2 Soil Fertility Management
Learning targets for farmers:

- Understand that soil fertility management is neither limited to the addition of mineral fertilizers nor to increasing crop yield alone. It consists of protecting the soil and enhancing the organic matter content as well as biological activity in the soil to encourage optimal nutrition, water supply and health of plants and increases consistency of yields.
- Know the tools and approaches for organic soil fertility management and be able to combine them in an appropriate way so as to correspond to local conditions and combat soil degradation.

1. Introduction
Fertile land and sufficient water are vital for sustaining agriculture and livelihoods. Productivity of land, however, has been decreasing with the increasing intensification of agriculture. Though there are other constraints, the intensification of agriculture is a major factor contributing to the recurrent cycles of famine in many African regions. 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 changing 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.
- On forest land, biological degradation occurs through: deforestation; removal of valuable species through logging; replacement of natural forests with monocrop plantations or other land uses (which do not protect the land), which have consequences including biodiversity loss and soil and water degradation.
1.1 Factors influencing soil improvement in sub-Saharan Africa

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

- **Cultural beliefs.** The way land or soil is managed in many areas in Africa is deeply embedded in the cultural beliefs. Some common practices generally not good for soil fertility include cutting trees, bush burning and burning of crop residues.

- **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 numerous 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 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 unpredictable and high rainfall intensities cause severe flooding in some areas. Lack of water also limits crop growth and unpredictable rains make timely sowing and successful establishment of crops difficult.

Inappropriate use of synthetic fertilizers. Increases in harvests achieved by small farmers in the tropics in the last decades have largely been realized through the use of chemical fertilizers. Although the fertilizers have helped overcome some limitations of nutrients, mainly nitrogen, they have not significantly improved the productivity of the soil. This is because use of chemical synthetic fertilizers supplies plants with water-soluble nutrients. These nutrients readily mix with the soil water and are rapidly taken up by the plants, but they also become easily lost through erosion and leaching leading to soil and water contamination. Phosphorus fertilizers are often poorly available, as they are quickly absorbed and fixed in the soil.

1.2 What is fertile soil?

Fertility of soil is defined by its capacity to hold water and nutrients and supply them to plants when they need them, independent of direct application of nutrients. The more attention is given to farm-own resources and to nutrient cycling within the farm, the more important the efficiency of nutrient transfer in the soil becomes.

Transfer of nutrients from the soil’s organic matter to the mineral stage strongly depends on the soil organisms’ activity and diversity. Soil organisms also contribute to buildup of soil organic matter, including humus, the soil’s most important nutrient reservoir. When nutrients are bound in biological or organic form, they are neither lost nor bound to soil particles in a way which makes them unavailable to plants.

Therefore, soil fertility can be described in terms of soil organic matter content of the soil, with good living conditions for soil organisms and growing conditions for the roots, which are closely linked to soil structure, the availability of nutrients, the soil’s water holding capacity and its biological activity.
a. Soil structure

Plant roots prefer soil with a crumby 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 and access more nutrients to support good growth. The soil structure is the arrangement of soil particles forming big and small pores between soil aggregates. 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.

In soils with good structure, mineral particles and soil organic matter form stable crumbs or aggregates. This process is supported by soil organisms such as earthworms, bacteria and fungus. This makes it clear that soil structure can be improved by supplying organic matter to the soil and by enhancing the biological activity of the soil. At the same time, it also important to avoid incorrect soil management practices such as tilling the soil in wet conditions, which causes compaction.

b. Soil organic matter

Besides mineral particles, soil contains smaller or larger quantities of organic matter, which includes fresh or partially decomposed plant or animal residues or humus (well-decomposed organic matter). Though humus makes up only a few percent or even less than one percent of most agricultural soils in the tropics, it is of tremendous importance for the soil’s fertility.

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. In soils of good structure, mineral particles and soil organic matter form stable crumbs or aggregates. Organic matter works as a kind of glue, helping the soil particles to stick together.

Soil’s capacity to hold water and nutrients is closely linked to its humus content. Humus attracts, holds and interchanges nutrients from the soil’s water solution that otherwise may get lost through drainage. Doing so, humus slowly makes the nutrients available to the soil solution for plant uptake. In fertile soil, most nutrients are bound to soil humus. Organic matter also helps to buffer the soil against nutrient toxicities and extremes of soil pH.
The more soil organic matter a soil has, the more fertile it is likely to be. Soil organic matter is normally indicated by the colour of the soil. Darker soils with a brown/black colour tend to have more organic matter and are, hence, more fertile than lighter coloured soils.

c. 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.

d. Availability of nutrients

Commonly, the fertility of soil is determined by the presence of certain nutrients required by a given crop. This is normally determined in a laboratory through soil analysis.

   The nutrients can be divided into macro (major) and micro (minor) nutrients. Macro nutrients include nitrogen (N), phosphorus (P) and potassium (K). These major nutrients are usually depleted from the soil first because plants need them in large amounts for their growth and survival. The secondary macro nutrients are calcium (Ca), magnesium (Mg) and sulfur (S). These nutrients are usually available in sufficient amounts in the soil. Where soils are acidic lime is often added, which contains large amounts of calcium and magnesium. Sulfur 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 (as well as macronutrients) to growing plants.
e. Biological activity

A teaspoonful of fertile soil contains billions of soil organisms. Some can be seen with the naked eye such as earthworms, mites, spring-tails or termites, while others are so small that they can only be seen with a microscope and are called microorganisms. The most important microorganisms are bacteria, fungi, algae and protozoa.

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 and biologically active soils are the foundation for successful organic farming.

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

When we talk about fertility in the future we will be talking more and more about the power of biology. This will include the root system, biological activity of the roots, its micro-flora and beneficial fauna.

Among the most important soil organisms are the earthworms, termites, rhizobia (bacteria) and the mycorrhiza fungi.

Most farmers are well aware that the presence of earthworms is a sign of fertile soil. But what makes them so valuable? Earthworms fulfill 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 magnesia 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 water-logging.

Earthworms need sufficient supply of biomass, moderate temperatures and sufficient humidity and air. That’s why they are very fond of mulching. Frequent tillage and pesticides, on the other hand, decrease the number of earthworms in the soil.

Due to their high activity and biomass, termites 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.

Soil bacteria such as Rhizobium bacteria help some plants to fix nitrogen from the air. These bacteria grow in symbiosis in the roots of these plants and supply nitrogen while receiving energy from the plant roots in return. Where farmers use chemical nitrogen fertilizers, the bacteria stop fixing nitrogen – why should they work, when there is enough nitrogen?

A major part of the soil microbial biomass is composed of fungi. Important representatives of the soil fungi, the mycorrhizae, grow in symbiosis with about 90% of all plant roots. The plant roots provide sugar for the growth of mycorrhiza. In reverse, the fungus explores the soil and brings back water as well nutrients such as phosphate, zinc and copper that are not easily available to plants.

Mycorrhizae enlarge the rooting zone of plants and enter small soil pores, where plant roots cannot access. Researchers find root hairs extend only about 1 mm from the root surface while mycorrhizae can extend 15 cm based on their small size and web behavior. The capacity of roots that are in symbiosis with mycorrhizae to take up water and nutrients exceeds 10'000 times that of plant roots without its symbiotic partner. Mycorrhizae also dissolve minerals such as phosphorus, and carry them to the plant, make soil aggregates more stable, improving soil structure, and take plant carbon from the air and deposit into soil organic matter and stable soil aggregates.

Soil tillage, flooding, bare fallow and burning drastically harm the mycorrhizae. High nutrient levels (especially phosphorus) and chemical pesticides suppress the symbiosis. Whereas mixed cropping, crop rotation and the cultivation of perennial plants encourage mycorrhizae. Moderate soil temperature and moisture favor mycorrhizae.

Among the naturally occurring species of mycorrhizae, not all show the same efficiency in taking up phosphorus from the soil. That is why artificial inocula-
f. Other properties of fertile soil

Soil pH, its acidity or alkalinity, is highly relevant to how readily available nutrients become in soil, known as solubility. 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 and to improve. In both cases, modification of the pH in soil and an increase of soil organic matter content markedly improve nutrient availability and prevent nutrient toxicity.

Farmers may find getting their soil analysed in a laboratory helpful. 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 sample amount 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 spade diagnosis and dig a soil profile to better understand their soils, and in-
1.3 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 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 and the need to implement other soil conservation measures to maintain soil fertility.
2. Organic agriculture approach to soil fertility management

Proper soil fertility management is very important for successful organic crop production and farming. Organic farmers approach soil fertility management by protecting the soil and feeding it organic material, and then letting it 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.

2.1 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 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.

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.
2.2 Tools for 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 protecting the soil with mulch and reducing the movement of water with contour ridges and bunds, grass strips and terraces.
- Harvesting water with pits and water catchments.
- Application of reduced tillage to minimize soil distribution.

2nd step: Improvement of soil organic matter
These practices aim at enhancing the organic matter content of the soil as the basis for soil fertility and for management of plant nutrients and water. The practices related to it include:

- Growing green manures to provide large quantities of fresh plant material to the soil to feed the soil organisms and provide nutrients to the crops that follow.
- Composting to provide stable soil organic matter to the soil and improve its structure and water holding capacity.
- Recycling of valuable animal manures for composting or fertilization of the crops.

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 micronutrients. Specific measures may be necessary to speed up improvement of the growing conditions for plants. These supplementary measures include:

- Use of liquid manures that are easily available to plants.
- Use of commercial fertilizers to satisfy specific nutrient needs.
- 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.
Understandably, the tools of the 3rd 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.

3. 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 hill 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 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.
3.1 Soil erosion control

Soil erosion is the most serious form of soil degradation. It is the physical movement of soil particles and organic matter from a given site by the action of water or wind. First signs of the soil’s disposition to erosion are recognized by the separation of soil particles that often have a different color. 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).

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.

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

- 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 eventually be cleaned to bare ground.
- Overcultivation of cropland resulting in exhaustion of soil organic matter destroys soil structure and makes soils very susceptible to erosion.
- Utilisation of erosion susceptible areas without any soil conserving measures such as terracing, automatically results in soil erosion if no conservation measures are undertaken.
- 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.

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.

a. 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 especially a problem with annual crops where the land sometimes needs to be opened for planting and this time coincides with the rainy season. To avoid erosion during this period, crop residues can be used to cover the space between plant rows and digging or plowing can be done only in the planting strip.

i. Use of cover crops
Cover crops are short term crops planted to provide soil cover and improve soil fertility. They are planted as intercrops or during the no-crop or fallow seasons. They cover the soil and prevent weed growth. They are then pruned at the time of planting of the main crop or completely cut to act as mulching material.

   Basically, every plant which covers the soil and improves soil fertility can be a cover crop. It could be a leguminous plant with other beneficial effects, or it could be a weed characterised by its rapid growth and enormous production of biomass. The most important property of cover crops is their fast growth and the capacity of maintaining the soil permanently covered. Some cover crops can also be used as a source of food and feed. The following characteristics make an ideal cover crop:
   » The seeds are cheap, easy to get or to reproduce on the farm;
   » Grows fast and covers the soil in a short time;
   » Is resistant against pests and diseases;
   » Produces large amounts of organic matter and dry material for firewood and fencing material;
   » Tolerates drought;
   » Fixes nitrogen from the air and provide it to the soil;
   » Has a root system able to decompact soil and regenerate degraded soils;
   » Is easy to sow and to manage as single crop or associated with other crops;
   » Can be used as fodder, grains as food grains, medicines;
   » Does not transmit any pests or diseases to the main crop;
Cover crops can be grouped into legumes, grasses, leguminous shrubs and other crops such as pumpkin or watermelon, which also cover the soil well. Most common cover crop species include:

**Legumes:** Cowpea (*Vigna unguiculata*), Crotalaria (*Crotalaria spp*), Desmodium (*Desmodium intortum*), Jackbean (*Canavalia ensiformis*), Lablab (*Dolichos lablab*), Alfalfa (*Medicago sativa*), Mucuna or velvetbean (*Mucuna pruriens*), Mungbean or green gram (*Vigna radiata*), Pigeon pea (*Cajanus cajan*) and Siratro (*Macroptilium atropurpureum*).

**Grasses:** pearl millet (*Pennisetum glaucum*), Andropogon, gamba grass (*Andropogon gayanus*).

**Leguminous shrubs:** Sunn hemp (*Crotalaria juncea*), calliandra (*Calliandra spp.*), Gliricidia (*Gliricidia sepium*), Sesbania (*Sesbania sesban*), Tephrosia (*Tephrosia candida*)

Usually legumes are preferred, as they fix nitrogen from the air and decompose quickly when cut. This means that the nutrients become available to the next crop. For a lasting 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 food.

Example: Cowpea as a cover crop

Cowpea (*Vigna unguiculata*, French: Niébé) is an important grain legume throughout the tropics and subtropics. It has some properties that make it an ideal cover crop:

- It is drought tolerant and can grow with very little water.
- It can fix nitrogen and grows even in very poor soils.
- It is shade-tolerant and therefore compatible as an intercrop.
- It yields eatable grains and can be used as an animal fodder rich in protein.
- It is resistant to pest attack.

Subsistence farmers in sub-Saharan Africa usually intercrop cowpea in maize, sorghum, millet and cassava.

Ideally cover crops contribute to a more or less permanent cover of the soil in an existing cropping system. To choose the right species, cover crops must match the local crops and local climatic and soil conditions. Cover crops should not compete with the main crop for nutrients, water and light.
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 should be grown on different fields. With food crops, cover crops should also be rotated to avoid buildup of pests and diseases.

Recommended practices for sowing cover crops vary depending on the cropping 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 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.

**Mulching**

Mulching is the process of covering the topsoil with plant material such as leaves, grass, twigs, crop residues or straw. Covering the soil with a mulch cover 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 rhizo-

**Exercise:**

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.
ADVENTAGES OF MULCHING

Why use mulch?

- Stringy material
- Pruned foliage
- Natural chaff
- Mulched surface
- Soil biological structure
- Water infiltration
- Reduced runoff
- Plant growth
- Mixing of nutrients

APPLICATION OF MULCH

How to build contour bunds with catchment strips

1. Mix compost with the soil
2. Spread the material over the bunds
3. Mulch on top of the bunds

bacteria and mycorrhiza. Earthworms help to build soil humus and create a good soil structure encouraging easy infiltration of water into the soil, thus reducing surface runoff. Rhizobia and mycorrhiza can live in symbiosis with plant roots and improve nutrient supply of crops. 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 humus, increasing soil 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 mulch 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 providing nutrients to the crops while decomposing. 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 material (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. 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 rare, and production or collection usually involves a considerable amount of labour and thus may compete with the production of crops. Especially in such climates, however, application of mulches is worthwhile.
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?

In specific situations some 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 stem borers may survive in the stalks of crops like cotton, corn or sugar cane. 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 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 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.

b. Reducing movement of water
i. Contour 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
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.

How to make 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.
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.

ii. Grass strips

Fodder grasses such as vetiver grass (*Vetiveria 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 run-off 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 legumi-
nous fodder trees such as *Leucaena diversifolia*, *Calliandra calothyrsus*, *Sesbania sesban*, *Gliricidia sepium*.

### 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?

### iii. Terracing
Mechanical measures for controlling erosion are usually more costly than those that depend primarily on vegetation. They require more labor, 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 where it will cause no damage, such as man-made ponds or natural water ways. 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.

- **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.
c. Conservation of 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.

3.2 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 water 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 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.

### 3.3 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.

Most farmers, who plough their land, must wait for the rains to cultivate the soil. Thus 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.

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. 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 renounce herbicides and chemical fertilizers, may require specific adaptations to prevent weed problems and ensure appropriate plant nutrition.
a. 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 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 a 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, subsoiling 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.

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.

Discussion

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?
b. 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 buildup 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 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.

4. 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.
SOURCES OF ORGANIC MATTER

Plant nutrition in organic farming focuses on sound humus management. If the soil is well managed, soil organic matter remains stable. Mineralisation or decomposition of humus increases if temperature, oxygen and moisture conditions become favourable for decomposition, which often occurs with excessive tillage.

Building soil organic matter is a long-term process. But investing into building soil organic matter is highly beneficial to crop or forage production.

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, which break down slowly, or rolling crop residues or a green manure crop as a dry soil protection, also contributes to an 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.
> Crop 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.
Assessment of sources of organic matter
Assess together with the farmers available sources of organic matter in the local context.

- How are they used by the farmers?
- What are the potentials and constraints related to their use?
- What sources remained unused so far?
- How can the use of organic materials be improved?

Depending on the financial situation of the farm, additional materials either from agro processing or food industry can be purchased into the farm. For example, products from primary processing like wood shavings, or coffee or rice husks.

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 influences 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 percent 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 derive from incorporating organic matter are lost and if the plant material is burned, the atmosphere 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.

Proper management of soil organic matter requires some basic knowledge of dynamics of soil organic matter. The main processes include:

- Aeration of the soil in combination with increasing humidity and temperatures increase activity of soil-borne bacteria and thus enhance decomposition of biomass in the soil. The same conditions also enhance humus production (10 to 20 percent of biomass is transformed into humus) and its decomposition. Bacterial decomposition reaches its maximum at 30 to 35 °C.

- Under dry conditions soil biological activity is strongly reduced resulting in a standstill of transformation processes.
4.1 Green Manuring

Green manuring means growing plants with the primary purpose of incorporating them into the soil to improve its structure and nutrient content and thus its fertility. Cover crops and green manures are near synonyms. While the main purpose of growing cover crops may be to cover the soil with a low vegetation cover to protect it from 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, 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.

Farmers in certain 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. But the potential of green manuring is not nearly as well used in Africa as it could be.

There are, however, also some challenges and constraints related to the adoption of green manuring.

- Scarcity of cropland can be a constraint to growing green manures. In spite of the advantages of green manures, many farmers cannot afford to give up cropland to grow a soil amendment. There are though a number of ways to grow green manures without reducing land for other crops. This can be done by growing the green manure among traditional row crops, or by relayed intercropping of the green manure when crop harvest nears, so the green manure will primarily grow during the dry season. Or the green manure, for example jack bean or velvet bean, is 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 green manure requires far less water than is needed for composting. The plants get the water themselves and take advantage of available rainwater.
- Green manuring creates extra work.
- Also, seed may not be easily available.
4.1.1 Benefits of green manures

**Improvement of soil fertility**
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.

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 dug 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.

Legumes and other nitrogen fixing plants can provide considerable amounts of nitrogen to the soil and are particularly beneficial.

**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.

**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.

**No transportation**
As green manure crops are mostly grown in-field and usually do not require any transportation, in contrast to compost or other fertilizers.
4.1.2 Choice of green manures
Most farmers do not effectively use green manures because they do not know which species to plant and how to include them in the farming system. It is, therefore, important to plan which species to plant, where, when and how to plant them in order to obtain good results.

When choosing green manure plants to use, the following points 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 have few enough natural enemies and suit local climate and soil to 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.
> The seeds should be readily available and affordable. For long term sustainability, a farmer’s own seed should be easily producable. If the green manure crop is cut down before seeds have ripened, seeds must be produced on a separate small plot.
> 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.

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. 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. Normally, green manures with light seeds easily blown by wind or creeping stems are problematic to control. 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. 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.

4.1.3 Integrating green manures into the farming system
There are different ways of integrating green manures into the farming system.

a. Green manures in a crop rotation
Integration of green manures in crop rotations is important in organic farming because it contributes to a balanced rotation maintaining soil fertility. Green manures are particularly useful when grown before crops which need a lot of nutrients.

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 nutrients to leach out of the soil. Or they are placed as break crops in a rotation between closely related crop species for pest and disease control.

The time lag between digging in the green manure and planting the next crop should not be more than two weeks in rainy periods, to prevent nutrients from the green manure leaching out of the soil, before being taken up by the next crop.

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. The major growth of green manure occurs during the dry season after the harvest of the crop. It thereby uses land that normally would not be under cultivation. This procedure has the further advantage that no extra time is needed for preparing the land and sowing the green manure.

Sowing is often combined with weeding. The green manure seeds are then broadcasted after the weeding, for example in maize after the second weeding.
c. Long-term green manures
Green manures can be grown for more than one season in the following ways:
› Green manures planted in a bush-fallow system to restore poor soil. They are broadcast and left to grow uninterrupted for as long as required.
› 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 (see transparency 30).
› They can also be grown to build biomass, which can be 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
Agroforestry is the practice of growing trees or shrubs together with crops. The trees or shrubs act as long-term green manures, where the leaves are distributed on the field and dug into the soil. For example, every sixth row, pigeon pea trees can be intercropped with traditional grain crops. At the end of the season the crop residues are gathered under the pigeon pea plants and left for decomposition together with pigeon pea leaves. After six months the mixture is distributed 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.

4.1.4 Management of green manures
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. The ideal seed density depends on the species chosen and must be tested for each individual situation. For germination and growth, green manures need water as well. In general, when legumes are grown, no additional fertilization is necessary.

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 down.
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 on their own, 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.

### 4.2 Composting

**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 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.

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. Nutrient losses are lowest under such conditions, when crop residues are recycled through composting compared to mineral fertilization. Compost also increases the effect of even small amounts of manure, when applied to crops. 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.

Depleted soils in arid climates can be made arable again by applying 10 tons of compost per hectare over several years.

**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.

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. 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 a good compost during the wet season as the rain saves on labour for watering.

Introduction of 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.

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.

4.2.1 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 from 60–70 °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 bacte-
Composting process

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 odor, 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 from 25–45 °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 color and the smell of fertile soil and is ready to use. Water requirements during this phase are low.

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

4.2.2 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 leveled ground minimizes the risk of sieving out of nutrients by run-off 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 making

Ideally composting plant material is a mixture of 50 percent different fresh green material and 50 percent of dry material. The rate of coarse material should not exceed 10 percent. 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 lacks 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.

Besides crop residues, materials from shrubs such as tithonia, glyricidia, leucaena, sesbania, crotalaria and lantana leaves are good materials to use as well.

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 mixed with the other material 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.

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 prickers or thorns, which may hurt the persons
Practical demonstration: 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.

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

Only the heap/pit method and vermi-composting are described in further detail here.

Procedure of 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 5–10 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 presoaked 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.
Maintenance of 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.

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 seed-
Compost should not be ploughed deeply into the soil. Compost can also be hoed into the topsoil as a top dressing.

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.

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.

4.2.3 Vermicomposting

Vermicomposting is the method where compost is prepared using specially introduced earthworms, Red Wigglers (Lumbricus rubellus or Eisenia fetida), 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 color, 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.
4.3 Farmyard manure

Many farmers still underestimate the value of animal manure. In many places, farmyard manure is dried and burned for cooking or is 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. Farmyard manure is extremely valuable organic manure. 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.

Farmyard manure contains large amounts of nutrients. The availability of phosphorus and potassium from farmyard manure is similar to that of chemical fertilizers. Chicken manure is rich in phosphorus. When dung and urine from cattle are mixed, they form a well-balanced source of nutrients for plants.

Improving the value of animal manure

Farmyard manure is ideally collected and stored for a while, as fresh manure can inhibit crop growth considerably. Fresh manure can result in a temporary nitrogen block and 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. Stamping 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 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.
5. Soil fertility supplements

In spite of proper soil organic matter management, application of 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 should only be the last step of an integrated approach to soil and plant fertility. 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.

5.1 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 and also fungal spores.
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.

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.

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:
1. 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.
2. Cover the drum with a polythene sheet to prevent nitrogen from escaping and let it stand under shade.
3. 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.
4. 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.
5. 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.
6. 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 leave burns and nutrient losses. Apply in the early morning or on cloudy days.

**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.

**5.2. Commercial fertilizers in organic farming**

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. 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 or trainers 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 the fertilizers in general, large-scale liming or sulphuring appears to be an unsustainable approach to solve the problem. Thus, as a general rule, commercial organic fertilizers should be mixed with other organic materials from the farm or composted together.

*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.*
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.

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 and Azotobacter. Other microbes, such as Mycorrhizal fungi, help to supply plants with phosphorus. Azospirillum and Azotobacter are bacteria that can fix nitrogen. 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, mixture with compost or with irrigation water. These products have living microorganisms and need to be stored and applied cautiously. Make sure they are not expired before using and it is important to find out the effect of these products first by testing on a small-scale and comparing results with the untreated plots.

It should, however, be noted that microbial fertilizers cannot substitute an appropriate soil management practice on the farm. Most of the bacteria, fungi and other microorganism are naturally present in the soil and can be enhanced by proper application of compost.

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