green manure crops

Hedge 3 m		Horizontal																Total
		Row		No.	1	2	3	4	5	6	7	8	9	10	11	12	13	m
		No.	cm	200	100	300	100	200	100	200	100	200	100	200	100	200	100	22
		1	200		UL													200
		2	100		BT		C	R	C	R	ST		C		C		BT	100
		3	200		ST		BE	R	ST	R	C		BE		ST		C	200
		4	100		C		C	R	C	R	C		C		C		C	100
		5	200		BE		ST	R	BE	R	C		ST		C		BE	200
		6	100		C		C	R	C	R	C		C		C		C	100
		7	200		C		BE	R	C	R	ST		C		BE		ST	200
	Vertical	8	100	MB	C	MB	C	R	C	R	C	O	C	MB	C	O	C	100
		9	200		ST		C	R	ST	R	C		BE		ST		C	200
		10	100		C		C	R	C	R	C		C		C		C	100
		11	200		BE		ST	R	BE	R	C		ST		C		BE	200
		12	100		C		C	R	C	R	C		C		C		C	100
		13	200		C		BE	R	C	R	ST		C		BE		ST	200
		14	100		BT		C	R	C	R	C		C		C		BT	100
Total		m	21															21
			No of trees (seeds) row -1															
BT			4		2												2	
ST			15		2		2		2		3		2		2		2	
C	No.		58		6		8		9		10		9		9		7	
BE			13		2		3		2		0		2		2		2	
R			26		0			13		13								
MB (seeds)			1.880	416	0	1,248								416				
UL (seeds)			2.275		325		325		325		325		325		325		325	
O			Open space for further crops															
Trees*			32		6		5		4		3		4		4		6	

Source: Own illustration
* incl. banana / enset
For shortcuts see Table 43

Table 43. Number of plants

Plot +15%	Plant type	Short cut (comp. Table 42)
4	Big tree	BT
15	Small (Legume) tree	ST
67	Coffee	C
13	Banana/enset	BE
30	Rosemary	R
1,914	Maize + beans	MB
2,616	Under-sown legumes	UL
0	**Open space for further crops**	O

Source: Own illustration

12.3 Economic considerations

The question arises how far the implementation of e.g. banana into the coffee system is economically advantageous. One example from Uganda (CIALCA, 2010) introduces a banana-coffee intercropping comparison of revenues per ha a^{-1}, which shows an economic advantage of banana and coffee intercropped (4,450 USD ha^{-1}) in comparison to coffee mono-cropped (2,400 USD ha^{-1}) or banana mono-cropped (1,700 USD ha^{-1}). The same is reported from agroforestry home gardens in Ethiopia when compared to non-agroforestry gardens (Linger, 2014). Furthermore, climate resilient strategies, such as the integration of shading trees, are economically of high relevance to keep coffee production resilient in terms of plant health and productivity.

An often posed question is whether certification guarantees higher income for the farmers through better prices (see Jena, Chichaibelu, Stellmacher & Grote, 2012). Insignificant premium prices, as well as poor access to credit and information from the cooperative is discussed. As a consequence, farmers and cooperatives need a monitoring scheme and advise on how to manage the coffee in a proper way and make the OF approach also economically competitive.

12.4 Further information

- Hirons et al. (2018)
- Tsegaye (2017)
- The Consortium for Improving Agriculture-based Livelihoods in Central Africa (CIALCA): www.cialca.org, https://www.youtube.com/watch?v=YYlQYmC1CiU

13 Grassland

Section 13 introduces the diverse pasture types, cut and carry systems for fresh fodder, hay and silage production, and species characteristics to optimise grassland performance.

13.1 Pasture types

Currently, pasture productivity is often below 1 t DM ha^{-1} a^{-1}. The oftentimes unregulated, free grazing practices hinder a production of high quality feed. Overgrazing, a lack of additional seeding and pasture management lead to erosion, landslides, and low productivity. However, there are diverse pasturing types that allow an environmental sound and efficient use of grassland (Table 44), to increase animal productivity and income.

Table 44. Animal pasturing types

Type	Description	Advantages	Disadvantages
Free grazing	Animals are moving with a cowboy anywhere.	Diversity of feed.	Low energy and protein density, labour demand.
Continuous grazing	Animals are moving free in a fenced pasture.	Low workload.	Quality of pasture might be low, risk of overgrazing.
Rotational grazing	Fenced areas, animals move from area to area, all the same size.	High forage quality.	High management demand.
Strip grazing	Animals get stepwise a new share of pasture.	High forage quality.	High management demand.
Arable land after harvest	Animals are moving with a cowboy.	Additional feed at the end of the season.	Soil compaction risk.

Source: Own compilation

13.2 Cut and carry systems

There is a saying that grassland is the mother of arable land due to the manure that is produced through animal feeding and manure collected, at least overnight, in stables, and finally distributed on arable land.

However, currently grassland management is of low quality, and far away to do this saying justice. Seeding with adapted plants, adapted cutting, and fertiliser systems are missing. The amount of animal manure is low or mostly lost, i.e. nutrients washed out or transferred to arable fields. As a consequence, grassland productivity is low. In the next years, cut and carry with the classical pasture systems will be an exception. In the meantime, hybrid grass species for a monocrop production of grass, like Napier grass or *Brachiaria spp.*, could provide a relevant amount of forage specifically in the Kafa Zone, with its relatively high rainfall. If space is limited due to competition with cash crops, every piece of land where erosion control measures are obviously necessary, hybrid grass stripes for cut and carry purposes should be established.

13.3 Grassland vegetation

Pastures are often poor in species and overused, and therefore ask for a re-seeding of the sward. For refreshing the sward, a mixture of grass and leguminous species is recommended (Table 45).

Before sowing during the first half of the rainy season, the soil has to be slightly opened with a harrow. After sowing, the pasture should not be used for six weeks to not threaten the establishment of the new plants. Fencing is a must and should be regulated and protected by the community. Additional manure is not a must, however small amounts of farmyard manure compost have a positive effect on plant growth. Refreshing the pasture with new plants leads to a potential biomass yield increase of 100-300%, which will have a similar impact on animal performance.

Table 45. Species for optimising pastures / grassland use

Species	Soil characteristics	Altitude M.a.s.l.	Rainfall mm	Utilisation	Yield t DM ha^{-1} a^{-1}	Plant characteristics
Grasses						
Brachiaria brizantha	Loamy soils	Up to 2,000 m	1,500-3,500	Pasture, cut & carry, soil conservation	8- 20	Can be heavily grazed.
Panicum coloratum	Fertile sandy to clay soils	Up to 2,100 m	400 – 2,000	Pasture or hay	4-23	Hardy species but should not be grazed during establishment, good with legumes.
Pennisetum purpureum	Well drained soils	Up to 2,000 m	200-4,000	Mainly cut & carry	20-80 (+ fertiliser) 2-10 (- fertiliser)	One of the highest yielding tropical grasses! Grazing at six to nine week intervals at a height of about 90 cm gives good utilisation.
Cynodon dactylon	Thrives best on heavier silt	Up to 2,600 m	625-1,750	Pasture, hay, cut & carry	5 - 15	Very resistant and robust grass, should be grazed heavily; potential weed!
Setaria sphacelata	Thrives on fertile loamy soils	Up to 2,600 m	>750	Pasture, cut & carry, soil conservation	10 - 15 (Up to 25 when fertilized)	Can be sown with companion legumes, only light grazing until establishment.
Cenchrus ciliaris	Light, sandy, rocky soils	Up to 2,000 m	375-750	Mainly pasture	2 - 18	Needs time to establish (up to six months), good in combination with *Chloris* or *Megathyrsus.*
Paspalum dilatatum	Heavy clay soils	Up to 2,300 m	900-1,300	Mainly pasture	3- 15	Resistant to heavy grazing, good in combination with *Cynodon* or *Trifolium.*
Avena sativa	Best in loam soils	Best above 2,000 m	>800	Pasture, cut& carry, hay	4- 15	Often sown in mixture with legumes; light and continuous grazing is recommended, should not be grazed when the soil is very wet.
Chloris gayana	Wide range	Up to 2,400 m	310-4,030	Pasture, hay, cover crop	10-16	Drought resistant, grazing should not be too heavy; grows well with legumes, *Setaria, Avrna, Chenchrus, Megathyrsus.*
Megathyrsus maximus	Well drained, moist and fertile soils	Well adapted to sloping, cleared land in rainforest areas	>1,000	Pasture, cut & carry, hay, silage	25- 30 (+ fertiliser) 5-7 (- fertiliser)	Should not be grazed under 35 cm height; helps to prevent soil erosion, but can become a weed in not grazed areas.

			Legumes			
Arachis pintoi	Wide range, well drained	Up to 1,400 m	>1,100	Pasture	1-5	Tolerant to heavy grazing and compatible with aggressive grasses such as *Brachiaria*.
Vicia sativa	Wide range	Originated in southern Europe	310-1,630	Pasture	1-6	Susceptible to drought in first phases of development; overconsumption can lead to gastrointestinal problems in livestock.
Medicago sativa	Best on deep, well drained, sandy to fertile loamy soils	Up to 2,400 m	600-1,200	Pasture, cut & carry, hay, silage	15-25	One of the most important forage legumes; does not tolerate close grazing well, and some form of rotational grazing is necessary to maintain the persistence and production of plants.
Lablab purpureus	Wide range	Up to 2,400 m, but prefers lower altitudes	2,500-3,000	Pasture, cut & carry, hay, silage	2-9	The crop should be first grazed about 10 weeks after sowing, does not withstand heavy grazing; may cause bloat; a well-managed stand can provide three grazing periods per season.
Desmodium spp.	Wide range (pH above 4,5)	Up to 2,500 m	900 -3,000	Pasture, cut & carry, hay, silage	12-19	Can be grazed as a long-term pasture, requires a well-prepared seed-bed for establishment; grows well with a wide variety of grasses; initial grazing should be very light to permit establishment, rest periods minimum 3-12 weeks.
Trifolium pratense	Wide range; prefers well drained loams	Can be grown at high altitudes	310- 1,920	Pasture, cut & carry, hay, silage	4- 20 (Pure stands, very region-dependent)	Red clover can replace alfalfa in areas too wet or too acidic for it; can be major source of honey; rotational grazing is best suited for persistence; during the year of establishment, light grazing is recommended.

Sources: feedipedia.org; Indian Grassland and Fodder Research Institute; INRA; CIRAD; AFZ; FAO

13.4 Pasture management

Uncontrolled, free grazing, which is commonly practiced in the area, leads to many problems. Animals eat the most palatable plants first and with a short recovery time, they will eventually die off. At the same time, weeds and plants of lower palatability will spread. In the practice of rotational grazing, a high stocking rate is kept on a smaller paddock for a short period of time, followed by a period of rest. Although paddock construction and moving the animals requires more labour demand and fertiliser input (manure), the advantages of rotational grazing are manifold (Table 46). Pastures are grazed more efficiently, grass nutritional value is higher, and weeds are better suppressed. Strip grazing follows the same principle. To reduce weed pressure, pasturing with different animals contributes to the control of grassland weeds and the regrowth of a diverse plant family.

Table 46. Rotational grazing: effect of the herbage growth rate on number of paddocks

Herbage accumulation rate* kg DM ha^{-1} day^{-1}	cm day^{-1}	Stocking rate AU ha-^{1}**	Return to the plant*** days	Period of Occupation (days)****	Resting (days)	Paddocks n
20	0.5	1	30	30	30	2
44	1	2	15	15	30	3
60	1.5	3	10	10	30	4
80	2	4	7.5	7.5	30	5
100	2.5	5	6	6	30	6
120	3	6	5	5	30	7
200	5	10	3	3	30	11

Source: Adapted from Corsi, Martha , Nascimento & Balsalobre (2001)
AU = animal unit (500 kg = 2 TLU, Table 49); DM = dry matter; * = herbage density of 40 kg DM cm^{-1} ha^{-1}; ** = Intake of 10 kg DM AU^{-1} day^{-1}; *** = Assuming the animal returns to the same patch grassland when regrowth is about 15 cm high; **** = Assuming the animal must not return to a given patch faster than the established period of time.

13.5 Silvo-pastoral systems

Pastures can be improved by additional seeding of suitable grass and legume species (Table 45) and/or the inclusion of trees (silvo-pastoral system). In such systems valuable fodder trees and shrubs (Table 37) are interplanted in a pasture. Silvo-pastoral systems provide several benefits (Table 47):

- No need for fertiliser due to nitrogen fixing trees.
- Higher fodder yield per m^2 and fodder trees with high palatability.
- Reduced disease risk for animals, additional habitats attract beneficial organisms which naturally control tick populations.
- Less land for producing more meat.
- Less methane emissions.

Rotational grazing is recommended to avoid continuous tree damages.

Table 47: Effects of different pasturing systems on meat production and methane emissions

Measure	Unit	Conventional extensive pasture	Improved pasture without trees	Intensive silvo-pastoral system*
Animal load	Large animals ha^{-1}	0.5	1	3
Per animal weight gain	kg day^{-1}	0.37	0.5	0.75
Per hectare weight gain	kg ha^{-1}	0.185	0.5	2.25
Annual meat production	kg ha^{-1} yr^{-1}	67.5	182.5	821.3
Methane emissions of 1 t meat	kg CH_4 ton^{-1}	229.5	208.2	127.9
Land area to produce 1 t meat	ha ton^{-1} a^{-1}	14.8	5.5	1.2

Source: Broom, Galindo & Murgueitio (2013)
* in this example, a very high density (10,000 shrubs ha-^{1}) of *L. leucocephala* has been planted

13.6 Further information

- http://www.igfri.res.in/pdf/old_bulletins/tropical_pasture.pdf
- https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/21121/IDL-21121.pdf?sequence=1
- http://www.fao.org/3/i2433e/i2433e07.pdf

- http://www.fao.org/agriculture/crops/thematic-sitemap/theme/compendium/tools-guidelines/how-to-management-grassland-and-pasture-areas/en/
- http://www.fao.org/agriculture/crops/thematic-sitemap/theme/spi/scpi-home/managing-ecosystems/management-of-grasslands-and-rangelands/en/
- http://www.fao.org/ag/againfo/themes/documents/PUB6/P614.htm

14 Livestock

Section 14 gives general information about animal husbandry, including the specific rules for housing in organic farming, the demand for land, feed, forage per animal and forage balances.

14.1 Animal husbandry in organic agriculture

Animal husbandry is a traditional part of smallholder farmer activities. Animal husbandry, and specifically cow milk production, is of importance for the integration of forage legumes into the cropping system and their efficient use. Animals are mostly kept outside, e.g. in a kraal, or living in the house, together with the people, or in small stables.

Three important IFOAM norms guide the establishment of animal housing in organic agriculture (OA):

1. "The operator shall ensure the following animal welfare conditions:
   a) Sufficient free movement and opportunity to express normal patterns of behaviour, such as space to stand naturally, lie down easily, turn around, groom themselves and assume all-natural postures and movements such as stretching, perching and wing flapping;
   b) Sufficient fresh air, water, feed and natural daylight to satisfy the needs of the animals;
   c) Access to resting areas, shelter and protection from sunlight, temperature, rain, mud and wind adequate to reduce animal stress."

   (IFOAM norm 2021, point 5.1.3)

2. "All animals shall have unrestricted and daily access to pasture or a soil-based open-air exercise area or run, with vegetation, whenever the physiological condition of the animal, the weather and the state of the ground permit. Such areas may be partially covered. Animals may temporarily be kept indoors because of inclement weather, health condition, reproduction, specific handling requirements or at night. Lactation shall not be considered a valid condition for keeping animals indoor."
   (IFOAM norm 2012, point 5.1.8)

The last point is often difficult to apply in tropical smallholder systems, but there are many ways that try to solve this. Therefore, the newest version of IFOAM norms also adds that:

3. "On holdings where, due to their geographical location and structural constraints, it is not possible to allow free movement of animals, tethering of animals may be allowed for a limited period of the year or of the day. In such cases, animals may not be able to turn around freely but other requirements of 5.1.3 must be fulfilled."

IFOAM norms (Table 48) also note that herd animals may not be kept in isolation from other members of the species. In special cases (keeping males from females, diseases) or if smallholders can only afford one animal, isolation is acceptable. If the farm only has one animal of a species, close human contact or contact with other animal species is recommended.

Dependent on the feed source, i.e. the size of the grazing area, additional land is necessary to cover the feed demand. To collect animal manure, separate units for animals are necessary. Straw that could be used for the uptake of urine is limited and often used as forage. Under high rainfall conditions, slurry and water management is a must, organised via roofing, channelling, and collecting the slurry. A combination with biogas production is always advantageous (see section 20).

Table 48. Animal indoor spacing and feeding area (stable / pasture / arable land / alleys)

Animal	Unit	Min. indoor space animal	Min. outdoor space	Pasture	Forage	Alley	Water consump-tion per animal	Remarks
	No.	m^2 $animal^{-1}$*	m^2 $animal^{-1}$	ha	ha	m	l day^{-1}	
Cow (300-400 kg)	1	6	4.5	0.3	0.3	10	30-80	0.4 ha fodder crops per cow in zero grazing systems; 1 ha per cow if 100% pasture.
Cattle	1	5	4	0.3	0.1	8	30-80	
Steer	1	10	30	0.3	0.2	2	30-80	If together with herd, run out 9 m^2.
Sheep	1	1.5	2.5	0.05	0.05	2	5-20	0.5 m^2 space per lamb.
Goat	1	1.5	2.5	0.03	0.05	2	5-20	0.5 m^2 space per fawn.
Pigs (>40 kg)	1	1.5	1.2				15-25	
Sow + piglet	1	7.5	2.5				10-25	
Broiler	6	1	60	5 m^2		0.5	0.5-0.75	
Chicken	6	1	60	5 m^2		0.5	0.5-0.75	
Donkey/ horse	1	6	12	0.1	0.1	5	10-25, twice a day	
Rabbit	1	1.6	1.2	10 m^2	10 m^2	1	50-150 ml kg^{-1} LW	

Sources: Own compilation; (EG) Nr. 834/2007; * Kraal (see Excel for own calculations); www. infonet-biovision.org

Furthermore, sufficient water is a must for healthy animals. Ideally, they should have access at all times. Roughly calculated, the water demand per cow is 1 l per 10 kg live weight, plus 1.5 l per 1 l of milk produced (see Table 48). For example, a cow with 300 kg live weight and a milk yield of 10 kg a day needs 30+15 = 45 l of water every day.

14.2 Forage balances

Animal feed in organic farming (OF) is mainly based on farm own roughage. Feed deficits lead to a loss of animal performance, and the recreation time to become productive again is increasing and economically critical. To maintain and increase animal performance, forage supply and demand should be planned in advance.

Forage balances are an instrument to approximately estimate the demand and supply of forage. Yields of forage crops can vary according to seed quality, rainfall, and overall crop management. Forage demand has to be adapted to the breed, age and, in case of cows, to their milk productivity. For planning, the tropical livestock unit is defined with 250 kg (Table 49), which is of relevance for the rough estimation of forage, approximately 2.2 kg DM 100 kg-1 LW (Table 51).

For rough planning, a forage balance based on DM quantity is enough. However, specifically for the milk production, a more detailed energy and protein calculation is necessary. Depending on the source, the following DM intake requirements for animals may vary, and care has to be taken to observe livestock response to adapt requirements to farm-specific conditions!

Feeding cereals to ruminants is not an economic option, if the potential for roughage production is high, which is the case for the Kafa Zone. An exception are residues from cereals and grain legumes. The main forage mix is based on forage legumes and Napier grass or similar grasses, stover and crop residues (Table 51), pasture, alley trees and shrub branches (see also Table 115 for other feed). Three feeding intensities provide a general overview on the amount of forage per year (Table 50).

Table 49. Tropical livestock unit

Animal	kg LW	TLU
Cattle in herd	175	0.7
Cow	250	1
Sheep	25	0.1
Goat	20	0.08
Donkey	125	0.5
Camel	313	1.25

Sources: Diverse sources; own data (Excel)

Table 50. Approximate feed requirements per herd TLU / animal in low to high technology input systems

Livestock system	Input level per herd TLU kg day^{-1} DM			Input level per animal kg day^{-1} DM		
***Non-pastoral (>120 days LGP)**	**Low**	**Intermediate**	**High**	**Low**	**Intermediate**	**High**
Cattle	7.8	8.5	8.9	7.8	8.5	8.9
Goat	10.0	11.5	16.1	0.8	0.9	1.3
Sheep	9.1	11.3	11.6	0.9	1.1	1.2

Source: FAO
LGP = Length of growth period, DM = dry matter
*non-pastoral systems: feed intake from crop residues restricted to 30% (low), 20% (intermediate), and 10% (high) of diet

There are several commonly available options for making effective use of shrub and tree foliage. Trees and shrubs provide green biomass of moderate to high digestibility and protein content when other feed reserves are scarce and low in nutrient quality. One of the most successful methods is the cultivation of *Leucaena leucocephala* as a palatable, high-protein browse, or cut and carry feed component, often used with crop residues or native grasses as the basal roughage (for more information see Renard, 1997).

Forage balances give important information, e.g. if animals are undernourished, when the current system does not provide enough forage for the given animal density in smallholder farms (Table 51**)**. Following the feeding ratio definition of animal feed demand, 1 ha is necessary additionally, or approx. 2 t of concentrates, assuming their nutrient and protein content is two times higher than of the mostly pure overgrazed grasslands.

Table 51. Forage balance (roughage) for an average animal husbandry group in a smallholder farm per year

Forage supply Crops	Yield DM kg ha-1	Area ha		Margin DM t ha-1	Total yield DM kg ha-1
Forage legume	8,000	0.1		5-1	800
Napier grass	10,000	0.1		7-15	1,000
Alley branches	2,000	0.1		1-4	200
Pasture	1,500	0.1		0.5-3	150
Maize stover	1,000	0.1		0.5-2	100
Teff straw	500	0.1		0.25-2	50
Free grazing for covering the feed deficit	1,000			0.5-2	
Total forage supply		**0.6**			**2,300**
Forage demand Animal	**Animal weight kg LG**	**Demand** DM kg day-1**	**Animals No.**	**Days No,**	**Total demand DM kg a-1**
Cow	300	6.6	1	365	2,409
Calve	65	1.43	1	200	286
Cattle	300	6.6	1	365	2,409
Oxen	400	8.8	1	365	3212
Sheep	25	0.55	1	365	201
Goat	15	0.33	1	365	120
Donkey	200	4.4	1	365	1,606
Rabbit	2	0.044	10	365	161
Total forage demand					**10,404**
Forage balance					**-8,104**
Covering via free grazing					**Approx. 8 ha**

Sources: Own compilation, different sources
Remark: Excel B2; ** 2.2 kg DM 100 kg-1 LW; * Desmodium, clover, alfalfa or mucuna; calculation of dry matter (Broom et al., 2013): Fresh matter (FM) x 0.8 directly after harvest.
Forage balances have to be positive or at least neutral. In this case, the provided crops and area would be barely enough to feed one cow. The given forage balance is negative due to the exemplary housing of every kind of farm animal and thereby acts only as draft. It can be found and modified in the additional materials provided together in this handbook.

Dependent on the lactation period and milk performance, feeding demand as well as specifically protein differs (Table 52). The diverse digestibility of the forage sources is of relevance, as the feed demand of animals for milk production increases accordingly.

Table 52. Quantities and qualities of feed fed to different species within household premises

Animal category	Feed types				Nutrients	
	Green fodder*	Dry fodder	Concentrates	Dry matter***	Total digestible nutrients (TDN)	Digestible crude protein (DCP)
Unit	kg DM	kg DM	kg DM	kg DM	TDN	DCP
Cattle						
In milk	4.75	5.50	0.64	6.71	3.44	0.27
Dry	3.40	4.02	0.40	4.83	2.46	0.18
Adult male	4.06	6.03	0.33	6.74	3.36	0.21
Young stock	2.18	2.13	0.18	2.62	1.33	0.10
In milk	5.96	6.34	1.05	8.14	4.25	0.37
Dry	5.44	4.95	0.52	6.28	3.21	0.25
Adult male	4.04	7.47	0.36	8.06	3.99	0.24
Young stock	2.29	2.22	0.19	2.74	1.39	0.10
Goat	1.04	0.20	0.06	0.49	0.27	0.03
Sheep	1.01	0.20	0.04	0.46	0.24	0.03
Others**	2.35	6.72	0.49	7.08	3.54	0.22

Source: NATP project database
* Includes cultivated fodder, and the fodder gleaned and gathered from cultivated and uncultivated lands
** Includes camel, horse, donkey, and mule; *** Broom et al. (2013)

14.3 Further information

- http://www.fao.org/3/t0828e/T0828E12.htm
- http://www.fao.org/3/t0828e/T0828E00.htm#TOC

15 Dairy cattle

Section 15 provides the most relevant key data for dairy cattle, including herd size, dairy breeds, feeding strategies dependent on the expected / planned milk production, minimum hygienic standards, and examples for housing.

15.1 Herd composition and stocking rate

Herd composition is important to ensure the annual replacement of old and milked-out cows. The ratio of cows to followers (heifers, calves) should be around 2:1, which allows the selection of the best breeds. The overall stocking rate will depend on the available grassland, forage legumes, and grasses like Napier grass or *Brachiaria spp*. and other high value grasses (see also demand for land, Table 51).

The quality and amount of produced feed influences the stocking rate (
Table 53). Grazing systems generally need more land than cutting systems (zero grazing), due to the often low quality of the grassland. In general, the aim should be to feed with optimised pastures, where management is on a high level, and grassland for cutting, forage legumes, high yielding grass, alley shrubs and tree branches is provided.

Table 53. Stocking rates of cattle under different production intensities

Feeding quality	TLU* ha^{-1}	Roughage	Concentrates
High	3-4	Forage legumes, high yielding grasses, optimised pasture systems, etc.	++
Medium	1,5-3	Lower yielding grasses, interspersed shrubs.	+
Low	1	Overgrazed pastures, residues from arable lands, weeds.	-

Source: Own compilation
* 1 TLU (tropical livestock unit) is defined with 250 kg live weight (see Table 49)
-, +, ++: low to high addition of concentrates

15.2 Dairy breeds

The right breed of cattle depends on environmental and management factors. In organic systems, the choice of locally adapted, hardy animals that show a long productivity is generally advised over high-yielding, susceptible breeds (Table 54). These breeds should only be chosen if adequate care and feeding can be guaranteed.

Table 54. List of potential indigenous and exotic dairy/ dual purpose cattle breeds

Name of breed	Purpose In order	Milk yield Ø l /day^{-1}	Lactation period Ø days	Average body weight kg	Remark
Abergele	Drought, meat, milk	1-1.5l	150	140 – 170	Tolerant to heat, parasites and diseases, ability to cope with feed shortages. Low yields.
Afar	Milk, drought	5	250-290		Resistant and adapted to harsh conditions. Low yields.
Ayrshire	Milk	10	300	450	High yield potential, good milk composition. Relatively adaptable and resistant. High feed and water requirements.
Begait	Milk, drought	5	250-300	250-300	Adapted to hot climate and water shortage. Low yields.
Boran	Dual purpose	2.5-10	250-300	250-300	Heat and drought tolerant, well developed herd instinct, excellent mothering ability, docile, long-lived. Difficult to breed, low yields.
East African Zebu	Dual purpose	5	250-300	250-300	Very hardy and resistant. Low milk yields, late maturing.
Friesian/ Holstein	Milk	Up to 50	300	550- 650	Highest potential milk yield of all breeds, frequent calving. Need high level of management for high yields, heavy feeder, susceptible to diseases and high temperatures.
Fogera	Drought, meat, milk	2	250-300	250-300	Adapted to swampy conditions, tolerate flies and ticks.
Guernsey	Milk	Up to 25	300	475	High milk yield potential, good feed converter, minimum calving complications. Need plenty of clean water.
Horro	Drought, meat, milk	4-5	100-240	320-480	Adapted to humid conditions.

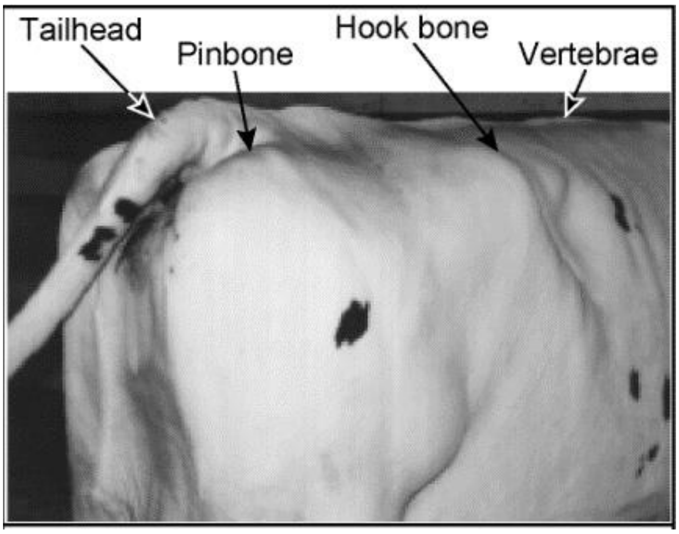
Jersey	Milk	22	300	350	High yield with small bodyweight, milk with high butter fat content (5.2%), relatively hardy, high fertility, suitable for crossbreeding, longevity. Susceptible to milk fever and tick-borne diseases.
Raya	Drought, meat, milk	3	210	210-230	Adapted to local conditions (Tigray) and as drought animals.
Sahiwal	Dual purpose	5-10	250-300	350-400	Docile, adapted to harsh conditions, milk with high butter fat content (4.8%). Difficult to breed.
Sheko	Milk, meat, drought	2	250-300	200	Adapted to humid areas in south-western Ethiopia.

Sources: https://www.infonet-biovision.org/; Hailu (2018)

15.3 Dairy health

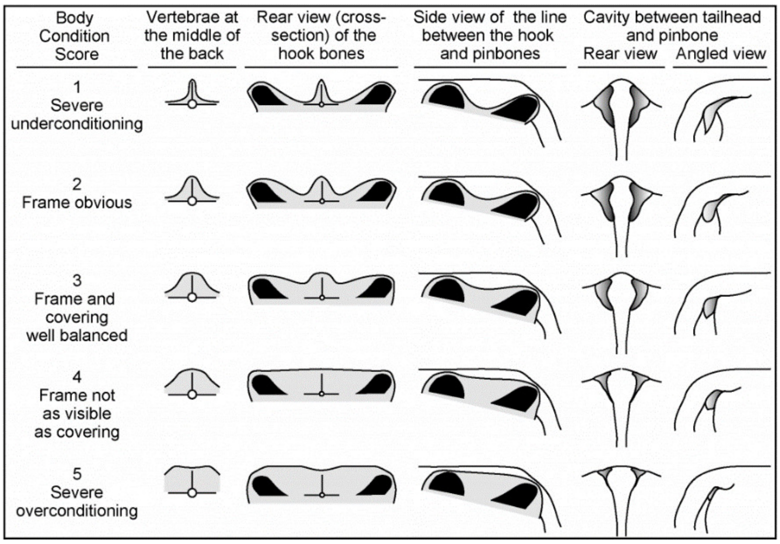
Increased production of milk is demanding the cows, therefore animals should be surveyed closely on their health and feeding status. The body condition score (BCS) for cows tells much about the health and feeding status of an animal and is determined by observing the animal's rump area (Figure 12 and Figure 13). Cows are ranked on a scale from 1 (severe under-conditioning) to 5 (severe over-conditioning). A low score indicates a lack of adequate nutrition, a high score indicates an imbalance in nutrition (not enough protein). A BCS of 2.5 - 3 indicates a healthy animal.

Figure 12: Identification of body parts used for the BCS



Source: Babcock institute, adapted after Edmonson, Lean, Weaver, Farver & Webster (1989)

Figure 13: Body condition scores (BSC)



Source: Babcock institute, adapted after Edmonson et al. (1989)

15.4 Feed ratios for cows

Feed ratios depend on the breed and the performance potential of cows (see also section 15.2). The higher the targeted milk yield, the more relevant is feed amount and quality. Currently, milk yield per lactation period is often around 1,000 kg or even below, although most dairy breeds would be capable of producing 3 – 4,000kg! This is most often the result of poor feeding and watering. When feeding dairy, some general aspects have to be considered (Table 55).

Table 55. Topics to be considered when producing dairy

Topic	Description	Remark
Water	See Table 48	Restricted access to enough fresh water is oftentimes the most restricting factor for milk yield in tropical countries.
Roughage	At least 60% of diet should be forage-based roughage to allow for adequate fibre levels; with increasing milk yield, forage has to be increasingly supported with supplements/ legumes/ concen-trates.	Inadequate levels of effective fibre lead to tumen acidosis.
Supplements/ concentrates	Supplement rations should be at a maximum of 40%.	It is advised to use supplementary feeds that can be produced on-farm!
Legumes & leguminous trees	Good source of protein and nutrients. Can easily be produced on-farm.	Do not feed more than 30% legumes in total diet, to avoid bloating issues.
Minerals & vitamins	Minerals, especially salt, should be provided daily.	1-2% of diet, e.g. Maclick super.
Temperature	Provide enough shading structures for the animals.	Heat stress induced feed uptake reduction and resulting lower milk yields are a common problem in the tropics.
Forage management practices	Cut/ graze forage at the right time, processing can be applied for better uptake (e.g. chopping, silage).	For example, Napier grass: Cut at the right time, after 35-40 days, wilting for one day before feeding increases DM %, chop before feeding for easier uptake.

Sources: FAO, various sources

For calculating dairy cattle feed requirements, several steps have to be followed (Table 56).

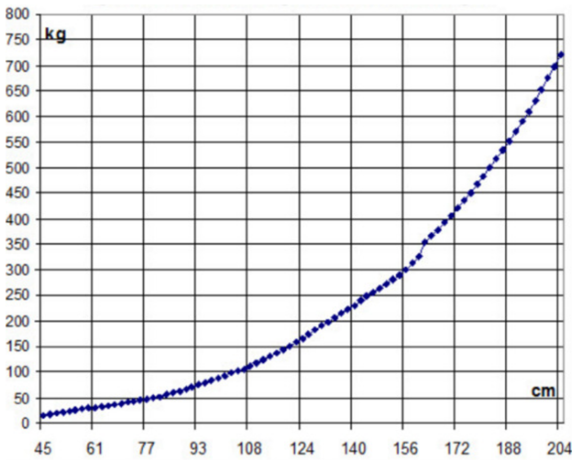
Table 56. Steps for dairy feed formulation

Step	Description	Example
1: Estimate live weight	Use chest girth measurement (Figure 14).	Cow with girth of 160 cm weighs approx. 300 kg.
2: Calculate maximum DM intake	Max DM/cow/day = 0.025*live weight + 0.1*kg milk (or see Table 57).	Cow with 350 kg and 5 l milk production: 0.025*350 + 0.1*5 = 9,25 kg / or around 10 kg. max. DM intake (Table 57).
3: Daily nutrient requirements per cow?	See Table 57	350 kg cow, 5 l milk per day = 72 MJ ME, 800 g CP, 27 g Ca, 27 g P.
4: Is the energy need being met?	Calculate weather available feedstuff meets energy requirements. Divide the ME requirement of the cow by the ME content of the available feedstuff (Table 58).	350 kg cow, 5 l milk, fed only Napier grass: 72 / 7.9 = 9.11 kg DM → this is below the max. DM intake of the cow, therefore possible! 450 kg cow, 20 l milk, fed only Napier grass: 161 / 7.9 = 20.4 kg DM of Napier grass → this is far above the max. DM intake capacity of the cow (17 kg), more diverse feedstuff needed!

5: Are nutrient requirements being met?	Estimate nutrients supplied by the feedstuffs (Table 58) and nutrient requirements (Table 57).	350 kg cow, 5 l milk, fed only Napier grass: Napier grass: (CP: 98, Ca: 3.6, P: 2.9) * max DM intake of 10: CP = 980 g (806 g required) Ca = 36 g (27 g required) P = 29 g (27 g required).
6: Estimate the amount of feed	Calculate amount of fresh feed from % DM (Table 58), include some margin for wasted food (e.g. 5%).	350 kg cow, 5 l milk, fed Napier grass: Napier grass has 20% DM (or 200 g/kg), Max. DM intake is 9.25 kg, 9.25 * (1000/200) = 46.24 kg fresh grass With 5% wasted feed: 46.24 * 1.05 = 48.5 kg fresh Napier grass per cow.

Source: https://www.infonet-biovision.org/
DM = dry matter, CP = crude protein, Ca = calcium, P = phosphorus

Figure 14. Live weight estimation using chest girth circumference



Source: Kenya Agricultural Research Institute (KARI)

Chest girth can be measured using a simple measuring band. The band is placed around the chest, a hand's breadth behind the front legs (not too tight). E.g. a cow with a girth of 172 cm will weigh approximately 400 kg. Nutrient requirements per animal vary greatly depending on live weight and milk yield, an approximation of these requirements can be found in Table 57.

Table 57. Daily nutrient requirements of dairy cows

Live weight kg	Milk yield kg (4% fat)	DMI kg	Metabolisable Energy (ME) MJ	Crude protein (CP) g	Calcium g	Phosphorus g
350	0	10	45.5	294	14	10
	5	10	72	806	27	27
	10	11	97	1,093	42	36
	15	13	123	1,393	57	45
400	0	10	50.3	318	16	11
	5	11	78	874	29	29
	10	12	103	1,161	44	39
	15	14	129	1,448	58	48
450	0	11	54.9	341	18	13
	5	11	84	946	31	32
	10	13	110	1,234	45	41
	15	15	135	1,521	60	50
	20	17	161	1,826	75	59

500	0	12	59.4	364	20	14
	10	14	113	1,275	46	43
	15	16	138	1,560	59	51
	20	18	162	1,823	74	59
550	0	13	63.8	386	22	16
	10	15	121	1,359	48	46
	15	17	145	1,635	61	53
	20	17	168	1,892	75	62
	25	21	194	2,179	90	71
600	0	13	68.1	406	24	17
	10	16	129	1,431	50	49
	15	18	152	1,710	63	55
	20	20	174	1,984	77	65
	25	22	201	2,262	91	75

Source: https://www.infonet-biovision.org/
DMI = Maximum dry matter intake

There is a long list of possible available feedstuffs (Table 58), which provides a rough and general estimation of the feed values of different roughage and concentrate sources.

Table 58. Nutritional aspects of some commonly available roughages and concentrates

Roughage	DM %	CP g	ME MJ	Ca g	P g
Acacia, husk	92	110	12.5	3.8	1.6
Acacia, leaves	38	151	10.6	17	1.8
African locust bean, pod husks	93	47	12.5		
African locust bean, pod pulp	35	49	12.4	13.2	17.6
Banana, leaves	94	146	8.7	7.5	2.4
Banana, stalks	7	51	7.5	7.5	2.9
Barley, straw	90	38	6.5	4.9	0.8
Calliandra	15	220	7.7	2	1.5
Camel’s foot, leaves	90	153	11.3	8.2	3.9
Cassava, fresh foliage	22	249	9.9	11.9	3.7
Cassava, foliage silage	24	238	9.8	25.1	3.3
Cassava, foliage wilted	36	263	10.2	14	3
Coco hulls	88	178	5.4	3.7	4.4
Coffee hulls	88	94	7.2	4.5	1.4
Coffee leaves, dried	92	167	3.6	6.2	1.2
Columbus grass, fresh	17	100	8.7	4.5	4.1
Cotton seed hulls	91	60	7	1.7	1.4
Cowpea, aerial parts, fresh	20	181	9.8	13.2	2.4
Cowpea, husk	25	110	8.1	13	2.5
Desmodium	25	151	7.4	8.5	2.2
Grey love grass	23	153	9.7	9.3	2
Groundnut, forage	26	175	10.4	9.3	2
Guinea grass	22	112	8	4.9	2.4
Guinea grass, hay	92	43	7.6	4.7	2.6
Guinea grass, straw	89	91	7.7	4.6	3
Jackfruit, leaves	40	156	7.5	14.7	3.2
Kenya sheep grass	25	82	7.6	3.9	2.3
Kikuyu grass, aerial parts, fresh	20	151	9.7	3.1	3.7
Kikuyu grass, hay	90	113	8	3	3.9
Leucaena	29	233	11	10.7	2.1
Lucerne, fresh	19	205	9.3	19.5	2.5
Lucerne, medium fresh	20	180	9	14.1	2.2

Lucerne, hay	89	182	8.4	16.8	2.6
Maize, stover	28	69	9.3	3.7	2
Maize, silage	32	70	10.8	1.9	1.8
Mango, leaves	33	94	11.7	16.9	1.5
Mango, peels	15	62	11.9		
Napier grass, 40cm	20	98	7.9	3.6	2.9
Napier grass, 80cm	20	90	7	3.6	2.9
Napier grass, early bloom	25	72	6.2	3.6	2.9
Napier grass, hay	93	107	8	2.8	2.3
Napier grass, silage	27	66	7.2	2.5	3.6
Neem tree, leaves	34	166	7.7	20	2.5
Nile grass, aerial part, fresh	21	140	9.1		
Nile grass, aerial parts, hay	90	85	5.9		
Nile grass, leaves, fresh	21	213	10.3		
Oat, straw	87	102	8.3	4.7	2
Pawpaw, leaves	20	240	9.9	34.6	3.5
Pineapple, leaves	20	91	11.5		
Pumpkin, hulls	89	190	4.2		
Pyrethrum marc (extracted)	90	130	8.7		
Rhodes grass, hay	25	89	8.4	3.8	2.9
Rhodes grass, medium maturity	86	94	8	3.1	2.6
Rib grass, fresh	92	204	10	18.2	2.8
Rice straw	92	42	5.8	2.9	0.9
Sesbania	26	244	11.5	15.9	3.3
Sorghum, aerial parts, fresh	25	173	8.6	3.5	2.8
Sorghum, straw	93	37	7.3	3.1	0.7
Soybean, aerial parts	25	137	9.1	15.3	2.8
Star grass	30	228	6.2	1.8	1.6
Sugarcane forage, fresh	22	41	9.3	1.9	1.1
Sugarcane leaves, fresh	42	52	2.4		
Sunflower, stover	75	57	6.2	11.2	0.8
Wheat, straw	91	42	6.8	4.8	0.7

Feedstuff	**DM**	**CP**	**ME**	**Ca**	**P**
	%	**g**	**MJ**	**g**	**g**
Acacia, seeds	92	284	14.2	2.8	4.2
African locust bean, seeds	90	318	15.9	0.8	3.9
Barley, grain	87	118	12.4	0.8	3.9
Brewers grain, fresh	25	259	6.6	3	5.7
Brewers grain, silage	25	276	10.2	3	5
Cassava peels, dry	87	52	11.5	4.5	0.8
Cassava tubers, fresh	37	26	12.4	1.6	1.2
Cotton seed meal, high oil, high fibre	92	374	11.9	2.2	11.9
Cotton seed meal, high oil, low fibre	92	450	13.2	2	12.4
Cowpea, seeds	89	249	13.4	1.1	4.1
Maize bran	88	120	11.3	4.8	3.4
Maize grain and cobs	87	88	11.9	0.5	2.8
Mango, pulp	17	42	13.7	1.9	1.1
Millet, grain	90	142	12.2	0.4	3
Millet, husk	92	24	5.4		0.5
Pineapple, by-product	88	45	10.8	4.9	1.2
Rice bran	91	88	6.7	4.7	7.4
Sorghum grain, ground	87	108	13.5	0.3	3.3
Sorghum bran and milling offal	89	117	13.2	0.9	4.9
Soybean, cake (expeller)	90	493	14.7	4.6	7.2
Sugarcane molasses	73	55	9.6	9.2	0.7
Sunflower, cake	91	279	10.9	3.9	9.2

Sweet potato vines	15	132	8.8	12.4	3.1
Wheat, bran	87	173	11	1.4	11.1
Wheat, grain	87	126	13.1	0.7	3.6
Wheat, pollard	90	150	11.5	1	7

DM = dry matter, CP = crude protein, ME = metabolizable energy, Ca = calcium, P = phosphorus
Sources: www.infonet-biovision.org; www.feedipedia.org

The following tables provide some information for exemplary feed ratios for animals with different weight and milk yield using widely available feedstuff. Energy and nutrient demands are easily met in the first diet (Table 59). At the indicated level of milk production, feeding only with Napier grass would be sufficient, but more diverse feedstuff is recommendable to fully provide for protein, vitamin, and micronutrient needs of the animals.

Table 59. Example feed ratio cow, 350 kg weight, 2,000 kg milk a^{-1}

Feed	kg DM day^{-1}	ME	CP	Ca	P	kg FM day^{-1}	kg FM a^{-1}
Napier grass	9	71.1	882	32.4	26.1	45	16,425
Lucerne, fresh	0.5	4.5	102.5	1.25	6.5	2.5	960
***Gliricidia* leaves**	0.5	5.5	27.5	5.5	1.15	2	730
Sum	10	81.1	1,012	39.15	33.75	49.5	18,115
Requirement*	10	72	806	27	27		

Source: Own data, see Excel
DM = dry matter, CP = crude protein, ME = metabolizable energy, Ca = Calcium, P = Phosphorus; FM = fresh material; * see (Table 57)

The second example (Table 60) describes a situation, where the energy demand is just slightly met, while there is a surplus in protein. The addition of another feed source, with higher energy and lower protein levels, like residues from cereals, would be beneficial.

Table 60. Feed ratio cow, 400 kg weight, 3,000 kg milk a^{-1}

Feed	kg DM day^{-1}	ME	CP	Ca	P	kg FM day^{-1}	kg FM a^{-1}
Napier grass	7.2	56.88	705.6	25.92	20.88	36	13,140
Lucerne, fresh	2.4	21.6	492	6	31.2	12.6	4,610.5
***Gliricidia* leaves**	1.2	10.56	158.4	14.88	3.72	8	2,920
Sweet potato vines	1.2	13.2	66	13.2	2.76	4.8	1,752
Sum	12	102.24	1,422	60	58.56	61.4	22,422.5
Requirement*	12	103	1,161	44	39		

Source: Own data, see Excel
DM = dry matter, CP = crude protein, ME = metabolizable energy, Ca = calcium, P = phosphorus; FM = Fresh material; * see (Table 57)

The third example (Table 61) uses the same diet but adapted to higher yielding and higher animal weight. As before, fresh lucerne is included in the diet. As protein levels become lower in older plants, the diet can still be maintained with lucerne of medium hay quality.

Table 61. Feed ratio cow, 450 kg weight, 4,000 kg milk a-1

Feed	kg DM day-1	ME	CP	Ca	P	kg FM day-1	kg FM a-1
Napier grass	7.8	61.62	764.4	28.08	22.62	39	14,235
Lucerne, fresh	2.6	23.4	533	6.5	33.8	13.7	4,994.7
***Gliricidia* leaves**	1.3	11.44	171.6	16.12	4.03	8.7	3,163.3
Sweet potato vines	1.3	14.3	71.5	14.3	2.99	5.2	1,898
Sum	13	110.76	1,5405	65	63.44	66.6	2,4291
Requirement*	13	110	1,234	45	41		

Source: Own data, see Excel
DM = dry matter, CP = crude protein, ME = metabolizable energy, Ca = calcium, P = phosphorus; FM = fresh material; * see (Table 57)

Currently, 4,000 kg per cow is an exception and if so, mostly concentrates or residues from industries are added in a serious amount, while feed like lucerne or *Gliricidia* is hardly used. Kafa Zone has a relatively short period without rainfall, enabling farmers to prepare silage from lucerne and still having enough Napier grass.

15.5 Cattle housing

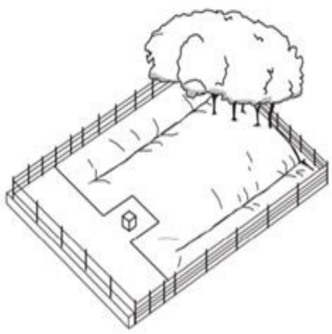
To ensure animal welfare, as well as efficiency in production and reproduction, cattle has to be kept safe from heat stress, particularly direct sunshine. Thus, some kind of shading structure is essential. A structure allowing 2.5–3 m^2 per animal will give the minimum desirable protection for cattle, whether for one animal belonging to a smallholder or many animals in a commercial herd. A 3 x 3 m roof will provide adequate shade for up to three cows. The roof should be min. 3 m high to allow air circulation. Roof water should me collected to reduce the mud in the yard. More adapted to the climate and economic circumstances are silvo-pastoral systems where shadow is provided by trees. These IFOAM guidelines, however, will not always fit available space and financial circumstances of all farmers.

15.5.1 Earth mounds

If housing structures are unaffordable for smallholders, the construction of a yard with an earth mound and draining ditches (Figure 15, Figure 16) can be an alternative. 15 to 25 m^2 per cow should be considered. The soil in the mounds can be stabilized with chopped straw or straw and manure. The yard has to include trees for sufficient shading. However, if these measures are realistic for a smallholder farm must critically be discussed.

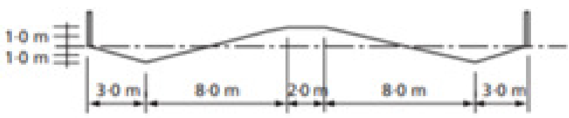
Latest before the rainy season, the mound will be used as manure and transferred to the crops. Management of manure depends on amount, ensuring that the animals stay clean and losses of nutrients are minimised.

Figure 15. Fenced earth mound with paved feeding area



Source: Mrema, Gumbe, Chepete & Agullo (2012)

Figure 16. Dimensions for an earth mound

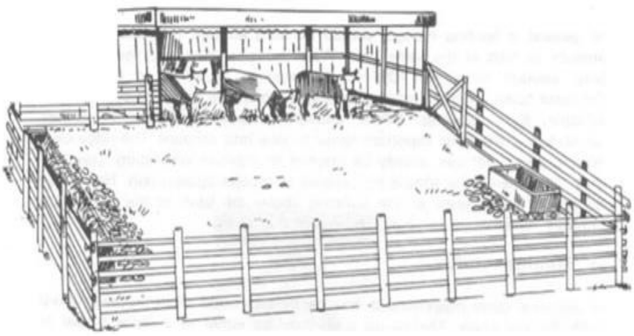


Source: Mrema et al. (2012)

15.5.2 Loose housing

Loose housing describes a system in which animals move freely, except for milking or treatment. It consists of an open paddock and a partially covered house. Such systems are cheap to construct and easy to expand (Table 62, Figure 17). Feeding and watering is comfortable and the free movement is good for animal welfare. Dung collection is more time consuming than in closed housing systems and care has to be taken to keep the stalls clean. This type of housing system is suitable for all kinds of livestock.

Figure 17. Typical loose housing system



Source: Felleke, Woldearegay & Haile (2010)

Table 62. Floor and trough space requirement of dairy cattle in loose housing

Type of animal	Floor space per animal		Trough length per animal in cm
	Covered area m²	Open area m²	
Cows	6 - 9	24 - 30	51 - 61
Young stock	4.5 - 6	15 - 18	38 - 51
Pregnant cows	12	55 - 61	61 - 76
Bulls	12	61 - 120	61 - 76

Sources: Own compilation, modified after SNV (2017); Mbindyo, Gitao & Peter (2018)

15.5.3 Closed housing

The construction of a cattle shed offers many advantages. It can be used for feeding and milking and makes the collection of dung and urine possible. The availability and cost of building materials will ultimately decide what can be used in construction. It does not matter which kind of timber is used for support, or which sheets or tiles are used for the roof, but at least a partly cemented floor is of highest priority, to allow for the collection of animal excretions and to facilitate cleaning.

15.5.4 Zero-grazing system

When faced with limited, overgrazed or degraded pasture land, the establishment of a half zero-grazing (hours outside the stable are limited) establishment is recommended (Table 63).

Table 63. Advantages and disadvantages of a zero / half zero-grazing system

Advantages	Disadvantages
Controlled handling, observation, feeding, herd management	Investment costs might be high
Higher milk production	Higher workload for feed collection
Easy manure collection, higher crop yields	Animal movement is limited

Sources: Own compilation, FAO

A zero-grazing system consists of some essential and optional parts (Table 64). Two examples of feasible zero-grazing systems are given in While the following illustrations show an idealised situation, many farmers may have two cows on average and stables must be reduced according to the building elements introduced in the examples.

The zero-grazing unit in Figure 19 shows an example of a smallholder farmer with a minimal land of 3 ha and a considerable number of animals, but the principle of the zero-grazing unit can be up- or downscaled, dependent on need and livestock numbers.

Figure 18 and Figure 19.

Table 64. Essential and optional parts of a zero-grazing system

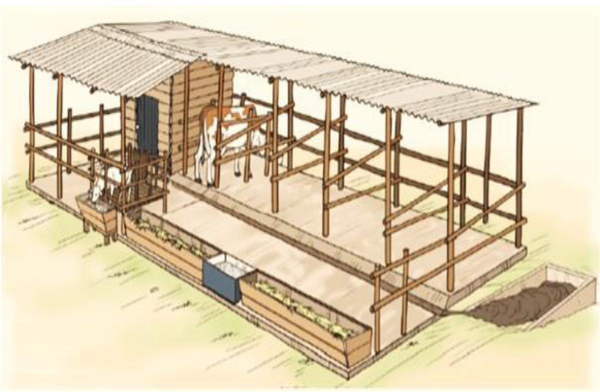
Essential parts	Optional parts
Cubicles (resting area)	A store
Walking area	Manure storage
Feed and water troughs	Fodder cutter
Milking place	Roof water catchment
Calf pen	Water tank
Fodder chopping area	Holding crush

Source: SNV (2017)

While the following illustrations show an idealised situation, many farmers may have two cows on average and stables must be reduced according to the building elements introduced in the examples.

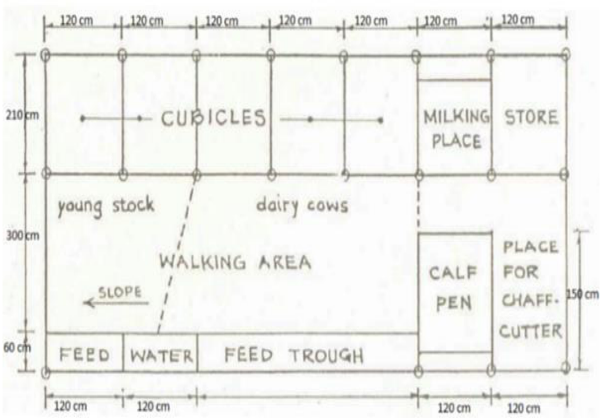
The zero-grazing unit in Figure 19 shows an example of a smallholder farmer with a minimal land of 3 ha and a considerable number of animals, but the principle of the zero-grazing unit can be up- or downscaled, dependent on need and livestock numbers.

Figure 18. Illustration of a basic zero grazing unit



Source: Felleke et al. (2010)

Figure 19. Plan view of a zero-grazing unit with five cubicles



Source: SNV (2017)

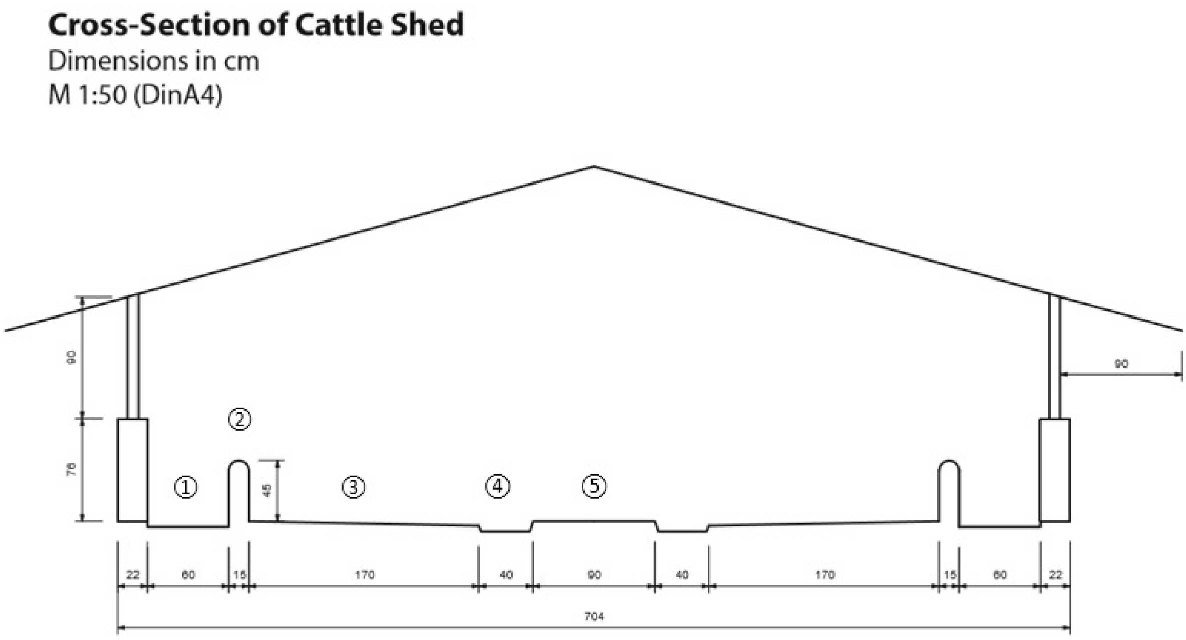
While the kind of wood used in the construction is less important, any wood within 50 cm of the ground should be well treated with some kind of wood preservative or mechanically protected. The floor of the raised cubicles can be made from wood, or plain soil with a high share of clay. Soft bedding needs to be provided for the animals. A concrete pit or sloping slab, in which the manure from the slightly sloping walking area can be collected, is essential to keep hygienic standards and thus milk quality.

The floor of the walking area should be paved, as it allows for the collection of urine as well as dung. If the floor is made of concrete, it is important to roughen the surface to prevent slipping. In case that concrete floor is unaffordable, the distance between the free stalls (cubicles) and the feed trough should be doubled or tripled. In case pasture is unavailable, an adjacent exercise paddock, where the animals can move freely for four to five hours each day, is strongly advised, as animal welfare is a key concern in organic agriculture (OA).

15.5.5 Cattle shed

The construction of a cattle shed is an option for bigger herds in combination with pasture. The openness of the shed offers plenty of light and ventilation. The floor should be cemented to facilitate regular washing and cleaning. A feasible option is a tail to tail shed with a double-slope roof (cross section Figure 20).

Figure 20. Cross section of a cattle shed



Source: Own illustration
(1) Feeding trough, (2) Inside wall, (3) Stall, (4) Drain, (5) Central alley

The dimensions of the stall (③ depend on the used breed, but on average at least 1.7 x 1.3 m per animal. The stall floor should be sloped downward by 3% and covered by sufficient bedding. The animals can be tethered to tie-points at the inner wall (② Manure from the drains (④ should be collected in an adjacent concrete tank.

15.6 Further information

- http://targetethiopia.com/wp-content/uploads/2018/01/DVC-Dairy-Policy-Inventory-2009.pdf
- https://snv.org/cms/sites/default/files/explore/download/dairy_housing_and_manure_management_training_manual_and_guide.pdf
- https://www.infonet-biovision.org/AnimalHealth/Cattle

- http://www.fao.org/3/i2433e/i2433e07.pdf
- http://www.fao.org/3/a-y4176e.pdf

16 Sheep & Goats

Section 16 introduces housing requirements of sheep and goats, feeding strategies, breeds, and health issues.

16.1 Housing

Housing requirements for sheep and goats need less consideration than for cattle or poultry (Table 65).

Table 65. Housing requirement for sheep and goats

Housing part	Sheep	Goats	Remark
Floor	Elevated, sloped (droppings), rammed earth or partly slatted.	Elevated, sloped (droppings), rammed earth, platforms for climbing.	Needs to be dry, especially goats are susceptible to diseases caused by damp floors.
Feed	Trough outside of shed.	Hay racks, elevated troughs.	Elevated feedstuff for goats, add mineral licks. Min. 50 cm per animal.
Water	Troughs best outside.	Troughs best outside.	Outside troughs are easier to fill and to keep clean. Min. 50 cm per animal.
Roofing	Minimum height 2.5 m.	Minimum height 3 m.	
Shed orientation	East-west orientation recommended.	East-west orientation recommended.	Take care with wind direction, good ventilation but also wind protection.
Separation	Own shed for rams/ sick animals.	Own shed for bucks/ sick animal.	Do not rear goats together with cattle! Risk of diseases.

Sources: Modified after Jayewardene (1977), Vukasin et al. (1995)

16.2 Feeding

When feeding sheep and goats, optimal pasture management is the foundation of feed supply in many farms. As frugal animals they need no additional concentrates/feedstuffs, if pasture quality is high. Whereas sheep are grazers, goats as browsers should be offered a more diverse diet of tree and shrub branches and foliage. The additional feeding with cut and carry forage legumes covers the protein needs. Overfeeding on lush and damp feeds, like alfalfa or clover, can lead to life threatening bloat. As a rule of thumb, no more than 2/3 of the diet should contain forage legumes. Introduced feeding examples represent an ideal situation, but with certain challenges. Currently, compared to the following numbers, max. 50% of feed energy and protein supply is reached in practice. But if seeds and seedlings for forage production are available, food supply can boost towards what is calculated in the tables below.

16.2.1 Feeding strategies in different life stages

Feeding ratios should consider the different life stages of the animal (Table 66). Especially during late pregnancy and milking period, when the animals need twice as much energy and protein as normal.

Table 66. Sheep/goat feeding during different life stages

Stage	Sheep Animal day^{-1}	Goats Animal day^{-1}	Remark
Before breeding season	Watch for over-fattening in ewes 1-3 months before breeding season.		Over-fattening in sheep can lead to reduced fertility.
Breeding season	Good pasture, grass and legumes mix.	Good pasture.	
Early and mid-pregnancy	Pasture + 1 kg legume hay / animal /day.	4-5 hours pasture + 5 kg green fodder.	
Late pregnancy	Good Pasture + 7 kg green fodder.	Good pasture + 7 kg green fodder.	
Lactation	Good pasture or 8 hours of grazing + 10 kg green fodder / 1 kg legume hay*.	6-8 hours pasture + 10 kg green fodder / 1 kg legume hay.	
After weaning	Pasture.	Pasture.	The least critical period with respect to nutrient require-ments.
Young animals	See Table 70.	See Table 70.	

Source: http://agritech.tnau.ac.in/
* alternatively pasture and silage

16.2.2 Feed demand

For high yielding goats, a detailed calculation of feed demands is recommended (Table 67,

Table 68). A rough estimation of the feed value of different fodder, that might be available for small ruminants, is given in Table 69.

Table 67. Steps for calculating feed rations for goats

Step	Description	Example Goat with 10 kg, should grow 100 g per day Available fodder: old grass & cowpea grains
1	Check for protein and energy requirements.	6 MJ ME and 33 g DP day^{-1}
2	Check the values of the available feedstuff.	Old grass: 1.9 MJ ME / 0 g DP Cowpea: 12.6 MJ ME /190 g DCP
3	Calculate the ratio to ensure protein needs are covered (protein need / g DP in fodder). How much energy does this provide? (kg feed * MJ ME)	33/ 190 = 0.18 kg cowpea 0.18 * 12.6 = 2,3 MJ ME
4	How much of my other feed source is necessary? Remaining ME need / MJ ME of fodder.	6 MJ ME – 2.3 MJ ME = 3.7 MJ ME 3.7/ 1.9 = 1.9 kg
5	Does it match maximum DM intake day^{-1}?	Maximum DM day-1 for 10 kg goat = 0.4 kg DM! With old grass, it would need to eat 1.9 kg, which is too high.
5	If energy needs are not met: - Accept slower growth rate. - Search for different feed sources.	 E.g. sorghum: 3.7/ 13.3 = 0.27 kg

Source: Modified after Jansen & van den Burg (2004)

Table 68. Total energy and protein requirement and feed intake of goats of different ages and weights

Weight kg	Growth g day^{-1}	Energy need MJ day^{-1}	Protein need g DP day^{-1}	DM intake g day^{-1}	DM intake as % of weight
10	50	4	23	400	4
	100	6	33	600	6
20	50	6	32	600	3
	100	7	42	800	4
	150	9	52	1,000	5
30	50	7	40	700	2
	100	9	50	1,000	3
	150	10	60	1,000	4

Source: Modified after Jansen & van den Burg (2004)

Table 69: Dry matter content and feed value of several feeds

Type of feed	DM (%)	CF (%)	DCP (g)	ME *	Quality
Young grass	18	4	25	1.9	Reasonable
Old grass	54	20	0	1.9	Poor
Good hay	85	32	50	5.8	Reasonable
Cereals					
Maize	87	3	65	14.6	Good
Millet	88	9	80	11.7	Good
Wheat straw	91	41	42	6.8	Good
Sorghum	87	2	55	13.3	Good
Pulses					
Field beans	87	9	205	11.8	Good
Chickpea	91	11	150	12.5	Good
Cowpea	88	5	190	12.6	Good
Groundnut (with shell)	94	18	240	20	Good
Soya bean	89	6	300	17.3	Good
Root crops					
Cassava root	87	3	725	12.8	Good
By-products					
Barley draff	89	15	600	10.8	Good

Source: Modified after Jansen & van den Burg (2004)
DM = dry matter in the feed; DCP = Digestible Crude Protein; CF = Crude Fibre, ME = metabolisable energy, MJ = Megajoule
* Giller, Beare, Lavelle, Izac & Swift (1997)

16.2.3 Lamb nutrition

Lambs are weaned around three months. Especially in the first three to four days, they should be kept with their dam to allow suckling. In the first few days, access to colostrum is important for the health of young animals. A feeding plan for the time until weaning is given in Table 70.

Table 70. Feeding plan for lambs

Age days	Mothers milk or cow milk ml	Creep feed g	Forage per day
1-3 days	Colostrum 300 ml, 3 feedings	-	-
4-14days	350 ml, 3 feedings	-	-
15-30 days	350 ml, 3 feedings	A little	A little
31-60 days	400 ml, 2 feedings	100-150	Free choice
61-90 days	200 ml, 2 feedings	200-250	Free choice

Source: http://agritech.tnau.ac.in/

16.3 Sheep and goat breeding

The productivity of local sheep and goat breeds in Ethiopia is low and efforts to improve productivity are currently limited. One of the major constraints to increase output is that purebred exotics, or crossbreeds of exotics with local breeds, are not adequately adapted to tropical management requirements and often do not survive. To better use the available genetic resources, selective breeding practices can help to produce good stock. If a farmer wishes to control breeding, some precautions have to be taken (

Table 71).

Table 71. Management practices for controlled sheep and goat breeding

Steps	Description
First pairing	Female goats are often still growing when being in heat for the first time; if serviced, the pregnancy will put a lot of stress on the animal resulting in a smaller and weaker goat and kids. Let only young goats/sheep be serviced when they have reached 3/4 of the normal, mature weight for that breed.
Planning of delivery date	Servicing at the right time ensures that there is sufficient feed available during the gestation and suckling period; correct planning of the servicing / delivery date (five months after servicing) helps to raise healthy animals.
Heat	If the farmer wishes to control breeding, he has to search for signs of heat: - Mounting of other animals. - Restless behaviour. - Slightly red and swollen labia (vulva).
Male animals	From 4 months on, raise male animals separately until breeding; if this is not possible, an animating apron can be used. Male animals that are not suited for breeding should be castrated before fourth month
Feeding (flushing for ewes)	Provide extra food for the last month before breeding

Source: IRACC (1997)

For goats, a guideline to select productive animals can be used (Table 72). The selection of productive animals, and the culling of unproductive ones, is a major step in controlling stocking rates and prevent the many common negative consequences of overgrazing.

Table 72. Traits of productive and unproductive dairy goats

Body part	Productive milking goat	Unproductive milking goat
Head and neck	Long and lean neck and head.	Short head and neck.
Back, ribs	Strong, muscular back. Deep, wide-sprung ribs.	Shallow, straight ribs.
Rump	Long, sloping.	Short, steep.
Udder and teats	Large, elastic.	Small, tough-skinned.
Milk veins	Large, knobby, easy to feel.	Hard to discern.
Hocks and legs	Straight, well placed apart.	Hocks nearly knock together.

Source: IRACC (1997)

16.4 Sheep and goat health

The “organic understanding” of animal health and welfare concentrates on health promotion through proper management practices and “prevention before curing”, which is of special importance in areas where mainstream medicine is expensive and hard to come by (Table 73).

Table 73. Practical measures to ensure health through preventative animal husbandry practices

Prevention steps	Description
1: Breeds and strains	Appropriate breeding; choose robust breeds adapted to the climate and available fodder.
2a: Animal husbandry practices	Hygiene, regular exercise, as much access to pasture as possible to strengthen the immune system of the animals, appropriate housing, diversified feedstuff of good quality.
2b: Stock densities	Overstocking and overgrazing is a common problem in the zone, resulting in many weak animals prone to diseases.
2c: Grazing rotation and management	Changing pastures helps to prevent infestation with parasites.
3: Alternative treatments	Usage of plant based and traditional medicine.
4: As a last resort	Usage of antibiotics, other chemical remedies.

Source: Eyhorn, Heeb & Weidmann (2003)

A list of common tropical diseases for sheep/goats is given in Table 74. But remember that this handbook does not substitute any veterinary advice if animals show symptoms. Treatment with antibiotics should always be seen as last option.

Table 74. Common goat / sheep diseases and parasites in the tropics

Disease	Symptoms	Treatment	Control
Sheep pox	High fever, small red pimples around mouth and tail.	None.	Vaccination.
Blackleg	Swelling limbs, lameness, fever.	None.	Vaccination, careful disposing of carcasses to prevent spread of infections.
Enzootic virus abortion	Abortion in late pregnancy, placenta is retained, uterine in-fection.	No treatment to prevent abortion. Uterine infection can be treated with antibiotics.	Vaccination of susceptible first lambing ewes, hygienic lambing practices.
Lamb dysentery	Diarrhoea, fever, sudden death at 2-21 days of age.	Antiserum to reduce death rate.	Vaccinate ewes during the last month of pregnancy.
Navel ill	Swollen joints, fever.	Medicine / antibiotics can be given during the initial stage of the disease.	Disinfect navel at birth, disinfect wounds of castration and ear tagging.
Pulpy kidney	Bleeding in the heart and softening of the kidneys. Animal may die suddenly after a change of diet.	Medicine / antibiotics can be given during the initial stage of the disease.	Vaccinate ewes during the last month of pregnancy, vaccinate lambs when weaning, careful disposing of carcasses to prevent spread of infections.
Anthrax	High fever, followed by rapid bowel inflammation and death.	Medicine / antibiotics can be given during the initial stage of the disease.	Vaccinate the animals once every year and once every six months in high risk areas.
Foot and mouth	High fever, salivation, lame-ness caused by blisters in the mouth and on the feet.	No known specific treatment, medicine/ antibiotics can help against bacterial secondary infections.	Vaccination, control livestock movement.

Heart water	Rise in temperature, animal may walk in circles or against obstacles, nervous symptoms like jaw-clenching or muscle twitching.	Effective if given in early stages.	Tick control.
Rabies	Uncoordinated movement, aggression, paralysis of the throat.	None.	Vaccination, particularly of dogs.
Trypanoso-miasis	Acute cases: high temperature, anaemia, progressive weakness followed by death. Chronic cases: temperature variation, dry coat, animals become listless and thin.	Several drugs can be prescribed by veterinary department.	Clear bushes near the shed to destroy the tsetse fly's habitat.
Tubercu-losis	Animal is emaciated, enlarged udder, curdled milk, coughing.	None.	Cull animals that are not resistant.
Parasite	**Symptoms**	**Treatment**	**Prevention**
Round-worms	Diarrhoea, wasting, anaemia.	Weaners should be drenched monthly during the rains and one month after.	Practice rotational grazing, dose ewes after lambing and then move them two days after dosing, allow lambs access to the next new pasture.
Tapeworm	Wasting, rickets.	Young stock should be drenched at six weeks and at weaning.	Rotational grazing, graze young stock first.
Liver flukes	Animal is dull and has a distended abdomen, anaemia.	Animal should be drenched.	Keep stock out of wet pastures and stream banks.
Ticks, fleas, lice, scab	Appear on the body, especially on ears and rump.	Dip the animal.	Weekly dipping.
Salmonella	Fever, bad smelling diarrhoea.	Medicine / antibiotics can be given, see a veterinary officer.	Provide animals with clean water and feed.
E. coli	Watery, yellow diarrhoea, fever.	Medicine / antibiotics can be given, see a veterinary officer.	Provide animals with clean water and feed.

Source: IRACC (1997)

16.5 Further information

- https://www.dcbd.nl/sites/www.dcbd.nl/files/documents/Goat%20keeping%2C%20useful%20management%20practices%20for%20smallholders.pdf

Concerning breeding:

- http://www.fao.org/3/ah651e/ah651e08.htm
- https://utt.edu.tt/uploads/library/ebooks/AD07-Goat-Keeping-in-the-Tropics.pdf

Concerning health:

- https://oxfamilibrary.openrepository.com/bitstream/handle/10546/123108/bk-where-there-is-no-vet-part1-010199-en.pdf?sequence=50&isAllowed=y
- ITDG (1996)

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

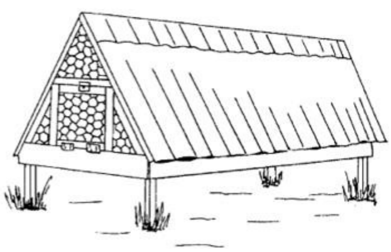
The construction of a mobile chicken house (Figure 21) is advised as a minimum housing structure for free-range chicken, which has to follow some guidelines (Table 77).

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

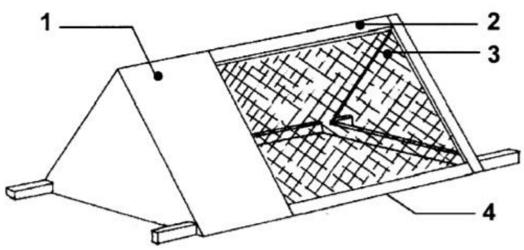


Source: Eekeren et al. (1995)

17.3.2 Fold units for chick protection

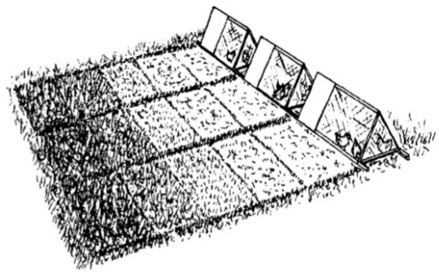
Foldable mobile housings can provide a simple shelter (0.5 m^2 space needed for each bird) for chicks and mother hens (Figure 22). As chicks are especially prone to drought and cold during the first days of their life, the area underneath the boarded section of the folding unit has to be provided with 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).

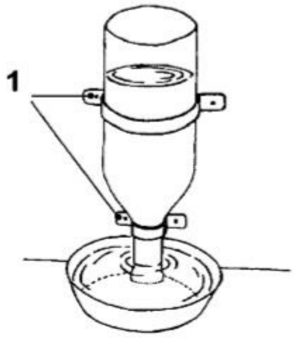
Table 78. Comparison of free-range and permanent poultry housing systems

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



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

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.

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 %		N total		NH_4-N		P_2O_5		K_2O		Mg	
			kg t^{-1} FM (= g kg^{-1})									
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

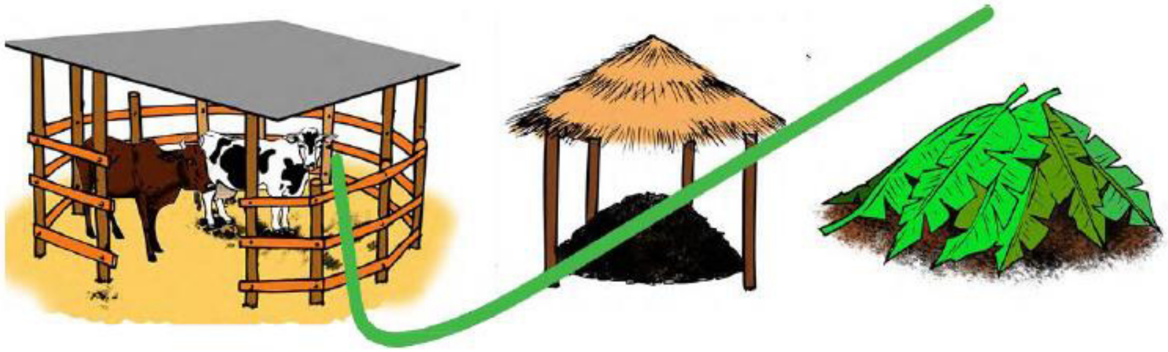
Sources: Various sources (see Excel – manure calculations)

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

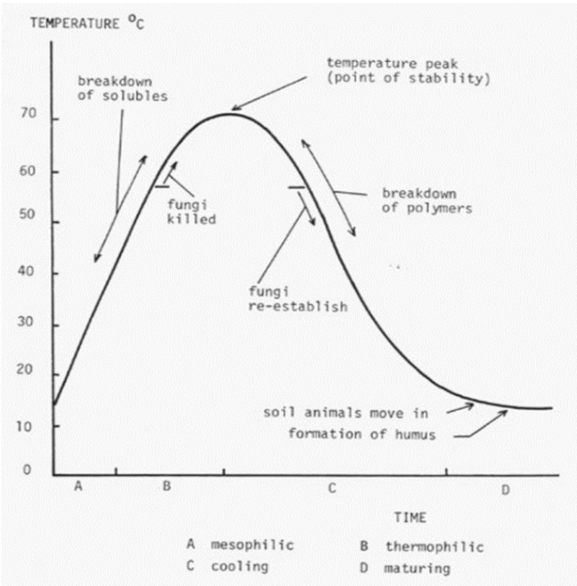
Section 1 introduces diverse composting techniques, their multiple values and applications.

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

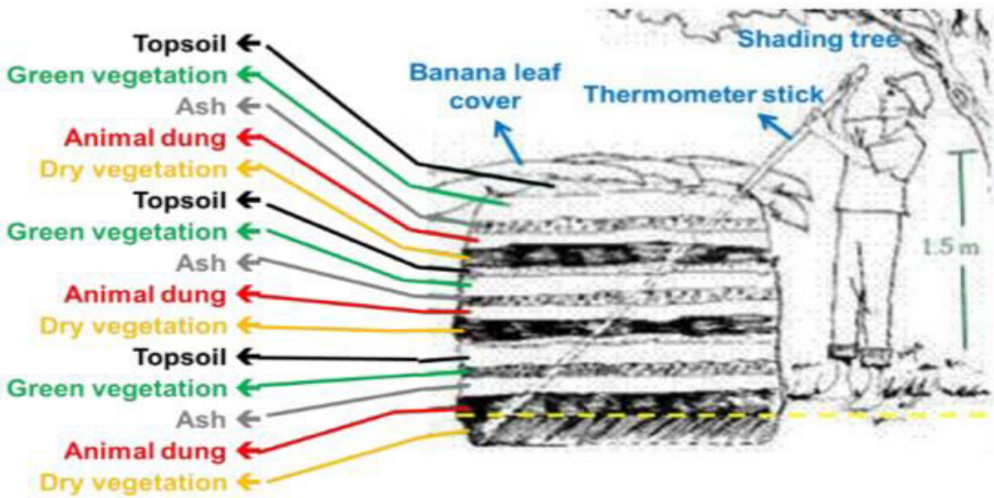
A compost heap is suitable for larger scale operations as well as small-scale systems in areas with high rainfall (Table 88 and Figure 27).

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)

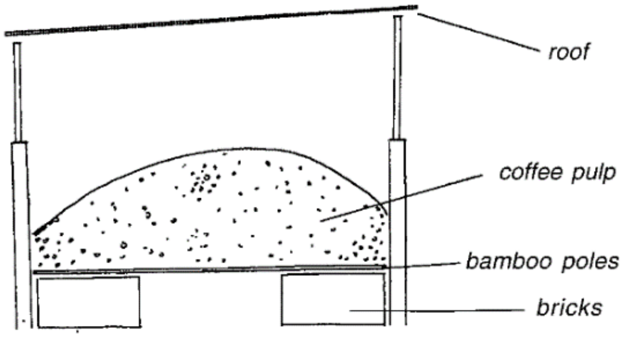
Figure 28. Slurry flowing into compost pit

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

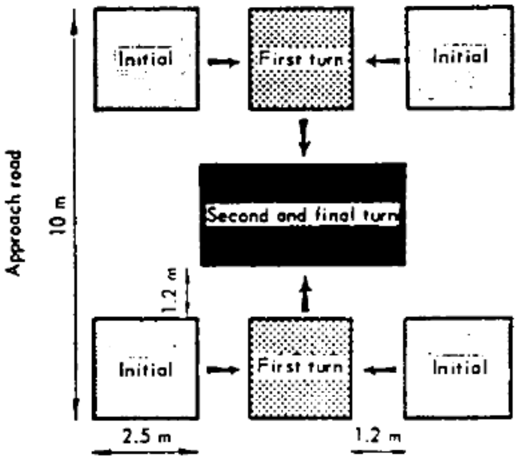
Material	C/N ratio
Ashes (wood)	25 / 1
Alfalfa	12/ 1
Cardboard, shredded	350 / 1
Cattle manure	20 / 1
Chicken manure	10 / 1
Coffee grounds	20 / 1
Food waste	30 / 1
Fruit waste	35 / 1
Grasses and weeds	20 / 1
Goat/sheep manure	14 / 1
Legume hay	25 / 1
Leafs	20-60 / 1
Maize stalks	60 / 1
Paper	800 / 1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

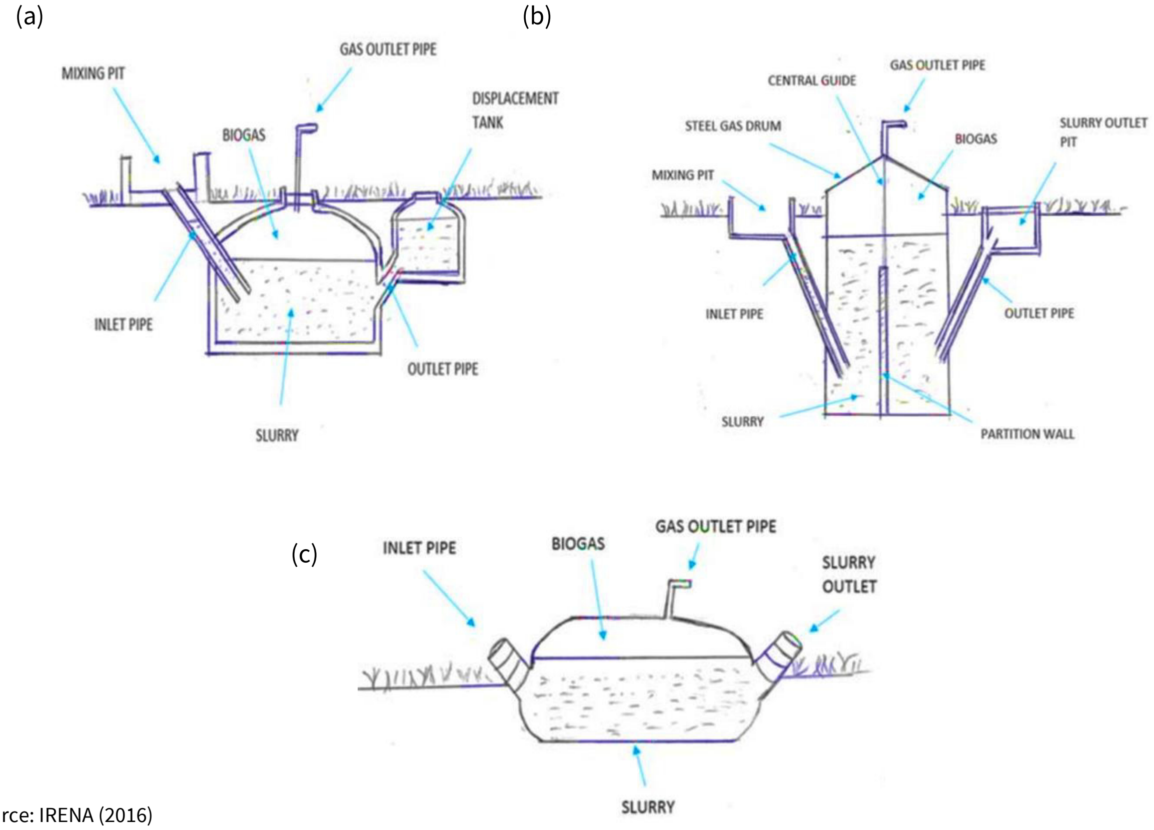
- Producing energy for light and cooking.
- Producing a nutritious organic fertiliser.
- Reduction in workload for women, as less firewood is required.
- Fewer greenhouse gases.
- Protects the unique rainforest of the Kafa Zone through replacing firewood by biogas for fuel.
- Enhances on-farm nutrient 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 m³	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	N uptake	P_2O_5 uptake	K_2O uptake
	t ha^{-1}		kg $unit^{-1}$	
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

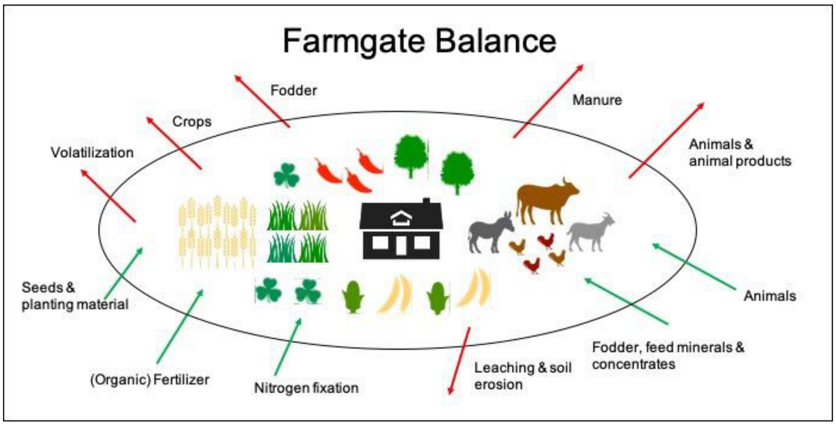
For optimising the nutrient management of a farm, two nutrient balance types can be distinguished:

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)

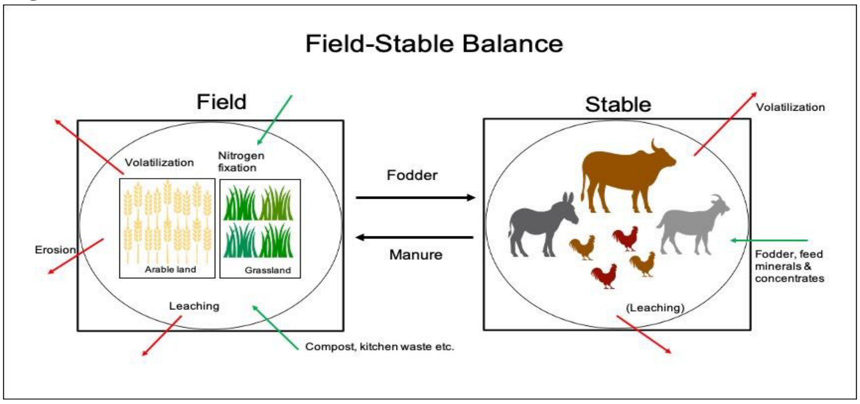
21.2.2 Field nutrient balance

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, ⊠, 24				
Relief	5, ⊠				
Crop production					
Crop rotation	⊠				
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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