

2 Soil Fertility Management



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2 Soil Fertility Management



SEPARATE SET OF TRANSPARENCIES



BOOKLET 2: SOIL FERTILITY MANAGEMENT



BOOKLET 3: SOIL AND WATER CONSERVATION



BOOKLET 4: SOIL ORGANIC MATTER MANAGEMENT



BOOKLET 5: SOIL FERTILITY SUPPLEMENTS

Learning targets for farmers:

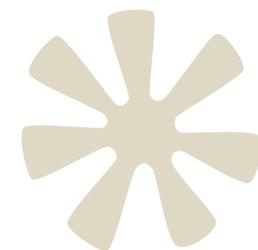
- › Get familiar with local soils and their characteristics.
- › Understand that soil fertility management is neither limited to the addition of fertilizers nor to increasing crop yield alone. It consists, first of all, of protecting the soil and enhancing its organic matter content as well as its biological activity to prevent loss of soil and encourage optimal nutrition, water supply and health of plants, increase yields and maintain yield consistency.
- › Know the tools of organic soil fertility management and be able to combine them in an appropriate way so as to correspond to local conditions and needs of the crops.

1. Introduction

Concerns are growing about long-term sustainability of agriculture. Fertile land and sufficient water are vital for sustaining agriculture and livelihoods. In Africa productivity of land, however, has been decreasing with the increasing intensification of agriculture due to land degradation. The major causes of land degradation are unsustainable agricultural practices like farming on steep slopes without sufficient use of soil and water conservation measures, monocropping, excessive tillage, or declining use of fallow without appropriate replenishment of soil nutrients, burning of crop residues, conversion of forests, woodlands and bushlands to permanent agriculture, or their excessive exploitation through fuel wood and timber harvesting, overgrazing of rangelands, and lack of proper soil organic matter management.

Land degradation occurs in different forms on various land use types:

- › On cropland, soil erosion occurs through: water and wind; chemical degradation – mainly fertility decline – due to nutrient mining and salinity; physical soil degradation due to compaction, sealing and crusting; biological degradation due to insufficient vegetation cover, decline in soil organic matter; and water degradation mainly caused by increased surface runoff (polluting surface water) and declining water availability due to high evaporation.

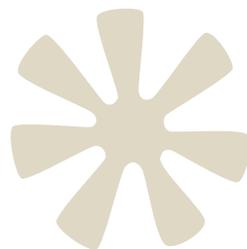


- › On grazing land, biological degradation occurs through loss of protective vegetation cover and valuable species. As a result, alien and ‘undesirable’ species settle in the soil. Physical degradation of soil results in widespread and severe water runoff and erosion. In terms of affected area, it is estimated that overgrazing has been the most important contributor to degradation, followed by poor agricultural practices and then by overexploitation.
- › On forest land, biological degradation occurs through deforestation; removal of valuable species through logging; replacement of natural forests with mono-cropped plantations or other land uses (which do not protect the land), which have negative consequences including biodiversity loss and soil and water degradation.

Therefore, attempts at reducing hunger on the African continent must begin by addressing its severely depleted soils; intensifying and diversifying land use in combination with application of sustainable soil fertility management practices based on erosion control, soil protection, soil organic matter management, reduced soil cultivation, and appropriate use of soil amendments, fertilizers and irrigation. Use of appropriate seeds, and improved access to inputs and food markets also contributes to significantly improve productivity and sustain overall food production in Africa.

This training module outlines soil fertility management practices that can contribute significantly in improving productivity of African soils. It shall help farmers to manage their soils, water and farm-own, as well as foreign soil fertility resources in a sustainable way.

To begin with, the module introduces readers to perceive soil in its diversity as the basic resource to plant production and to recognize different soil types and their characteristics.



2. Soils

2.1. What is soil?

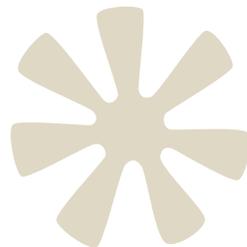
‘Soil’ is the mantle (or layer) on the land surface that acts as a medium for plant growth. It is developed through continuous action of weathering depending on environmental factors. Soil formation is largely governed by five major factors: climate (e.g. rainfall, temperature, and wind), relief or topography of the area (i.e. landscape position), living organisms (vegetation and microorganisms), nature of parent material (type of rocks and minerals from which soil is derived) and time.

2.2. What is soil made of and what does it do?

The basic components of soil are minerals, organic matter, water and air. Ideal soil (ideal for the growth of most plants) consists of approximately 45 % minerals, 25 % water, 25 % air, and 5 % organic matter. In reality, these percentages of the four components vary tremendously depending on numerous factors such as climate, water supply, cultivation practices, and soil type. Soil air and water are found in the pore spaces between the solid soil particles. The ratio of air-filled pore space to water-filled pore space often changes seasonally, weekly, and even daily, depending on water additions through precipitation, through flow, groundwater discharge, and flooding. The volume of the pore space itself can be altered, one way or the other, by several processes. Organic matter content is usually much lower than 5 % in most soils where it is not properly managed.

Mineral portion

The mineral portion of soil is divided into three particle-size classes: sand, silt, and clay. The sand, silt, and clay are collectively referred to as the fine earth fraction of soil. They are less than 2 mm in diameter. Larger soil particles are referred to as rock fragments and have their own size classes (pebbles, cobbles, and boulders). The relative proportion of sand, silt, or clay in a soil is known as soil texture. Soil texture has an important role in nutrient management because it influences nutrient and water retention. For instance, finer textured soils tend to have greater ability to store soil nutrients. Soils with the finest texture are called clay



soils, while soils with the coarsest texture are called sands. However, a soil that has a relatively even mixture of sand, silt and clay, and exhibits the properties from each, is called a loam.

Soil water

All nutrients in the soil that are provided to the plants come from water held in the soil. In a critical way, water determines the potential for realized soil fertility and plant nutrition. Only a moderate amount of soil water is needed to allow for soil aeration. If there is too much water in the soil and if it remains for many days – meaning the soil is waterlogged – the soil becomes depleted in oxygen. Under these conditions, plant nutrients will not be available to the plants, and most of the beneficial soil microorganisms will not survive. Most plants will die under such conditions, with only a few exceptions such as rice and yams.

The main functions of water in the soils are:

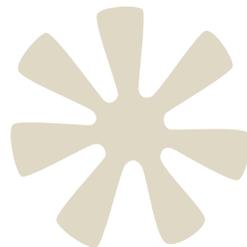
- a) Promotes many physical and biological activities of soil
- b) Acts as a solvent and carrier of nutrients
- c) Acts as an agent in photosynthesis process
- d) Acts as a nutrient itself
- e) Maintains turgidity of plants
- f) Acts as an agent in weathering of rocks and minerals.

Soil air

Oxygen is essential for all biological processes occurring in the soil. It is provided to microorganisms and plant roots through larger and smaller spaces in the soil.

Soil organic matter

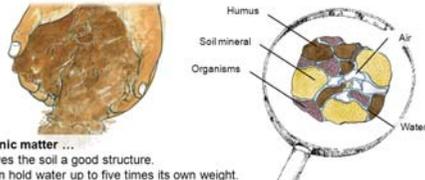
The organic matter component of soil, known in short as soil organic matter, can be divided into three general pools: living biomass of microorganisms, fresh and partially decomposed residues, and humus. Humus is the well-decomposed organic matter and highly stable organic material. Organic matter is mainly present in the top layer of the soil, which is subject to a continuous transformation process. Soil organic matter that is decomposed by soil organisms can recombine with mineral soil particles to form very stable humus structures, which can remain in the soil for many years. This long-term soil organic matter or humus contributes a lot to improve the soil's structure. Organic matter constitutes from





MICROSCOPIC VIEW OF A SOIL AGGREGATE

Why organic matter is so important



Organic matter ...

- > gives the soil a good structure.
- > can hold water up to five times its own weight.
- > provides food and an environment for beneficial soil organisms.
- > has a great capacity to retain nutrients and release them continuously.
- > prevents soils from becoming too acidic.

Microscopic view of a soil aggregate consisting of mineral particles, humus and soil organisms

1 to 6 % of the topsoil weight of most upland soils. Soils with more than 12 to 18 % organic carbon (approximately 20 to 30 % organic matter) are called organic soils. There are numerous benefits to having a relatively high stable organic matter level in an agricultural soil. These benefits can be grouped into three categories:

- Physical benefits:** Soil organic matter enhances aggregate stability, improves water infiltration and soil aeration, reduces runoff; improves water holding capacity; reduces the stickiness of clay soils making them easier to till; reduces surface crusting, and facilitates seedbed preparation.
- Chemical benefits:** Soil organic matter increases the ability of the soil to hold onto and supply over time essential nutrients such as calcium, magnesium and potassium – also known as Cation Exchange Capacity (CEC); it improves the ability of a soil to resist pH change – this is also known as buffering effect capacity; accelerates decomposition of soil minerals over time, making the nutrients in the minerals available for plant uptake.
- Biological benefits:** Soil organic matter provides food for living organisms in the soil; it enhances soil microbial biodiversity and activity, which can help in the suppression of crop diseases and pests; and enhances pore space through the actions of soil microorganisms. This helps to increase infiltration and reduce runoff.



MACRO- AND MICROORGANISMS

Soil organisms



Larger soil organisms:

- > Pull dead biomass into the soil
- > Feed on organic materials and mix them with the soil
- > Dig tunnels and facilitate aeration and drainage

Soil micro-organisms:

- > Decompose organic matter
- > Improve the soil structure
- > Make nutrients available for plants
- > Protect the plants from disease attack

Soil organisms and soil microorganisms

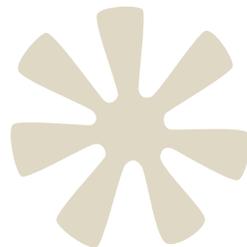
Soil is also the home for many organisms, some of which are visible to the naked eye like earthworms and termites. Others are tiny and can only be seen under a magnifying glass like bacteria. They are called microorganisms.

Among the most important soil organisms are the earthworms and termites. Most farmers are aware that the presence of earthworms is a sign of fertile soil. Earthworms fulfil several crucial functions: First, they accelerate the decomposition of plant material on the soil surface by removing dead plant material from the soil surface. During the digestion of organic material, they mix organic and mineral soil particles and build stable crumbs in their excrements, which help improve the soil structure. Earthworm excrements contain 5 times more nitrogen, 7 times more phosphate, 11 times more potash and 2 times more magnesium and calcium than normal earth. The tunnels created by earthworms promote infiltration and drainage of rainwater and thus contribute to prevention of soil erosion and waterlogging. Earthworms need sufficient supply of biomass, moderate temperatures and sufficient humidity and air. That's why they are very



Demonstration: Discovering the microcosm

Fill a handful of moist topsoil rich in organic matter (or compost) into a half-cut water bottle (or kitchen sieve). Fill a shallow vessel with a mixture of water and alcohol. Place the bottle in a paper cylinder or similar structure above the vessel and fix a strong lamp above the whole structure. Make sure the lower part of the construction is kept dark inside. The light and heat will slowly make the soil organisms move downwards and drop into the vessel and die in the alcohol. Make the farmers aware that these organisms are the most valuable free of cost helpers of a farmer. Also point out that the vast majority of soil organisms are too small to be discovered in this way.



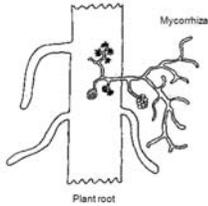


MYCORRHIZA

Mycorrhiza – a beneficial fungus

Mycorrhizae ...

- > live in symbiosis with plant roots.
- > enlarge the surface of the roots and penetrate small soil pores.
- > support the plants in taking up nutrients and water.
- > improve the soil structure and preserve moisture.
- > are sensitive to chemical fertilizers and pesticides.



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fond of mulching. Frequent tillage and pesticides, on the other hand, decrease the number of earthworms in the soil. Termites due to their high activity and biomass can also be considered as almost always positive for soil structure and soil properties. In some cases, especially in the Sahel zone of Africa, termites are artificially introduced in order to degrade fine wood matter to produce compost to use as fertilizer for agriculture.

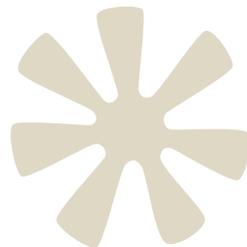
The most important microorganisms are bacteria, fungi, algae and protozoa. Soil bacteria such as Rhizobium bacteria help some plants to fix nitrogen from the air. Soil fungi constitute the major part of microbial biomass. An example of soil fungi is the mycorrhizae. Mycorrhizae grow in symbiosis (a close mutually beneficial relationship) with about 90 % of all plant roots. The plant roots provide sugar for the growth of the fungi. In reverse, the mycorrhizae explore the soil and bring back water as well as nutrients such as phosphate, zinc and copper that are not easily available to plants. Mycorrhizae also dissolve minerals such as phosphorus, and carry them to the plant, make soil aggregates more stable thus improving soil structure, and take plant carbon from the air and deposit into soil organic matter and stable soil aggregates. Incorporation of biomass into the soil, maintenance of a ground cover, mixed cropping, and reduced use of chemicals encourages build up of soil organisms.

In organic and sustainable cropping systems, the soil life is the engine of soil fertility and crop production, as well as the guardian of long term soil health.

2.3. Soil structure

Soil structure refers to the arrangement of soil particles with resultant formation of big and small pores between soil aggregates. Soil structure influences movement of water into and through the soil, the degree of aeration, the ability of the soil to resist soil erosion and crop roots to grow through the soil profile. Small pores are good in preserving moisture, while the larger ones allow a fast infiltration of rain or irrigation water and help to drain the soil and ensure aeration.

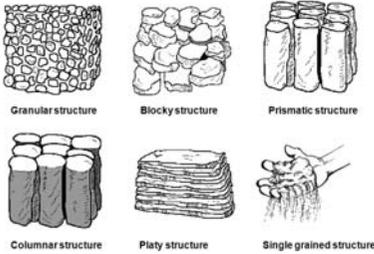
Soil material fits and binds together in different ways. In some soils the bonding is very weak, in others very strong. The size of aggregates in some soils is very fine, whilst in others aggregates are coarse and large. In some soils the aggregates are dense containing few pores, in others they are quite open with plenty pores.





TYPES OF SOIL STRUCTURES IN SOILS

Types of soil structure



In soils with good structure, mineral particles and soil organic matter form stable aggregates. This process is supported by soil organisms such as earthworms, bacteria and fungi. The soil organisms excrete substances that act as cementing agents and bind the particles together. Fungi have filaments, called hyphae, which extend into the soil and tie soil particles together. Organic matter works as a kind of glue, helping the soil particles to stick together. This makes it clear that soil structure can be improved by supplying organic matter and by enhancing the biological activity of the soil. Whereas incorrect soil management practices such as tilling the soil in wet conditions cause compaction and may damage the structure of the soil. Compacted layers, plough pans, surface crusting and root restriction are indicators of damaged soil structure.

2.4. Soil types and their characteristics

There are different types of soil. All the types are a combination of the three mineral particles sand, silt and clay. The chemical composition of the parent material of the particles and how these three particles are combined defines the soil's type. It helps to determine the fundamental characteristics of soil whether it is acidic, alkaline, or neutral. The different soil types are as follows: Sandy soil, silty soil, and clay soil.

Sandy soil

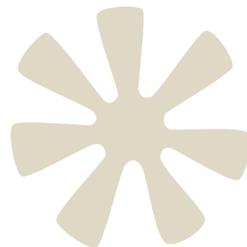
Sandy soil is formed by the disintegration and weathering of rocks such as limestone, granite, quartz and shale. Sandy soils contain large particles which are visible to the unaided eye, and are usually light in colour. Sand feels coarse when wet or dry (texture is gritty), and will not form a ball when squeezed in the fist. Sandy soils stay loose and allow moisture to penetrate easily, but do not retain it for a long time. It adapts very fast to air temperatures. Easy drainage prevents root rot problems.

Sandy soil allows drainage more than is needed, which results in over-drainage and dehydration of the plants in dry periods. So if one grows plants in sandy soil, they depend on regular water supply in dry periods. Sandy soil has little humus and is usually acidic. For certain crops like pear, which require an alkaline soil condition in order to flower and fruit successfully, there is a need to neutralize the acidic nature through addition of hydrated lime, powdered lime or



Group work: Studying soil samples

Collect soil samples from the area and keep them in plastic bags to preserve their moisture. Place the samples in small heaps on a table. As part of the exercise, write the origin and type of each sample on a piece of paper and turn the piece of paper upside down, to be revealed at the end of the exercise. Ask the farmers to use the soil assessment questionnaire to characterize them by their composition, structure, colour and smell. Let them identify the type and the fertility properties. Then discuss the findings together. Further questions could be: Which types of crops could one grow on such a soil? How could the fertility of such a soil be improved?





SOIL ASSESSMENT QUESTIONNAIRE

| Soil assessment questionnaire | |
|--|---|
| Tactile properties: | How does the soil feel between the fingers? |
| Soil type | gritty? → rich in sand, smooth, but not very sticky? → rich in silt, smooth and sticky? → rich in clay Is the soil sticky enough to form a square and a roll? Try to make a firm square of soil. Next, try to roll up the square into a thin roll. roll is not possible → sand or sandy loam; thin roll is possible → loam or clay Is it possible to form a stable ring? If a roll was possible, try to bend the roll into a ring, ring not possible → loam, ring with cracks outside → light clay soil, firm ring without cracks → heavy clay soil |
| Visual properties: | What colour does the soil have? What might be the reason for the colour? |
| Colour and structure | Can you find structures of plant residues? Which? Do you find pieces of soil organisms? Which? |
| Smell | Can you feel a smell of the soil? Which kind of smell? |
| Site information | On which kind of place the sample was collected, or on which sites usually this kind of soil is found? |
| Suitability for agricultural use | How are these sites usually used? What crops are grown? Is this type of soil suitable for agricultural use? Will it keep moisture well? Will water logging occur? Is it easy to till? Does it have a good structure? Do you suppose to find earthworms in this type of soil? Is it rich in nutrients? Which crops would you grow on it? |
| Treatment for improvement of soil fertility | Soil cultivation, tillage Fertilisation, manuring Plant cover, mulching Crop rotation, fallows |

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calcium carbonate each year to maintain optimum conditions. Sandy soils are sensitive to erosion and therefore need to be protected from wind and rain. Regular supply of organic matter strongly improves their water and nutrient holding capacity, as well as their resistance to erosion. Mulching also helps the sandy soils to retain moisture through a reduction in evaporation from the soil.

Silty soil

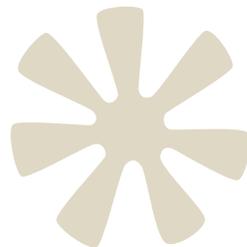
Silty soil has much smaller particles than sandy soil therefore is smooth to the touch. When moistened, it is soapy slick. When you roll it between your fingers, dirt is left on your skin. Silty soil can occur in nature as soil or as suspended sediment in water column of a water body on the surface of the earth. It is composed of minerals like quartz and fine organic particles. It is granular like sandy soil but holds more nutrients and moisture. It easily builds a crust on the soil surface, which prevents water infiltration and can hinder emergence of crops. In moist condition it offers good drainage and is much easier to work. The higher its organic matter content is, the better it absorbs rain water and maintains its structure also after strong rains, thus resisting to erosion.

Clayey soil

Clayey soils are made of very small particles with very little air space. Clayey soil is formed after years of rock disintegration and weathering. It is also formed as sedimentary deposits after the rock is weathered, eroded and transported. Clay soil due to its formation process is rich in mineral content. Clayey soils feel slick and sticky when wet but smooth when dry. Clay holds moisture well, but resists water infiltration, especially when dry. Often puddles form on clay soils, and the soils easily become compacted. Due to their poor drainage, risk of water logging and compaction, clayey soils are difficult to work. Supply of compost and gypsum improves the soils' qualities making them more flexible to cultivation. The gypsum and the compost push the clay soil particles apart, making room for drainage and proper water retention. Supply of organic material promotes development of earthworms, which help further to improve the soils qualities.

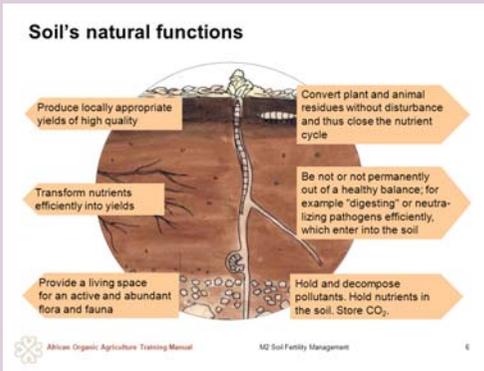
Loamy soil

Loamy soil consists of a balance of sand, silt and clay plus humus. It is considered to be the perfect soil for arable farming. Loam is dark in colour and is mealy in the hands. The texture is gritty and retains water very easily, yet the drainage is





THE FUNCTIONS OF SOIL



good. There are various kinds of loamy soil ranging from fertile to very muddy and thick sod. Yet out of all the different kinds of soil, loamy soil is ideal for cultivation.

3. Soil fertility

3.1. What is soil fertility?

Fertility of a soil is defined by its ability to provide all essential nutrients in adequate quantities and in the proper balance for the growth of plants – independent of direct application of nutrients – when other growth factors like light, temperature and water are favorable. This ability does not depend on the nutrient content of the soil only, but on its efficiency in transforming nutrients within the farm's nutrient circle.

In transformation of nutrients soil organisms play a key role. They break down biomass from crop residues, green manures and mulch and contribute to build up of soil organic matter, including humus, the soil's most important nutrient reservoir. They also play an essential role in transferring nutrients from the soil organic matter to the mineral stage, which is available to plants. Soil organisms also protect plants from disease and make the soil crumbly.

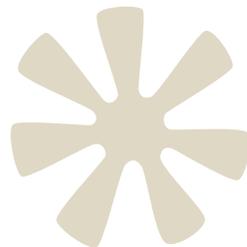
A fertile soil is easy to work, absorbs rain water well, and is robust against siltation and erosion. It filters rain water and supplies us with clean drinking water. It neutralizes (buffers) acids, which pass through contaminated air to the soil surface, and decomposes pollutants such as pesticides rapidly. And last but not least a fertile soil is an efficient storage for nutrients and CO₂. In this way a fertile soil prevents the eutrophication of rivers, lakes and oceans and contributes to the reduction of global warming.

In the context of biological agriculture soil fertility is thus primarily the result of biological processes, not of chemical nutrients. A fertile soil is in active exchange with the plants, restructures itself and is capable of regeneration. The biological properties can be observed in the soil's conversion activity, in the presence and the visible traces of the organisms in it. The communities of microorganisms are robust and active at the right moment. In the self-regulating ecological equilibrium animals, plants and microorganisms all work for each other.



Discussion: Defining soil fertility

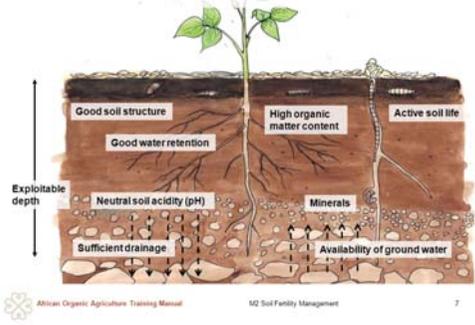
Ask farmers, what in their perception makes soil fertile. What are the characteristics of fertile soils?





PROPERTIES OF A FERTILE SOIL

The measurable properties of a fertile soil



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PRIMARY PLANT NUTRIENTS

Major primary nutrients: functions and common deficiency symptoms

| Nutrients | Functions | Deficiency symptoms | Comments |
|-----------------------|--|--|--|
| Nitrogen (N) | <ul style="list-style-type: none"> Necessary for the formation of amino acids (the building blocks of proteins) Essential as plant cell division (cell for plant growth) Adult production of carbohydrates (component of leaf chlorophyll) Affects energy reactions in the plant | <ul style="list-style-type: none"> General yellowing of the plant starting with older leaves (bottom of plants) Late and slow plant growth Reduced flowering in severe cases | <ul style="list-style-type: none"> Common in plants grown on soils low in organic matter (<4%) Plants containing less than 1.5% N are generally deficient |
| Phosphorus (P) | <ul style="list-style-type: none"> Involved in photosynthesis, respiration, energy storage and transfer Promotes early root formation Stimulates growth and early maturity Improves quality of fruits, vegetables and grain Important in seed and fruit formation Increases water use efficiency | <ul style="list-style-type: none"> Slow, weak and stunted growth Leaf tips look burnt, followed by older leaves turning dark to blue green or reddish purple in severe cases Delayed maturity and poor seed and fruit formation | <ul style="list-style-type: none"> Common in crops grown on acid soils, limy soils, coarse textured soils low in organic matter Best P uptake at pH 6.5 to 7.5 |
| Potassium (K) | <ul style="list-style-type: none"> Increases photosynthesis Increases water-use efficiency Essential to protein synthesis Important in fruit formation Improves quality of seeds and fruit Increases disease resistance Activates enzymes and controls their reaction rates Required for translocation of carbohydrates within the plant | <ul style="list-style-type: none"> Stunted growth (often) Chlorosis along the margin or edge of leaves Weakened stalks, causing lodging and toppling | <ul style="list-style-type: none"> Common in: <ul style="list-style-type: none"> soils inherently low in total or non-exchangeable K coarse textured leached soils soils under intensive cultivation with N and P fertilizers alone |



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It is the responsibility of farmers to understand soil ecology to the point that they can create or restore the conditions for a robust balance in the soil. If a soil does not regularly bring good yields, farmers should investigate the reasons for it.

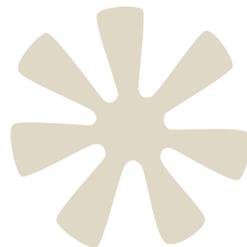
3.2. Properties of a fertile soil

A fertile soil:

- is rich in nutrients necessary for basic plant nutrition (including nitrogen, phosphorus, potassium, calcium, magnesium and sulphur);
- contains sufficient micronutrients for plant nutrition (including boron, copper, iron, zinc, manganese, chlorine and molybdenum);
- contains an appropriate amount of soil organic matter;
- has a pH in a suitable range for crop production (between 6.0 and 6.8);
- has a crumbly structure;
- is biologically active;
- has good water retention and supply qualities.

Appropriate amount of plant nutrients

There are 16 essential nutrients that plants need in order to grow properly. Out of the 16 essential elements hydrogen, carbon and oxygen are obtained mainly from the air and from water. The other essential elements come from the soil and are generally managed by the farmers. Some of these nutrients are required in large amount in the plant tissues and are called macro (major) nutrients. Others are required in small amount and are called micro (minor) nutrients. Macronutrients include nitrogen (N), phosphorus (P) potassium (K), calcium (Ca), magnesium (Mg), and sulphur (S). Of these N, P and K are usually depleted from the soil first because plants need them in large amounts for their growth and survival, so they are known as primary nutrients. Ca, Mg and S are rarely limiting and are known as secondary nutrients. Where soils are acidic lime is often added, which contains large amounts of calcium and magnesium. Sulphur is usually found in sufficient amounts from the slowly decomposing soil organic matter. The micronutrients are boron (B), copper (Cu), iron (Fe), chloride (Cl), manganese (Mn), molybdenum (Mo), and zinc (Zn). Recycling organic matter such as crop residues and tree leaves is an excellent way of providing micronutrients to growing plants.





LOW SOIL PH

Characteristics of acid soils and suitable crops

Characteristics of acid soils

- › pH is less than 6.5
- › Open textured with high massive structure
- › Low in Ca and Mg with negligible amount of soluble salts
- › Brown or reddish brown, sandy loams or sands

Suitable crops

| | |
|-----|---|
| 4.5 | Citrus, pineapple |
| 5.0 | Apple, grapes, tobacco, watermelon |
| 5.5 | Cassava, cotton, cowpea, peas, tomato, sorghum, soybean |
| 6.0 | Cabbage, carrot, cassava, cashew nut, cauliflower, groundnut, mango, onion, peanut, radish, spinach |
| 6.5 | Alfalfa, groundnut, sugarbeet |



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HIGH SOIL PH

Characteristics of alkaline soils and suitable crops

Characteristics of alkaline soils and symptoms in crops

- › pH more than 7
- › High exchangeable sodium decreases the availability of calcium and magnesium to plants
- › Toxicity due to excess hydroxyl and carbonate ions
- › Growth of plant affected mainly due to nutritional imbalance
- › There is restricted root system and delay in flowering in sensitive varieties
- › Leaf burn in annuals and woody plants due to excess of chloride and sodium

Suitable crops

| | |
|-----|---|
| 7-8 | Asparagus, banana, beetroot, cabbage, cauliflower, coconut, cotton, cucumber, date palm, grape, guava, maize, pumpkin, rice, sesame, sorghum, spinach, sugarcane, sunflower, tomato |
|-----|---|



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Plant roots require certain conditions to obtain nutrients from the soil:

- First, the soil must be sufficiently moist to allow the roots to take up and transport the nutrients. Sometimes supplying water to plants will eliminate nutrient deficiency symptoms.
- Second, the pH of the soil must be within a certain range for nutrients to be releasable from the soil particles.
- Third, the temperature of the soil must fall within a certain range for nutrient uptake to occur.
- Fourth, the nutrients must be within the root zone in order for the roots to access them.

The optimum range of temperature, pH and moisture is different for different species of plants. Thus, nutrients may be physically present in the soil, but not available to plants. A knowledge of soil pH, texture, and history can be very useful for predicting what nutrients may become deficient.

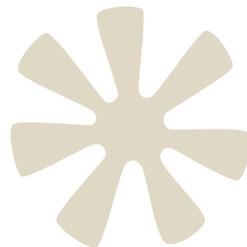
On the other side, too much of any nutrient can be toxic to plants. This is most frequently evidenced by salt burn symptoms. These symptoms include marginal browning of leaves, separated from green leaf tissue by a slender yellow halo. The browning pattern, also called necrosis, begins at the tip and proceeds to the base of the leaf along the edge of the leaf.

Neutral soil pH

Soil pH, its acidity or alkalinity, is highly relevant to how readily available nutrients become in soil, known as solubility of nutrients. In Africa, about one-third of the soils are acidic or prone to acidity and another one-third is either saline or alkaline and both are difficult to manage. Plants differ in their sensitivity to a low or high pH level. Some plants can withstand or even prefer a somewhat low pH level, others a higher one.

Soils with pH less than 6.5 and which respond to liming may be considered as acid soils. When potassium, calcium and magnesium leach from the soil, it becomes acidic. This may happen if there is a lot of rain (or irrigation water) that washes nutrients away, or if too much mineral nitrogen fertilizers are applied.

In acid soils plant roots do not grow normally due to toxic hydrogen ions. Phosphorous gets immobilized and its availability is reduced. Most of the activities of beneficial organisms like Azatobacter and nodule forming bacteria of legumes are adversely affected as acidity increases under acidic conditions, the





SOIL STRUCTURE FOR SOIL EROSION CONTROL

Resistance to soil erosion

Good soil structure:

- > Crumbly soil surface with stable soil aggregates
- > Many soil pores resulting in easy drainage
- > Good penetration and rooting of plant roots



Soil fertilized with compost and animal manure

Poor soil structure:

- > Crusty soil surface and poor structure
- > Few pores and compacted soil layers resulting in poor drainage
- > Poor root growth



Soil fertilized with mineral fertilizers only

Pictures taken in FIBL's DOC Long Term Comparison Trial in Switzerland after the same rain incident



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bacteria fix less nitrogen and decompose less organic matter, which results in fewer available nutrients.

Addition of lime or compost with high pH (8) will help to neutralize acidity and to increase the pH, so that the availability of nutrients will be increased.

Alkaline soils are formed due to concentration of exchangeable sodium and high pH. Irrigated soil with poor drainage may lead to alkali soils. In coastal areas, if the soil contains carbonates, the ingress of sea water leads to formation of alkaline soil due to sodium carbonate deposition.

pH of alkaline soil can be corrected through application of gypsum: For every 1 milli-equivalent of exchangeable sodium per 100 gram of soil about 1.7 tonnes of gypsum should be added to an acre of land. If the requirement is 3 tonnes per acre, application should be done in one dose. If the requirement is 5 or more tonnes per acre, application should be done in 3 split doses. Application of molasses or growing of green manure crops and their incorporation in the field can also help to correct an alkaline soil.

Crumbly structure

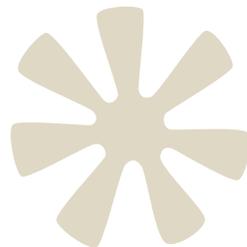
Plant roots prefer soil with a crumbly structure, like well-made bread. Such soil is well-aerated and the plant roots are able to penetrate easily. This allows them to grow both wide and deep allowing them to access more nutrients to support good growth.

Soil aggregation is also an important indicator of the workability of the soil. Soils that are well aggregated are said to have “good tilth”. A good soil structure also contributes to reduction of erosion of topsoil, as water infiltrates more easily into the soil and the aggregates resist to the raindrops.

High biological activity

Even if we cannot see most soil organisms doing their work, the majority of soil organisms are very important to the quality and fertility of soils. They contribute to the transformation of crop residues and organic fertilizers to soil organic matter, to the improvement of plant health by controlling pest and disease organisms and to helping release nutrients from mineral particles. High biological activity is an indicator of fertile soil.

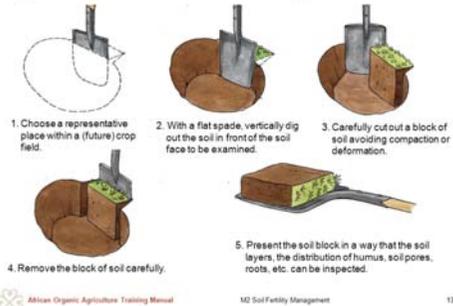
Most soil organisms prefer the same conditions as plant roots: humid conditions, moderate temperatures, air and organic material are best for them. Most are very sensitive to changes in soil moisture and temperature. Their activity is





PROCEDURE FOR SPADE EXAMINATION OF THE SOIL (1)

Spade examination of the soil (1)



generally low when soils are dry, very wet or too hot. If the soil is compacted, dried out, baked by the sun, or is poor in organic matter, it becomes like a piece of concrete and soil organisms cannot do a good job. Even the bacteria, as tiny as they are, cannot work in a dead soil. Good air circulation within the soil is crucial for their development. Activity is highest in warm and moist soils when “food” is available.

3.3. Assessing the fertility of soils

Soil analysis

Farmers may find getting their soil analysed in a laboratory helpful to know more about the fertility of their soils. Soil analysis, however, often has limited relevance as nutrient uptake depends on many soil factors, such as biological activity. While soil analysis may provide good results for soils fertilized with mineral fertilizers, the higher activity of soil organisms in organically managed soils can result in better nutrient availability, making the results of a test not fully appropriate or accurate. In addition, the content of nitrogen in soil fluctuates extremely within just a few days, so that the amount in the sample is highly dependent on the point of time when the sample is taken.

Chemical soil analysis can be useful to analyse the level of acidity in soil (pH) or for detecting deficiencies or toxicities of nutrients such as Phosphorus (P), Potassium (K) or Zinc (Zn). Organic farmers may especially be interested in knowing and monitoring the content of soil organic matter (Corg). For soil that has presented problems such as low yields during several consecutive years, doing the traditional analyses of P, pH and Corg can certainly give an indication as to what should be done to improve soil fertility.

Chemical soil analysis on pesticide residues is highly complicated, as one must know which pesticide to look for, and they are very costly. Physical testing related to water retention capacity or soil structure can yield interesting information, but samples must be taken very carefully. Biological analysis of the activity of soil organisms must be done in specially equipped laboratories and is rather costly.

If soil tests are used, farmers should make sure that the relevant aspects are investigated and that the results of the test are critically discussed with an extension officer. For most farmers in Africa, it may be more appropriate to use a



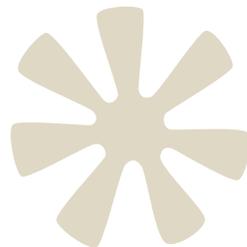
Practical demonstration of the spade examination of a soil

Demonstrate to the farmers how to use a spade to get an undisturbed soil cube and assess the visible soil properties. Discuss how each of these properties affects soil fertility.



PROCEDURE FOR SPADE EXAMINATION OF THE SOIL (2)

Spade examination of the soil (2)



spade diagnosis and dig a soil profile to better understand their soils, and invest in soil fertility in general. Extension officers should encourage farmers to watch the activity of soil organisms that are decomposing plant material and also watch the fate of the plant material upon degradation. This may be part of a spade diagnosis, but could also be a first step to recognizing the soil as a living and active ecosystem.

3.4. General fertility status of African soils and its management

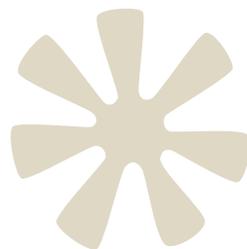
Africa has a wide range of soils and climatic conditions. Its soils are inherently low in fertility because they developed from poor parent material, are old and lack volcanic rejuvenation. In addition to low inherent fertility, about 65 % of the arable land in Africa is degraded due to water and wind erosion, loss of nutrients, physical deterioration and salinization. Soil fertility is highly heterogeneous with large on-farm variation from field to field and nearly as much variation on a local level as across all of Africa.

Several attempts have been made in the management and development of soil fertility in Africa. In the 1960s and 1970s soil fertility in agricultural systems was maintained through long term bush fallows of 10 or more years, but this is no longer being practiced because of increased shortage of land. The appropriate use of external inputs such as mineral fertilizers, lime, irrigation water and improved cereal germplasm was championed because it was believed to be able to alleviate constraints that are associated with crop production. However, unlike Asia and Latin America where the application of these technologies has boosted agriculture production leading to the `Green Revolution`, this did not work in the case of Africa due to the diversity of the agro-ecologies and cropping systems, variability in soil fertility, weak institutional arrangements and policy failure. The Low External Input Sustainable Agriculture (LEISA) paradigm was also championed in the research and development agenda in the 1980s, which advocated a shift from external input only, to limited external inputs and optimal use of locally available resources in efficient manner. But nevertheless, lack of sufficient organic resources and labour intensiveness of the LEISA technologies had caused a shift in soil fertility management. Significant progress has also been made in the combined use of organic and mineral fertilizers in the mid-1980s and



Sharing experiences on the use of mineral fertilizers

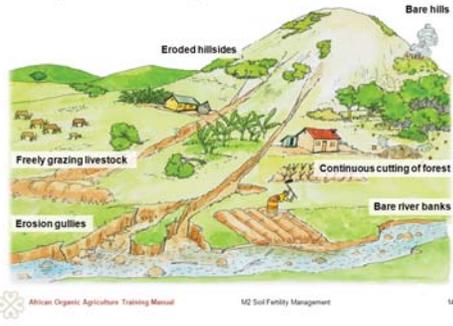
Ask the farmers about their experiences with mineral fertilizers. Which fertilizers did they use? How and in which quantities did they apply them? What were the short- and long-term impacts on plant growth, water holding capacity of the soil, soil structure or biological activity? Did they compare the use of mineral fertilizers with the use of compost or animal manure?





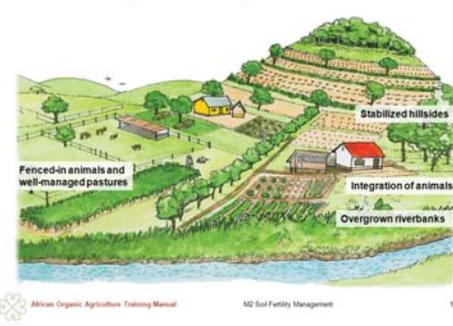
DEGRADATION OF LAND

A degraded landscape



PREVENTION OF LAND DEGRADATION

A well-managed landscape



1990s. However, a lot of challenges still remain to be overcome in soil fertility management.

Today most African soils are deficient of organic matter due to repeated ploughing, erosion of the topsoil, mono-cropping and lack or insufficient supply of organic materials. These soils have low capacity to retain and supply nutrients to plants, high nitrogen leaching and phosphate fixation potential, low to medium water holding capacity, weak soil structure and are deficient in minor nutrients.

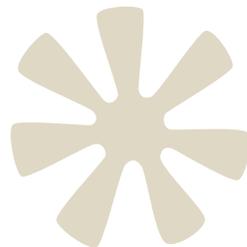
3.5. Challenges associated with mineral fertilizers

- › The nutrients in mineral fertilizers are highly soluble, easily taken up by the plant, but also easily leached out of the soil (especially nitrogen). They have to be applied cautiously so as to not to end up polluting streams or groundwater, which causes health problems in humans. Nitrates found in well water, for instance, are known to cause methaemoglobinaemia, also known as ‘blue baby syndrome’, where the blood is short of oxygen.
- › When plants receive nutrients in the form of mineral fertilizers through the soil water, they are forced to grow quickly, making them vulnerable to diseases and attractive to pests. On the other hand, when nutrients are supplied through biological activity from the decomposition process or humus, for instance, then the flux of nutrients (although water soluble) is slower and in more continuous supply compared to mineral fertilizers where nutrients are only available for a short period of time.
- › Mineral fertilizers are salts that may help to neutralize alkalinity such as ammoniated fertilizer. In African acid, infertile, red soils in arid and semi-arid climates, however, ammoniated fertilizers contribute to acidity, increasing problems with plant nutrition
- › Mineral fertilizers are very expensive for most farmers in Africa. Farmers who take out a loan to buy farm inputs depend on a good harvest to pay back the credit. Repayment becomes a problem when crops fail due to other reasons or when crop returns are low.
- › Reliance on mineral fertilizers cannot halt the continued degradation of African soils, because these fertilizers only address the mineral fraction of the soil and ignore, if used solely, the role and potential of soil organic matter



General assessment of local soil fertility status

Present the farmers with the two illustrated landscape scenarios – a degraded landscape and a well-managed landscape. To which situation does the local situation correspond more? What are the similarities between the two situations and what are the differences? Which qualities relate to the one situation, which to the other? Together with the farmers, assess the situation and define the factors that influence the situation.

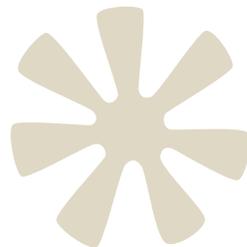


and the need to implement other soil conservation measures to maintain soil fertility.

3.6. Factors influencing soil fertility improvement in sub-Saharan Africa

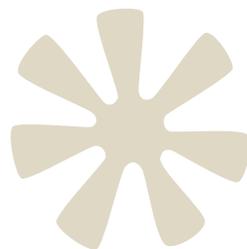
Creating long-term soil improvement can be challenging due to the following circumstances:

- › **Cultural beliefs and remains of early extension.** The way land or soil is managed in many areas in Africa is deeply embedded in the cultural beliefs. Some common practices that are generally not good for soil fertility include cutting of trees, burning of bush and crop residues, and deep ploughing of the entire field. Some practices were brought through early extension messages and are not cultural beliefs per se. For example, long back extension used to recommend a clean field without any trees yet the farmers had been practicing some form of agroforestry where they used to leave some trees uncut. Or, cutting and burning of certain crop residues like cotton and tobacco is regulatory in some African countries as a preventive measure for pests and disease.
- › **Migratory communities.** With ever moving communities such as pastoralists and shifting cultivators, soil protection becomes very challenging. Communities move to new areas, cut all trees and burn bushes to grow crops or graze animals for 2 to 4 seasons. When the soil becomes less productive, the community moves to a new area. Since these communities do not stay in a given area for a long time, there is little incentive to undertake soil conservation measures.
- › **Land tenure systems.** Most farmers do not own the land on which they are farming; it is either customarily owned or rented land. Such tenure systems, which do not provide security to the farmer, are major obstacles to soil conservation. Farmers in such situations find no incentive to invest in soil conservation measures, especially if the lease is short term. In some cases, farmers are also not allowed to plant long-term crops including trees.
- › **Scarcity of organic materials.** During land preparation, potentially good mulching materials from slashed bushes, crop residues and weeds are instead burnt to clear the way for digging or ploughing. Farmers have numer-



ous other uses for crop residues such as fodder for animals, roofing, fencing or fuel for cooking or using the ashes for soap production. Sometimes, even cow dung is dried and used as fuel for cooking meals. Such competition for organic materials for the various household needs limits availability of these materials for soil conservation needs. Scarcity of organic material is more pronounced in dry climates.

- › **Fuel needs.** Most households in Africa use and produce firewood or charcoal for their fuel and income needs. As a result, many forests and individual trees have been cut, rendering the land susceptible to degradation.
- › **High population densities.** Growing population is causing land use intensity, which is increasingly putting pressure on marginal land such as forests, wetlands and steep slopes as well as challenges related to land fragmentation. Such circumstances render soil improvement very difficult.
- › **Climate change.** High temperatures and water scarcity alternating with high inter-annual variability and erratic rain distribution in space and time, cause severe drought and flooding in some areas. This will lead to a reduction in the area suited for intensive agriculture. Lack of water also limits crop growth and unpredictable rains make timely sowing and successful establishment of crops difficult. Increase in soil temperature aside having negative effect on crop growth accelerate soil degradation processes and patterns. Together, these harsh climatic factors, coupled with poor soil management, have reduced soil fertility by contributing to erosion and to general soil and water degradation.
- › **Inadequate use of synthetic fertilizers.** Farmers have neither access to nor can they afford the fertilizers due to high prices as a result of the removal of subsidies, transaction costs, poor infrastructure, poor market development and inadequate access to credit facilities. The use of inorganic fertilizer in Africa is also limited by inherent low conversion efficiency due to lack or excess supply of water, soil compaction, inappropriate application, and low soil organic matter content of the soils. Phosphorus fertilizers are often poorly available, as they are easily fixed in some soils. Sole reliance on inorganic fertilizers cannot sustain the productivity of soil since it has very little effect on soil structure, resistance to erosion, moisture retention and biological activity.
- › **Low availability of organic soil amendments and fertilizers.** Application of organic sources of nutrients such as manure, compost and others not only provides some nutrients to the present and the following crops, but also





THREE STEP APPROACH TO SOIL FERTILITY MANAGEMENT



improves the physical, chemical and biological quality of the soils. On most farms availability of animal manures or organic materials for compost production are low and access to organic soil amendments and fertilizers from surrounding farms or nearby industrial production is very limited. Better availability and integrated use of farm-own and affordable foreign organic and mineral fertilizers may significantly contribute to higher productivity and resilience of farms.

4. Organic agriculture approach to soil fertility management

Intensively managed farming systems require good soil fertility management to ensure long term sustainability of own food production. That is why proper soil fertility management is of central importance in organic crop production and farming. Basically organic farmers approach soil fertility management by conserving and protecting their soils from sun, rain and wind, and feeding it with organic material in an appropriate way, so as to allow it to feed the plants in a balanced way. When the soil is fertile in the organic sense, it can produce good crop yields for several years.

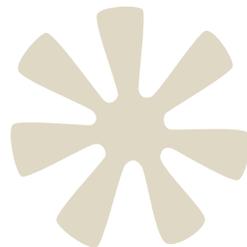
4.1. The three-step approach

Organic soil fertility management can be seen as a three-step approach with a range of tools to manage soil fertility and plant nutrition.

Step 1 – The first step consists of conserving the soil, soil organic matter and soil water from loss. Applied measures aim at protecting the soil surface from being exposed to the sun and drying out, and from being carried away by wind or washed down by rain. The aim is to establish a stable and less vulnerable soil as the foundation to managing its fertility.

Step 2 – The second step consists of improving organic matter content and enhancing biological activity in the soil. The aim here is to identify appropriate organic resources that can build an active soil with good structure which can hold water and supply plant nutrients.

Step 3 – The third step consists of supplementing the nutrient requirements as well as improving the growing conditions by applying some soil amendments.





ORGANIC SOIL FERTILITY MANAGEMENT TOOLBOX

The soil fertility management tools



Each step of the three-step approach builds the foundation for the next one. The aim is to optimize steps 1 and 2 that encourage natural rejuvenation of the soil and to minimize application of foreign fertilizers, soil amendments and irrigation water (step 3). Proper and efficient application of steps 1 and 2 saves on costs for fertilizers and other supplements and prevents possible negative impacts on the farm ecosystem.

4.2. Tools for organic soil fertility management – The organic soil fertility management toolbox

1st step: Soil and water conservation

The first step practices aim at protecting precious soil and water from being lost. This provides a good foundation for building fertile soil. Soil conservation can be achieved through the following practices:

- › Preventing soil erosion by reducing the movement of water with contour ridges and bunds, grass strips and terraces, and application of mulch to the soil surface.
- › Protecting the soil with mulch and cover crops.
- › Harvesting water with pits and water catchments.
- › Application of reduced tillage to minimize soil disturbance.

2nd step: Improvement of soil organic matter

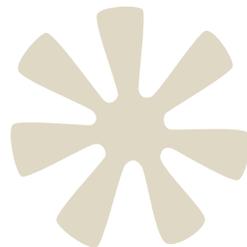
These practices aim at enhancing the organic matter content of the soil as the basis of soil fertility and for efficient management of plant nutrients and water. The practices related to it include:

- › Producing own compost or supplying compost or other organic materials from outside the farm supplies stable humus substances to the soil and thus improves its structure and water holding capacity contributing to improvement of soil organic matter content on a long term.
- › Growing green manures to produce large quantities of fresh plant material, which are incorporated into the soil, feed the soil organisms and mineralize rapidly to provide nutrients to the crop that follows.
- › Recycling of valuable animal manures for composting or fertilization of the crops.



Discussion on the value of soil conservation practices

Discuss with the farmers the sense of the proposed approach. Do any farmers have experience with soil conservation practices? Did the measures prove valuable in limiting soil erosion? Discuss advantages and possible difficulties related to the practices.



Soil fertility is best improved through combined implementation of the different practices. One practice alone may not be sufficient to maintain or even improve fertility of soils.

3rd step: Soil fertility supplements

In situations of heavy nutrient depletion or unfavourable growing conditions such as extreme pH levels, there can be a great shortage of macro- and micro-nutrients. Specific measures may be necessary to speed up improvement of the growing conditions for plants. These supplementary measures include:

- > Use of self-made liquid manures that are easily available to plants.
- > Use of soil amendments such as lime to correct soil pH and microbial inoculations to enhance biological activity of the soil and nitrogen fixation in the soil.
- > Use of irrigation to supplement water requirements.
- > Use of commercial organic and selected mineral fertilizers to satisfy specific nutrient needs.

Understandably, the tools of the third step will only be fully effective, when tools of the other two steps are properly applied, for example where valuable top-soil is lost because of poor erosion control, soil amendments will get lost as well.

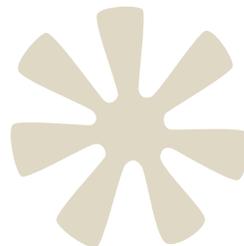
There is a general debate on the potential of soil fertility management in Africa based on farm-own or organic resources. Modern integrated soil fertility management advocates the use of synthetic mineral fertilizers in addition to organic resources to add nutrients that have been removed with harvested products or lost from the farm ecosystem. This approach is based on the perception that the farm cannot provide sufficient nutrients from biological fixation of air nitrogen, biomass production and transport of nutrients from lower soil layers to the soil surface to produce economic yields and build up reasonable soil fertility.

Organic soil fertility management, in contrary, principally relies on natural sources and biological processes only and seeks for a long-term improvement of soil fertility based on optimization of farm-own nutrient management. In some conditions though, it may be necessary to supply organic materials from outside the farm to build up soil fertility and produce reasonable harvests in a short time. In certified organic agriculture mineral fertilizers shall be used as a supplement to biologically-based fertility methods only. Their use shall be justified by appropriate soil and leaf analysis. In certified organic agriculture only naturally



Field assessment of soil and water conservation

Divide the farmers into small groups and send them to different fields to assess soil conservation measures being practiced in the area assessing to what extent measures are undertaken to keep the soil covered, to reduce the movement of water and to hold the soil together. Share and discuss the findings in the plenary session.





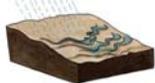
SPLASH, SHEET, RILL AND GULLY EROSION

Common forms of erosion

Splash erosion



Sheet erosion



Rill erosion



Gully erosion



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occurring mineral fertilizers are allowed. Chilean nitrate and all synthetic fertilizers, including urea, are prohibited.

5. Soil and water conservation

Rainfall is becoming more unreliable and yet most farmers in Africa highly depend on it to grow crops and raise animals. Unexpected droughts are experienced everywhere, leading to reduced or no yields at all in some cases. Sometimes when the rain comes, it is quite heavy and washes away the soil, destroys plants and causes floods or landslides. The extent of damage is usually greater on croplands along hilly slopes. Depending on the extent of damage, the productivity of the land is instantly or gradually reduced, because either all or part of the topsoil that is rich in organic matter and nutrients is lost to the lowlands, leaving behind the less productive part of the soil.

The implication of such scenarios is that farmers need to protect the entire landscape in order to protect the soil and conserve water needed for sustainable production of crops and animals. Whereas flat and well-drained land is good for farming, sloping lands can only be used under proper soil conservation. Steeper lands should not be used for growing annual crops, but kept under grass, perennial tree crops or put under controlled grazing. Very steep land with shallow soil should rather be left in its natural state and also as home for wildlife.

The two main aims of soil conservation on cultivated lands are, therefore, (i) to maintain the soil covered with dead plant materials or living plants or trees as much as possible to hold the soil and break the wind force, and (ii) to reduce the movement of surface water, encourage water infiltration and storage in the soil. Soil conservation is achieved by controlling soil erosion (the extent of soil and organic matter loss) and regulating tillage practices. Proper soil conservation is the foundation for effective organic production of crops and animals.

5.1. Soil erosion control

5.1.1. What is soil erosion?

Soil erosion is the physical movement of soil particles and organic matter from a given site by the action of raindrops, runoff or wind. Soil erosion accounts for



Field assessment of soil erosion

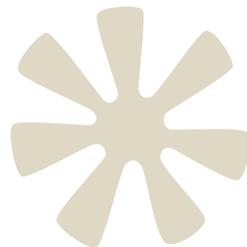
Inspect together with the farmers local fields located on slopes. Can any splash, sheet, rill or gully erosion be observed? Ask the farmers what their observations are during strong rains. Does the soil take up rainwater easily or does most of the water runoff? What do their soils look like after strong rains?

Ask the farmers, which possibilities they see to stop the process of erosion.



Demonstration

If available, pour some water over a heap of ripe compost. What can be observed? Do the crumbs stay stable? Does water run in easily?



about 80 per cent of land degradation in Africa.

How to recognise soil erosion: First signs of the soil's disposition to erosion are recognized by the separation of soil particles that often have a different colour. The extent of soil erosion will advance from sheet erosion (uniform removal of a thin layer of topsoil), rill erosion (small channels formed in the field) to a more destructive stage, gully erosion (large channels formed in the field). Exposed root systems of plants are also a sign of erosion.

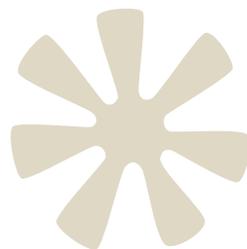
Loss of soil organic matter from upper soil layers destroys the physical properties of the soil, its structure, aeration, water-holding capacity and biological activity, and involves loss of soil nutrients, which leads to nutrient deficiencies and poor plant growth. The amount of erosion on a farm land depends on the slope of land, nature of plant or vegetation cover, land use, erodibility (the estimate of the ability of the land to resist erosion), erosivity of eroding agent (i.e. the ability of wind or water to cause erosion).

- (i) Slope of land: Naturally, the steeper the slope of a field, the greater the amount of soil loss from erosion by water.
- (ii) Vegetation: Soil erosion potential is increased if the soil has no or very little vegetative cover of plants and/or crop residues. Plant and residue cover protects the soil from raindrop impact and splash, tends to slow down the movement of surface runoff and allows excess surface water to infiltrate.
- (iii) Land use: Certain land management and cropping practices (tillage, strip cropping, terracing) can directly affect the overall soil erosion problem and solutions on a farm.
- (iv) Soil erodibility: Soil erodibility is an estimate of the ability of soils to resist erosion, based on the physical characteristics of each soil. Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion. Sandy loam and loam textured soils tend to be less erodible than silt and certain clay textured soils.

5.1.2. Causes of soil erosion

Soil erosion occurs naturally. Human intervention can, however, accelerate these natural processes, for example, through:

- i. Overgrazing of rangelands that reduces plant cover, exposing the soil surface to rain and animal stamping impacts, which in turn loosens the topsoil making it susceptible to erosion. As the stocking rates increase and new animal species such as sheep and goats are introduced, the grazing land will eventu-





POSSIBILITIES OF COVERING THE SOIL

Different possibilities of covering the soil



Covering the land with a cover crop



Covering the land with mulch



Covering the land with crop residues



Growing crops in a multistorey system



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ally be cleaned to bare ground.

- ii. Over cultivation of cropland resulting in exhaustion of soil organic matter, destroys soil structure and makes soils very susceptible to erosion.
- iii. Utilisation of erosion susceptible areas without any soil conserving measures such as terracing, automatically results in soil erosion.
- iv. Continued destruction of forests in search of firewood, material for charcoal production and new cultivable land leads to soil erosion, floods and landslides, and reduces storage of rainwater in the soil and modifies the availability of water in water bodies and groundwater.

How erosion affects agriculture:

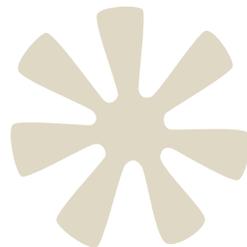
- i. Decrease in agricultural productivity:- Loss of the nutrient rich and biologically active upper soil layers results in loss or decrease of productivity of the soil.
- ii. In high rainfall areas part of the water which cannot be retained percolates to a deeper level or ground water and leach nutrients out of reach of the plant roots in the process.

5.1.3. How to control soil erosion

Irrespective of the extent of damage by soil erosion, land and soil can still be rehabilitated. If the topsoil is lost and erosion is severe, it will take much effort and considerable time to rehabilitate the land. Usually it takes the commitment of the entire community in order to improve the situation. However, even at the individual household level, there are many measures a farmer can establish to control soil erosion. These measures will at the same time control erosion and conserve soil moisture.

5.1.3.1. Covering the soil

The easiest way to protect the soil from being eroded by water or wind is to keep it covered by a plant or mulch cover as much as possible. The soil can be covered with living plants (cover crops), especially within perennial crops, or dead mulching material. Erosion due to rains is more a problem in annual crops where the land is regularly tilled for planting and when soil preparation coincides with rainfall. To avoid erosion during this period, the soil is best covered with residues from the previous crop and other dry plant material, and soil cultivation is reduced by tilling strips only.





COVER CROPS

Cover crops for erosion control

| Species | Characteristics | Additional/alternative uses | Integration into the farm |
|--|---|---|---|
| Wild groundnut (<i>Arachis pinto</i>) | <ul style="list-style-type: none"> Grows well in humid climates; tolerates waterlogging, and survives dry seasons of 4 months Low-growing, but excellent weed control once established Tolerates low grazing | <ul style="list-style-type: none"> Forage: pasture crop for grazing; combines well with competitive sward grasses | <ul style="list-style-type: none"> Ground cover under tree crops like avocados, bananas, cassava, cocoa, coffee, citrus, mango or pineapples Permanent pasture for extensive grazing systems |
| Stylo (<i>Dolichosbiflorus guianensis</i>) | <ul style="list-style-type: none"> Herbaceous perennial legume Grows in humid climates, but can survive long dry periods Grows 20 to 120 cm high Has a low P requirement | <ul style="list-style-type: none"> Forage: pastures, cut-and-carry forage systems or production of conserved feed; combination with grasses possible | <ul style="list-style-type: none"> Used primarily as a pasture legume Cover crop in plantation and orchard crops Fallow crop |
| Siratro (<i>Macroptilium atropurpureum</i>) | <ul style="list-style-type: none"> Perennial hairy legume Grows in humid climates, but persists well under dry conditions High P requirement | <ul style="list-style-type: none"> Forage: can be grazed, but not heavily; combines with tall grasses | <ul style="list-style-type: none"> Pasture legume Cover crop in plantations Fallow crop |
| Cowbirds (e.g. <i>Vatairea</i>) | <ul style="list-style-type: none"> Climbing No nitrogen fixation | <ul style="list-style-type: none"> Food: Marketable flowers and fruits | <ul style="list-style-type: none"> Intercropping with cereal crops Rotation with veget. and root crops |
| Grasses (e.g. Elephant grass or Tropic Lili <i>Pennisetum</i>) | <ul style="list-style-type: none"> Low or medium high growing, stoloniferous perennial grasses No nitrogen fixation Combines well with leguminous forage plants | <ul style="list-style-type: none"> Forage: pastures, cut-and-carry forage systems or prod. of conserved feed | <ul style="list-style-type: none"> Soil cover in permanent crops Full ground cover as permanent grazing pasture or for fodder prod. Allely cropping with fodder legumes such as <i>Lucerna</i> sp and <i>Sebania</i> sp. |

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a. Growing cover crops

Cover crops are usually low-growing perennial plant species, which are sown with the main intention to protect the soil, prevent weed growth and maintain soil fertility. They are also called 'green' or 'living mulch'. Cover crops are used in a similar way as green manures with the main difference that green manures are grown to produce maximum biomass mainly and are usually slashed before flowering and incorporated into the soil. Cover crops may also require regular slashing, mowing or grazing to avoid competition with the main crop.

Some information sources do not distinguish between cover crops and green manures, as both can include the same species, and differences are little depending on their management. But it makes sense to approach them separately due to the different functions they can have in a cropping system.

The primary strength of cover crops is to rapidly cover the soil and to maintain it permanently covered. Cover crops benefit both short and long term productivity of a cropping system. They improve physical properties of the soil, reduce runoff and erosion, suppress weeds and, if the cover crop is a legume, transfer nitrogen to the main crop, when mulched. Soil organic matter levels are usually maintained under a cover crop from a combination of increased input of residues, reduced soil organic matter decomposition due to reduced exposure as a result of reduced or zero tillage, and decrease of soil temperature.

The benefits of cover crops can be limited by the competition of the cover crop for water and nutrients and the very slight increase of soil organic matter level. Slashing, mowing or selective cultivation temporarily reduce competition from the cover crop. While leguminous cover crops supply some nitrogen to the main crop, pure grass-based cover crops require nitrogen for proper growth.

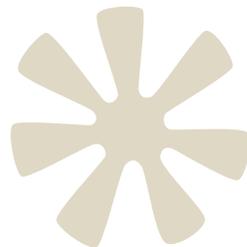
The following characteristics make an ideal cover crop:

- > It is low-growing and not climbing;
- > It grows fast and covers the soil in a short time;
- > It is resistant against pests and diseases, and does not transmit any to the main crops;
- > It tolerates drought;
- > It fixes nitrogen from the air;
- > It develops a deep root system which is able to loosen the soil and contribute to regeneration of degraded soils;
- > It is easy to sow and to manage, and can be slashed, grazed or cut for fodder;



Sharing knowledge on locally grown cover crops

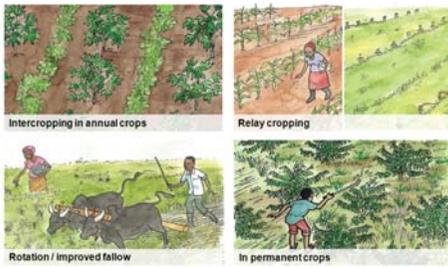
Ask the farmers what plants they know that are grown as cover crops. Why are these plants grown? What are their characteristics?





INTEGRATION OF COVER CROPS

Possibilities of growing cover crops

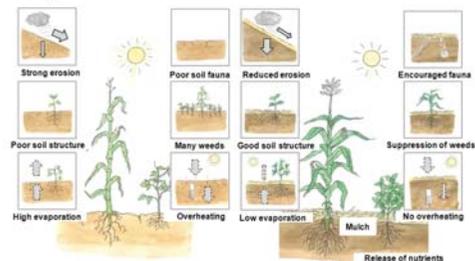


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ADVANTAGES OF MULCHING

Why use mulch?



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- > The seeds are cheap, easy to purchase or can be easily reproduced on the farm.

The residues of cover crops are usually not harvested, but are left to decompose in place. This explains, why they are also called living mulch. Some cover crops can be grazed, provide food or can be used to produce forage. Growing a cover crop limits possibilities of soil tillage. Therefore cover crops are usually grown in cropping systems, which include reduced tillage.

Cover crops can be grouped into legumes, grasses, and other groups such as cucurbits, which also cover the soil well. For a permanent soil cover, a mixture of legumes and grasses is best, as their root systems usually complement each other well in their growing depths and together they provide a balanced source of feed for livestock.

How to integrate cover crops

Cover crops can be planted in different ways depending on the site conditions, the main crop and intended benefits:

- > **Intercropping.** The cover crop is planted at the same time as the main crop. In this case, the main crop should be one that grows high like maize to avoid being smothered by the cover crop. Creeping cover crops like mucuna should be avoided, because they will also smother the main crop. Intercropping is preferable in perennial crops.
- > **Relay cropping.** The cover crop is planted in an advanced growth stage of the main crop. For example, in a maize-bean intercrop the cover crop can be planted after beans are harvested. Here the farmer is able to harvest more crops and the risk of competition is greatly reduced. The cover crop is then left to continue growing, protecting the soil and smothering weeds.
- > **Crop rotation and improved fallows.** In this case, the cover crop is planted after the harvest of the main crop. If the soil has enough moisture, this can be done immediately after harvesting or it can be done as part of the main crop rotation cycle or incorporated during the fallow season.

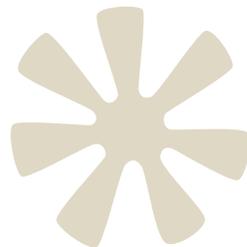
To reduce the risk of damage by pests and diseases, different species of cover crops can be grown on different fields. If planted together with food crops, cover crops should also be rotated to avoid build-up of pests and diseases.

Recommended practices for sowing cover crops vary depending on the crop-



Integration of cover crops

Ask the farmers to select a main crop in the region and to draft an agricultural calendar on a paper chart in which they mark the typical agricultural activities related to the crop, such as digging, planting, weeding, harvesting, sowing a second crop, etc. Ask them to indicate the dry and rainy seasons, and the periods when the soils are most affected by soil erosion. The availability of farm labour should also be taken into account. Based on this calendar, the farmers shall discuss options of how to adapt the cropping pattern in order to avoid soil erosion. The proposed alterations can be marked in the calendar, e.g. with a different colour.





APPLICATION OF MULCH

How to apply mulch



When applying mulch:

- > Apply before the rainy season.
- > Not a too thick layer.
- > Apply in rows or around single plants avoiding direct contact with the plant stems.
- > Or evenly spread the mulch on the field.



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ping system, seed size and climate. Small seeds are either broadcasted or sown in lines by hand or with a seed drill. Large seeds are best sown using a hand hoe or an animal drawn direct planter. In pure stands narrower spacing is recommended, while in intercropped cover crops and in dry climates, a wider spacing reduces competition with the main crop. In general, 2 to 4 seeds are planted per hole. Most cover crops will need at least one weeding during early stage of growth.

b. Mulching

Mulching is the process of covering the topsoil with plant material such as leaves, grass, twigs, crop residues or straw. Sometimes artificial mulches, such as plastic cover, are used (for weed control mainly; they do not provide the same advantages as organic mulch). Mulching has many advantages, including protecting the topsoil from being washed away by strong rain and from drying out by the sun. Protection reduces evaporation of water and thus keeps the soil humid. As a result the plants need less irrigation or can use the available rain more efficiently. A humid soil also enhances the activity of soil organisms such as earthworms, and microorganisms as rhizobia and mycorrhiza.

Organic mulch material is an excellent food source for soil organisms and provides suitable conditions for their growth. As the mulch material decomposes, it also releases its nutrients, while part of the mulch material is transformed to stable humus, contributing positively to the soil's organic matter content. A thick mulch layer further suppresses weed growth by inhibiting their germination. For all these reasons mulching plays a crucial role in preventing soil erosion.

Application of mulching materials

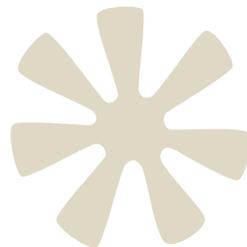
Sources of mulching material include weeds or cover crops, crop residues, grass, pruning material from trees, cuttings from hedges and wastes from agricultural processing or from forestry. Fast growing nitrogen-fixing shrubs that tolerate strong trimming provide good and considerable amounts of mulching material. The shrubs can be grown in hedgerows.

The kind of material used for mulching greatly influences its effect. In humid climates green material will decompose rapidly making nutrients available nutrients to the crops during the process. Soil protection is then limited to 1 to 3 months. In this case application can be repeated. Hardy materials such as straw or stalks in contrary will decompose more slowly and therefore cover the soil for a longer time. Where soil erosion is a problem, slowly decomposing mulch mate-



Evaluating possibilities of covering the soil

Discuss with the farmers possibilities of covering the soil to protect it. What materials are available for mulching? What plants may be grown to cover the soil? Which approaches to cover the soil may be most advantageous? Do any of the farmers practice one or the other method?





TRASH LINES

How to build trash lines



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rial (with low nitrogen content and a high carbon to nitrogen ratio) will provide long-term protection compared to quickly decomposing material.

When carbon rich materials are used for mulching, nitrogen from the soil may be used by microorganisms for decomposing the material (a process called immobilization). During this time, the microbes compete with the plants for nitrogen and the crop may suffer from malnutrition. To avoid nitrogen immobilisation, old or rough plant materials should be applied to the soil at least two months before planting or sowing the main crop. The decomposition of the mulch material can be accelerated by spreading organic manure such as animal dung on top of the mulch, thus increasing the nitrogen content.

In arid climates mulch material may be scarce and production or collection usually involves a considerable amount of labour and thus may compete with labour for the production of crops and of household activities. Especially in such climates, however, application of mulches is worthwhile.

In specific situations organisms such as slugs, snails, ants or termites can proliferate too much in the moist and protected conditions of the mulch layer and may cause damage to the crops. Damaging organisms such as stemborers may survive in the stalks of crops like cotton, corn or sugar cane. In such situations mulching materials must be carefully selected to avoid any disadvantages, or farmers renounce to protection of the soil with mulch and apply other methods for soil protection. As a general rule plant material infected with viral or fungal diseases should not be used if there is a risk that the disease might spread to the next crop. Proper crop rotation is very important to overcome these risks.

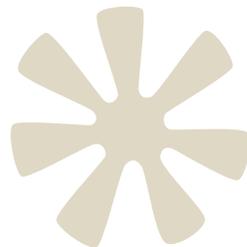
If possible, the mulch should be applied before or at the onset of the rainy season, as then the soil is most vulnerable. If mulch is applied prior to sowing or planting, the mulch layer should not be too thick in order to allow seedlings to penetrate it. If the layer of mulch is not too thick, seeds or seedlings can be directly sown or planted in between the mulching material. Mulch can also be applied in established crops, best directly after digging the soil. It can be applied between the rows, directly around single plants (especially for tree crops) or evenly spread on the field. On vegetable plots it is best to apply mulch only after the young plants have become somewhat hardier, as they may be harmed by the products of decomposition from fresh mulch material.

In humid climates loose, bulky materials such as twigs are usually more appropriate for mulching, as they ensure adequate ventilation. Materials should not be too bulky though to prevent damage on crops or being blown away. If



Practical exercise of making and using an A-frame

Divide the farmers into groups of four. Show them how to make and use an A-frame and then give them the opportunity to construct an A-frame themselves, and to use it in the field.





CONTOUR BUNDS

How to build contour bunds with catchment strips

A method for dry climates and depleted hill sides



1. Heap up soil along the contour lines.

2. Sow mixed crops in strips above the contour bunds into mulch.



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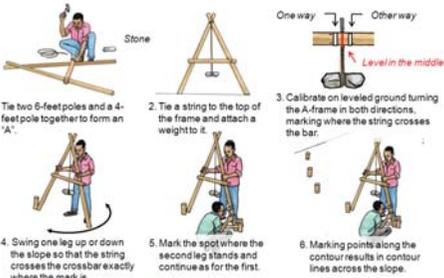
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A-FRAME

How to make and use the A-frame



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mulch material is introduced into a field, attention must be paid to not to introduce any unwanted seeds.

The ideal strategy for mulch application finally depends on local conditions and the crops that are grown. Whether mulch is best applied before or after planting, in strips along the rows or evenly over the entire surface, in a thick or a thin layer, must be found out through testing over several seasons.

5.1.3.2. Reducing movement of water

a. Building contour bunds and digging ridges

An effective measure to limit above soil movement of water is digging ridges along the contour lines of a slope. Or natural drain ways are identified and planted with grass to allow storm water to move smoothly over the fields without breaking into gullies. Waterways need dense vigorous vegetation and water should be directed with diversions. Ditches may be dug along the contour to trap the running water and encourage infiltration into the soil. Contouring is often combined with strip cropping furrows between the contour ridges, in which strips of a crop such as maize alternate on the side of the hill with strips of denser vegetation like legumes. Much of the soil washed downhill from each strip of row crops is trapped by the strip of denser vegetation growing below it. Laying trash lines of stalks and other crop residues, instead of the dense vegetation, is also helpful.

The A-frame is a simple, cheap and easy-to-construct tool for marking contour lines along a slope, making it readily accessible to African farmers. The A-frame is made from three poles, some rope, a stone and a supply of stakes.

How to build and use an A-frame:

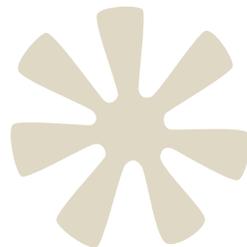
1. Fix three poles of about 2.5 meters long each in a position forming an even 'A'. If rope is not sufficient to tie the ends, use nails.
2. Tie one end of a piece of cord to the top of the A and fix a stone tied to the other end so that the stone is at some distance from both the ground and the crossbar.
3. Put the A-frame upright and mark the position of both legs. Then, mark the point where the string passes the crossbar of the A.
4. Turn the A-frame so that the placement of the legs is reversed. Again mark the point where the string passes the crossbar. If the two marks are not at the same point, mark a third point with a knife exactly halfway between the first two.



Discussion:

Ask the farmers

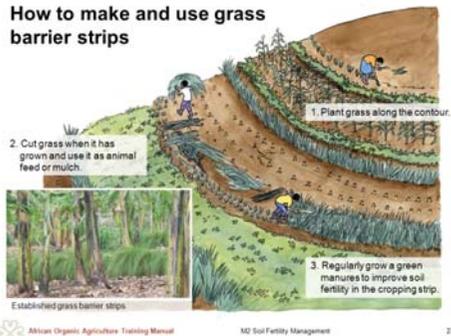
which grass species are known to grow well in local conditions. Has any farmer collected any experiences with growing grass in strips along the contours of a slope? Which recommendations can be given to the other farmers?





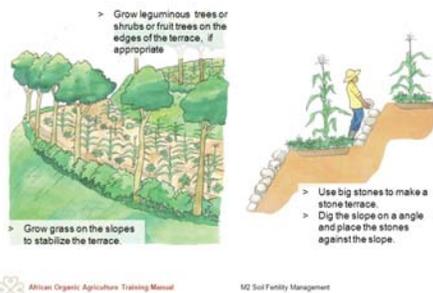
GRASS BARRIER STRIPS

How to make and use grass barrier strips



BENCH TERRACES AND STONE LINES

Building a bench and a stone terrace



5. Drive the first stake at the edge at the top of the field. Place one leg of the A-frame above and touching the stake. Place the other leg in such a position that the string passes the level position point on the crossbar.
6. Drive another stake into the ground just below the second leg. Move the A-frame and continue in the same way across the field.
7. The next contour line is placed 3 to 6 meters below the first line. The steeper the slope, the closer the lines should be.

b. Placing grass strips

Fodder grasses such as vetiver grass (*Vetiver zizanioides*), napier grass (*Pennisetum purpureum*) and guinea grass (*Panicum maximum*), Bahia grass (*Paspalum notatum*) can be planted in strips at intervals across the slope to slow down runoff of water. In addition to reducing soil erosion, the grasses provide feed for the animals. The grass strips can be mixed or replaced with a hedge row of leguminous fodder trees such as *Leucaena diversifolia*, *Calliandra calothyrsus*, *Sesbania sesban*, *Gliricidia sepium*.

c. Terracing

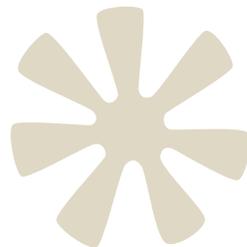
Mechanical measures for controlling erosion are usually more costly than those that depend primarily on vegetation. They require more labour, materials and skill to install. Terracing includes many different types of terraces, diversions and grade stabilization structures. Terraces break up a long slope into a series of short ones. Each terrace collects and controls the excess water from a definite area of the slope above it. Water collected in a terrace channel may be connected to protected outlets such as man-made ponds or natural water ways where it will cause no damage. If the soil in the field is permeable enough, terraces may be built level and water allowed to stand and soak into the ground. Even well-constructed terraces need continuous repair in order to be effective. Unless kept in good condition, terraces may cause more erosion than if they were not built.

Bench terraces. They are found on medium slopes and transform the steep slope into a series of level shelves or beds running across the slope on which crops are grown. The steps are separated by almost vertical risers (walls or bunds) of rock or earth protected by a heavy growth of vegetation. The risers need to be kept covered with grass and continuously repaired to maintain their stability. Although bench terraces take a lot of labor and time to construct, they can last a long time if well maintained.



Discussion in the field on constructions against soil erosion

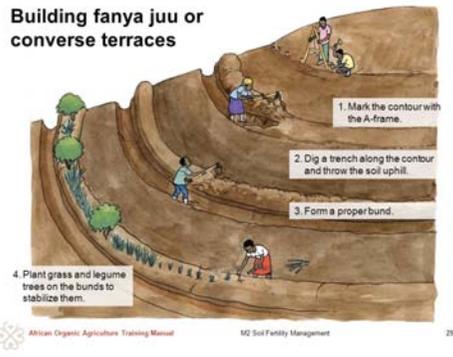
Take the farmers to a site that is affected by soil erosion. Discuss with them possibilities of stopping soil degradation. What suggestions do they make for the site and why?





CONVERSE TERRACES

Building fanya juu or converse terraces



PLANTING PITS

Digging planting pits



Stone lines. Use of stone lines is most applicable when stones are easily accessible in the area. Here stones are piled across the slope, breaking it into small sections where crops are grown. They slow down runoff and soil eventually builds up behind them, forming nearly leveled beds.

Fanya juu (Converse) terraces. Fanya juu ('throw it upwards' in Kiswahili) terraces are made by digging trenches along the contours and throwing the soil uphill to form embankments (bunds), which are stabilized with fodder grass such as Napier (*Pennisetum purpureum*) and multipurpose agroforestry trees. The space between the embankments is cultivated with crops and over time, the fanya juu develop into bench terraces. They are useful in semi-arid areas to harvest and conserve water.

d. Conserving vegetation

Plant roots hold soil particles together and protect the soil from being washed away by water or wind. Land that is covered with vegetation is less susceptible to erosion than unplanted land. This can be achieved by maintaining natural grass cover in perennial crops or by growing a cover crop. On the other hand, very steep slopes should be planted with trees instead of cultivating them for crops.

Growing trees in rows (alley cropping) and hedges in the fields or around the fields will reduce wind speed. They also create a micro-climate, which reduces evaporation and protects the soil and crops from the drying effects of wind. When trees are planted in rows in the field, they often compete with the crops for water, and in drier areas, this will reduce the yields of the field crops. In such areas, planting hedgerows is recommended or if planted with crops, they should be heavily pruned at the beginning of the growing season of the field crop to reduce competition. During the dry season the trees will have grown again and be able to shade the soil.

5.2. Water harvesting

Water harvesting, water saving and soil moisture conservation strategies have highest priority in semi-arid and arid regions. As water is the limiting factor for crop yields, every drop of rain or irrigation water should be retained in the field. Sufficient soil water supply requires proper water harvesting of the available rainfall and reduction of runoff, and soil management strategies to increase wa-



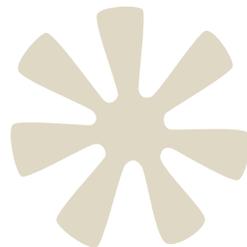
Discussion: Water harvesting

Ask the farmers, how they harvest water in the area. Do they practice any measures to ensure maximum harvesting of rainwater?



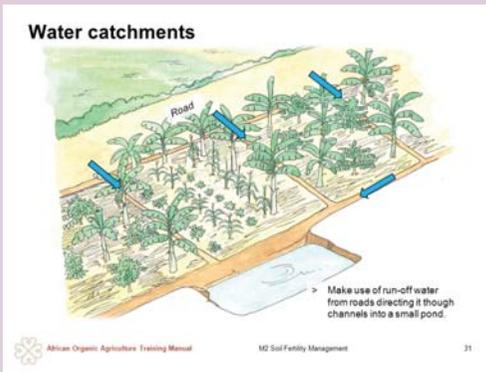
Demonstration: Comparing soil profiles

Take the farmers to an undisturbed forest soil (or to a soil that has been cultivated with little disturbance for several years) and to a regularly tilled field. At both sites, dig a soil profile. Then discuss with the farmers the qualities of both soils. Which layers are visible? Which colours do the layers have? How is soil structure? Is there a compaction layer? Which soil looks more active and fertile?





WATER CATCHMENTS



ter infiltration, holding capacity and decrease evaporation through mulching and minimum tillage. Even where irrigation water is available, water application should be kept to an absolute minimum in order to avoid problems of salinity and over-exploitation of ground water.

Organic farmers seek to optimize the use of on-farm resources for water management improving their soils and designing farming systems in a way to capture water and store it for later use. The following measures have been used successfully in many areas:

Planting or water-retaining pits. Water retaining pits (also known as Zai in Burkina Faso and as tassa in Niger) are hand-dug circular holes along planting rows which collect and store water. The soil from the pits is used to make banks around the pits. The size of the pit depends on the amount of runoff. Manure or compost may be added in the pit before planting in the pits. After planting, the pits are not completely covered to allow more collection of water. The pits can be used season after season while improving soil fertility with application of manure or compost.

Water catchments. Water from roads and homestead compounds can be channeled into the farmland via field ditches or a water pond. From here the water can be slowly diverted into the field or used for irrigation.

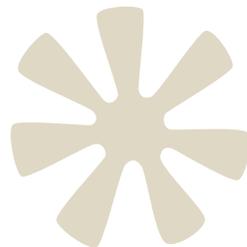
5.3. Minimizing soil disturbance

Farmers till land for various reasons: to loosen the soil and prepare a seed bed to encourage seed germination, control weeds or incorporate manure and plant material into the soil. Turning the entire surface area of the field that is to be planted is common in many African countries. General ploughing, discing and harrowing are encouraged by the introduction of tractors. But also ridging using a hoe involves disturbance of the entire surface. These soil cultivation systems leave bare soil exposing it to erosion and water loss through evaporation, result in capping of the soil surface, accelerate decomposition of soil organic matter and contribute to destruction of soil structure. Repeated working depth and cultivation of soil in humid condition bears the risk of soil compaction and creation of a hardpan at the working depth. Mixing of soil layers can also severely harm certain soil organisms such as earthworms.



Discussion on local tillage practices

Ask the farmers how soil cultivation is commonly done locally. Do they use tractors, oxen or hand hoes? How often do they till the land, for what reasons and under what circumstances? Do farmers have to wait for the rains to till their land? Does tillage result in delayed planting? Does any farmer have experience with no-tilling or reduced tilling? Discuss with them the advantages and inconveniences of soil tillage.



Most farmers, who plough their land, must wait for the rains to cultivate the soil. In this case planting cannot happen as long as the land is not prepared. In many regions each day of delay in seeding after the first rains results in yield loss. Cultivation of the entire surface area of a field is labour, energy and time intensive. Preparing a field may take several days or weeks, requires strong draught power and much fuel if a tractor is used.

Traditional organic farming practices involve deep soil cultivation with inversion of the soil to allow incorporation of plant material and animal manure, and bury weeds. Increasing knowledge on the negative impacts of such a practice on soil organic matter, nutrient losses, soil biology, climate, use of energy and costs presently results in a basic change in the approach to soil cultivation with increasing adoption of practices, such as they are promoted by the approach of soil conservation farming.

Any soil cultivation activity has a more or less destructive impact on soil structure. But there are soil cultivation systems that minimize soil disturbance, maintain a protective cover on the soil surface and allow early land preparation before the rains. Such systems contribute to a good soil structure, reduce the risk of soil compaction, increase water infiltration and reduce runoff, reduce evaporation and thus improve water storage. When the soil is protected and stays undisturbed, the topsoil layer becomes a favourable habitat for plant roots, worms, insects and microorganisms such as fungi and bacteria. This soil life recycles the organic matter from the soil cover and transforms it into humus and nutrients, and thus contributes to fertile soil and plant nutrition. This process may also be called 'biological tillage'.

Reduced soil cultivation and maintenance of a soil cover, as they are recommended by the conservation farming approach, allow farmers to prepare their land after the harvest of the previous crop. Early land preparation allows planting at the onset of rains and early weeding. The soil conservation farming approach is very suitable to women, as labour for soil cultivation is reduced and can be done over a long period without loss of nutrients and precious time.

Soil cultivation should provide good growing conditions for seeds and seedlings, loosen the soil in a way to facilitate the penetration of the young plant roots, destroy or control weeds and soil pests, if necessary, and repair soil compaction caused by previous activities. Whether soil cultivation should serve incorporation of crop residues and manures into the soil or not, is a basic decision that needs to be taken in the local context.



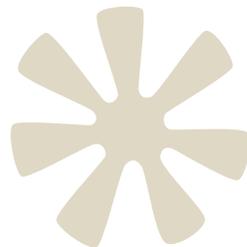
Field visit

If possible, take the farmers to a field that has been cultivated following conservation farming principles. Let the farmer of the field speak about his experiences. Which advantages does he or she observe? Which challenges does he or she face? Nearby there may be a conventionally managed field. Which differences are visible?



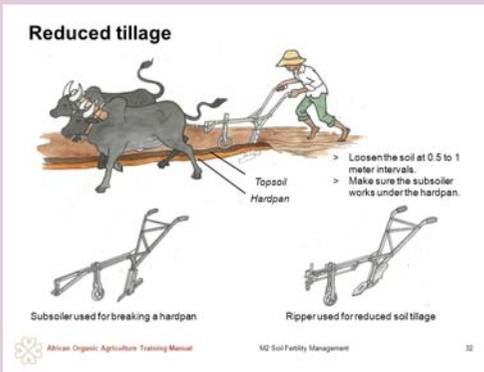
Discussion on zero-tillage

Do any farmers practice zero-tillage locally? What are their experiences? Which advantages and constraints are known? Are the soils suitable to zero-tillage? Is zero-tillage practiced without the use of herbicides?





TOOLS FOR REDUCED TILLAGE



To minimize the negative impacts of soil cultivation while benefiting from its advantages, farmers should aim on reducing the number of interventions to the minimum and choose methods that best conserve the natural qualities of the soil.

There is not just one right way to cultivate the soil. There is a range of options. Finding the most appropriate soil cultivation method depends on the crops that are grown, the cropping system, the soil type, climate, weed pressure and other factors. Thus, each farmer must assess the soil cultivation practice which is most suitable for his or her conditions minimizing the negative impacts of soil cultivation while benefiting from its advantages. Organic farmers should aim to keep the number of interventions to a minimum and choose methods that conserve the natural qualities of the soil. Adoption of reduced soil tillage by farmers, who fully rely on natural practices and avoid herbicides and chemical fertilizers, may require specific adaptations to prevent weed problems and ensure appropriate plant nutrition.

5.3.1. Zero-tillage or No-till systems

No-till systems work without any soil tillage and seeds are planted or drilled directly into the vegetation cover without any seedbed preparation. Crop residues are left on the soil surface. The vegetation cover and weeds are destroyed by slashing them manually or mechanically or using herbicides to avoid competition between the crop and the soil covering vegetation. In conventional farming, synthetic fertilizers are either broadcasted or applied during seeding. For seeding, usually a narrow slot only wide and deep enough to obtain proper seed coverage is made, while crop residues basically remain undisturbed on the soil surface.

Zero-tillage systems help to build-up a natural soil structure with crumbly topsoil rich in organic matter and full of soil organisms. Nutrient losses are reduced to a minimum as there is no sudden decomposition of organic matter and nutrients are caught by a dense network of plant roots. Soil erosion will not be a problem as long as there is permanent plant cover or sufficient input of organic material. Last but not least, farmers can save a lot of labour.

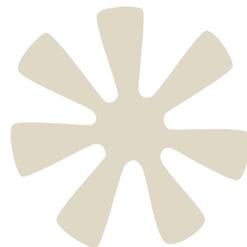
Zero-tillage requires soils with good drainage. Water-logged soils and soils with poor drainage are not suitable for zero-tillage, as the seeds and plant roots will rot in the soil. In compacted soils, sub-soiling deeper than the soil pan may be necessary to enhance drainage. Or deep rooting crops such as pigeon peas are grown in rotation to break pans before weaker rooting crops.



Sharing experiences on reduced tillage

Invite the farmers to share their experiences on reduced tillage asking the following questions:

- › Is equipment owned by individual farmers or is it shared within a group, or are the cultivation and planting services provided by an entrepreneur?
- › Has the equipment proved suitable for local soils and different farm situations?
- › Do the farmers use herbicides? If no, as it is required in certified organic production, how do they control weeds?
- › Do the farmers use mineral fertilizers? If no, as it is required in certified organic production, how do they insure nutrient supply to the crops?





IMPLEMENTATION OF REDUCED TILLAGE

Recultivation of land with old fallow



1. Slash the thick grass and weed mulch.



2. Sow velvet beans into the dry mulch.



3. Flatten the velvet stems with a beam.



4. Rip the land through the dry mulch cover before sowing the next regular crop.



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Successful zero-tillage depends on high biomass production to ensure a thick mulch cover. Proper crop rotation including leguminous green manure crops is essential to this system. Managing weed growth may be a challenge to organic farmers, who renounce the use of herbicides and rely on mechanical or natural methods for weed control only. Nevertheless, there is potential for introducing zero-tillage in organic farming.

In annual crops, for instance, zero-tillage can be applied easily when sowing a legume crop after a grain such as maize, wheat, sorghum or millet between the stalks.

Zero-tillage with living mulch is good mainly for perennial crops, for example coffee or banana, where competition by annual vegetation is limited and weeds can be controlled by regular slashing.

5.3.2. Reduced or minimum tillage systems

Reduced tillage is shallow soil tillage or loosening of the soil by a chisel without deep soil cultivation or making furrows or holes where seed is planted. Minimum tillage promotes build-up of organic matter in the soil, activity of soil organisms and contributes to more stable soil aggregates resulting in better water infiltration. Minimum tillage also implies reduced labour and about half as much energy and effort for land preparation. The greater the part of the soil surface that remains undisturbed and covered, the more positive the impact is. Ideally the seedbed is prepared only where the seeds are planted and the residues remain on the topsoil and are not buried.

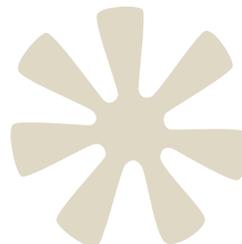
Minimum tillage involves techniques such as scraping out shallow planting holes with a hoe, planting with a dibble stick or digging narrow furrows with a chisel-shaped ripper pulled by animals or a tractor. The distance between the furrows results from recommended spacing for the crop. Compared to a conventional plough a ripper is smaller, lighter and easier to operate, and also cheaper to buy and maintain. As a ripper requires about half of the draught force of that of a plough, farmers can use weaker and smaller animals also. For making planting holes with a hoe a long string with knots or bottle tops indicating the planting distance and pegs are helpful.

Reduced or minimum tillage is well suited to many tropical soils, in which intensive tillage leads to rapid breakdown of the soil structure and loss of water and organic matter. However, the adoption of reduced tillage also involves some challenges. The most important is weed control. Farmers who renounce the use



Discussion on the relevance of soil organic matter for sustainability of farming

Ask the farmers, how they feed the soil. What attention do they pay to management of soil organic matter? Do they think efforts into improving soil organic matter pay off? Have they experienced that it does pay off?





SOURCES OF ORGANIC MATTER

Farm-own sources of organic matter



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of herbicides depend on mechanical weed control or on a thick mulch cover or on cover crops and proper crop rotation to prevent weed growth.

In systems, however, where the inter-row is never ploughed, weed pressure decreases over time, as weeds are not allowed to germinate.

6. Improving soil organic matter

When plant material and manure are mixed into the soil, they are decomposed and partly transformed into humus. Humus serves many purposes, for example:

- > It acts as a reservoir of nutrients. The nutrients are released to the plants in a balanced way, which contributes to good plant health. Soil organic matter is the main nutrient pool for the plants beside nitrogen from symbiotic fixation.
- > It increases the water holding capacity of the soil as it acts like a sponge with the ability to absorb and hold up to 90 % of its weight in water.
- > It causes the soil to form strong complexes with clay particles, which improve soil structure and thus increase water infiltration, making the soil more resistant to erosion. Better soil structure also enhances root growth.
- > Humus improves the exchange capacity for nutrients and avoids soil acidity.
- > Soil biological activity is enhanced, which improves nutrient mobilisation from organic and mineral sources and the decomposition of toxic substances.
- > Mycorrhizal colonisation is enhanced, which improves phosphorus supply.
- > Compost has the potential to suppress soil borne pathogens, when applied to the soil.

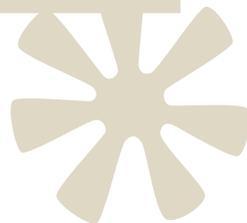
Plant nutrition in organic farming relies on sound humus management. Proper management of soil organic matter requires some basic knowledge of the dynamics of soil organic matter. Aeration of the soil in combination with humidity and high temperature create favourable conditions for soil organisms and result in high biological activity enhancing decomposition of organic matter in the soil. Under dry and cool conditions soil biological activity is strongly reduced resulting in a reduction or even in a standstill of transformation processes. Managing soil organic matter for plant nutrition and soil organic matter level means knowing, when and how to manage temperature, oxygen and moisture conditions of the soil and interfering (or not interfering) to stimulate or calm down decomposition and build-up of soil organic matter. Excessive tillage for example stimulates



Identifying local sources of biomass

Identify with the farm sources of biomass in the local context, which can be used for soil fertility management.

- > Is animal manure available? If yes, how is it used?
- > Are harvest residues recycled on the field? Or are they fed to livestock and recycled as manure? Or are they composted?
- > Do the farmers grow green manures?
- > Are there any other sources of biomass that have remained unused so far, such as prunings of leguminous trees, nutrients from fish ponds or others?
- > Are there any nearby sources of organic by-products or wastes from food processing such as seed cakes, fish meal or bone meal that may be used?
(continued on next page)



decomposition of soil organic matter, whereas cooling the soil with a soil cover slows it down.

Building soil organic matter is a long-term process, but investing into it is highly beneficial to crop or forage production, and contributes to higher and more reliable yields.

There are different ways of maintaining or improving soil organic matter:

- › Growing green manure, mostly legumes, for the amount of biomass they build. Before flowering they are cut and worked into the soil.
- › Intercropping cover crops such as velvet bean, Tithonia, lablab and others as living mulch. The cover crop is regularly slashed, when it competes too much with the main crop.
- › Mulching with especially hard-to-compost or woody materials, like dry crop residues or green manure crops, which have been grown to maturity, also can contribute to a slow increase of soil organic matter over time.
- › Trees and shrubs for agroforestry can be grown in the fields with crops where they are regularly pruned and the branches are used as mulch. They may also be planted on the edges of a field or on fallow plots.
- › Residues from harvested crops in the form of husks, leaves, roots, peelings, branches and twigs should be returned to the fields either as compost, as mulching materials, or for incorporation into the soil.
- › Depending on the financial situation of the farm, additional materials from agro-processing like wood shavings, or coffee or rice husks, or from food industry like seed cakes can be purchased.
- › Integration of livestock helps to quickly improve soil organic matter, when livestock excreta and bedding are properly recycled.

The amount and the quality of organic matter supplied to the soil influence the content of organic matter in the soil. A regular supply of organic matter provides the best conditions for balanced plant nutrition. Estimates say that in humid tropical climates 8.5 tons, in sub-humid climate 4 tons, and in semi-arid 2 tons of biomass are needed per hectare and year to maintain soil carbon levels of 2, 1 and 0.5 % respectively.

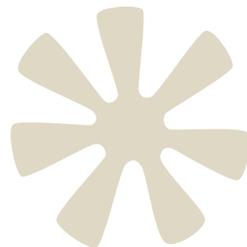
Burning organic residues and standing dead biomass (such as crops left on a field) is a crime to the environment! All the benefits that may be derived from incorporating organic matter are lost and, if the plant material is burned, the at-



Identifying local sources of biomass (continuation)

- › Are there any commercial livestock producers in the area to source animal manure?
- › Are there any large scale producers of compost in the area?
- › Is there any source of wastes from crop processing such as coffee pulp?

Discuss with the farmers potentials and constraints of increasing supply of organic materials to the soils using farm-own sources of biomass more efficiently, increasing own production of organic soil fertility inputs, or introducing inputs from nearby sources. Clarify as to whether the farmers have the ability or interest of purchasing fee-based biomass or commercial organic fertilizer.



mosphere is polluted. The ashes contain nutrients that are directly available to the plants; however, large amounts of carbon, nitrogen and sulphur are released as gas and are lost. The nutrients in the ash are also easily washed out with the first rain. The burning also harms beneficial insects and soil organisms.

Identifying sources of biomass

The majority of the farmers by far do not exploit the potentials of on-farm production of organic soil inputs. Realizing the potentials of farm-own resources can be essential for long-term sustainability of the farm, as it helps to reduce the cost of buying organic materials like manure or mineral fertilizers. Instead of buying farm inputs the farmers may use part of the savings for buying seeds for green manures and feed plants or for purchasing own livestock.

Due to limited landholdings and lack of livestock, some of the farmers may be unable to produce adequate quantities of green manure and compost. These farmers will depend on outside sources of organic materials to maintain the fertility of their soils.

6.1. Green manuring

6.1.1. Challenges and constraints

Green manuring means growing plants with the primary purpose of incorporating their biomass into the soil to supply “organic food” to the soil to improve its nutrient content and thus its fertility. Cover crops and green manures are near synonyms. While the main purpose of growing cover crops is to cover the soil with a low vegetation cover to protect it from exposure to sun and rain as well as to suppress weeds, green manures are grown with the main purpose to build maximum biomass.

Green manures play a key role in organic farming. They are an invaluable source of food for soil organisms and thus of nutrients for the following crop. They are a farm-grown fertilizer and, therefore, are a cheap alternative to purchased fertilizers. Green manures complement animal manures well and are of high value on farms where animal manure is scarce. Green manures can provide an incentive to abandon harmful traditional practices, such as burning crop residues or allowing animals to graze during the dry season, if their benefits are sufficiently large.



Assessment of alternative approaches to biomass production

Discuss alternative approaches to biomass or compost production for soil fertility improvement:

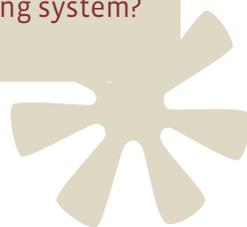
- › Production of large quantities of green manures for sale as live-stock feed or compost production by individual farmers.
- › Bulk commercial compost production at strategic sites, as in proximity to irrigation schemes.



Assessment of local adoption of green manuring

Collect information among the farmers on the use of green manures:

- › Do they practice green manuring? If not, why not?
- › How do they integrate green manures into their cropping system?





BENEFITS OF GREEN MANURES

Benefits of green manures



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In Africa, the potential of green manuring is not nearly as well used as it could be. Farmers in some regions of Africa have practiced green manuring in their traditional farming systems since a long time, for example by undersowing legumes and composites in ripening millet fields. In some regions farmers collect tree leaves and incorporate them into the soil of arable land. Though grain legumes, particularly cowpea, occur widely in traditional cropping systems, few farmers use the legumes for soil fertility management. Usually legumes are cultivated in relatively intensive production systems only, where farmers are oriented to markets. Most African farmers, who grow crops for subsistence, grow legumes only if they provide valuable food.

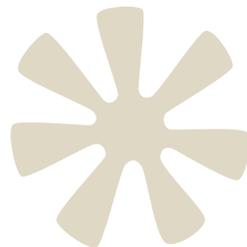
Challenges and constraints related to the adoption of green manuring:

- › The main reason for the lack of broader adoption of green manures in Africa is due to the need of many farmers for an immediate economic product, such as grains, from any crop that is grown. While legumes that are grown for harvesting the grains are grown to maturity of the plant, green manures are ideally harvested when they are still green and have produced maximum biomass.
- › In spite of the advantages of green manures, many farmers cannot afford to give up cropland to grow a soil amendment on an entire or part of a field, due to scarcity of cropland. Legumes are only grown in rotation, if the added benefit from them is very high, for example that it can be used as fodder or marketed. Growing green manures among traditional row crops (intercropping) is more common, as it allows growing green manures without reducing land for other crops. Or green manures are relay intercropped, when crop harvest nears. This avoids competition between the crop and the green manure, as the green manure will primarily grow during the dry season. Or green manures, for example jack bean or velvet bean, are grown in alleys.
- › Water may be considered the limiting factor to growing a green manure crop in arid and semi-arid climates. Fact is though, that growing green manures requires far less water than is needed for producing compost. The plants get the water themselves and take advantage of available rainwater.
- › Green manuring creates extra work.
- › Also, especially in the beginning, seeds may not be easily available.



Discussion on advantages and inconveniences of green manures

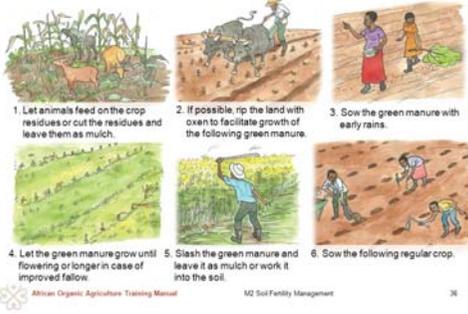
Ask the farmers about their estimation of green manures. Do they see any other advantages to the ones mentioned? What impact do the legumes have on yields of subsequent crops? Have they contributed to increase of household food security? Have the farmers observed any changes in soil attributes? What constraints do they see to growing green manures? Is it worthwhile growing green manures, even if labour to sow and cut green manures must be hired and no money is earned to replace the money spent?





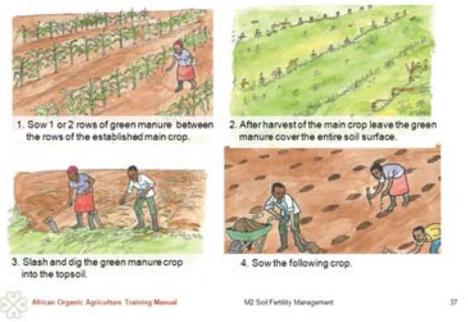
GREEN MANURES IN CROP ROTATIONS

Green manure in rotation or as improved fallow



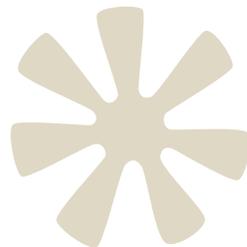
RELAY CROPPING OF GREEN MANURES

Relay cropped green manures



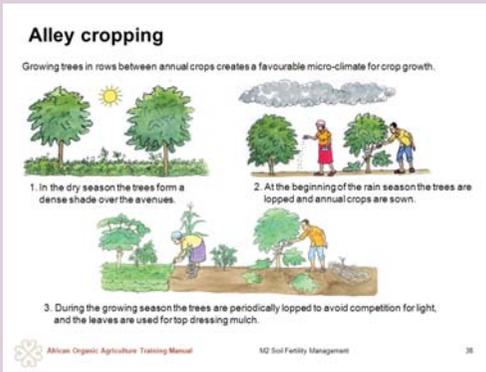
6.1.2. Benefits of green manures

- › **Recycling of nutrients.** Green manures contribute to recycling of nutrients. They help prevent nutrients from being washed out of the soil when they are grown in the rainy season. They take the nutrients up into their biomass and release them when they are ‘harvested’ and decomposed in the soil, making them available to the next crop. Ideal timing of slashing of green manures is required to avoid loss of nutrients.
- › **Production of biomass.** Green manures supply the soil with great amounts of fresh biomass. This material is easily decomposed by soil organisms – within about two weeks under humid and warm conditions – after having been incorporated into the soil. Most nutrients are then readily available to the plants. A small percentage is transformed into stable soil organic matter contributing to a better soil structure, better aeration, drainage and water and nutrient holding capacity of the soil.
- › **Collection of nitrogen.** Legumes and other nitrogen fixing plants can provide considerable amounts of nitrogen to the soil and are particularly beneficial. But legumes do not significantly contribute to higher soil nitrogen contents when their grains and residues are removed for human and/or animal nutrition. If legume biomass or residue is burnt or fully exported from the fields where they are grown, negative nutrient balances arise. It is therefore important to ensure that all or part of the legume residues are retained in the fields, if soil organic matter content is to be maintained.
In intercrops of legumes and cereal crops, cereals can take up some nitrogen from adjacent legumes. But evaluation of traditional cropping systems in Africa showed that rotation of legumes and cereals is by far more sustainable than intercropping of both.
- › **Prevention of soil erosion.** Green manures help to stop the soil from being carried away by wind and rain by providing a ground cover during their growth and a root system that holds the soil in place. As they contribute to increasing soil humus, they also contribute to better soil structure thus improving water infiltration and reducing the susceptibility of the soil to being carried away by run-off water.
- › **Suppression of weeds.** Most green manure plants are fast growing and build a dense plant cover. This prevents weeds from growing beneath them and saves on time and labour which would otherwise be needed for weed control. Green manures, which leave a thick dry mulch cover at the end of their life





GREEN MANURING WITH ALLEY CROPPING TREES



ANNUAL GREEN MANURES IN AN ALLEY CROPPING SYSTEM



cycle, can provide favourable conditions for planting of the following crop without any need for weeding or soil preparation.

- › **High quality fodder.** Some green manures can provide generous amounts of high protein fodder for livestock. This fodder can be especially valuable, if it is available during the last months of the dry season. Of course the value of the green manure for soil fertility improvement is reduced, if the above soil plant parts are used as fodder. On the other side the livestock will produce manure, which can be of high value, if it is handled properly.
- › **No transportation.** Green manures are mostly grown in-field and usually do not require transportation, in contrast to compost or other organic fertilizers. Green manures are probably best suited to supply adequate amounts of biomass and nitrogen to arable land. But, if used as a sole soil fertility management measure, it may not be sufficient to maintain or even improve soil fertility.

6.1.3. Integration of green manures into the cropping system

Many farmers do not grow green manures because they do not know which species to plant and how to integrate them in their cropping system. It is, therefore, important to plan where, when and how to plant which species in order to obtain good results.

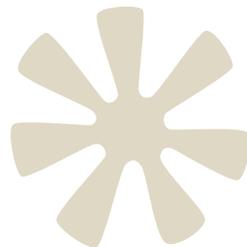
There are several ways of integrating green manures into the farming system:

- i. Food and non-food legumes can be intercropped with cereals and tree crops
- ii. Short duration non-food legumes can be grown towards the end of the cereal growing season using residual moisture.
- iii. Legumes are grown as short-term rotational fallow.
- iv. Long term green manures are grown for more than one season.
- v. Or legume trees are grown in an agroforestry system to provide nutrient rich plant material.

a. Green manures in a crop rotation

Integration of green manures in crop rotations supplies nutrients to the rotation and balances crops that take many nutrients out of the soil. Rotated green manures can also serve to break pest and disease cycles, when they are grown between closely related crop species.

Green manures can be integrated in a rotation whenever there is no crop in the ground, rather than leaving the land bare and allowing weeds to grow and





GREEN MANURE SPECIES

Green manures providing dense soil cover

| Species | Characteristics | Additional/alternative uses | Integration into the farm |
|---|---|---|---|
| Greenleaf Oenothera (<i>Oenothera litoralis</i>) | <ul style="list-style-type: none"> Grows on a wide range of soils, but has no tolerance to salinity Low drought tolerance Perennial, long trailing and climbing High biomass production High N fixation rate Tolerates shade, but no constant or repeated defoliation (grazing) | <ul style="list-style-type: none"> Frage in pastures and irrigated pastures, for conservation as hay and silage, for out-and-carry systems | <ul style="list-style-type: none"> Intercrop with maize and sorghum in the humid tropics to repel stem-borer grass moths (Chilo partellus) and witch weeds Ground cover under permanent crops In mixed stands with other legumes or grasses |
| Lablab (<i>Dolichos lablab</i> , <i>Dolichos purpurascens</i>) | <ul style="list-style-type: none"> High drought tolerance when established, may stay green throughout the dry season Climbing High biomass production Medium to high N fixation rate | <ul style="list-style-type: none"> Food: leaves, flower buds and green pods edible Frage: green or dried leaves and dried seeds; green plants for silage | <ul style="list-style-type: none"> Improved fallow after maize during the dry season Maize crop for plantation crops Mixed forage crop with summer grass crops (high forage quality) |
| Velvet bean (<i>Mucuna purpurea</i>) | <ul style="list-style-type: none"> Can grow on very poor soils also Prefers humid climates (but no vernal frosts); tolerates some drought, dies during the dry season Climbing High biomass production Fixes up to 150 kg per ha of N Suppresses nematodes | <ul style="list-style-type: none"> Food: young leaves as vegetables, cooked beans Frage: leaves mixed with 4 times Napier grass, grass only if baled; residues can be used as forage; silage or hay; the seeds can be used to make concentrate feed | <ul style="list-style-type: none"> Improved fallow on severely degraded soils (planted at the onset of the rainy season) Relay cropping in cereal crops with repeated pruning (and subsequent Maize fallow), sowing of the following crop into dead mulch Soil cover in citrus or coffee |

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GREEN MANURE SPECIES

Green manures with erect growth

| Species | Characteristics | Additional/alternative uses | Integration into the farm |
|---|---|--|--|
| Cowpea (<i>Vigna unguiculata</i>) | <ul style="list-style-type: none"> Climbing, bushy and erect forms Moderate drought tolerance, not tolerant to excessive soil moisture Moderate biomass production N fixation 30 to 100 kg per ha | <ul style="list-style-type: none"> Food: young leaves, green pods and dried beans Frage: fresh cut and carry forage; hay and silage (mixed with forage sorghum or millet) | <ul style="list-style-type: none"> Intercropping with maize, sorghum, millet or cassava |
| Jackbean (<i>Crotalaria retusa</i>) | <ul style="list-style-type: none"> For humid and sub-humid climates, but high drought tolerance Grows on poor or degraded soils Moderate biomass production N fixation up to 230 kg per ha Mature crop provides good mulch | <ul style="list-style-type: none"> Food: young leaves, tender pods Frage: as fodder in small proportions of the diet; mature seeds ground | <ul style="list-style-type: none"> Intercropping in young bananas, cocoa or coffee, cassava or sweet potatoes Relay cropping in cereal crops |
| Black Sunhemp (<i>Crotalaria juncea</i>) | <ul style="list-style-type: none"> Grows on poor or degraded soils also Drought tolerant Annual, growth to 3 m Moderate biomass production N fixation 100 to 200 kg per ha Controlled nematodes Regrows when cut before flowering Mature crop provides good mulch | <ul style="list-style-type: none"> Food: young leaves only Frage: no more than 10% of the diet of cattle, not to be fed to pigs Insect repellent Production of bast fibres | <ul style="list-style-type: none"> Sole crop in rotation for green manuring Intercropping with taller grain or forage crops Intercropping or relay cropping with vegetables, beans, sweet potatoes, cassava or pineapples |
| Red Sunhemp (<i>Crotalaria retusa</i>) | <ul style="list-style-type: none"> High drought tolerance Grows to 2 m, regrows, if not cut too low Suppresses nematodes Can be used as mulch | <ul style="list-style-type: none"> Food: young leaves, pods and flowers Frage: leaves reported to be non-toxic before flowering Insecticide: seeds used in storage to keep weevils away | <ul style="list-style-type: none"> Intercropping with food or cash crops |

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nutrients to leach out of the soil. To prevent nutrients from the green manure leaching out of the soil before being taken up by the next crop, the time lag between digging-in the green manure and planting the next crop should not be more than two weeks in rainy periods. From a nutritional point of view, integration of green manures is particularly useful when they are grown before crops with high nutrient demand.

b. Intercropping or relay cropping in annual crops

Green manures can be grown underneath row crops such as corn, millet and sorghum. To avoid or reduce competition with the crop, green manures are usually sown toward the middle or the end of the growing season, when the crop is well established or near maturity. In relay cropped green manures major growth of the green manure occurs during the dry season after the harvest of the main crop. This procedure has the advantages that the green manure uses land that normally would not be under cultivation, and extends the period with a soil cover. In relay cropping sowing of the green manure is often combined with weeding of the crop, for example in maize after the second weeding. The green manure seeds are either broadcasted or are planted in bunches on hills.

c. Long term green manures

Green manures can be grown for more than one season in the following ways:

- They can be planted in a bush-fallow system to restore poor soil. They are broadcast and left to grow uninterrupted for as long as required. The longer the period, the greater the benefit on soil fertility is.
- They can be grown on new land before it is prepared for use, especially to help control difficult perennial weeds like couch grass and spear grass.
- They can also be grown to produce large amounts of green plant material, which are then cut and carried to other fields, fed to livestock or used for composting. An example of such a perennial species is alfalfa (*Medicago sativa*).

d. Green manures in agroforestry systems

Agroforestry involves growing trees or shrubs together with crops. The trees or shrubs act as long-term green manures, where the leaves are spread on the field and dug into the top soil layer. For example, every sixth row, pigeon pea trees are intercropped with traditional grain crops. At the end of the season the crop



Evaluation of green manure species for integration into the cropping system

Define together with the farmers criteria for the selection of green manure plant species for local use. The following questions may guide you:

- Is there enough land to grow green manures as a sole crop; or must they be intercropped in existing crops?
- If they should be intercropped: in which crop(s) should they be integrated (cereals, a small crop, permanent crop)?
- Is a short- or rather a long-term green manure more appropriate?
- Is there need for additional food or a market for leguminous grains?
- Should it suppress persistent weeds?
- Should it leave a thick mulch?
- Should it suppress nematodes?



residues are gathered under the pigeon pea plants and left for decomposition together with pigeon pea leaves. After six months the mixture is spread on the surface and incorporated into the soil.

Regular pruning of agroforestry trees, before or as soon as they flower, increases the amount of green materials obtained and reduces competition with the main crop.

6.1.4. Selection of appropriate green manure species

Proper selection of green manures is essential to enable them to maximize their potential and minimize possible inconveniences like competition with crops. Green manures must suit the local climate, soil, and pest and disease situation, and fit into the cropping system. Therefore, when choosing green manure plants to use, the following aspects should be considered:

- › Annual green manures must be fast growing, have vigorous growth and be non-woody.
- › Green manures should grow well in the poorest soils and not need any fertilizer.
- › They must be adapted to local climate. In dry climates they should not need extra irrigation.
- › They must have few enough natural enemies and grow vigorously without any pesticides.
- › They should not be closely related to the incoming crop, as they could attract pests and diseases and affect the following crop. They should either be very shade-tolerant for intercropping or drought-resistant, when grown into or through the dry season.
- › They should first cover the ground well to protect the soil and suppress weeds, and then climb stalks, if desired, but should not smother the main crop.
- › Leguminous green manures can collect considerable amounts of nitrogen. However, non-legumes can also be grown, as long as they produce enough biomass and develop a good root system. Non-legumes may also survive better in the local conditions, may grow faster and sometimes tolerate extreme weather conditions or poor soils.
- › Last but not least farmers may request that green manures provide food, if food is in short supply and little land is available.
- › The seeds should be readily available and affordable. For long term sustaina-

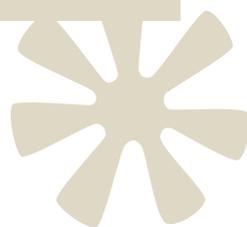


Evaluation of green manure species for farm integration

List the species the farmers are familiar with and evaluate them based on the criteria selected together with the farmers. Present further green manure species, if any highly valuable species are not mentioned.

Discuss with the farmers possibilities of integrating green manures into their cropping systems:

- › growing them in rotation with annual crops;
- › intercropping or relay cropping them in annual crops;
- › growing them on neglected land or using them for improved fallows;
- › introducing agroforestry trees or introducing green manures in agroforestry systems;
- › growing green manures alongside food crops.



bility, farmers should be able to produce their own seed for the green manure crops. If the green manure crop is cut down before seeds have ripened, seeds must be produced on a separate small plot.

Some green manures may grow too vigorously and become weedy among the crop or even spread into new areas. This is especially true for plants that are not locally sourced. Normally, green manures with light seeds, which are easily blown away by wind, or creeping stems are problematic, as they may spread uncontrollably. Growing perennial green manures as annuals will prevent them from taking over other crops and growing in areas where they are not wanted. In case of unreliable climate, similar plants with different properties can be combined with one variety having good drought-resistance.

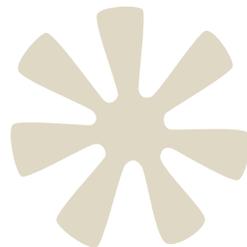
The green manure should be able to produce enough biomass within the period the land is free (not under main crop production). Therefore, the species must be selected in relation to the period the land is free for the green manure to grow to flowering and decompose after cutting.

If a green manure is to be used for the first time in an area, it should be tried on a small plot first to check how it behaves.

After cutting, the green manure plants can either be left to wilt for some days or incorporated into the soil immediately after cutting. Green manures should be worked into the top soil only.

Wilting saves on labour for incorporation, but results in some nutrient (nitrogen) losses. Incorporating the green manure should happen before the rainy season. In heavy soils, incorporation during the dry season may be difficult. If incorporation into the soil is difficult, the green manure can be cut down partially only when the rain comes and cut down entirely two weeks later. When grown in a rotation, the period between digging the green manure into the soil and planting the next crop should not exceed two weeks to prevent nutrients from leaching out of the soil.

In the case that green manures grow too old and tough to easily decompose by-themselves, they may instead be cut in small bits and composted or used as mulch. Mulching releases nutrients slowly, but has other advantages of hindering weed growth, protecting the soil from erosion and reducing water loss through evaporation.



6.1.5. Management of green manures

To keep farmland productive, green manures must produce at least 10 to 25 tons of fresh organic matter per hectare and year. Under favourable conditions common green manure species may produce up to the double amount of biomass and collect at least 80 kg of nitrogen per hectare and year.

Green manures are ideally allowed to grow up to flowering stage. At this stage, biomass is highest and the plant material is still easily decomposed, as it is still green and not yet woody. If plants become too old and tough, they will be more difficult to dig under and soil organisms will find it difficult to break the biomass down.

Instead of incorporating the legumes into the soil to directly improve fertility and soil moisture or enhancing the effectiveness of the legumes, they may be composted together with other plant residues and manure. When applied to the soil, the compost produced will be more effective in improving soil fertility and physical conditions such as structure and water infiltration and hence will contribute to greater harvesting of rain water, and higher moisture holding capacity and soil aeration.

Another possibility is to use the material from green manures to cover the soil surface as mulch. Compared to incorporation of the plant material into the soil, mulch releases nutrients slowly, contributes to suppression of weeds, protects the soil from erosion, and keeps it moist during dry weather. In this case green manure plants are best grown through their full life cycle, as this will result in more woody plant material, which is better suited for mulch. Such an approach extends the period with a living plant cover and allows harvesting of large amounts of ripe seeds. The residues can then be allowed to cover the entire soil surface, or are arranged into strips along the contour, if another crop is to be planted.

Leguminous green manure species grow well in nitrogen deficient soils. But they depend on the availability of sufficient phosphorus, the presence of the right rhizobium and sufficient soil moisture. High pest and disease pressure can hinder proper development of the crop and production of reasonable grain yields. It furthermore requires use of healthy seeds, sowing at recommended planting distances or seeding rates, and the consideration of other management measures.

The following management measures may be relevant, when growing green manures:

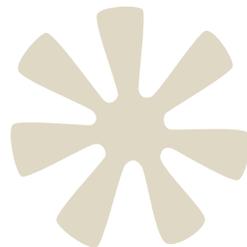


Assessment of knowledge on composting

Find out, what the farmers know about composting.

- > Have the farmers ever heard of composting?
- > What is their perception of composting?
- > How do they estimate the value of compost?
- > Do they think it is worthwhile to invest into composting?

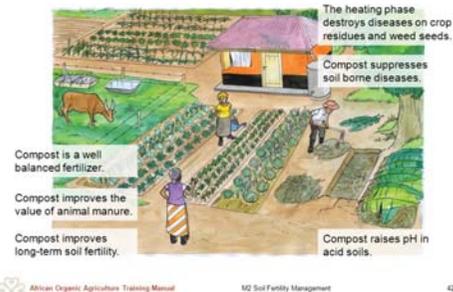
If possible, visit the farm of a farmer, who has made and applied compost for some years. Let him tell about his experiences making composting and results of compost application.





BENEFITS OF COMPOST

Why invest in compost production?



- › If legumes are grown in a field for the first time, inoculation of the seeds with the specific rhizobia may be necessary to profit from potential nitrogen fixation. Farmers can consult their extension agents for possible sources of and information on how to apply the rhizobium.
- › Continuous cropping of the same legume on the same field may result in increase of pests and diseases and decline of performance of the green manure. Therefore, it is recommended to alternate between different species on the same field.
- › Performance of green manures also depends on seed rates and planting distances. Both can vary from one species to the other and must be tested for each individual situation.
- › Green manures need sufficient soil humidity for germination and growth.
- › Leguminous green manures normally do not need additional fertilization.
- › Climbing legumes may need regular pruning.
- › The availability of nutrients and the impact on soil quality can be increased with a light top-dressing of compost (even of poor compost) to the green biomass, which is incorporated into the soil.

6.2 Composting

6.2.1. Benefits of compost

Compost is a common name used for plant and animal material (mainly animal manure) that has been fully decomposed in a targeted process initialized and controlled by man. Compared with uncontrolled decomposition of organic material as it naturally occurs, decomposition in the composting process occurs at a faster rate, reaches higher temperatures and results in a product of higher quality.

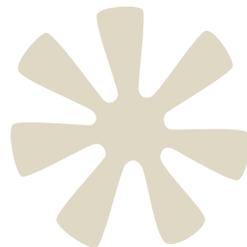
Composting is a means of ensuring or improving long-term soil fertility, especially to smallholder farmers with no or little access to manures and fertilizers. Compost is more than a fertilizer. It is not just a nutrient source, but also acts on the structure of the soil and on its capacity to hold and provide nutrients and water. Its main value lies in its long-term effect on soil fertility.

Compost contributes to an increase of the organic matter content of the soil and thus to a better soil structure. It clearly enhances drought resistance of crops.



Discussion on investment into compost production

Discuss with the farmers advantages and constraints of compost production under local circumstances compared to green manuring, mulching and other approaches to improvement of soil fertility. Instead of making compost one-self, it may be purchased from nearby producers. Are there commercial compost producers in the area? Are their products suitable in terms of availability (quantity and distance to the farm), costs and quality (including the risks of heavy metal or other residues)? Discuss the feasibility of such an approach and the acceptance of such products with the farmers.





FORMATION OF SOIL ORGANIC MATTER

The formation of soil organic matter



During the composting process diseases, pests and weed seeds are destroyed. Even viruses are destroyed, if a high temperature is reached. Thus, composting helps solve common problems associated to the management of plant residues. Compost also increases biological activity of the soil and its capacity to positively influence biological control of root rot diseases from fungi, bacteria and nematodes.

In the composting process nutrients are adsorbed into the organic matter, microorganisms and humus. The humic substances are relatively resistant to microbial decomposition. Thus, the nutrients are released slowly and are not easily lost.

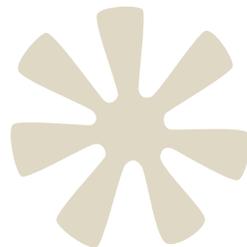
The total nutrient content of compost is similar to that of cow manure with an average nutrient content of 0.5 % N, 0.1 % P and 0.5 to 2 % K. Nevertheless, the values of compost cannot be estimated high enough. Compost has proven to be the best type of organic fertilizer in dry climates. It also increases the effect of even small amounts of manure. Deficiencies of trace elements are less likely, when compost is applied, as compost contains trace elements as well. Compost also increases the availability of phosphorus to plants in soils rich in iron oxides. Due to its neutral pH, compost improves the availability of nutrients in acid soils. Where soils tend to be water-logged, composting helps avoid nitrogen losses occurring from incorporation of green plant material under such conditions.

6.2.2. Potentials and constraints of composting

From a farmer's perspective, there are a number of reasons for investing time and effort into making good compost. Compost production is labour intensive, however, and demands regular attention. Collecting the composting materials, setting up the heap, regular watering and repeated turning of the heap make composting a very labour intensive activity. But the work can be done, when the farm's labour forces are free. It is not restricted to a particular season. Livestock can greatly ease transportation of plant material to the composting area and when adding compost to the fields.

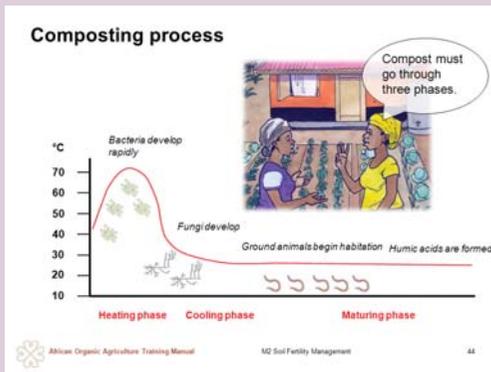
If labour requirements for compost production are considered, composting may not be economical when used on grain crops such as corn or millet, whereas compost application to vegetables or other cash crops may be highly worthwhile.

In African context, it is more economical to produce compost than to buy the equivalent amount of nutrients in mineral form. This is especially true if the compost's effect on soil quality improvement is considered.





Composting process



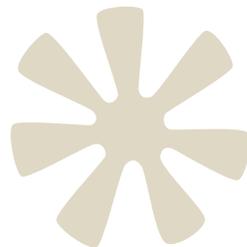
On a basic level no or little cash is needed for compost production, as it relies on materials that are available on the farm and does not require special equipment for small scale production. This keeps the financial risks very low, whereas expenditures for inputs prior to harvesting always bear a certain risk.

For composting, considerable quantities of water are needed to maintain humid conditions in the heap for development of decomposing bacteria. Scarcity of water or distance of the water source from the fields can be critical for compost making. If water is scarce, it should rather be used for composting than for irrigation, as this will result in a more efficient use of water, because compost will improve fertility and water holding capacity of the soil in the long term. If little or no water is available to moisten composting material, compost heaps can be built during rainfall, heaping the wet materials. For easy watering, the composting area should be placed in proximity of a permanent water source. In general, it is easier to produce good compost during the wet season as the rain saves on labour for watering. Water harvesting can help to make water available for composting during the dry season.

Starting with composting may be difficult when organic materials are rare or competition for other uses of organic materials is high. In this case, special efforts would be necessary to produce more organic material in the farm growing hedges, establishing agroforestry systems and growing other plants to provide material for composting.

During the composting process the volume of the organic materials is halved. This means that a farmer needs 2 tons of organic material to produce 1 ton of compost. With biomass yields of green manure species like *Mucuna* being as high as 35 to 50 tons of fresh matter or 7 to 9 tons of dry matter per hectare, the amount of fresh organic material required to produce 1 ton of compost can easily be achieved from about 0.05 hectare.

Depleted soils in arid climates can be made arable again by applying 10 tons of compost per hectare over several years. Compost application should be limited to 40 tons of moist compost (or 25 tons of dry matter or 90 m³) per hectare in three years. Application of large quantities of compost, which is rich in wood parts, can result in temporary unavailability of nitrogen in the soil, and therefore would require additional application of a nitrogen rich source. Although contents in P and K are similar in compost (approx. 1.5 kg per m³) annual supply of 30 m³ of compost per hectare covers plant needs in phosphorus, whereas needs in potassium are covered by 20 % only. Total nitrogen content of compost is low





MATERIALS FOR MAKING COMPOST

Materials used for composting



(about 1 %) and only 10 % of it is easily available to plants.

Composting is an appropriate measure for soil fertility improvement, especially when soil fertility is low, land is scarce and organic materials, labour and a water source in proximity of the fields are available.

6.2.3 The composting process

Properly made compost goes through three phases: the heating phase, the cooling phase and the maturing phase.

The heating phase. During the heating phase, within three days after setting up the compost heap, temperature in the center of the heap rises to about 60 to 70 °C. It usually stays at this level for two to three weeks. The high temperature is a result of the energy that is released during the decomposition of easily digestible materials by the bacteria. The warm temperature is typical and important for the composting process. The heat destroys diseases, pests, weed-roots and seeds and thus prevents their further propagation.

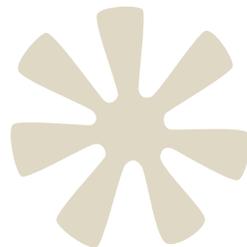
Due to the rapid development of their population, the oxygen demand of the bacteria is very high during this phase of the composting process. High temperatures in the heap indicate that oxygen supply is adequate. If temperature stays low or the compost develops an unpleasant odour, this can be an indication that the heap is compacted and oxygen supply is low.

Bacteria not only depend on oxygen, but also on humidity for their development. Due to the high biological activity and high evaporation, the humidity requirements are highest during the first phase of composting.

The cooling phase. After decomposition of the green plant material by the bacteria, the temperature in the compost heap declines slowly to 25 to 45 °C. When temperature declines, fungi settle and start the decomposition of straw, fibres and wooden material. As this decomposition process is slower, the temperature of the heap does not rise.

The maturing phase. During the maturing phase, red compost worms and other soil organisms start to inhabit the compost heap. Nutrients are mineralised and humic acids and antibiotics are built up. At the end of this phase the compost has lost about half of its original volume, has taken on a dark colour and the smell of fertile soil and is ready to use. Water requirements during this phase are low.

The longer the compost is stored, the more it will lose its quality as a fertilizer. Its capacity to improve soil structure, however, will increase.



6.2.4 How to make compost

a. Selection of a suitable composting site

The composting process should be conducted in a place that is easy to access for easy transport of materials to the composting site and close to the fields where the compost is to be used after production, and next to a water source. A well-drained and levelled ground minimizes the risk of sieving out of nutrients by runoff rainwater. Natural shade such as a tree or a built shade reduces evaporation. An adjustable structure may allow its removal during rain.

There should be an appropriate distance from short term crops such as vegetables to avoid the risk of contamination, especially if animal waste is used.

b. Materials and tools for compost production

Ideally composting plant material is a mixture of 50 % different fresh green material and 50 % of dry material. The rate of coarse material should not exceed 10 %. If too much fresh material is used, aeration of the heap will be poor. As a result the heap will start to smell and nitrogen will be lost. If too much dry material is used, bacteria lack food and the composting process will not start. Larger quantities of dry material are thus best left in the field to protect the soil surface from drying out and being washed away.

As most crop residues are low in nitrogen, sources high in nitrogen such as leaves of green legume plants or prunings from leguminous trees or legume stalks may be used to insure sufficient nitrogen for the composting process. Also materials from shrubs such as tithonia, gliricidia, leucaena, sesbania, crotalaria and lantana leaves are good materials to use.

Whenever possible, plant materials should be composted together with animal manure. Addition of animal manure accelerates the composting process and results in compost with higher fertilizer value. Dung can be dissolved in or mixed with water and poured over the compost heap when preparing the compost. Urine and slurry, both rich in nitrogen, can encourage decomposition of dry material when poured over it.

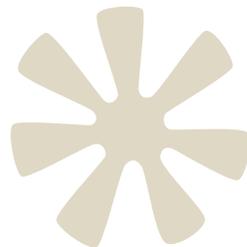
Ashes can be spread in thin layers between the other materials. Too much ash, however, can result in gaseous nitrogen losses. Some earth or old compost can be used as well. Earth will adsorb escaping nitrogen well.

Where soils have the tendency to fix phosphate, ground rock phosphate is best added to the compost, as it will be more readily available to the plants than if it is added to the soil directly.



Practical demonstration on compost making

Obtain the different materials required for compost making and demonstrate to the farmers how compost is made. During the compost making, explain to the farmers the main points to be considered.





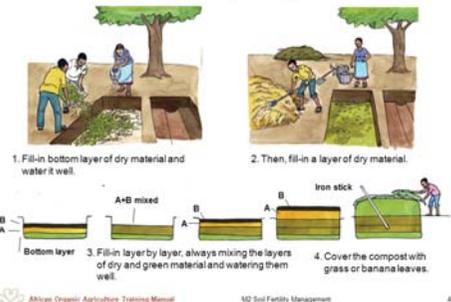
MAKING OF COMPOST (PART 1)

How to make good compost (1)



MAKING OF COMPOST (PART 2)

How to make good compost (2)



Lime can be added in small quantities, but is in general not necessary for the composting process.

Tools needed for composting include a hand hoe, machete (panga), stick pegs, spade or forked hoe, watering can, wheelbarrow, sharp stick or compost thermometer (to monitor the temperature changes in the compost heap). For watering, a watering can or a sprayer should be used rather than a bucket, as this allows the material to better soak up the water.

Materials that should not be used for composting include materials from diseased or pest infested plants or plants that have been sprayed with pesticides or herbicides, materials with hard prickles or thorns, which may hurt the persons handling the compost. Persistent perennial weeds should not be composted either. Instead they should be destroyed by spreading them out in the sun to dry, or even burning. The dried material or ashes can then be added to the compost heap. Non-organic materials such as metal or plastic, rubber, leather and textile materials cannot be composted.

c. Compost making procedure

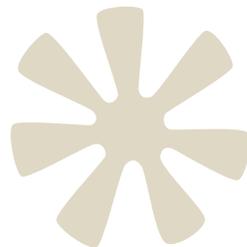
There are different methods for making compost based on different approaches and origins. They include the Indore and the Bangalore method, which were developed in India, the heating process/block method, the Chinese high temperature stack, the pit, trench, basket or the Boma composting. Each of these methods has advantages and disadvantages.

In the Bangalore method, the composting materials are mixed with urine, slurry or dung. The heap, once set up, is plastered with a layer of mud and is not turned. Due to the mud layer, the composting process becomes semi-anaerobic after a few weeks. The method is simple to use and needs little labour and water. It has fewer nutrient losses than the Indore-method, but may not destroy all diseases and needs more time to reach maturity.

In the Indore method the heap is turned twice. It is more labour intensive and needs more water than the Bangalore method, but has a shorter composting period. The materials go through an intensive heating phase.

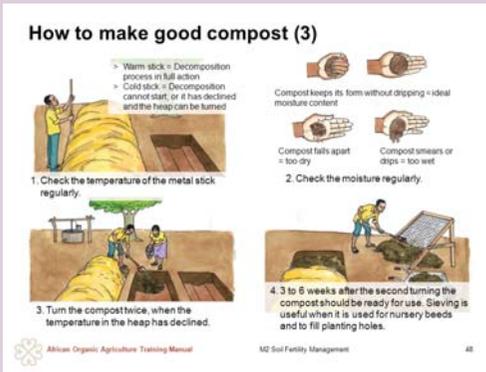
In dry climates composting is mainly practiced in pits to keep the compost humid and save on water and labour for maintaining ideal conditions.

Vermi-composting uses specially introduced earthworms for decomposition. It is a good technique for recycling food waste and crop residues from vegetable gardens in the proximity of the house. The composting period is longer as com-





MAKING OF COMPOST (PART 3)

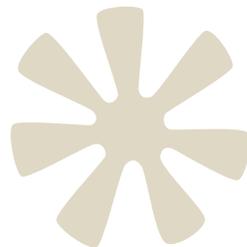


pared to other methods and varies between six and twelve weeks.

In this manual only the heap/pit method and vermi-composting are described in further details.

How to proceed for making compost:

1. Collect adequate quantities of the materials needed.
2. Measure out an area 1.5 meters wide and of any convenient length. The width should enable to work with the compost without having to walk on it.
3. Dig out a shallow pit of the planned size of the compost heap. The more arid the climate, the deeper the pit is usually dug. Compost pits should, however, not be deeper than 50 cm to ensure aeration. If no pit is dug in a humid climate, loosen the ground where the compost heap will be, as the materials need close contact with the loose soil at the bottom. The topsoil obtained when digging the trench should be carefully put to one side beside the trench so that it can be used in the compost.
4. Woody materials should be chopped into pieces 5 to 10 cm in length or spread on a road or used as livestock bedding before composting to be bruised and increase its surface for better decomposition. Wet plant material such as seaweed or fresh grass should be wilted before mixing it with other material. Straw should be pre-soaked in water, if possible. Ideally dry material is thoroughly mixed with urine and animal dung.
5. Lay down the bottom layer of rough vegetation such as maize stalks or hedge cuttings. This layer should be about 30 cm thick. Such materials allow for air circulation into the heap.
6. Then add a layer of mixed green material and animal manure (if available) followed by a layer of dry material. Then mix both layers and water well. The better the different materials are mixed, the better the composting process. Plant material infected with viruses should be placed in the center of the compost, and should be covered fast to avoid that the viruses are propagated to healthy plants by sucking insects.
7. Repeat the process to build a heap to a height of 1 to 1.5 meters. Make sure to water each new layer well to create humid conditions. As for composting, aerated conditions are needed, the compost heap should not be stamped. A well-made heap has almost vertical sides and a flat top. If you have a lot of materials, it is good to make several heaps of about 2 meters in length.
8. To complete the pile, ideally cover it with 10 cm of topsoil to prevent gases



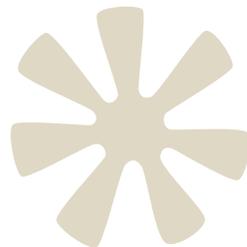
from escaping from the compost pile. Lastly, cover the whole pile with dry vegetation or banana leaves to prevent loss of moisture through evaporation.

9. Take a long, sharp, pointed stick and drive it into the pile at an angle. The stick helps to check the condition of the pile from time to time. If the stick is pulled out and is warm after two to three days, this indicates that decomposition has started. If the stick is white, this is an indication that the heap is dry inside. The heap should be turned and watered well.
10. Do not grow cover plants such as pumpkin on the compost heap itself, as this dries it out. Plant them next to it.

How to maintain the compost heap:

1. About every third day, depending on the weather conditions and if it has rained or not, the heap must be watered.
2. If all goes well, the heap should be turned after 3 weeks, after the temperature of the pile has fallen. Compost heaps are usually turned 2 to 3 times in their early stages. When turning the compost heap, make sure the outside material comes inside. Thus, when turning the heap, first take the material from the top and the outside to make the new heap. This procedure ensures that all parts of the compost go through a proper heating phase. Do not add new material during turning.
3. After 3 to 6 weeks the heap should be turned again. By now the compost should have a fresh earth smell and no grass, leaves or animal droppings should be visible. Some woody branches or stalks may still be present, as they take a longer time to rot.
4. In 3 to 6 weeks after the second turning, the compost should be ready for use. Mature compost turns blackish-brown in colour and has a pleasant smell. If the planting season is still far off, leave the pile covered where it is. The pile should always be kept moist and covered with dry material. If the heap becomes too wet it should be opened up and mixed with dry organic matter or allowed to dry in the sun before rebuilding.

The decomposition process is quickened by adding large amounts of fresh animal manure and by turning the heap more frequently.



d. Applying compost in the field

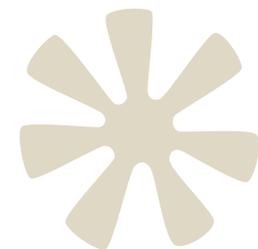
In an African context, there is no such thing as too much compost. Usually the amount that can be produced by a smallholder farmer is rather small. So it is, therefore, important that compost be applied where the cultivated plants can use it and where it directly contributes to better plant nutrition and water retention. Efficiency of the compost can be improved through targeted application to the root zone of the crop plants through banding or placing into planting holes rather than spreading it over the entire field. Labour requirements may be higher with targeted application, it may however result in higher productivity and help to reduce the size of land required to produce the required quantities of food.

In planted crops, compost is best applied into the planting holes and mixed with topsoil. Compost should be applied first to the crops with high nutrient demands such as tomatoes. In sown crops, compost is best brought out in the sowing rows prior to sowing and worked into the topsoil. In perennial tree crops, compost application is most efficient when applied along the drip line of the trees (and not at the foot of the trunk). Good quality compost is ideal for seedbeds also. Compost should not be ploughed deeply into the soil. Compost can also be hoed into the topsoil as a top dressing.

Effect of nitrogen from compost is generally little and extends over a long period. Availability of nitrogen and other nutrients from compost can be increased, when the compost is supplemented by nitrogen rich liquid manure or fresh animal manure after its application before crops.

Compost that has not fully decomposed can be used for mulching between crops or around tree crops. It will continue to mature on the ground and organisms in the soil will draw it into the soil where it will decompose further. When using compost as mulch, it should be covered with a thin layer of straw or dry grass or leaves. This will avoid loss of nutrients due to direct exposure to sunlight and heat. Young composts are best applied to the soil together with nitrogen rich plant material like green manures, or they are applied before sowing a green manure crop.

The compost can be used immediately or stored for later use. Ripe compost for storage should be kept in the shade and covered with 10 cm of top soil to keep it humid and prevent loss of nutrients.



4.2.5. Vermicomposting

Vermicomposting is the method where compost is prepared using specially introduced earthworms, Red Wigglers (*Lumbricus rubellus* or *Eisenia foetida*), as agents for decomposition. In contrast to ordinary composting, vermicomposting is mainly based on the activity of worms and does not go through a heating phase. Vermicomposting is a good technique for recycling food waste and crop residues from vegetable gardens in the proximity of the house. It creates small volumes of very rich manure. Though vermicompost is very good manure, it requires more investment (a tank and worms), labour and more permanent care compared to ordinary composting. On the other hand, letting worms recycle farm or household waste saves time and labour input because no turning is required to keep the compost aerated.

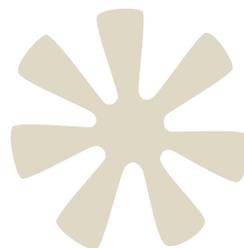
Red Wigglers reproduce quickly, adapt well to life in a confined environment, and compost food rapidly as they consume their weight in food per day. They are three to five inches in length, dark red in colour, and will tolerate temperatures from 12 to 30 degrees Celsius. They prefer to live in the dark and moist places, and about half a kilogram of Red Wigglers is needed to start a colony.

The worms are very sensitive to fluctuations in moisture and temperature, however, and need a continuous supply of organic material for 'food'. To protect the worms from predators, a solid base is needed as they are also attacked by ants and termites.

Some experienced farmers use 'vermiwash', the liquid collected from the compost heap after sprinkling, as a leaf fertilizer and plant tonic. This can even help plants to get rid of pests, such as aphids and diseases. Vermicompost can also be used to make compost tea.

How to proceed for vermicomposting:

Build a brick and mortar enclosure with a concrete bottom, one or two chambers and proper water outlets. Convenient chamber size is 2 m x 1 m x 0.75 m. However, the size of the chambers should be determined according to the volume of the composting material. Alternatively, a sizeable plastic or metal container or wooden boxes with a secure and removable lid to keep out predators and with ventilation holes on the side walls and holes on the bottom to release excess moisture from the container, but small enough to keep out flies if possible. The 'four tank' or 'four chamber' method of chamber construction is also commonly used because it facilitates easy and continuous movement of earthworms from



one chamber with fully composted matter to a fresh chamber. Whatever container is used or built, it should be placed in a dark and damp place.

- › A layer of good moist loamy soil (vermin bed) is placed at the bottom, about 15 to 20 cm thick above a thin layer (5 cm) of broken bricks and coarse sand.
- › Earthworms are introduced (about 150) into the loamy soil, which the worms will inhabit as their home.
- › Then, a small quantity of fresh cattle dung is placed over the vermin bed.
- › The compost pile is then layered to about 5 cm with dry leaves or preferably chopped hay/straw or agricultural waste biomass such as vegetable peels, leftover food, dead leaves and plants. Egg shells can also be broken into small pieces and added to the pile.
- › For the next 30 days, materials are continuously added to the pit until it is full and is kept moist by watering it whenever necessary. Meat or fish scraps, greasy foods, dairy products or bones should not be added into the pile, as these will attract ants and rodents. The pile should be covered with porous material to keep off predators.

The compost should be ready within 60 to 90 days. The material will be moderately loose and not as heavy and with a dark brown colour.

In the two or four pit system, watering should be stopped in the first chamber so that worms will automatically move to another chamber where the required environment for the worms are maintained in a cyclical manner and harvesting can be done continuously in cycles.

To remove some of the compost, let the top of the heap dry out by discontinuing the watering for two to three days so that the worms move down to the cool base of the heap. Compost can then be removed and taken back to a fresh pile.

6.3 Farmyard manure

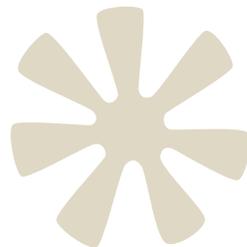
Farmyard manure commonly describes a more or less decomposed mixture of livestock dung and urine (mostly from cattle) mixed with straw and litter, which was used as bedding material. It may also contain residues from the fodder fed to the cattle and decomposed household waste.

Farmyard manure is an extremely valuable organic manure. Farmyard manure contains large amounts of nutrients. The availability of phosphorus and potassium from farmyard manure is similar to that of chemical fertilizers. Chicken



Discussion: Is farmyard manure just a waste product?

Discuss with the farmers the role farmyard manure plays in plant nutrition in local farming systems. How is it stored, how is it applied? If possible, visit a local farmer, who practices appropriate treatment of manure. With the farmer and the group, discuss the advantages, constraints and possibilities for storing farmyard manure.



manure is rich in phosphorus. When dung and urine from cattle are mixed, they form a well-balanced source of nutrients for plants.

Many farmers still underestimate the value of animal manure. In many places, it is dried and burned for cooking or just not recognized as a source of nutrients and organic matter. By drying or burning farmyard manure, large quantities of organic matter and nutrients are lost from agricultural systems. Appropriate recycling of nutrients on the farm, especially if it comes from a high-value source, is a principle of organic farming. Therefore, proper handling and use of animal manures are essential to ensure that the nutrients in the manure are preserved and the risks of causing environmental pollution are minimized.

Most farmers do not own animals, and neither do they have access to animal manure. Growing animal feed and integrating livestock into the farm not only provides milk and or meat and other animal products, but also some animal manure. In areas with mixed crop-livestock farming systems manure is likely to be available to most households, although at varying levels.

Improving the value of animal manure

Farmers should optimize the use and effectiveness of animal manure. Rather than apply raw animal manure, the farmers should be encouraged to compost the manure from cattle and other ruminants, while making liquid fertilizer from poultry manure, which is less suitable for composting due to its high moisture content.

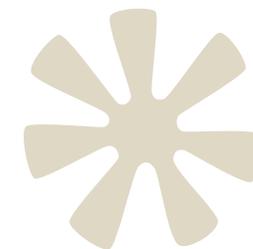
Farmyard manure is ideally collected and stored for a while before use. When used fresh the manure can inhibit crop growth considerably. Fresh manure can result in a temporary nitrogen lock-up, as it is used by the microorganisms to decompose the fresh manure, and it also does not contribute to improving soil humus. Animal manure with a small amount of litter is best composted or mixed with plant material for composting. Manure with a high proportion of litter, however, is best stored under anaerobic conditions. Compression of manure slows down decomposition and prevents overheating and thus reduces loss of nutrients. Collection of farmyard manure is easiest if the animals are kept in stables. For storage, the manure should be mixed with dry plant material such as straw, grass, crop residues or leaves to absorb the liquid. Straw that has been cut or mashed by spreading it out on a roadside can absorb more water than long straw.

The manure can either be stored next to the stable in covered heaps or pits. Or it is stored within the stable as bedding, provided it is covered with fresh



Discussion on investment in livestock

Encourage a discussion with the farmers on investments in livestock production. Discuss benefits of integration of livestock in the farm including income generating options such as dairy production, increase of overall farm productivity and improved access to animal manure for crop production. Which challenges do farmers see?





PRODUCTION OF PLANT TEA

How to make plant tea



bedding material. To minimize nutrient losses, the farmyard manure should be protected from sun, wind and rain. Ideally, a trench collects the liquid from the manure heap and the urine from the stable. A dam around the heap prevents uncontrolled in- and outflow of urine and water.

Water-logging as well as drying out should be avoided. If white fungus appears (threads and white spots), the manure is too dry and should be dampened with water or urine. A yellow-green colour and/or bad smell are signs that the manure is too wet and not sufficiently aerated. If the manure shows a brown to black colour throughout the heap, the conditions are ideal.

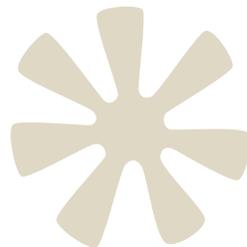
Storing manure in pits is particularly suitable for dry areas and dry seasons. Storage in pits reduces the risk of drying out and the need to water the pile. However, there is greater risk of water-logging and more effort is required, as the pit needs to be dug out. For this method a 90 cm deep pit is dug with a slight slope at the bottom. The bottom is compressed and then first covered with straw. The pit is filled with layers about 30 cm thick and each layer compressed and covered with a thin layer of earth. The pit is filled up until it stands about 30 cm above ground and then covered with 10 cm of soil.

The quality and value of manure can be improved by the following approaches:

- › Proper design of the animal housing to facilitate easy and efficient collection of manures.
- › Provision of adequate bedding material of straw or dry grass to capture as much excreta as possible. The more bedding is used the better.
- › Composted animal manure proves to be more efficient on yield in acidic, sandy soils than when applied directly, even if nitrogen is lost in the composting process.

7. Soil fertility supplements

In spite of proper soil organic matter management, application of farm-made or commercial organic or mineral fertilizers may be recommended to overcome distinct nutrient deficiencies. Deficiency may be due to unbalanced soil pH or slow release of nutrients from an organic source. Dry soil conditions or cold soils in high altitude may intensify the problem. Before choosing a specific fertilizer, farmers should know the reason for the problem. Use of external fertilizers





PRODUCTION OF MANURE TEA

How to make liquid animal manure



1. Fill a bag with manure.



2. Immerse the bag into a drum with fresh water and cover it. Stir the mixture every 3 to 5 days.

3. After 2 to 3 weeks dilute the mixture with 2 to 3 parts of water.

4. Apply to the foot of the plants.



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should only be the last step of an integrated approach soil fertility and plant nutrition. Reliance on the wrong fertilizer may be a waste of money. In case of signs of nutrient deficiency or slowed growth farm-own liquid organic fertilizers may boost plant growth. Such liquid fertilizers are simple to make and are available free of cost.

7.1. Natural liquid fertilizers

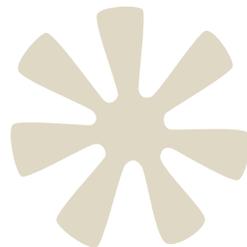
Liquid fertilizers are helpful to overcome temporary nutrient shortages and to stimulate plant growth. They can be made of animal manure, compost or green plant material. Liquid manures are made from animal manure and compost tea from ripe compost while plant tea is made from nitrogen rich plant materials. Liquid manures and plant tea are both a quick source of nitrogen, while compost tea is a nutritionally more balanced general fertilizer.

Liquid fertilizers are mostly used in vegetables, but can also be used for grains and other crops. Although all these liquid fertilizers may be made in the same way, manure tea is not generally recommended as foliar spray, but for application around the base of the plant. In case liquid manure is applied to the leaves in vegetable crops intended for raw consumption, a pre-harvest interval of at least 100 days is needed to avoid the risk of transferring human and animal pathogens.

Application of liquid fertilizers to the leaves is an interesting option in case of nutrient deficiencies, as plants absorb nutrients about 20 times faster through the leaves than through the roots. Besides promoting crop health and productivity, liquid manures that are applied to the leaves can also act as a good repellent for sucking insects, and may distort life cycles of some sap-sucking insects at the egg stage. They can also interfere with fungal spores.

7.1.1. Procedure for making plant tea

To make plant tea, nutrient rich material is soaked in water for several days or weeks to undergo fermentation. Frequent stirring encourages microbial activity. The resulting liquid can either be used as a foliar fertilizer or be applied to the soil.





ORGANIC FERTILIZERS

Fertilizers of organic origin for organic farming

| Fertilizer | Fertilizing effect | Availability of nitrogen | Origin | Comments |
|---------------------------------|--------------------|--------------------------|--|---|
| Guano | N, P | ●●● | Dried droppings of seabirds | <ul style="list-style-type: none"> P content higher than the plants' demand |
| Hoof and horn meal | N, P | ●●● | Slaughterhouse waste | <ul style="list-style-type: none"> The finer it is ground, the faster N is available |
| Algae | Minerals | ●●● | Seaweed | <ul style="list-style-type: none"> May contain heavy metals depending on the origin |
| Oil cakes | N, P | ●●● | By-products of oil production | <ul style="list-style-type: none"> Examples: castor cake, neem cake, peanut cake, rapeseed cake |
| Hair, wool, feathers | N | ●●● | Slaughterhouse waste, animal production | |
| Agro-industrial by-products | N, P, K | ●● | By-products from brewery, distillery, textile processing, hanks and peels, food processing | <ul style="list-style-type: none"> Must be free of significant contaminants Best composted before application to the land |
| Composts | N, P, K | ● | Mushroom waste, humus from worms and insects, urban and household wastes | <ul style="list-style-type: none"> Must be free of significant contaminants |
| Plant preparations and extracts | N, P, K | ●●● | Extracts of fresh or dried plants | <ul style="list-style-type: none"> The effect depends on the original material and can vary Older preparations are better for fertilization of plants |



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How to make plant tea:

- Chop the green plant materials like tithonia, velvet bean or any other sappy material, and put in a drum or any sizeable container until it is about three-quarters full. Fill with water and keep it under shade or cover to prevent excessive evaporation.
- Stir every three days and the mixture will be ready to apply in about 15 days.
- Remove the remains of the plant material, sieve the mixture and dilute the tea with 2 parts water for every 1 part of tea. Apply the diluted mixture as a top dressing, giving between ½ to ¼ litres per plant for as long as needed. Cover the remaining undiluted mixture in a cool place.

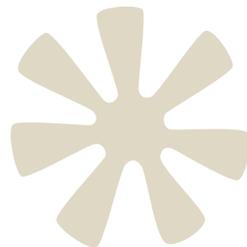
7.1.2. Procedure for making manure tea

Fresh manure from cattle, chicken, goats, sheep, rabbits or a mixture of any of these manures can be used. The procedure for making good manure tea is as follows:

- Fill a bag with about 50 kg of manure and tie it securely with a rope. Hang the bag with the manure to a pole placed over a 200 litre capacity drum to allow it to suspend into the drum, then fill the drum with water.
- Cover the drum with a polythene sheet to prevent nitrogen from escaping and let it stand under shade.
- Stir the mixture in the drum every 3–5 days by partially lifting the bag in and out of water several times using the pole.
- After 2–3 weeks, the water will have turned dark and most of the nutrients will have been dissolved into the water. The darker the colour, the more concentrated the mixture. It is then ready for use. Remove the bag with manure remains from the drum and the water solution is ready to dilute for use.
- Dilute the manure tea with 2 parts of water for every 1 part of tea. However, if the manure tea is very concentrated (very dark) use 3 parts of water to every 1 part of tea.
- Apply the manure tea to the crops, giving between 1/2 to 1/4 litres per plant starting 2–3 weeks after planting. Apply the manure tea around the stem and not on the leaves. Repeat the application every 3–4 weeks. Avoid application at full sunshine because of high risk of leaf burns and nutrient losses. Apply in the early morning or on cloudy days.



Ask the farmers to generate a list of commonly available commercial organic fertilizers in the region. Discuss some farmer experiences of using them and the results obtained.





MINERAL FERTILIZERS (PART 1)

Fertilizers of mineral origin for organic farming (1)

| Fertilizer | Origin | Characteristics | Application |
|--------------|---------------------------|--|---|
| Plant ashes | Burned organic material | <ul style="list-style-type: none"> Mineral composition similar to plants Easy uptake of the minerals Wood ashes rich in K and Ca | <ul style="list-style-type: none"> To compost (best) Around the base of the plants |
| Limestone | Ground limestone Algae | <ul style="list-style-type: none"> Buffers low pH (content of Ca and Mg secondary) Algae: rich in trace elements | <ul style="list-style-type: none"> Every two to three years when soil-pH is low (avoid excessive use, as it reduces availability of P and increases deficiencies in micro-nutrients) |
| Stone powder | Pulverised rock | <ul style="list-style-type: none"> Trace elements (depending on the composition of the source) The finer the grinding, the better the adsorbance | <ul style="list-style-type: none"> To farmyard manure (reduces volatilisation of N and encourages the transformation process) |



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MINERAL FERTILIZERS (PART 2)

Fertilizers of mineral origin for organic farming (2)

| Fertilizer | Origin | Characteristics | Application |
|-------------------|--|--|--|
| Mineral potassium | Natural potassium salts (e.g. sulfate of potash, muriate of potash, kainite, sylvanite, patenkali) | <ul style="list-style-type: none"> Sulphate of potash is easily available Patenkali: high contents of Mg and S; easily available In rock form slow reaction | <ul style="list-style-type: none"> Only in case of demonstrated deficiency |
| Rock phosphate | Pulverised rock containing P | <ul style="list-style-type: none"> Easily adsorbed to soil-minerals Weakly adsorbed to organic matter Slow reaction | <ul style="list-style-type: none"> To compost Not to reddish soils (as irreversibly adsorbed) and to soils with high pH |
| Clay | Natural | <ul style="list-style-type: none"> Good nutrient and water binding capacity | <ul style="list-style-type: none"> Large amounts required for soil improvement |
| Sulfur | Volcanic | <ul style="list-style-type: none"> Sulphate of potash is easily available, but can be washed out Elemental sulfur: slow reaction | |
| Trace elements | Anorganic or complexed salts | <ul style="list-style-type: none"> Complexed salts are more easily available to plants than anorganic salts, but are more expensive | <ul style="list-style-type: none"> Spraying onto plants where soil/plant nutrient deficiency is documented by soil or tissue testing or diagnosed |



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7.1.3. Application of compost tea

Compost tea can be used unfiltered by applying it directly to the soil area around a plant.

If it is used as a foliar spray, it must be strained tea through a fine mesh cloth first and diluted with good quality well or rain water at a ratio of 10 parts water to 1 part tea. The color should be that of a weak tea. Addition of 1/8 tablespoon of vegetable oil or mild dish-washing liquid per gallon helps the spray adhere to the leaves.

Application to the leaves should not be done during the heat of the day. Early morning or a cloudy day is best. Re-application is necessary after it rains.

7.2. Commercial fertilizers for organic farming

Based on the IFOAM Norms for Organic Production and Processing application of commercial fertilisers (including lime) is allowed in certified organic agriculture with some restrictions. While synthetic fertilizers such as urea are not permitted, use of commercial fertilizers should be justified by recommendations from soil or plant analysis. They must only be applied in their naturally occurring form and used in combination with other techniques such as addition of suitable organic matter, green manures, crop rotations and nitrogen fixing plants.

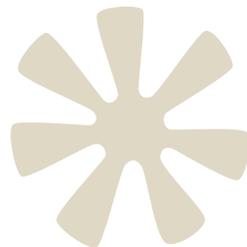
There are different commercial fertilizers available on the market that are produced from natural substances and do not contain chemical residues. To most African farmers, however, commercial organic fertilizers are not easily accessible mainly due to economic and physical barriers. They also tend to be quite expensive. Therefore, such fertilizers should only be used where using green manure and application of compost is not feasible or have not supplied sufficient nutrients for the crops, or where the crops show specific deficiency symptoms. In certified organic farming, it is the responsibility of the farmer to inquire from fellow organic farmers, trainers or certifying agents, whether a particular fertilizer is natural or not.

In many areas with the capacity to add lime in the case of acidic soils and sulphur in the case of alkaline soils, a conventional approach would be possible even if it did not represent the best solution. But considering constraints African farmers have to access fertilizers in general, large-scale liming or sulphuring appears to be an unsustainable approach to solve the problem. Thus, as a general



Discussion on commercial organic fertilizers

Generate together with the farmers a list of commonly available commercial organic fertilizers in the area. Discuss some farmer experiences of using them and the results obtained.





MICROORGANISMS

Some active ingredients of microbial fertilizers



- | | | | | |
|---|---|--|---|--|
| <p>Rhizobium</p> <ul style="list-style-type: none"> ▶ A bacterium ▶ Lives in soil, around and inside of the roots of legumes ▶ Forms a symbiosis with leguminous plants ▶ Fixes atmospheric nitrogen | <p>Azotobacter</p> <ul style="list-style-type: none"> ▶ A bacterium ▶ Lives free in the soil ▶ Can fix nitrogen | <p>Azospirillum</p> <ul style="list-style-type: none"> ▶ A bacterium ▶ Lives in soil ▶ Is able to live on its own in soil, or in close associations with plant roots ▶ A brasilense is able to fix nitrogen | <p>Pseudomonas</p> <ul style="list-style-type: none"> ▶ A diverse group of bacteria ▶ Can use a wide range of compounds that plants give off when their roots leak or die ▶ Various functions: e.g. Solubilizing phosphorus and making it available | <p>Mycorrhiza</p> <ul style="list-style-type: none"> ▶ A fungus-root symbiosis. Lives with the roots of nearly all plants ▶ Lives in the root and extends itself into the soil ▶ Helps the plant by gathering water and nutrients ▶ Improves soil structure |
|---|---|--|---|--|



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rule, commercial organic fertilizers should be mixed with other organic materials from the farm or composted together.

The East African Organic Product Standards (2007) permit the following fertilizers of mineral origin for East African organic farmers: basic slag, calcareous and magnesium amendments, limestone, gypsum, marl, maerl, chalk, sugar beet lime, calcium chloride, magnesium rock, kieserite and Epsom salt (magnesium sulphate), mineral potassium (such as sulphate of potash, muriate of potash, kainite, sylvanite, patentkali), natural phosphates, pulverized rock, stone meal, clay (such as bentonite, perlite, vermiculite, zeolite), sodium chloride, and sulphur. This list excludes Chilean nitrate.

Farmers are encouraged to consult with their extension agents or certifying agents before using any of these fertilizers as specific conditions might differ.

Commercial organic fertilizers

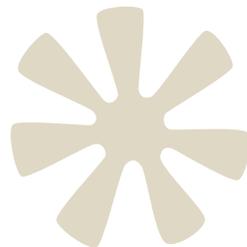
Commercial organic fertilizers are mostly by-products of agro-processing and food industrial waste. Examples include seed oil cakes (soybean, sunflower, neem, peanut), pelleted chicken manure, and agro-processing by-products such as brewery, fruit peels, coffee husks, wood shavings and dust, rice husks and plant ashes. Others include bone meal, feather meal, fish meal, horn and hoof meal, as well as commercially produced composts.

Commercial mineral fertilizers

Mineral fertilizers allowed in organic farming are based on ground natural sources and include lime, stone powder, rock phosphate, gypsum, potassium magnesium sulphate, sodium nitrate, vermiculite and other natural reserves like bat guano.

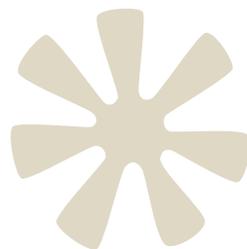
Microbial fertilizers

Microorganisms play an important role in the soil in providing nutrients to plants. Some microbes add nutrients to the soil through mineralisation. Others add nitrogen by fixing it from the atmosphere. These include Rhizobium, Azospirillum, and Azotobacter. Other microbes, such as Mycorrhizal fungi, help to supply plants with phosphorus. Pseudomonas species are a diverse group of bacteria that can use a wide range of compounds that plants give off when their roots leak or die. They are able to solubilize phosphorus and may help to suppress soil-borne plant diseases.



Some farmers and companies may recommend the application of microorganisms to the soil to enhance decomposition processes and control diseases. These microbial fertilizers are usually sold as ready-to-use products for application as sprays or with irrigation water, or for mixing with compost. These products contain living microorganisms and need to be stored and applied cautiously. Microbial products should be used before their expiry date. It is recommended to find out the effect of these products first by testing them on a small-scale and comparing results with the untreated plots.

Microbial fertilizers cannot substitute appropriate soil management practices on the farm. Most bacteria, fungi and other microorganism are naturally present in the soil and can be enhanced by proper application of compost.



8. Recommended publications and websites:

Recommended training materials:

Soil and water conservation:

- › Soil and Water Conservation in Organic Agriculture. Farmers' Training Notes. Kenya Organic Agriculture Network KOAN. www.koan.co.ke
- › Conservation Farming & Conservation Agriculture. Handbook for Hoe Farmers in Agro-Ecological Regions I & IIa - Flat Culture. 2009. Conservation Farming Unit. Zambia National Farmers Union. www.conservationagriculture.net
- › Conservation Farming & Conservation Agriculture. Handbook for Ox Farmers in Agro-Ecological Regions I & IIa. 2007. Conservation Farming Unit. Zambia National Farmers Union. www.conservationagriculture.net
- › Conservation Tillage with Oxen. Conservation Farming Handbook. No. 2. 2002. Study Circle Material. Land Management and Conservation Farming programme. Republic of Zambia. Ministry of Agriculture & Cooperatives
- › Combatting soil erosion. Sustainable production practices COLEACP.PIP. www.coleacp.org/pip

Composting:

- › Preparation and use of compost. Agrodok 8. 2005. Agromisa Foundation, NL. www.agromisa.org
- › Enriched Compost for Higher Yields. CTA Practical Guide Series, No. 7. 2007: Technical Centre for Agricultural and Rural Cooperation CTA, NL. www.anancy.net
- › Composting in the Tropics. 1998. Henry Doubleday Research Association HDRA. www.gardenorganic.org.uk
- › Composting in the Tropics II. 2001. Henry Doubleday Research Association HDRA. www.gardenorganic.org.uk

Green manuring:

- › Green fertiliser. Conservation Farming Handbook No.3. 2002. Study Circle Material. Land Management and Conservation Farming programme. Republic of Zambia. Ministry of Agriculture & Cooperatives
- › Green manure / cover crops for biomass transfer. Action sheet 39. www.paceproject.net
- › Green manure information leaflets from CIAT-Africa. www.ciat.cgiar.org
- › Green manure. Farmers' Training Notes. Kenya Organic Agriculture Network KOAN. www.koan.co.ke

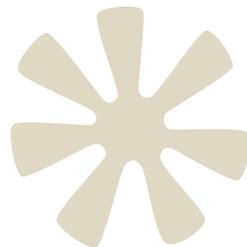
Use of animal manure:

- › Better manure, better crops. Kenya Agriculture Research Institute KARI, Henry Doubleday Research Association HDRA. www.kari.org

Recommended further readings for trainers and advisors:

Soil and water conservation:

- › Erosion control in the tropics. Agrodok 11. 2005. Agromisa Foundation, NL. www.agromisa.org
- › Producing in Harmony with Nature through Conservation Tillage. 2002. African Conservation Tillage Network. www.act-africa.org
- › Integrated soil management and conservation practices. 2000. FAO. www.fao.org
- › Water harvesting and soil moisture retention. Agrodok 13. 2005. Agromisa Foundation, NL. www.agromisa.org



- › Conservation Agriculture. A manual for farmers and extension workers in Africa. 2005. International Institute of Rural Reconstruction IRR; African Conservation Tillage Network ACT.

Soil fertility management:

- › Sustainable Land Management in Practice – Guidelines and Best Practices for Sub-Saharan Africa (2011). TerrAfrica, World Overview of Conservation Approaches and Technologies WOCAT and Food and Agriculture Organization of the United Nations FAO. www.wocat.net
- › Integrated soil, water and nutrient management in semi-arid Zimbabwe. Farmer Field School Facilitators' Manual, Vol. 1. 2005. Zimbabwe. FAO. www.fao.org
- › Integrated Soil Fertility Management in Africa: Principles, Practices and Development Process (2009). www.ciat.cgiar.org
- › Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan Africa. 2004. Academy Science Publishers ASP in association with the Tropical Soil Biology and Fertility Institute of CIAT. www.aasciences.org
- › Guidelines and Reference Material on integrated Soil and Nutrient Management and Conservation for Farmer Field Schools. 2000. FAO. www.fao.org
- › Farmer Field Schools Facilitators' Manual – Volume 1. Integrated Soil, Water and Nutrient Management in Semi-Arid Zimbabwe. 2005. FAO. www.fao.org
- › Sustainable Agriculture. Study circle material. 2007. Kasisi Agricultural Training Centre and Swedish Cooperative Centre. Zambia. www.loyno.edu; www.sccportal.org
- › Sustaining Growth. Soil fertility management in tropical smallholdings. 1994. Müller-Sämann & Kotschi. GTZ/CTA.
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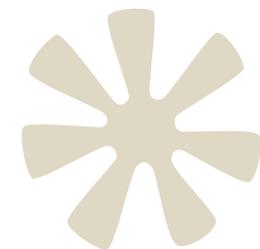
- › On-Farm Composting Methods. R.V. Misra, R.N. Roy, H. Hiraoka. 2003. Food and Agriculture Organization of the United Nations FAO. www.fao.org
- › How to make and use compost. Sue Edwards & Hailu Araya. 2010. Food and Agriculture Organization of the United Nations FAO. www.fao.org
- › On-farm composting methods. R.V. Misra & R. N. Roy: Food and Agriculture Organization of the United Nations FAO, Rome. www.fao.org

Green manuring:

- › Green manure crops. 1985. Echo technical note. Educational Concerns for Hunger Organization ECHO, US. www.echonet.org
- › Green Manure / Cover Crops and Crop Rotation in Conservation Agriculture on Small Farms. 2011. Plant Production and Protection Division. FAO. www.fao.org
- › Leaflets on green manure species. Henry Doubleday Research Association HDRA. www.gardenorganic.org.uk

Use of animal manure:

- › Manure Handling and Storage. Study Circle Manual. 2004. Kasisi Agricultural Training Centre and Swedish Cooperative Centre. Zambia. www.loyno.edu; www.sccportal.org



Useful websites:

- › www.organic-africa.net : Provides many links to training materials, which are available for free download
- › www.fao.org/ag/ca/: FAO's conservation agriculture website with information on cover crops, machinery and more
- › www.agriculturesnetwork.org: Resources on sustainable agriculture for trainers
- › www.fao.org/documents: FAO's Corporate Document Repository with documents on soil conservation practices, composting, green manuring and other topics
- › www.act-africa.org: Website of the African Conservation Tillage Network (ACT) with information on conservation tillage and related publications

