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.

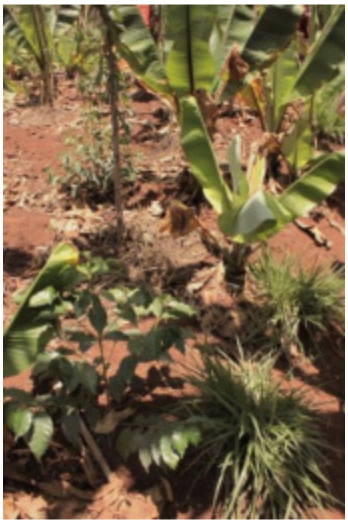
All these activities might additionally hamper the cultivation of the most relevant cash crop coffee. A further cutting of trees will increase the risk of intensifying the impacts of climate change and therefore reducing agricultural productivity and life quality of the whole zone.

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

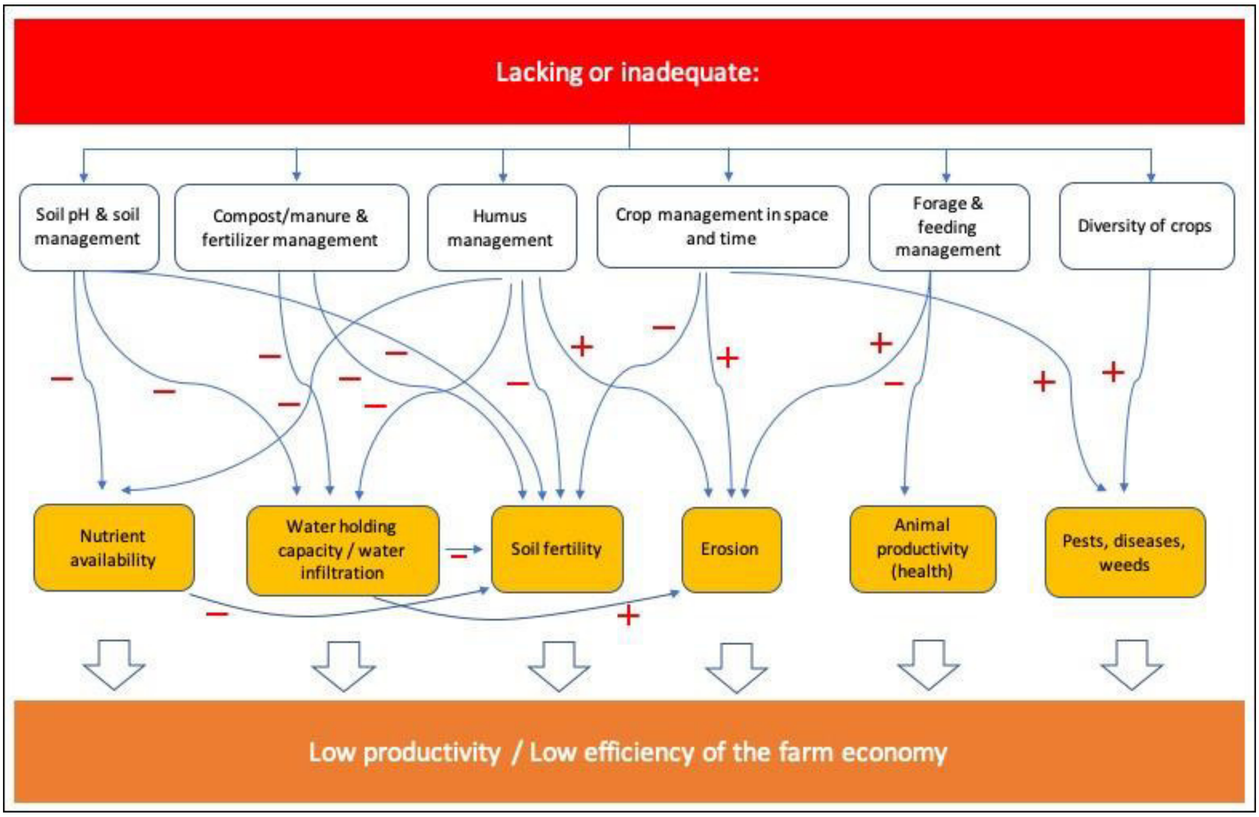


Source: Pierre Ellssel

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.

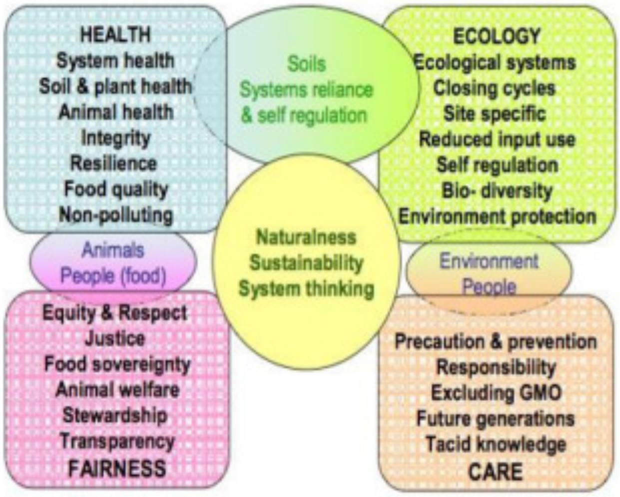
3. **The principle of fairness**

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
Documenta-tion	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 environ-ment, 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 condi-tioners 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 manage-ment 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).

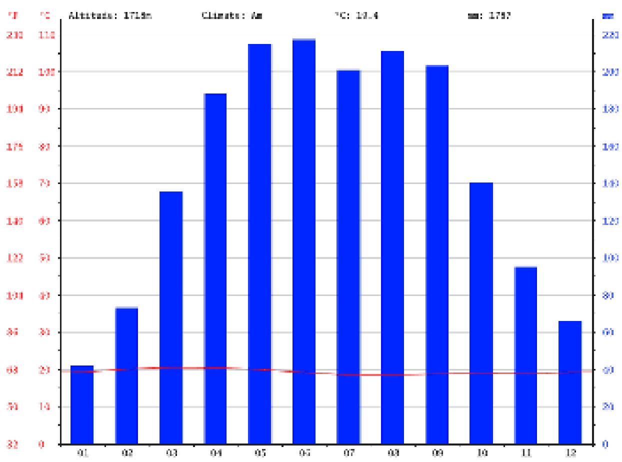
Table 10. Agroecological zones of the Kafa Zone

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).

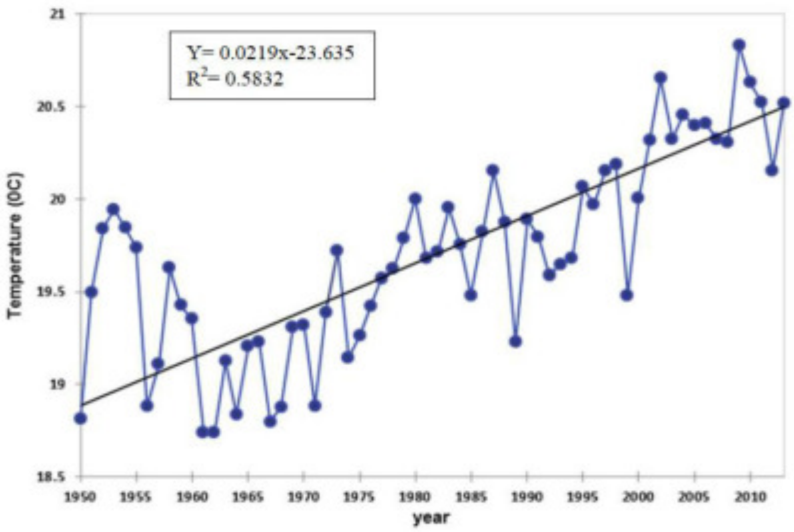
[1] Major landforms are mountains, hills, plateaus, and plains, while minor landforms comprise buttes, canyons, valleys, and basins.

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.

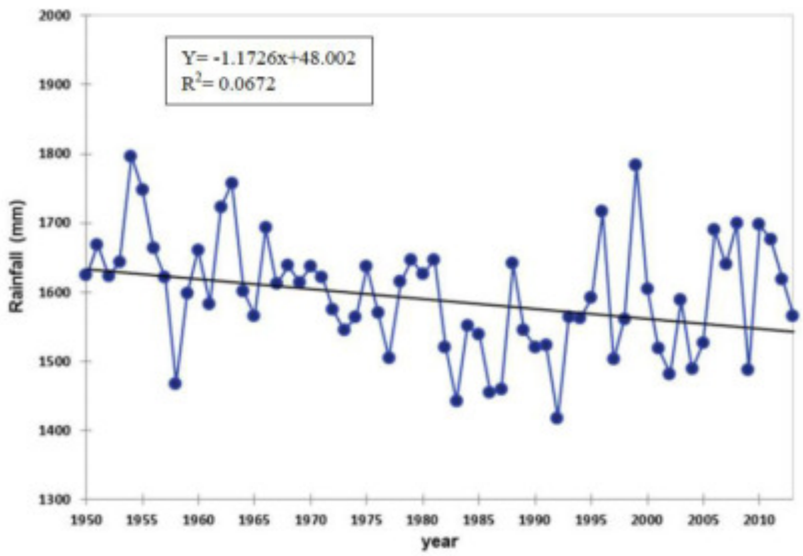
Organic farming (OF) methods, combined with an intensified tree management, provide practices for adaptation to and mitigation of climate change.

Figure 4. Mean temperature development in the Kafa Zone



Source: Kassahun & Bender (2020)

Figure 5. Mean rainfall over time in the Kafa Zone

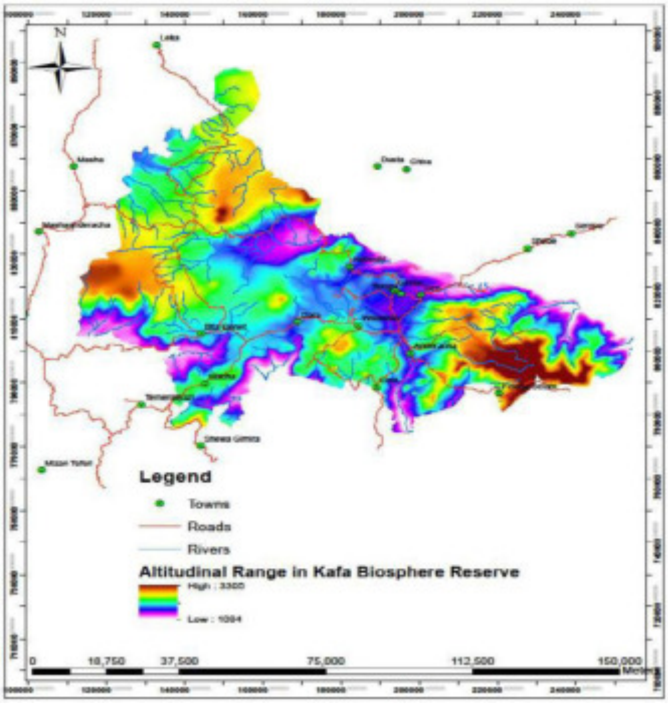


Source: Kassahun & Bender (2020)

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/

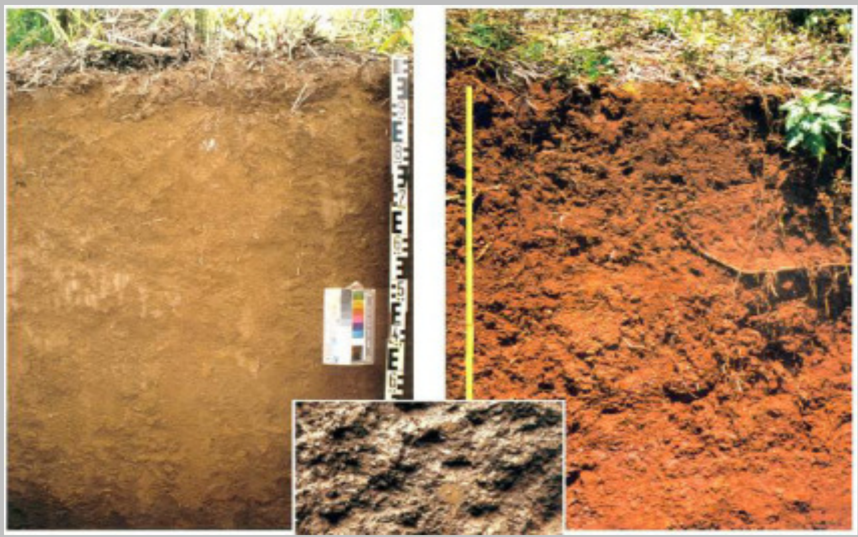
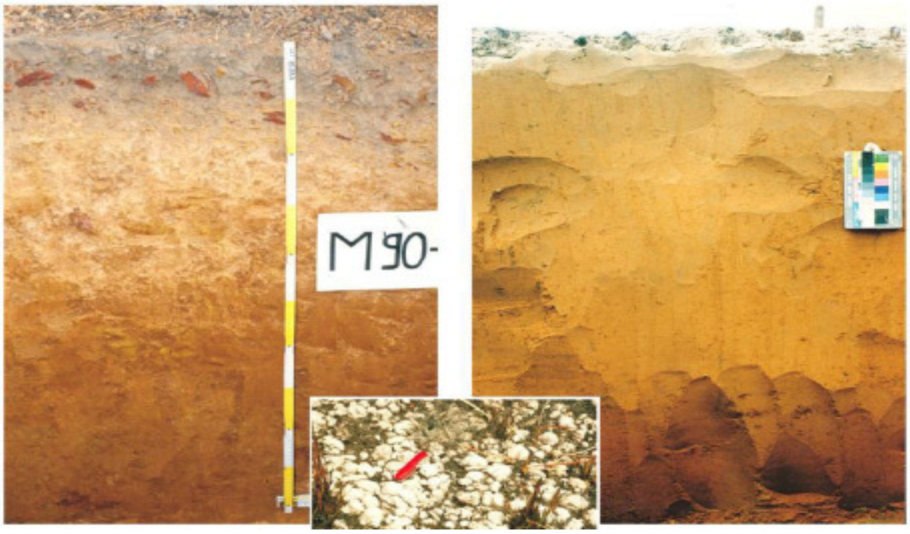
5 Soils and soil fertility

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

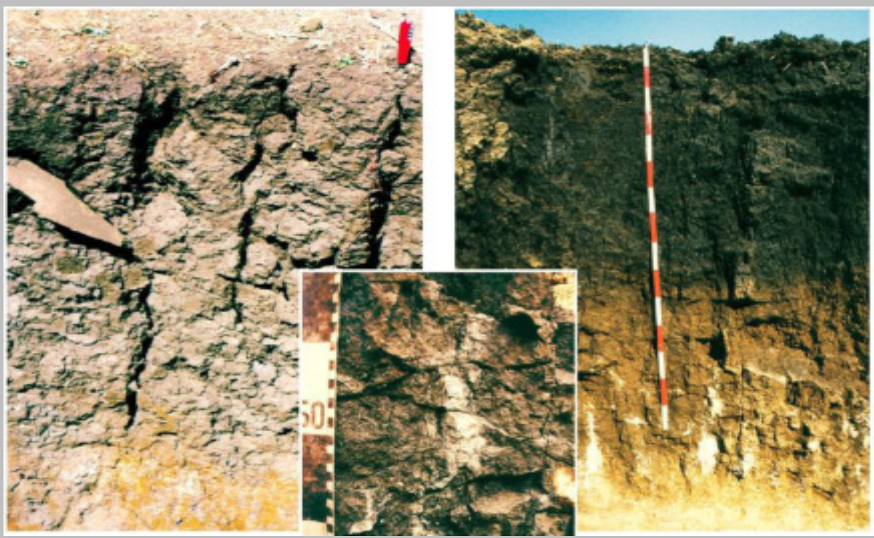
The dominant soil types in the Kafa Zone are Nitisols, Acrisols and Vertisols (Table 11). The most dominant soil types are Dystric Nitisols and Orthic Acrisols.

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.

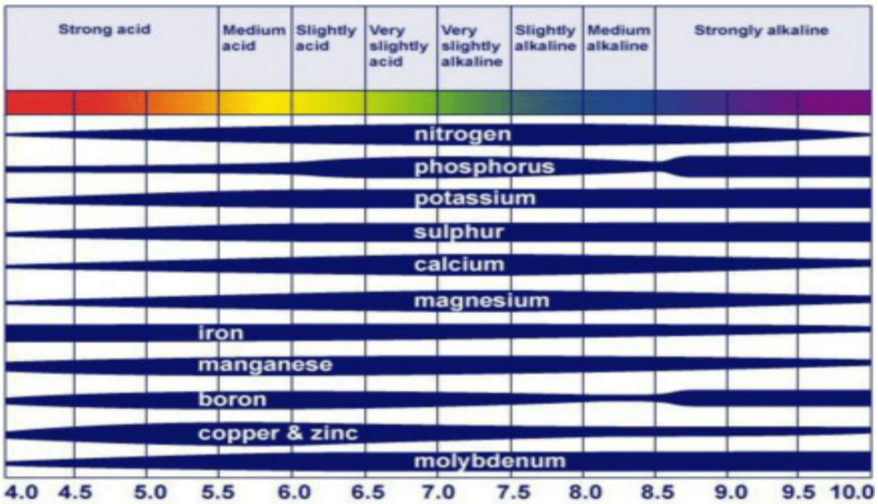
5.3.1 Significance of pH for crop growth

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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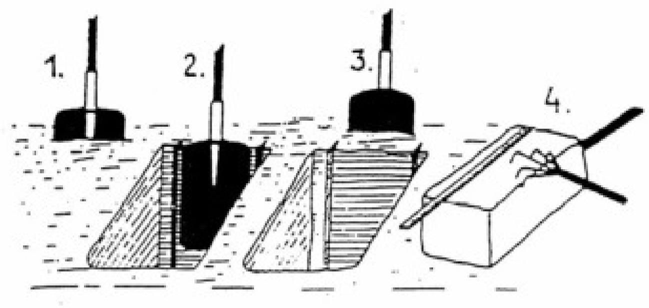
[2] The term "soil aggregate" describes microstructural elements which are formed by the aggregation of individual soil components (e.g. clay minerals, silt, sand grains, and OM) to form larger units (aggregations), and which stand out clearly from the surrounding area. Soil aggregates are formed by 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.

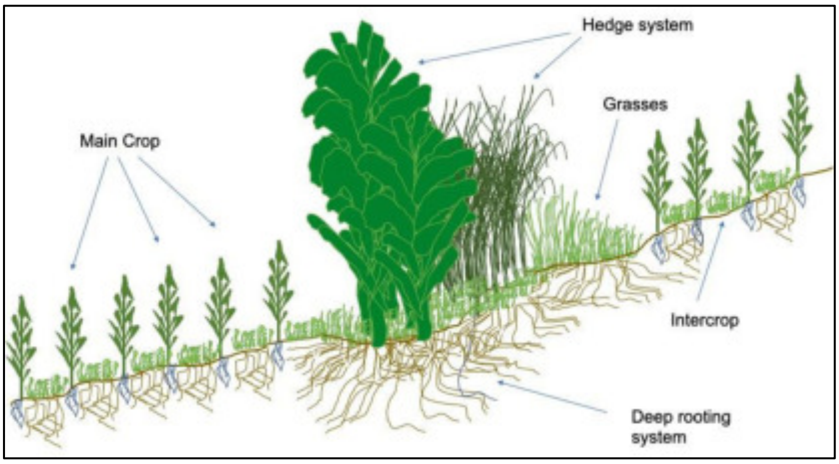
Group 2: Techniques to collect eroded soil – a combination of technical & crop specific measures (**Figure 9**).

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

	Share	Smallholder farm Seeds		Community 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.
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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.

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