AGRONOMIC PRACTICES FOR WATER MANAGEMENT UNDER SMALLHOLDER RAINFED AGRICULTURE

Nile Basin Initiative – NELSAP

Regional Agricultural Trade and Productivity Project (RATP)

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AGRONOMIC PRACTICES FOR WATER MANAGEMENT UNDER SMALLHOLDER RAINFED AGRICULTURE

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About this Training Manual

The Nile Basin Initiative (NBI) is a partnership of the riparian states (Burundi, Democratic Republic of Congo, Egypt, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda**,** Eritrea is participating actively in the NBI as an observer) that seeks to develop the river in a cooperative manner, share substantial socioeconomic benefits, and promote regional peace and security through its shared vision of "sustainable socioeconomic development through the equitable utilization of, and benefit from, the common Nile Basin water resources". NBI's *Strategic Action Program* is made up of the *Shared Vision Program (SVP) and Subsidiary Action Programs (SAPs).* The SAPs are mandated to initiate concrete investments and action on the ground in the *Eastern Nile (ENSAP) and Nile Equatorial Lakes sub-basins (NELSAP).*

NELSAP through its sub basin programs implements pre-investment programs in the areas of power, trade and development and natural resources management. As part of its pre-investment framework, the Regional Agricultural Trade and productivity Project (RATP), in concert with the NELSAP, intends to promote and disseminate best practices on water harvesting and small scale irrigation development as a contribution towards agricultural development in the NEL Countries. NELSAP has previously implemented completed a project called Efficient Water Use for Agriculture Project (EWUAP). One of the recommendations of EWUAP was the need to develop Training/Dissemination materials on "*adoption of low cost technologies for water storage, conveyance, distribution, treatment and use for agriculture that can be adapted by communities and households of the rural and peri-urban poor*". This Training Manual is the initiative of NELSAP, for that purpose.

This Training Manual summarizes the major components of water conservation techniques practiced in rainfed smallholder agriculture. It focuses more on soil moisture retention and soil fertility management. It covers four specific technologies adaptable by smallholder farmers in the Nile Basin countries. These are; crop husbandry, vegetative barriers, cover crops, mulches, soil nutrient management, conservation tillage and agroforestry. For each intervention, the salient characteristics of the technology are described, as well as the design, management and maintenance.

This manual is meant to improve the skills of engineers, technicians, extension workers, managers and practitioners engaged in soil and water management, especially those working in smallholder agriculture in Africa. It is meant to inform, educate, enhance knowledge and practice targeting smallholder agricultural livelihoods in the NEL region. The information contained here may not be exhaustive and thus, readers are encouraged to seek further information from references cited in this publication and elsewhere.

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Table of Contents

Definition of Key Terms

Term	Definition/Brief description
ASAL	Arid and semi-arid lands
Available water	The amount of water held in a soil that plants can use.
Available water holding capacity	The total amount of water a soil profile can hold for plant uptake. It depends on soil depth, texture, structure and organic matter content.
Bulk density	The apparent density of a soil, measured by determining the oven-dry mass of soil per unit volume
Compost	The decomposed organic matter that includes one or more of the ingredients like farmyard manure, slurry, compost manure, crop residues, kitchen wastes, hedge cuttings, grain husks and other materials.
Conservation farming	The holistic application of conservation tillage alongside other agronomic practices (e.g. manuring, crop rotations, mulching) to reduce labour and preserve the natural state of the soil. Also called conservation agriculture.
Conservation tillage	Tillage that tries to preserve the soil, water, crop residues and biological status of the soil with as little disturbance as necessary.
Contour (line)	An imaginary line joining all points of the same elevation on a land surface.
Conventional tillage	Land preparation that involves several soil turning and operations such as digging, ploughing, discing, harrowing, rotavating, or a combination of several soil turning operations depending on the crops to be grown
Cover crops	Crops grown to cover the soil during the cropping season, fallow periods or between harvest and planting of commercial crops.
Crop rotation	Planting different crops on the same piece of land every successive season
Cultivation	Tillage operations before or after planting to keep the crop free of weeds.
Deep percolation	Downward movement of water below the root zone under the force of gravity, eventually arriving at the water table.
Depression storage	Temporary holding of rainfall in crevices, hollows and surface depressions
Diversion ditch	A channel made across the slope to protect cultivated land from external runoff, normally with a gradient of 0.25-0.5%, also called cut-off drain
Evaporation	The amount of water that leaves a water surface or land as vapor. Evaporation can be beneficial or non-beneficial.
Farmyard manure	Animal droppings from domestic livestock such as cattle, goats, sheep, pigs, chicken including the sweepings, urine, remnants of fodder and animal beddings
Field capacity (FC)	The maximum amount of water held in a soil, measured a few days after it has been thoroughly soaked and allowed to drain freely.
Green manure	Leguminous green vegetation grown for the sole purpose of improving soil fertility, and which is incorporated into the soil during cultivation

Horizontal interval	The horizontal distance between two conservation structures
Hydraulic conductivity	The rate at which water can pass through a soil material, usually measured under saturated conditions to ensure water is moving through the soil via gravity and positive head pressure.
Infiltration	Entry, absorption and downward movement of water into the soil
Infiltration capacity	Limiting rate at which falling rain can be absorbed by a soil surface in the process of infiltration.
Infiltration rate	The rate at which water enters the soil profile. Infiltration rate can be relatively fast, especially as water enters into pores and cracks of dry soil. As the soil wets up and becomes saturated, the infiltration rate slows to the point where surface runoff occurs.
Interception	Catching and holding of rainfall above the ground surface by leaves, stems and residues of plants
Interflow	Movement of soil water through a permeable layer in a downslope direction parallel with the ground surface, also called throughflow
LEISA	Low External-Input Sustainable Agriculture technologies
Liquid Limit	The moisture content at which a soil begins to flow and behave like a liquid.
Liquid manure	A mixture of farmyard manure, urine, green manure and other soil nutrient additives which is prepared in liquefied form
Minimum tillage	Reduced tillage operations on a farm to the bare minimum required for crop production
Mulch	A layer of crop residue or other material, placed on the soil surface.
Mulching	The practice of covering cropped land with a layer of loose material such as dry grass, straw, crop residues, leaves, compost inorganic covers.
Nitrogen-fixing	The ability of certain small organisms (bacteria, algae) to convert atmospheric nitrogen into a form which can be used by plants. These organisms live on or near the roots of legumes
Organic farming	Growing crops without the use of artificial inorganic fertilizers, chemical pesticides and other "external" additives
Overland flow	Water flowing over a sloping ground surface to join a channel or stream
Overtopping	Water flowing over the top of a bund or ridge, and is usually undesirable
Perennial (crop)	A plant that lives for three or more years and which normally flowers and fruits at least in its second and subsequent years.
Permaculture	A system of farming in which farmland is maintained under some crop cover throughout the year. It is also known as permanent soil cover.
Permanent wilting point (PWP)	The soil water content at which water is no longer available to plants, which causes them to wilt because they cannot extract enough water to meet their requirements.
Plastic limit	The moisture content at which a soil changes from a semi-solid to a plastic state

Rainfed agriculture	Agricultural systems whereby natural rainfall is the predominant source of water for growing crops, trees or pasture on that field. It also includes crops grown with flood flows harvested from excess rainfall runoff.
Salinity	Soils having high concentration of soluble salts
Saturation	The moisture content at which all soil pores are completely water-filled.
Semi-arid	Fairly dry climate with average annual rainfall of about 300-700 mm, with high variability in rainfall.
Slope gradient	The angle of inclination of a slope, which may be expressed in degrees or as a percentage.
Slurry	A mixture of animal dung, urine and water.
Soil and water conservation (SWC)	Activities that maintain or enhance the productive capacity of land in areas affected by or prone to soil erosion.
Soil erosion	The movement of soil from one part of the land to another through the action of wind or water.
Soil fertility	The capacity of a soil to produce crops by supplying nutrients (macro and micro) in correct proportion and in adequate amounts over a long time.
Soil moisture	Water held in the soil and available to plants through their root system, also called soil water.
Soil moisture profile	The depth to which water infiltrates into the soil, also called infiltration boundary
Soil porosity	The percentage of a given volume of soil that is made up of pore spaces. Soils are oven-dried to measure bulk density, so porosity is a measure of air-filled pore space
Sub-humid	A humid climate with average annual rainfall of roughly 700-1000 mm.
Surface runoff	Excess rainfall which runs off the surface of the land, it includes both overland flow and stream-flow
Surface sealing	When soil forms a sort of clay cement after rain, because the finest grains clog the soil pores, preventing water infiltration. Also called clogging up
Sustainable land management (SLM)	The use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions.
Terrace	A piece of land whose slope steepness and/or length has been reduced by either construction works, or by creating barriers across the slope, so as to absorb and/or reduce surface runoff
Tillage	Preparation of the land for planting, or all the operations undertaken to prepare a seed bed in agriculture
Transpiration	Water that is taken up by plants from the soil and then lost to the air through small openings in the leaves of plants.
Vertical interval	Spacing between two conservation structures determined on the basis of the difference in ground elevation, also referred to as vertical distance.

Vertisol	A type of montimorillonitic clay (also called black cotton soil) with high clay content, which cracks when dry and is difficult to till when wet
Water conservation	The control, protection, storage, management and utilization of water resources in such a way as to optimize productivity
Water harvesting	Activities where water from rainfall and/or surface runoff is collected, diverted, stored and utilized.
Water logging	State of land where the water table is located at or near the surface resulting in poorly drained soils, adversely affecting crop production
Water storage capacity	Maximum capacity of soil to hold water against the pull of gravity, also called field capacity
Water table	Upper limit of the ground water

1. INTRODUCTION

1.1 Water management in rainfed agriculture

Water management in rainfed agriculture includes the conservation, control, protection, storage and utilization of water resources in such a way as to optimize crop and livestock production using natural rainfall. It also includes managing water for ecosystem services and natural habitats. Water management involves:

(i) Making optimal use of rainfall,

(ii) Reducing water losses (through runoff, evaporation, unnecessary transpiration,)

(iii) Increasing efficiency of irrigation water use,

(iv) Selecting best suited crops and cropping methods,

(v) Reducing losses of stored water and in conveyance

(vi) Improving water availability (e.g. through soil moisture storage, aquifer recharge).

Water management therefore improves the availability of rainwater, surface runoff or irrigation water for agricultural purposes, reduces the present size of water demand and protects water resources from being polluted or wasted. Water management also involves selecting best suited crops and cropping methods, using crops of high water use efficiency, making use of structures, practices and technologies that are efficient in water capture and soil moisture retention. Sometimes, water conservation on its own is enough to ensure crop production improvements, especially where water harvesting is either not feasible or desired. Rainfed water management is closely related to soil and water conservation.

1.2 Agronomic conservation practices

Agronomic measures involve land husbandry, cropping, use of equipment and vegetative measures and all the crop husbandry activities that are implemented on a farm, from land preparation to harvesting (figure 1.1). There is little earth moving or re-shaping of land. Instead terraces may form naturally through erosion and deposition. These methods used encompass a range of technologies and practices that facilitate optimal moisture retention in the soil and its use by desirable plants such as crops and pastures. Agronomic measures on their own are best suited to high rainfall areas and areas on gentle slopes, but they are even more beneficial in semiarid zones and areas with steep slopes when combined with structural methods.

Direct conservation of rainwater in the soil is sometimes referred to as ***in-situ water harvesting, or in-situ conservation.*** These are techniques which optimise the retention of direct rain falling on a piece of land, through improved infiltration and reduction of other losses such as runoff and evaporation (Figure 1.1). It is distinguished from water harvesting in that there is no deliberate effort to channel water from some other area (or catchment) onto the target cropped land.

Sustainable Land Management (SLM), on the other hand, is a broader term to encompass the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions. This training manual is part of a series of ten manuals, which put together, relate to SLM. This particular manual, however, focuses on water conservation in rainfed systems under smallholder agriculture.

Figure 1.1 Example of Agronomic conservation measures *(photos by A. Rakotondralambo)*

1.3 The case for water conservation

Water conservation is necessary in all agricultural systems, be they large scale or small-scale, mechanized or manual, commercial or subsistence, in wet areas or dry areas, fertile or infertile soils, cultivated food crops or in pasture lands, poor or rich farmers. However, whereas water conservation in very wet areas or wetlands involves some amount of land drainage (see Training Manual 9 in these series), this particular training manual is more concerned with water conservation under smallholder agriculture in the low to medium rainfall areas, which cover vast areas of Africa.

Typically, the arid, semi-arid and dry sub-humid areas (ASALs) receive low rainfall amounts spread within a few months, or weeks of the year. The rainfall events are erratic and unreliable even during the rainy season, falling in a few, heavy storms. As a result, soil water retention is poor as much of the rain water runs off the surface, causing flooding and soil erosion.

Another feature of African soils is that they are highly weathered with low organic matter contents, thus poor fertility and in low water retention properties. In some cases, the soils e.g. Alfisols and Luvisols, have soil sealing properties which inhibit infiltration, further increasing the incidence of surface runoff even after small storms.

High evaporation losses are another problem hampering crop production in smallholder farms. The high diurnal temperatures coupled with poor land cover result in much of the soil moisture getting lost as unproductive evaporation.

Another factor is rudimentary tillage practices such as use of the animal-drawn plough which creates a hard pan within the topsoil profile, further inhibiting infiltration. Poor agronomic practices such as failure to use manure or fertilizers, poor cover on the soil, and all activities that increase runoff are to blame for declining soil fertility. Therefore, water conservation practices are needed that prevent water from damaging the land but rather improve the absorptive capacity of the land to hold more water, just where it falls (in-situ conservation).

1.4 Advantages of water conservation

- Conserving water makes it available for crops, livestock and domestic use over a longer period.
- Controlling soil erosion improves crop or pasture yields.
- Conservation measures improve the supply of fuel and forest products.
- They increase the value of the land.
- Terraces make cultivating steep slopes easier.
- More and better livestock fodder is available, for example from grass strips, hedge barriers and terrace embankments.
- Employment opportunities in soil- and water-conservation work increase.

1.5 Limitations faced

- Fragmented land ownership makes it difficult for farmers to invest optimally in soil and water management systems.
- Agronomic water and soil conservation requires lot of labour
- The farmer still has to rely on natural rainfall (unlike irrigated systems), thus there are weather-related risks including very low rainfall or floods.
- extremes can cause damage to crop production

1.6 Basic principles of improving water management

There are many ways of improving soil-moisture storage and conservation, some of which are described elsewhere in the Training Manuals 1, 5 and 7 of these series). They can be divided broadly into physical conservation structures and agronomic measures. Physical measures (described in Training Manual 5) involve building permanent structures, usually of soil or stone, to control the flow of water. Agronomic or vegetative measures are covered by this manual include the use of vegetation, soil fertility enhancement and various tillage practices. In general the basic principles are the same as the ones described below:

(a) Improving soil infiltration

The basic principle for improving infiltration is by loosening soil and creating roughness on the surface. Depending on the characteristics of both the soil and rainfall, the methods includes ripping, deep chiseling, surface covers, contour plowing, ridging and pitting techniques.

(b) Reducing evaporation losses from the root zone

The main source of water loss from the root zone is through evaporation from bare soil and transpiration by weeds. The aim should be to reduce these losses and allow most of the water in the root zone to be transpired by useful crops. There is a strong relationship between crop transpiration and dry matter production. Based on the nature of evaporation process, surface covers using mulches and crop canopy will reduce evaporation. However, most mulches will increase evaporation during dry spells by prolonging the first stage of evaporation. Tillage is also an effective way of controlling evaporation by disrupting capillary continuity. Therefore, weed control is an important soil and water conservation measure. The weeds should be controlled when still very young, so as to effectively control the loss of water.

(c) Improving soil fertility

The effective utilization of water is important. Thus, soil water management goes with improvements in soil fertility so as to get due benefits of water conservation. Water conservation on soils which are infertile results in wastage of resources. The reverse is also true, that is, applying fertilizers where the soil-moisture is limited does not yield much. Thus, although shortage of soil-moisture is often the bigger constraint, improved soil fertility has high returns on investment in the long run.

(d) Improving crop water-use and productivity

Several agronomic practices are used for ensuring that crops use soil-water effectively and productively. These include:

- Selection of crops and varieties having growth patterns which match the soil-water availability patterns of the given locality.
- The adjustment of sowing times so as to ensure that the periods of critical water requirement by plants coincide with the periods of adequate available soil-water.
- A judicious fertilizer use commensurate with the status of soil, nutrient needs of crops, plant population and an available soil-moisture.
- Crop rotation including fallowing for purpose of using the difference in crop characteristics to restore soil structure and fertility.
- Limited supplementary irrigation to carry the crop through a particularly damaging dry spell.

(e) Technologies and practices

These technological practices for implementing water conservation without structural measures can be categorized as follows:

(i) Agronomic crop management practices,

(ii) Use of vegetative barriers,

(iii) Soil nutrient management,

(iv) Mulching,

(v) Conservation tillage, and

(vi) Agroforestry

2. AGRONOMIC CROP MANAGEMENT PRACTICES

Agronomic practices are all the preparatory and crop husbandry activities that are implemented on a farm during the crop production, starting from land preparation till harvesting. Ensuring a healthy crop stand is in itself a water conservation measure. This is because a good crop stand covers the soil well, sustainably makes use of nutrients and protects the land from excessive evaporation as most of the water is transpired as productive water consumption. The main reason for water conservation is to achieve increased productivity, which is affected by other factors such as seed type, variety, crop spacing, date of planting, weed control, fertility, pest and disease management. The agronomic practices relating to water management that support crop production include the following:

2.1 Crop husbandry

Crop husbandry or how well the crop is managed in the field is also a water management intervention, because it affects the overall value of water to crop productivity. There are many operations depending on crop type, climate, available technology and labour. However, good crop husbandry includes; early or optimum planting schedules, e.g. dry seeding, improved tillage and field preparation, use of best crop variety available, soil fertility, weed control, pest and disease management as well as appropriate timing of all operations. Good crop management reduces soil erosion by water and wind to tolerable levels and can improve soil fertility. Selection of appropriate crops for the soil and slope, use of suitable cropping systems and rotations to keep the soil covered.

2.1.1 Crop selection

Crop selection, in itself is a water management intervention because the crop should match the amount of water available for optimum production. Crops vary considerably in their water demand, drought resistance and drought avoidance (figure 2.1). It is recommended to grow fast-growing plants (but without greatly increased water requirements) that shorten the time in which water is lost by transpiration and evaporation. High-yielding crops that require no appreciable increase in water supply, and give high yields without increasing water demand and have high water-use efficiency should be selected. The idea is to give priority to crops with high water productivity.

Figure 2.1 (a) Sorghum is drought resistant *(Photos by B. Mati)*
(b) High yielding drought tolerant cowpeas

2.1.2 Early planting

Planting annual crops early at the beginning of the rains or dry-planting just before the onset of the rains has several advantages: It increases the chances of a crop reaching maturity before the rains end, and as a result of early growth shading the soil surface, evaporation is reduced enabling more water to become available for transpiration. This increases the efficiency of water use by the crop and so increases yields. These effects are also favoured by the flush of inorganic nitrogen and other nutrients liberated at the beginning of the rains from the decomposition of dead soil micro-organisms. Interaction between the additional nutrients and soil water enhances crop growth and yield. Crops planted early usually also benefit from less pest problems.

2.1.3 Contour farming

Contour farming is when tillage, planting and other farm operations are done along the contour (figure 2.2). It is one of the simplest methods to reduce surface runoff and control soil erosion. Contour farming is done on its own or on terraced farms. On slopes of 4 to 6 percent, contour cultivation can suffice to control soil erosion. It can reduce water loss (runoff) by 50 percent and soil loss by about 50 percent compared to up and down hill cultivation. It is advisable to compliment this technique by other interventions.

Figure 2.2 Contour cultivation combined with deep tillage *(photo by Bancy Mati)*

The effectiveness of contour farming decreases with increase in slope gradient and slope length, and increasing intensity of rains. If the rainfall exceeds the surface detention capacity of the contouring system, concentrated runoff flowing downstream unchecked can lead to accelerated erosion and even severe gulling. Therefore, contour farming alone is not sufficient to control erosion on steep, long slopes, erodible soils, and during erosive rains. The major drawbacks of contour farming are frequent turning involving extra labour and machinery time, and loss of some area that may have to be put out of production. Planting of crops should be in rows to permit inter-tillage as described later.

2.1.4 Seed priming

Seed priming is pre-germination of seeds before planting by soaking them in water to hasten germination and emergence. This ensures faster establishment thus providing ground cover to protect the soil from erosion. It also ensures that crop growth is more advanced in areas with erratic rainfall, so that a crop yield can be assured. Crops such as melons andpumpkins can be pre-germinated in paper tubings one month prior to the rains.

Maize seeds can also be primed before planting where rainfall is assured. Soaking the seed for as little as 5-10 hours can reduce the time to emergence by 10 hours which may be crucial in enabling seedling roots to grow down to below a rapidly drying or crusting soil surface. For most crops, soaking the seed for 12 hours is usually sufficient, but up to 24 hours are needed for rice and maize. Seed priming apparently does not work for finger millet.

2.1.5 Re-seeding grasslands

The re-seeding of grasslands or rangelands used for grazing livestock is a water management activity because when the land is covered by a good stand of grass, it absorbs rainfall, reducing runoff erosion and improving productivity. Rangelands that have been denuded by overgrazing can be re-seeded with selected grass varieties. Rehabilitation can be improved if re-seeding is accompanied by other conservation activities such as scratch-plowing the surface with a tined implement, or building stone scour checks to reduce runoff losses. The grass can be cut and baled for sale or use in times of drought. Natural grass should also be encouraged to revegetate rangelands as it is likely to be more sustainable. Some common natural grass varieties include common finger grass *(Digitaria eriantha*), Rhodes grass *(Chloris gayana)*, common thatching grass *(Hyparrhenia hirta),* spear grass (*Heteropogon contortus*), and goose grass.

2.2 Crop Rotation

When one annual crop is grown year after year on the same piece of land, the yields gradually decrease. The soil becomes less fertile, which reduces its water-holding capacity, thus becoming loose and more easily carried away by running water and wind. More weeds appear and there is an increase in pests and diseases. If maize, for example, is grown continuously on the same field, the stalk borer becomes a problem. This situation can be avoided by crop rotation because, when a crop is not grown over a period of two or three seasons, its pests and disease-causing organisms tend to disappear.

Crop rotation involves planting different crops on the same piece of land every successive season. Depending on the farmer's needs for food, income, a three to four or five-year rotation pattern is possible. Thus, crop rotation requires careful planning of both the season and the plots where each crop will be planted. Rotation of crops is recommended to control diseases, control insects and pests, and enable plants to extract nutrients from different soil horizons. Plants that take more nutrients from the soil should be followed by those that need less and legumes that replace soil nutrients.

Crop types suitable for rotations

Choice of varieties is important. Varieties which have proven excellence in irrigated or high rainfall areas are generally unsuited for dry land conditions. Variety requirements for dry farming include:

- Short-stemmed varieties with limited leaf surface minimize transpiration.
- Deep, prolific root systems enhance moisture utilization.
- Quick-maturing varieties are important in order that the crop may develop prior to the hottest and driest part of the year and mature before moisture supplies are completely exhausted.
- Leguminous plants which fix nitrogen in the soil .These include beans, garden peas, Lucerne, and cowpeas.

2.3 Intercropping

Intercropping is the growing of different types of crops on the same piece of land at the same time (figure 2.3). This reduces the chance of total crop failure in case of unexpected events such as drought, weeds, pests and plant diseases since most of these attack selected types of crops. It also increases the total production from a piece of land.

Figure 2.3 (a) Intercrop of maize and cow-pea *(Source: CFU-Zambia, 2007)*

(b) Intercrop of maize and beans *(photo by Espoir Bagula)*

Intercropping protects the soil from erosion, makes better use of water, sunlight and nutrients and provides your family with a better variety of food crops. For example, planting a row of beans between rows of maize and cassava or peas, beans and soya beans between strips of millet. Intercropping also enables a farmer to plant green manure and food crops together.

Important considerations for intercropping

- Crops belonging to the same plant family should not be planted together as they could be attacked by the same pests and diseases, e.g. tomatoes and potatoes, maize, sorghum and millet.
- The taller crops should not have a dense canopy that cuts out light from those below. The maize plant canopy does allow a reasonable amount of light for shorter plants like beans and groundnuts.
- The roots should not explore the same soil layer, i.e., plants with a shallow root system should be intercropped with plants with a deep root system, e.g., bananas (shallow rooter) and avocado (deep rooter). This is aimed at avoiding competition for nutrients and moisture. At the same time, nutrients from different soil layers are exploited.

2.3.1 Relay cropping

This is a farming practice whereby an annual crop is grown under an already established crop or one that is nearing harvest, e.g. Maize planted with beans. After about three months, the beans are ready for harvest while the maize is still growing. For instance, cassava can be planted under the maize after the beans are harvested. In relay cropping, two or more annual crops are grown together although not planted at the same time. This method reduces the need for re-ploughing the garden and ensures continuous soil cover by the crop from direct sun heat or being eroded by rainwater.

2.3.2 Nurse cropping

This involves growing an annual crop together with a perennial tree crop to provide ground cover during the establishment of the sparsely spaced tree crop. This provides soil cover while also improving the overall productivity of land. A runner crop e.g. mukuna beans, melons, pumpkins planted under fruit trees e.g. papaya (figure 2.4). Mango provides a green mulch as well as nitrogen fixation in the case of a legume annual crop.

Figure 2.4 (a) Bean nurse crop under papaya **(b) Sweet potato nurse crop with banana**
(photos by Bancy Mati)

2.3.3 Strip cropping

Strip cropping is a technique that serves to control erosion and increase water absorption thereby maintaining soil fertility and plant response. In effect, it employs several farming practices such as crop rotation, contour cultivation and stubble mulching. By growing in alternating strips crops that permit erosion and exposure of soil and crops that inhibit these actions, several functions are performed, such as; slope length is maintained, movement of runoff water is checked, silt in runoff water is filtered by the different strips, dense foliage of the erosion resisting crop prevents rain from beating directly on the soil surface and infiltration of rainwater by soil is increased.

The crop strips are normally planted perpendicular to either the slope of the land or the prevailing wind direction, according to whether water or wind presents the more serious erosion potential. Additionally, crops which do not resist erosion should be rotated with crops which do. Examples include growing groundnuts in strips with maize which is very effective in controlling runoff. The normal seed rate of leguminous crops other than groundnut does not provide sufficiently dense canopy to prevent raindrops from beating the soil surface; it should be raised to three times the normal seed rate.

2.4 Soil cultivation

Soil cultivation is done to break up the soil crust so as to improve water infiltration and to create a better environment for plants. What ever method is used for cultivation, it helps to loosen the soil and open it for plant roots. It also helps to reduce weeds further improving the crop cover and its productivity. Although conservation agriculture is advocated for, not all agricultural enterprises and soil conditions are suited to conservation tillage. There is therefore need, wherever possible to till the land for various types of crops and local circumstances. It is important to take care not to cause soil compaction, as this could result in short rooting depths of many plants. Some of the agents of soil compaction are animals, machinery, people walking, and continuous cultivation at the same depth.

2.4.1 Tillage practices

Tillage involves seedbed preparation as well as weed control. Tillage should be done using appropriate equipment for each type of soil and at the right moisture content. Ploughing when the soil is in the proper condition, wears the soil into thin layers, and forces the layers past each other. If the soil is too wet when ploughed (especially if it is heavy), the soil crumbs or granules are destroyed, thus puddling or compacting the soil. When the soil is too dry, the soil tends to pulverize and form dust. Tillage should therefore aim to:

- Result in a rough, cloddy surface that increases the moisture absorption and reduces runoff, as well as erosion from wind and water.
- Controls and destroys weeds that compete with crop for sunlight, nutrients, and water.
- Destroys or prevent the formation of a hard pan which can develop after repeated shallow ploughing or harrowing. This hard pan can stunt root growth, reduce water storage, and check the capillary rise of water from the subsoil.
- Promotes bacterial activity by aerating soil, encouraging the decay of residues and the release of nutrients.

2.5.2 Timing of tillage.

Ploughing, like planting, is sensitive to moisture and neither should be done when soil is either too wet or too dry. In the arid and semiarid zones, proper moisture conditions are likely to occur only at the beginning of the rainy season and should be done on the same day. If possible, planting should immediately follow ploughing, with seed rows centered on the furrow slices.

Testing soil for correct moisture content

The proper soil moisture condition for ploughing can be easily determined in the field. The usual test is to squeeze a handful of soil. If it sticks together in a ball and does not readily crumble under slight pressure by the thumb and finger, it is too wet for ploughing or working. If it does not stick in a ball, it is too dry. When examining soils, samples should be taken both at, and a few inches below the surface. Soil that sticks to the plod or to other tools is usually too wet. A shiny, unbroken surface of the turned furrow is another indication of excessive soil moisture. In general, sandy soils and those containing high proportions of organic matter bear ploughing and working at higher moisture contents than do heavy clay soils.

2.5.3 Tillage depth

Generally, heavy clay soils should be ploughed deeper than light, sandy soils, in order to promote circulation of the air and bacterial activity. Deep ploughing on sandy soils, which are naturally porous and open, tends to disconnect the seed bed from the subsoil and increases evaporative loss of moisture through capillary action. Deep ploughing need not necessarily be done annually. Depending on soil and rainfall, a deep ploughing can be done every 2 to 5 years.

Deep ploughing in some clay and loam soils can reduce yields for one or two seasons afterward, as a result of an acidic subsoil. This may be dealt with by liming the soil (neutralizing the acidity) or by varying the depth of the ploughing slowly so that the acidic subsoil is exposed a little at a time. This practice also eliminates the plough pan.

2.5.4 Seed bed preparation

In general, smaller seeds require a finer, seed bed than larger seeds. Seeds germinate and plants grow more readily on a reasonably fine, well prepared soil than on a coarse, lumpy one, and thorough preparation reduces the work of planting and caring for the crops. Even then, it is recommended not to overdo the tillage operations. The seedbed should be brought to a granular rather than a powder-fine condition for planting.

2.5.5 Trench Farming

Trench farming involves digging a small furrow measuring about 0.6 m deep and 0.6 m wide (figure 2.5). The furrow is packed with crop residues (manure is added if possible), then backfilled, resulting in a bed. The trenches are normally meant for incorporating large amounts of organic matter in the soil, and thus may end up being higher than the ground.. The purpose is three-fold: to improve soil fertility, infiltration and moisture storage capacity. Trench farming maximizes soil moisture storage in the crop root zone by soaking and storing most of the rain water. It is used to grow field crops or vegetables. The trench stores enough moisture to guarantee a crop yield even when there are only 2-weeks of rainfall. The trench can be re-used with good results for up to four crop seasons.

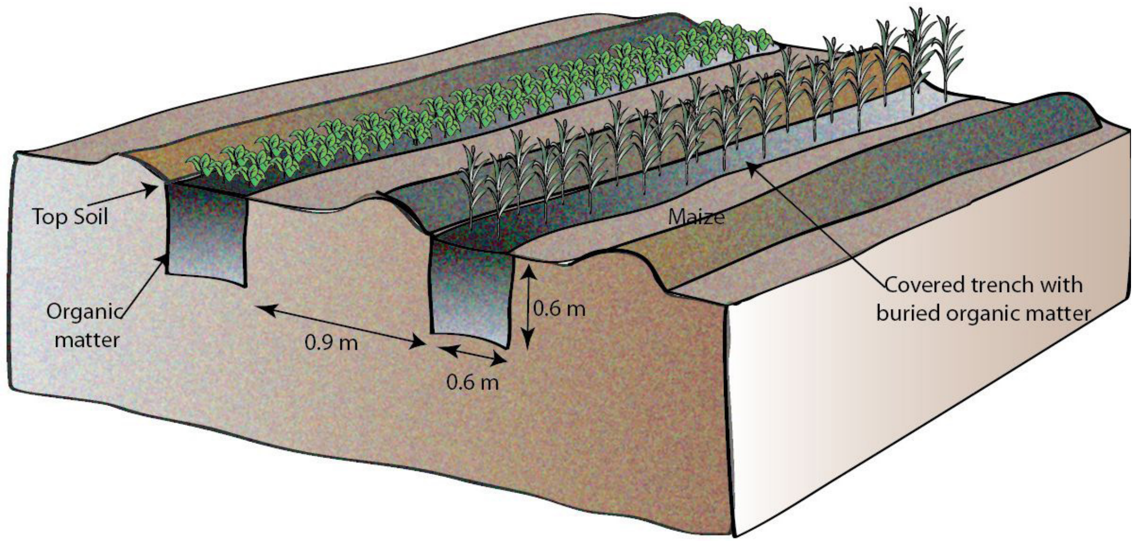


Figure 2.5. Illustration of trench farming with crop inside the trench

Another trench farming variation is also used for banana crops, in a system where a small trench is dug slightly ahead but uphill of the banana plant, and then filled with trash. During the rains, water accumulates within the trench and is held as soil moisture by the trash. During the dry season, the banana roots seek this moisture through hydrotropism and help the plant survive droughts while increasing yields.

2.5.6 Double digging

Double digging is a soil tillage practice in which a farmer can use small plots of land intensively over a long period. Double digging is commonly applicable in situations where the farmer has little cultivable land area or where the soils are too poor to support healthy crop growth. In very poor soils, the incorporation of compost manure during double digging greatly improves the fertility of the soil and enables the farmer to get good yields. Double-dug beds are meant to improve soil porosity and break hard pans by creating a deep layer of loose organic soil which is used for intensive cultivation to produce higher yields. The practice aerates the soil, improves water absorption and retention, allows plants to use available nutrients more efficiently and increases rooting depth. They are mainly used for cultivating high-value cash crops such as vegetables (figure 2.6).

Figure 2.6 (a) Double dug sunken beds with vegetables *(photos by Bancy Mati)* **(b) Double dug raised bed with vegetables**

The construction technique involves preparing the garden beds by digging out the topsoil and subsoil separately. The bottom of the trench is further tilled to improve infiltration. The topsoil is then mixed with organic manure and returned to the bed. Care is taken not to step on the bed in order to avoid compaction. The commonly recommended dimensions of a double-dug bed are approximately 1.5 x 7 m wide and 60 cm deep. The bed is filled with about six wheelbarrows of compost, which can be used for four consecutive cropping seasons before the process needs repeating. High-value crops are then grown on the beds with very good results since the bed absorbs more water than in conventional tillage. Farmers can adapt this method in various ways, digging less deeply when the soil is rocky or when labour is scarce, changing the length of the beds and adding a variety of organic materials. With double digging therefore, the farmer can grow crops closely in small plots of land and get high yields repeatedly over a long period.

3. VEGETATIVE BUFFERS

3.1 What are vegetative buffers?

Vegetative buffers comprise natural vegetative strips either planted for the purpose of soil and water conservation, or left un-ploughed during land preparation. They are normally planted across the slope and have a small width to allow runoff to slow down and deposit sediments, while also improving water infiltration. Vegetative buffers can be living hedges such as tree and shrub strips, grass strips or dead plant residues as in the case of trash lines. Runoff velocity can be reduced drastically by planting vegetative buffers. They are sited to high rainfall areas, where the survival of the vegetation is assured, and on gentle slopes, they can suffice as a soil and water conservation barrier. In dry areas, special varieties of trees, shrubs and grasses are used, such as euphorbia, sisal, croton and makarkari grass. Vegetative buffer strips are suitable on gently rolling topography with complex slopes, where contour strips are difficult to establish. The main types of vegetative barriers include:

3.2. Grass Strips

A grass strip is a vegetative buffer, in which grass is planted in dense strips, about 0.5 to 1 m wide, along the contour, and the space between the strips used for crop production (figure 3.1). These lines create barriers that minimize soil erosion and runoff, through a filtering process. Silt builds up in front of the strip, and with time, bench terraces are formed. For this reason, grass strips are sometimes grouped together with structural soil and water conservation measures.

Figure 3.1 (a) Grass strip on terrace bank for fodder *(photo by Janvier Gassasira)* **(b) Grass strip with bean crop** *(photo by Bancy Mati)*

The spacing of the strips depends on the slope of the land and is calculated to be equivalent to intervals of regular terrace spacing. They are effective soil and water conservation on soils that absorb water quickly, and on slopes as steep as 30%. On gentle sloping land, the strips are made with a wide spacing (20-30 m), while on steep land the spacing is about 10 to 15m. The grass needs to be trimmed regularly, to prevent spreading to the cropped area. Grass strips are suited to wetter areas where their survival is more assured.

Grass strips are not costly and require little labour to install. They combine characteristics of both biological and structural measures. Grass strips are a popular and easy way to terrace land, especially in areas with relatively good rainfall, where grass is used also as fodder. The grass is cut and normally used as livestock fodder or as mulch. Many grass varieties are used, such as napier, guinea and guatemala grass, *Axonopus micay, Brachiaria brizantha, Brachiaria decumbens, Brachiaria mutica, Cenchrus ciliaris, Eragrotis curvula, Molasses grass, Panicum antidotala, Panicum coloratum, Panicum maximum, Paspalum c conjugatum, Paspalum decumbens, Paspalum notatum, Pennisetum purpureum, Setaria vetiveria spp. and Vetiveria zizanioide.*

Sometimes, natural vegetative strips are left unploughed during land preparation leaving a living buffer strip, especially in dry areas where grass strips have a slim chance of survival. The main drawback with grass strips is that they harbour rodents and in dry areas, they may not survive the dry spells.

3.3 Hedgerow Intercropping

Hedgerow intercropping or alley cropping involves growing leguminous tree shrubs in narrow strips across the slope (figure 3.2), then the shrubs are lopped and the material used as a green mulch. Crops are planted within the space between the hedges. The system has the benefits of protecting the soil from runoff and erosion, since the lopped tree branches and leaves are used as mulch, and the tree stems act as a barrier to surface runoff. Moreover, nitrogen fixation by the hedge roots and its incorporation through pruning is supposed to replace the need for nitrogen fertilizers thus saving costs. Competition for moisture between crop and hedges is a major limitation in dry areas. Despite this limitation, hedgerow intercropping can be quite effective in soil and water conservation.

Figure 3.2 (a) Hedgerow intercropping of Calliandra with beans *(photos by Bancy Mati)*

(b) Hedgerow intercropping of Calliandra with maize and kales

Characteristics of a good tree species for hedge-row intercropping

- The tree should have a light, open crown that lets sunlight through.
- Ability to resprout quickly after pruning, coppicing or pollarding.
- Productive capacity that includes poles, wood, food, fodder, medicinal or other products.
- Good leaf litter making nutrients available at appropriate times in the crop cycle.
- Few and shallow lateral roots (or `prunable`).
- Ability to assist in nitrogen fixation.
- Resistance to droughts, flooding, soil variability and other climatic hazards.
- Deep thrusting tap-root system

Some commonly grown leguminous trees suitable for hedge-row intercropping include; *Centrosema pubescens, Desmodium buergeri, Medicago sativa, Mucuna puriens, Phaseolus acontifolius, Psohocarpus palustris, Pueraria phaseocoides, Stizolobium deeringianum, Stylosanthes guianensis, Trifolium alexrium, Vigna catjang, sesbania sesban, caliandra calothyrsus* and *leucena sp.*

3.4 Trash Lines

Trash lines are buffer strips created by arranging the previous season's crop residues or any other dead vegetative materials ("trash"), in lines across the slope (figure 3.3). Trash lines act more or less like grass strips, by providing a buffer which slows down runoff and traps eroded soil, while dissipating the energy of runoff beyond the strip at non-erosive velocities. Thus, trash lines can be used to develop bench terraces over time (progressive terracing) through the natural phenomena of erosion and deposition. The spacing between trash lines is calculated as terrace spacing for convention. They are preferred in areas where the slope is gentle, crop residue are available and there is no termite problem.

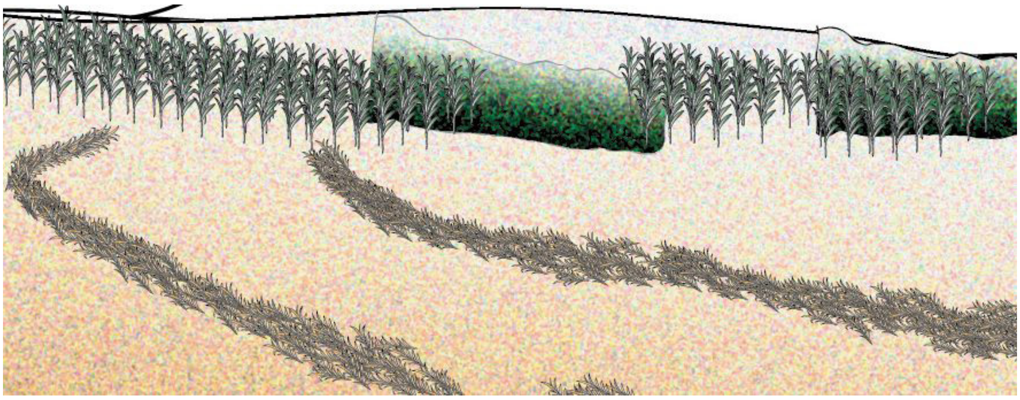


Figure3.3 Illustration of trash lines made with maize crop residues

Making trash lines is a traditional technique in many parts of Africa, although it is not widely practiced these days. This is due to the competition for crop residues for other uses such as livestock feed or fuel. In the wetter areas where farm sizes are restricted, farmers prefer to feed crop residues to livestock, while in the dry areas trash lines are associated with termite infestation. Trash lines have the advantage of low labour requirement, and the material is locally available on the farm.

4. COVER CROPS

4.1 What are cover crops?

Cover crops are those crops grown for the purpose of covering the soil during the cropping season, fallow periods or between harvest and planting of commercial crops. They utilize the residual moisture in the soil. They are also used for protecting the soil, even when it is not cultivated.

4.1.1 Utility of cover crops

Cover crops are grown to protect the soil from leaching, erosion and to improve soil fertility (figure 4.1). They build up organic matter in the soil, improve soil structure, suppress weed growth and increase soil fertility through nitrogen fixation. They also, shade the soil to reduce fluctuations in temperature and improve soil moisture conservation. Legumes, such as beans and peas, or grasses are often used. They cover the ground surface between a widely spaced perennial crop, such as young fruit trees such as mango, papaya, citrus, coffee, or between rows of grain crops such as maize. Cover crops can be a source of food, fodder and mulch and may provide some cash income. However, they may also provide a refuge for rodents and pests

Figure 4.1 (a) Pumpkins used as a cover crop (b)Water melons cover crop under papaya *(photos by Bancy Mati)*

4.1.2 Suitable cover crop types

A cover crop should be of a slow growing variety to minimize competition for water and nutrients with the main crop. It should be planted as soon as possible after tillage to be fully beneficial. This can be done at the same time as sowing the main crop, or after the main crop has established to avoid competition. Growing grass or leguminous cover crops once every two to three years may be necessary for the sustainable management of soil and water resources.

The most commonly used cover crops are sweet potatoes, melons, crotolaria, mucuna bean and various types of grasses. Cover crops are grown mostly in the wetter zones for their other utilities such as food and fodder.

4.1.3 Selecting suitable species

A wide range of cover crops can be used for soil and water conservation. In addition, cover crops are also used for food crop production and this is an important consideration in choosing an appropriate cover crop. The choice of an appropriate cover crop for different soils and ecological regions depends on many considerations, including:

- The ease and economics of establishment, including the availability of seed;
- Quick ground cover and growth rate during the off-season;
- Low possibility as alternative hosts for pests and cover for wildlife;

- Low canopy height;
- Deep-root system and low consumptive water use;
- Ability to suppress weeds;
- N-fixing rather than N-consuming;
- Feed value for livestock;
- Growth duration (i.e., permanent versus annual);
- Shade tolerance; and
- Ease of management for growing a food crop with conservation tillage.

4.1.4 Advantages of cover crops

Cover crops have many advantages for the sustained use of natural resources (e.g., restore fertility, control weeds, avoid repeated seeding and cultivation traffic, conserve rain, and reduce energy costs). In addition to controlling pests, cover crops improve soil physical properties and reduce soil erosion.

4.1.5 Major limitations of cover crops

Cover crops are not suitable for dry areas with annual rainfall of less than 500mm, as they might compete for water with the main crop. Under such conditions it might be better to keep the weeds and natural vegetation as cover. They may not do well on soils with low phosphorous.

4.2 Permanent soil cover

Permanent soil cover (or permaculture), is a special system of farming with cover crops, in which farmland is maintained under some crop cover throughout the year (figure 4.2). It is practiced like re-lay intercropping, such that a crop is planted before harvesting of anannual crop. But the method differs in that a permanent cover can also be grown alongside annual crops.

Permanent soil cover facilitates soil protection from surface runoff, crusting or evaporation, while also optimizing the productivity of land. A permanent soil cover helps to protect the soil against the impacts of rain and sun, provide the micro and macro organisms in the soil with a constant supply of "food", and alters the microclimate in the soil for optimal growth and development of soil organisms, including plant roots. The types of cover crops applied include different legume species like beans, forage and agroforestry species such as *Stylosanthes guianensis*, *Mucuna spp*, *Dolichos lablab, Pueraria phaseoloides, Cajanus cajan, Vigna umbellat*. Grass leys are sometimes also used in permanent soil cover, especially where the main crop are trees.

Figure 4.2 Permanent soil cover of groundnuts after maize *(photos by A. Rakotondralambo)* **(b) Permanent soil cover using crop residue with zero tillage**

4.2.1 Benefits of permanent soil cover

- Improved infiltration and retention of soil moisture resulting in less severe, less prolonged crop water stress and increased availability of plant nutrients
- Higher diversity in plant production and thus source of food and fodder,
- Habitat for diverse soil life: creation of channels for air and water, and biological activity
- Soil regeneration is higher than soil degradation
- Increased organic matter recycling
- Reduced rain drop impacts on soil surface resulting in reduced crusting and surface sealing
- Improved infiltration and consequential reduction of runoff and erosion
- Mitigation of temperature variations on and in the soil
- Better conditions for the development of roots and seedling growth,
- integrated management and reduced competition with livestock or other uses e.g. through increased forage and fodder crops in the rotation

4.2.2 Limitations of permanent soil cover

- Requires higher levels of soil moisture availability to reduce competetion withthe main crop. Thus, the method is suitable for irrigated fields or high rainfall areas,
- There is danger of pest infestation since the land is not rested between growing seasons,
- Can be quite labour intensive, and
- targeted use of herbicides for controlling cover crop and weed development may be costly.

5 MULCHING

5.1 What is mulching?

Mulching is the practice of covering the soil between crop rows or around trees with a layer of loose material such as dry grass, straw, crop residues, leaves, compost or inorganic membranes (figure 5.1). Mulching is normally done to conserve soil moisture, reduce runoff flows, evaporative losses and wind erosion, prevent weed growth, enhance soil structure and control soil temperature. Most smallholders do mulching only for special crops such as tomato, cabbage and potatoes due to the shortage of crop residues. It is practiced by farmers in the wetter areas due to the availability of vegetative materials. The importance of mulches in reducing surface runoff, soil erosion and evaporation losses cannot be overstated.

Figure 5.1 Mulched coffee field
(photo courtesy of Mary Kakinda)

(b) Mulched banana plantation
(photo by Bancy Mati)

5.2 The case for mulching

Mulching has positive effects by reducing raindrop impact, improving rainfall infiltration through enhancement of soil structure and reduce runoff and erosion. Mulching also increases the biological activities in the soil, increasing the activity and species diversity of soil flora and fauna, such as earthworms. Mulching results in increased biomass carbon, and improved crop growth; nutrient enhancement and influence on crop growth. Mulching also reduces loss of water by evaporation. It also protects the soil from wind damage.

Mulching needs to be monitored carefully to avoid related problems. Too much mulch prevents adequate air flow and encourages pest and fungal disease and , in dry areas termites. These problems can be avoided by using mulch during the dry season and applying mulch two weeks after planting to allow the seedlings to develop.

5.3 Types of mulches

There are different types of mulches, depending on the source and method of mulch procurement and application (figure 5.2). Although a wide range of materials is used as mulch, the most practical and feasible material is the residue from a previously grown crop. The technological methods of mulch farming differ on the basis of whether mulch is brought in or produced *in situ*. Mulch can be spread on a seedbed or around planting holes and it can also be applied in strips

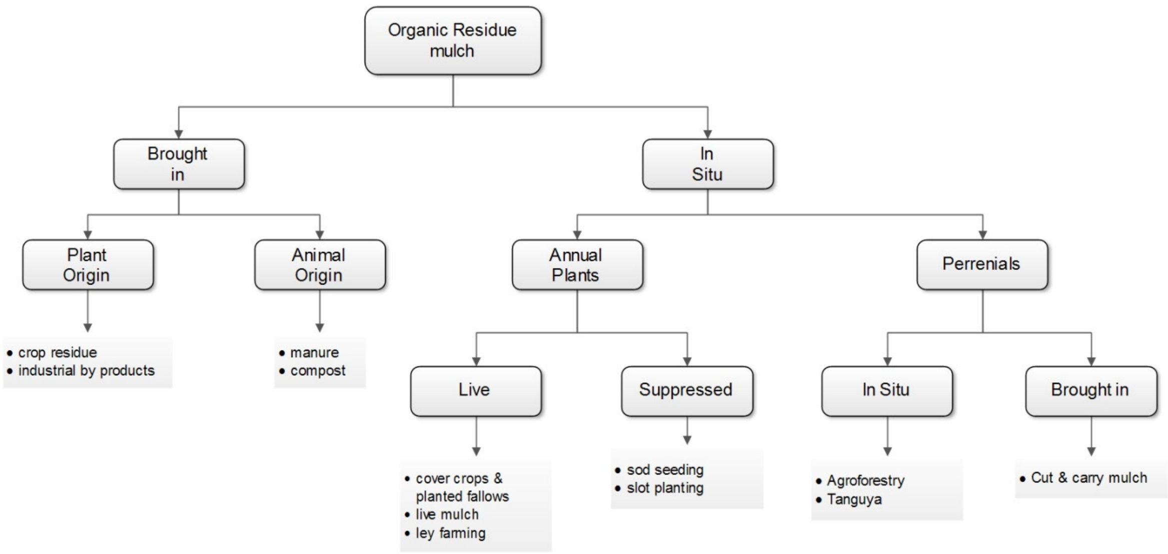


Figure 5.2 Types of mulch materials and associated agricultural practices

5.3.1 Crop residues

Use of the previous season's crop residues is the most prevalent method of mulching. The residues are carefully arranged on the soil surface of cultivated fields. It is difficult to get adequate residue material from the previous year's harvest. However, mulch densities range between 30 percent and 70 percent can be obtained from the previous season's crop residues. In certain cases, the residues or grasses to be used for mulch are out-sourced from outside the farm. Grass mulches are particularly useful where there are natural grasses which are cut and taken to the farm as mulches. The grass should be dried before applying as this reduces the chance of it rooting. Sometimes, the mulch can be covered with a layer of soil to protect it against wind.

5.3.2 Green mulches

Green mulches are usually leguminous plants that cover the ground as runners, grown together with other crops. They are sometimes also termed as green manure because of the ability of the companion legume to fix nitrogen in the soil. The legume could be cut and incorporated into the soil while green as manure. Alternatively the legume is used as a cover crop. Other types of crops such as pumpkins and water melons have proved useful green mulches.

5.3.3 Gravel-sand mulches

Gravel and sand mulching involves applying gravels or rock fragments onto the soil surface, preferably in rows. Crops are then grown in the rows between the gravel/sand cover. This has several functions, such as: (i) as a water harvesting system in which the gravel-sand mulch acts as a catchment, from which runoff can be channeled onto the cropped rows, (ii) as a mulch cover to reduce surface runoff and conserve the soil, (iii), by covering the ground to reduce evaporation losses, the stones provide a capillary fridge since they are porous, thus reducing water losses by capillarity from the more compact soil layers beneath, and (iv) reducing weed infestation in the rows covered by the gravel. Once the gravel mulch has been applied, the cropped rows are tilled using minimum tillage techniques e.g. strip tillage, spot tillage or direct seeding. The system is suited to areas with large volumes of stones and/or gravel.

5.3.4 Plastic mulching (plastic films)

Plastic material is also sued for mulch crops such as vegetables and fruits, particularly pineapple.

The plastic sheets are arranged across the slop in strips in between crop rows. Some plastic materials are bio-degradable while others are less degradable and must be removed from the field and disposed of at the end of the season. Plastic mulching can be expensive, and is used for high value crops. It serves several functions, e.g. the spaces covered by plastic smother out weeds, hence it acts as a weed control. The plastic-covered areas act as a catchment which increases runoff generation between the crop rows to improve the efficiency of micro-catchment water harvesting. Plastic mulches also reduce disease and pest incidences, especially soil-borne pests. In cold areas, black plastic mulches increase soil temperature thus improving crop performance. For water harvesting, a simple way of achieving effective plastic mulching is to buy a large plastic sheet, then puncture holes with spacing equivalent to crop spacing. Then plant directly through the holes. Care should be taken to ensure that plant roots get adequate air and the soil is not overheated. After crop harvesting, the plastic film is collected and re-used.

5.3.5 Alternate row-mulching

Alternative row mulching is sometimes preferred to full mulching, because it reduces the fire risk. It is most effective if applied at the start of the rains, as it intercepts and increases water take-up, but it is frequently more practical to mulch towards the end of the rains when grass is available. When crop remains are used for mulching, nutrients are released more slowly, so that more manure or fertilizer has to be applied.

5.4 Mulching techniques:

There are different ways of applying a mulch. It can be put on the soil surface, or incorporated during cultivation of the land. Two methods predominate.

5.4.1 Planted mulch

In this system, legumes, grasses and other suitable plants such as *Grevillea* and *Tithonia* can be planted along boundaries, on soil band or in spaces between crops or in fallow land. These can be cut, left to dry and used as mulch. Legumes, however, do not need to be dried first.

5.4.2 Live mulch

For perennial crops like bananas, creeping legumes such as lablab and mucuna bean can be planted between the rows and periodically uprooted to provide organic materials. The principle of live mulch is based on mixed cropping. The live mulch must be a ground legume which grows below the main crop. Live mulches are not recommended in situations where soil moisture stress occurs, as the live mulches will compete with crops for moisture.

5.5 Benefits of mulching

A principal benefit of mulch farming is reduction in runoff and soil erosion.

- Mulching helps to retain soil moisture by limiting evaporation, suppressing weed growth and enhancing soil structure, reducing runoff, protecting the soil from splash erosion and limiting the formation of crust.
- Mulching reduces fluctuations in soil temperature which improves conditions for micro-organisms. It is commonly used in areas affected by drought and weed infestation.
- Mulching protects the soil from the direct impact of rain drops, thus maximizing water percolation and protects the soil against water and wind erosion. It also reduces water loss from the soil by evaporation and maintains conducive soil temperatures for germination and growth of crops and for the life of soil organisms.

- Mulch improves soil conditions by improving soil plant and animal activity and adding organic matter to the soil. Good mulch also controls the rapid growth of weeds.
- Mulch can be produced on the farm. A mixture of deliberately grown grasses and legumes forming a cover can be cut down to provide the mulch. This mixture can be grown together with crops on bands or in separate fields.

5.6 Limitations of mulches

- The major limitations lie in the large quantities of residues required (usually 4 t/ha/yr)
- However, mulch materials are sometimes not available as farmers use them for other uses e.g. as fodder, fuels or construction material.
- There is some additional labour involved in mulch collection or procurement and application. Consequently, mulch farming is likely to be feasible on a small scale for high-value commercial crops.
- Weeds can be a problem if some grass species are used and mulches can provide a possible habitat for pests and diseases. Use a mixture of fast and slow decomposing material and break large pieces of crop residue before application.
- The mulch layer should not be too thick; otherwise this can lock-up nutrients in the soil.

6. SOIL NUTRIENT MANAGEMENT

6.1 What is soil fertility?

Soil fertility refers to the capacity of a soil to produce crops by providing adequate supply of nutrients in correct proportions, resulting in sustained high crop yields. In addition, a fertile soil has good rooting depth, good aeration and good water holding capacity. It is also necessary that there is a strong presence of soil organisms e.g. earthworms, adequate amounts of organic matter, the right pH balance and no adverse soil-borne pests and diseases. Efficient farm management practices should result in greater stimulation of activities of soil organisms, nutrient additions to the soil, minimal nutrient exports from the soil and optimal nutrient recycling within the farming system (figure 6.1). However, the concept of "poor" and "fertile" soil may mean different things to different communities and conditions. But it should be possible to say accurately whether a soil is fertile or not.

Figure 6.1 Effects of soil nutrient management comparing adjacent farms Left- without nutrients, and right-with proper soil fertility *(photo by Bancy Mati)*

Soil fertility management goes beyond just improving the nutrient levels in the soil. It is the holistic improvements made to a soil and its ability to produce crops, including water management and weed control. Thus, the term also includes soil and water conservation practices like terracing as well as water harvesting and drainage of waterlogged soils. Agronomic measures such as conservation tillage, deep tillage, residue mulching, contour tillage, crop rotations, intercropping, cover cropping and agroforestry are all fertility enhancing. Soil fertility management also includes off-farm activities such as biomass transfer, improved fallows and rotational grazing and proper care of rangelands. However, this Chapter is concerned with soil nutrient management.

6.2 What is soil nutrient management?

Soil nutrient management, are the activities and additives used to enhance the chemical and biological constituents of the soil so as to improve its fertility. Nutrient management involves adding manure and fertilizers to the soil in the right amounts to provide the required plant nutrients for vigorous crop growth. Good crop cover is an indicator of soil nutrient availability and is linked to protection of the land from excessive runoff losses and soil erosion (see Chapter 1 in this manual). Thus availability of nutrients (macro and micro) in the soil is one way of achieving water conservation resulting in higher yields and improving water productivity. There are many methods of soil nutrient management, such as addition of fertilizers, manures, and low input technologies.

6.3 Chemical fertilizers

Fertilizer is any organic or inorganic material added to a soil to supply one or more plant nutrients essential for improving the productivity of crops. Fertilizers are divided into two groups; inorganic and organic. In both types, fertilizers typically provide both macro nutrients and micro-nutrients. Macronutrients are the elements consumed in larger quantities and are present in plant tissue. They include: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). Micronutrients, on the other hand are consumed in smaller quantities and are present in plant tissue on the order of parts per million (ppm). They include: boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn).

6.3.1 Inorganic fertilizers

Inorganic fertilizers sometimes referred to as commercial or chemical fertilizers contain the major crop nutrients needed by plants, such as nitrogen, phosphorus, and potassium. These three essential nutrients should naturally occur in healthy soil, but some soils are deficient of them or plants require more nutrients than are available. Most inorganic fertilizers are rated based on the percentage of nitrogen, phosphorous, and potassium, with a rubric called NPK (Table 6.1).

Table 6.1. Common basic fertilizer types and their nutrient contents

Fertilizer name	Components	N (%)	P_2O_5 (%)	K_2O (%)
Ammonium nitrate	33-0-0	33	0	0
Ammonium sulphate (ASP)*	21-0-0-24S	21	0	0
Diammonium phosphate (DAP)	18-46-0	18	46	0
Potassium chloride (muriate of potash)	0-0-60	0	0	60
Potassium sulfate**	0-0-50-16S	0	0	50
Potassium magnesium sulfate***	0-0-22-23S-11Mg	0	0	22
Triple super phosphate (TSP)	0-46-0	0	46	0
Urea	46-0-0	46	0	0

Note: *Ammonium sulfate contains 24% sulfur (S)
**Potassium sulfate contains 16% S
***Potassium magnesium sulfate contains 23% S and 11% magnesium (Mg)
Source: Maguire et al, 2009.

The addition of nitrogen to the soil encourages growth of stems and leaves by promoting protein and chlorophyll. More flowers, larger fruits, and healthier roots and tubers result from added phosphorus. It also helps plants resist certain diseases. In addition, potassium from potash, thickens stems and leaves by fostering protein development. Different plants require different pH levels. A soil's pH can be lowered or made acidic by applying inorganic fertilizer such as aluminum sulfate or ammonium sulfate. Lime increases soil pH making it more alkaline. Sometimes blood meal or other organic matter can also affect acid levels in the soil.

The first step in applying the correct rate of fertilizer is calculating crop nutrient requirements. A soil test is the only way to measure how much phosphates and potash are available in soils, and soil tests are available through several private and public laboratories as nitrogen is much more mobile in soils and must be applied every year to cereal crops. Nitrogen requirements are based on the crop to be grown and the soil type that influences yield goals.

Blended fertilizers are mixes of these fertilizer materials that are made to vary the N-P2O5-K2O ratio to meet crop requirements. The phosphate fertilizers are categorized as natural phosphates, either treated or processed, and also by products of phosphates and chemical phosphates.

6.3.2 Rock phosphate

Rock phosphate is a naturally occurring sedimentary rock, which contains over 10% phosphorous and 38% calcium oxide as the main ingredients. It is mined in some countries including at Minjingu near Lake Manyara, in Tanzania, from where it derives its name as "Minjingu rock phosphate". This fertilizer type has its advantages and disadvantages. The advantage is that with adequate rainfall this fertilizer results in a long growing period which can enhance crops. Powdered phosphate fertilizer is an excellent remedy for soils that are acidic and has a phosphorous deficiency and requires soil amendments. However, the disadvantage is that although phosphate fertilizer such as rock phosphate contains 25 to 35% phosphoric acid, the phosphorous is insoluble in water. It has to be pulverized to be used as a type of fertilizer before rendering satisfactory results in garden soil. Thus, rock phosphate is used to manufacture superphosphate which makes the phosphoric acid water soluble. Rock phosphate is relatively affordable and can be used directly to correct phosphorous deficiencies in the soil especially targeting deficient parches in the farm. It has a positive residual effect in soils over several seasons and does not cause soil acidity.

6.3.3 Superphosphate

Superphosphate fertilizers are available in three different grades, depending on the manufacturing process. These are:

- **Single superphosphate** containing 16 to 20% phosphoric acid;
- **Dicalcium phosphate** containing 35 to 38% phosphoric acid; and
- **Triple superphosphate** containing 44 to 49% phosphoric acid.

Triple superphosphate is used mostly in the manufacture of concentrated mixed fertilizer types.

The greatest advantage of using superphosphate fertilizer is that the phosphoric acid is fully water soluble. Thus, when superphosphate is applied to the soil, it is converted into soluble phosphate. This is due to precipitation as calcium, iron or aluminium phosphate, which is dependent on the soil type to which the fertilizer is added, be it alkaline or acidic garden soil. Phosphorus deficiency is a common problem in most farms, hence most soil types can benefit from the application of superphosphate fertilizers. Used in conjunction with an organic fertilizer, it should be applied at sowing or transplant time.

6.3.4 Potassium fertilizer types

Chemical potassium fertilizers should only be added when there is certainty that there is a Potassium deficiency in the soil. Potassium fertilizers also work well in sandy soils as they respond to the application. Crops such as chillies, potato and fruit trees all benefit from this type of fertilizer since it improves the quality and appearance of the produce. There are basically two different types of potassium fertilizers:

- Muriate of potash (Potassium chloride) and
- Sulphate of potash (Potassium sulphate).

Both muriate of potash and sulphate of potash are salts that make up part of the waters of the oceans and inland seas as well as inland saline deposits.

Muriate of potash

Muriate of potash is a gray crystal type of fertilizer that consists of 50 to 60% potash. All the potash in this fertilizer type is readily available to plants because it is highly soluble in water. Even so, it does not leach away deep into the soil since the potash is absorbed on the colloidal surfaces. Muriate of potash is applied at sowing time or prior to sowing.

Sulphate of potash

Sulphate of potash is a fertilizer type manufactured when potassium chloride is treated with **magnesium sulphate**. It dissolves readily in water and can be applied to the garden soil at any time up to sowing. Some gardeners prefer using sulphate of potash over muriate of potash.

6.3.5 Commercially available fertilizers

The different types of chemical and organic fertilizers that are usually commercially available can be categorized further into:

- **Complete inorganic fertilizers**: – these types of inorganic fertilizers contain all three major macronutrients, Nitrogen (N), Phosphorous (P) and Potassium (K). On the containers, macronutrients are depicted as a ratio, e.g. 2:3:2 (22). Complete inorganic fertilizers are usually applied at a rate of 60g/m^2 or roughly 4 tablespoons per square meter.
- **Special purpose fertilizer**: – these types of fertilizer are formulated especially to target certain plants' requirements or certain soil deficiencies.
- **Liquid fertilizers**: – these types of fertilizer come in a variety of formulations and even include organic fertilizer, complete fertilizer as well as special purpose fertilizer.
- **Slow-release fertilizer**: – these types of fertilizer are formulated to release their nitrogen at a steady pace. On the packs of these fertilizer that are available commercially usually are depicted as 3:1:5 (SR) where the SR indicates slow-release.
- **Fertilizer with insecticide**: – these are types of fertilizer that are prepared and combined with an insecticide.

There are many other different types of chemical fertilizers in different formulations because different plants require different nutrients and different pH levels in the soil. However, organic fertilizers have more diversity, and do not burn plant roots, get into ground water, or affect surrounding growth as is the case when using the different types of chemical fertilizer and NPK amendments.

Generally, farmers are discouraged to use fertilizers because it is not a traditional practice among most communities. High fertilizer costs and poor prices from staple foods grown in the region mean that economic gains have not been quite evident. Even though expensive, the use of inorganic fertilizers needs to be promoted, as many types of soil lack adequate levels of phosphorus and nitrogen. The major type of fertilizer used in the region is DAP. The quantity of fertilizer used depends on the socioeconomic level of the farmers, with richer farmers using more fertilizers. Field trials on maize and sorghum with and without fertilizer application in semi-arid areas have shown that a substantial yield increase occurred when fertilizers are used along with water conservation practices.

6.4 Organic fertilizers

Organic fertilizers are those obtained from biological materials such as farmyard manure, crop residues, bat guano, compost, peat moss, wood ash and other soil amendments. They have many benefits over chemical fertilizers. For instance, organic fertilizers do not harm plants if applied in excess and have long-term positive effects on the soil without damaging ground water. The vegetative materials also help to aerate the soil, insulate the ground against temperature change, and add needed nutrients. However, they may have lower concentrations of nutrients and are thus required in larger quantities. Organic fertilizers are rich in organic nutrients and minerals and are gradually released to the soil, hence have a long lasting effect. There are various ways of preparing organic fertilizers as described below.

6.4.1 Organic manures

These are soil nutrient amendments made from organic materials, particularly those obtained from within the farm, such as crop residues, farmyard manure, weeds and tree prunings. There are several types of organic manures as well as the methods to prepare them. These include all types of farmyard manures, composts, green manures, liquid manures, slurry and fortified composts. Crop residues left on the soil also act as manures.

6.4.2 Farmyard manure

Farmyard manure is the animal droppings obtained from the sheds of various domestic livestock such as cattle, goats, sheep, pigs and chicken. It also includes the sweepings, urine, remnants of fodder and animal beddings and other biological materials found in animal dwellings (figure 6.2). Farmyard manure is easier to convert into humus since it is an advanced stage of vegetative material that has been digested and deposited by animals. It contains useful nutrients especially Nitrogen and carbon, which are derived from biological materials. Farmyard manure should first be composted before application to crops in the farm.

Figure 6.2 Farmyard manure *(photos by Bancy Mati)* **(b) Compost manure**

6.4.3 Compost manure

Compost manure is the decomposed organic matter that includes one or more of the ingredients like farmyard manure, slurry, compost manure, crop residues, kitchen wastes, hedge cuttings, grain husks and other materials. Compost is made by converting the large amounts of vegetation, such as crop remains, garden weeds, kitchen and household waste, hedge cuttings, and garbage, into valuable plant food called humus. When properly made and applied, compost is immediately available as plant food without the need to be first broken down by soil micro organisms. The use of compost allows a farmer to obtain a good crop without the need to apply expensive and toxic chemical fertilizers.

Composting is the natural process of turning organic materials, such as crop residues and farmyard manure, into valuable plant food or humus. The ingredients that produce good quality compost, such as leguminous residues and manure, are just as important as the methodology of composting. The normal procedure is to first make a foundation onto which ashes are spread to prevent termite infestation. Then layer after layer of dry crop residues (chopped), green vegetation e.g., *Lantana camara* or *Tithonia diversifolia* and topsoil are placed over each other, wetting with fresh water (non-chlorinated). The heap is then covered with soil and a stick driven into the middle to act as a thermometer (figure 6.3). The compost is turned (and wetted) after around 22 days and the compost is ready for use within 45 days, depending on temperatures.

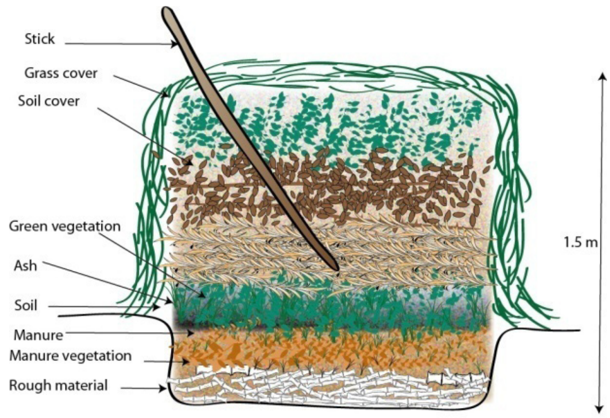


Figure 6.3 (a) Illustration of the arrangement of a composting system

(b) Composting manure by a group of farmers *(photo by Bancy Mati)*

6.4.4 Fortified compost

The making of fortified compost involves addition of low levels of fertilizer or finely-ground phosphate rock and urea to improve the quality of compost prepared from crop residues, particularly cereal-based residues such as maize stover, rice husks or wheat straw (figure 6.4). Low quality organic materials such as maize stover or wheat straw with a wide C:N are fortified with small amounts of fertilizer and manure for preparing fortified compost.

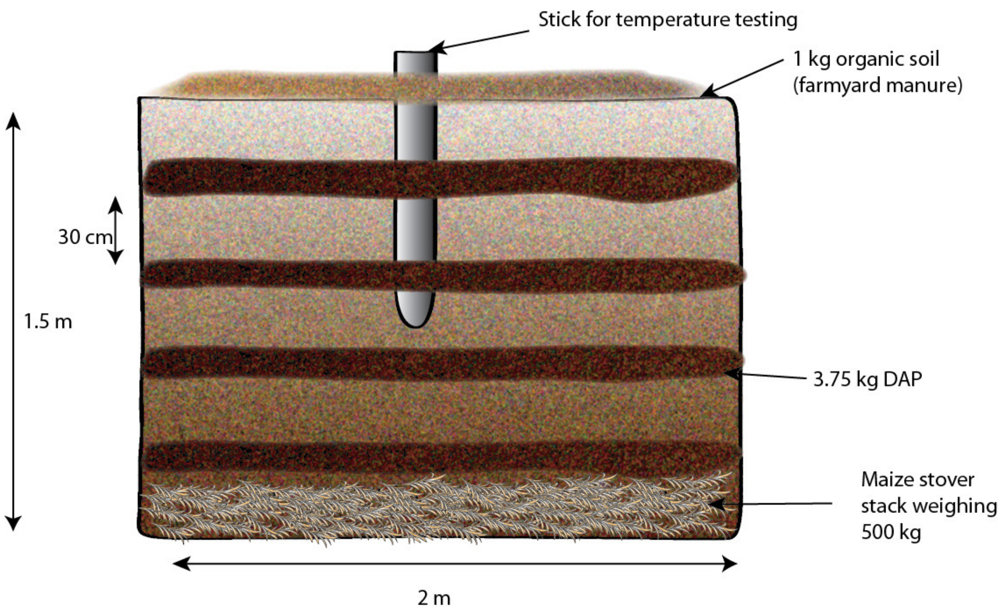


Figure6.4 Arrangement of a fortified compost under preparation

The process involves making the compost in the normal way but between the layers of residues, a nitrogenous fertilizer, e.g. DAP or rock phosphate is sprinkled. A layer of organic soil and farmyard manure are then spread over to act as "starter inoculants" and water sprinkled over. This forms one layer, five layers are packed in this way till the compost heap is done. It is then covered with soil and left to compost in the normal way (see compost manures). For most poor soils, the method recommends the application of 2 t/ha of fortified compost applied as a pre-plant application at the start of the rainy season. Fortified composts carry the advantages of mineral fertilizers as well as those of organic matter addition to the soil.

6.4.5 Liquid manure

Liquid manure is a mixture of farmyard manure, urine, vegetative materials and other soil nutrient additives which is prepared in liquefied form. The liquid manure is made in drums where all the ingredients are mixed with water, forming slurry. In preparation, some goat or cattle manure is soaked in a net/bag within a drum as well. The bag is then suspended using a stick in a drum of water (Figure 6.5). The drum is covered and left to stand. The bag can contain 30-50 kg of manure in 200 liters of water. The contents are stirred with a stick at least every 3 days to quicken the release of nutrients into the water. The process takes 10-15 days for the liquid manure to mature. The mixture is ready when the color of the water changes to dark brown.

The mixture is a good liquid fertilizer for top dressings growing crops. It can be applied to a variety of crops including vegetables. It is applied around the roots of the plants. Before use, the mixture is diluted as in the case of plant teas ratio 1:2. Slurry from an animal shed can be directed into a shallow pit, where it turns into liquid manure after several days. But the pit is kept well covered. Liquid manure can also be obtained from the sludge effluents of biogas digesters.

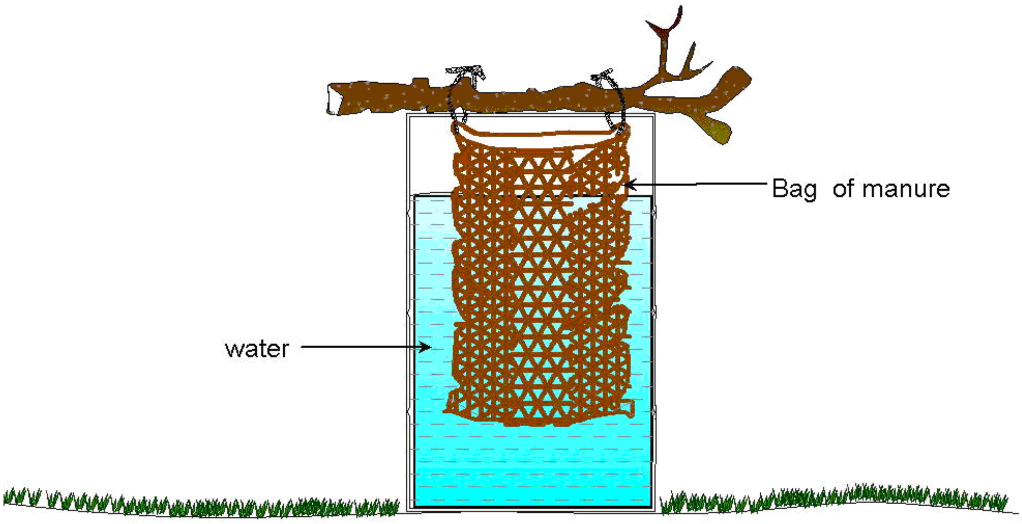


Figure 6.5 Illustration of the preparation of liquid manure

6.4.6 Plant tea

Occasionally, liquid manure is prepared in the form of "plant tea." Plant teas are especially necessary to quickly provide the crop with adequate natural plant food during the growing season, and as a top dressing. Plant teas are derived from plants and contain many minerals in addition to hormones that promote growth. Plants used should be broad-leaved young shoots that can easily decompose in water. Commonly used tree species include; stinging nettle, comfrey, amaranthus, mukuna and *Tithonia deversifolia*.

<u>Preparation of plant tea</u>

In preparation, plant teas the green sappy leaves and young branches of leguminous trees are chopped into small bits and put in the drum up to three-fourths full. Then the drum is filled with water. The mixture is left to stand. The material rots in the water, releasing nutrients. When the process is activated, the solution begins to smell like cow urine. To quicken the process, the solution is stirred every three days. Plant teas are ready for use when the solution turns a rich green color and has a pleasant smell. Depending on type of plant material used and the temperature, the plant tea is ready for use within two to three weeks.

Application

Plant teas should be used as soon as they are ready. The solution may remain effective for fourteen days but will gradually lose its useful nitrogen. The solution should be applied directly to plants. It may be too concentrated and can scorch plants. Thus, it should be diluted to reduce concentration by adding water, by a ratio of 1:2 (one part solution to two parts water). Plant teas are applied to the soil around the root zone of an actively growing young plant. It should not be applied on the leaves. It is advisable to cover the treated area with dry soil or mulch in order to minimize loss of nutrients, especially nitrogen, through solar radiation. Plant teas can be applied for three consecutive days, then wait for the plant to show the effects of accelerated growth of new leaves and branches. Plant teas may be applied to leafy crops and fruit crops .It is not necessary to use them on root crops.

6.4.7 Compost baskets

A compost basket refers to a method of composting *in-situ,* i.e. composting in which the crop utilizes the compost as it decomposes, and thus is expected to last longer. Compost baskets are woven from twigs and driven into the prepared beds at a spacing of 1 m as follows: holes of at least 15 cm deep and 30 cm wide are dug along the centre line of the prepared bed at a spacing of about 1 m. Sticks of about 60 cm long are then driven into the ground around each hole, and long flexible twigs woven around to form above ground baskets. The baskets are filled with manure and well-decomposed household wastes. The manure is translated from the soil below the basket into the root zone through natural processes. Due to hydrotropism, the roots also tend to grow towards the basket (figure 6.6). The compost basket also absorbs and retains a lot of water which the plants can withdraw during the dry season. It holds the composting materials in place and therefore minimizes nutrient depletion by run-off and stray animals. Birds, too, cannot scatter the compost materials. It is a popular method of water conservation for banana plantations.

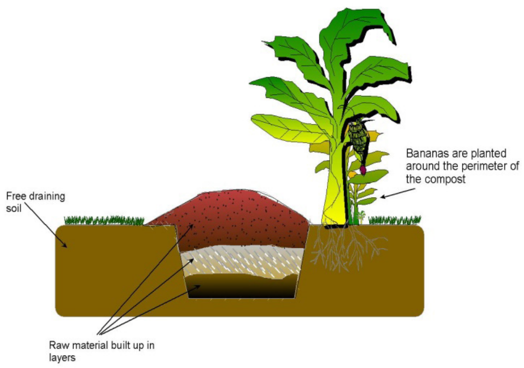


Figure 6.6 (a) Illustration of a compost basket with banana crop

(b) Making a compost basket for banana *(photo by Bancy Mati)*

6.4.8 Green manure

Green manuring is the use of crops, weeds, and other leguminous plants to maintain or improve soil fertility. Green manures help loosen the soil and let in needed air, and hold soil and water in place. Weeds should not be burnt, but instead, they are dug into the soil as green manure. Some crop remains like those of beans and peas that add nitrogen (an important plant nutrient) to the soil is used. Other plants suitable are: *Leucaena,* sunn hemp, *Tithonia*, *Sesbania*, lablab, *Pannicum, Calliandra*, elephant grass, *Lantana camara*, which are lopped and placed on the soil surface to act both as a green manure and as a mulch (figure 6.7). Crop fields left to fallow should be planted with green manure plants to increase the rate of soil fertility renewal. Also, intercrop green manure plants with food crops: plant green manure plants in-between rows of food crops, but make sure you minimize competition for water, sunlight and nutrients from other crops.

Figure 6.7 Trimming markhamia hedge for green manure (*photos by Bancy Mati*)

(b) Lopped markhamia prunnings for use as green manure

Green manure is made by digging into the soil three of four weeks before planting food crops. This allows green manure to rot completely and to provide plant nutrients. It is advisable to dig the green manure into the soil before any flowering. If the green manure has tough stems, they are chopped into small pieces before being incorporated into the soil.

6.5 Integrated soil fertility management

Integrated soil fertility management (ISFM) is achieved when all the components necessary to promote healthy and sustainable crop growth are applied to farmlands. ISFM encompasses both LEISA and conventional methods of implementing sustainable agriculture. It includes the use of mineral fertilizers, organic matter, manures, tillage operations, water management and even control of pests and diseases. Mineral fertilizers such as NPK, CAN, TSP, Urea and rock phosphate as well as biological measures, involving agroforestry, green manures, improved fallows that utilize *Sesbania sesban, Crotalaria grahamiana, lablab* or *Tephrosia vogelii,* and fortified composts can be used at various combinations. Combinations of two or more interventions is usually encouraged under ISFM in order to address the diversities in basic soil nutrient deficits, management systems and water management improvements brought about by biological measures, especially for long-term impacts on crop productivity. The focus of any soil fertility replenishment should be integrated nutrient management involving the application of inorganic and organic soil nutrients, as well as technologies that reduce the risks of acidification and salinisation.

6.5.1 Improved fallow

An improved fallow is the enrichment of a natural fallow with leguminous trees or shrubs to improve soil fertility. It is achieved by deliberately planting leguminous tree species or broadcasting seeds of leguminous shrubs onto land which has been left fallow. This ensures that beneficial plants colonize the fallow to improve nutrient replenishment and to fix nitrogen. Some suitable shrub species include *Sesbania sesban, Crotalaria grahamiana, Tephrosia vogelii and Tithonia diversifolia* (figure 6.8).

Figure 6.8 Improved fallow with Tephrosia vogelii *(photos by Bancy Mati)* **(b) Improved fallow with Tithonia diversifolia**

6.5.2 Biomass transfer

This is the incorporation into the soil of leafy shrubs, which accumulate high concentrations of nutrients in their leafy biomass and mineralize rapidly. It can also be defined as a form of cut and carry mulching and the shrubs are widely distributed along farm boundaries in the humid and sub-humid tropics of Africa. The shrubs include *Lantana camara and Tithonia diversifolia*. In smallholder agriculture, *Tithonia diversifolia* is commonly used as biomass material because it is readily available, easy to propagate and relatively richer in nutrients. One ton of dry weight *Tithonia diversifolia* leaves contains an average of 33 kg of nitrogen, 3.1 kg of phosphorous and 30.8 kg of potassium.

6.6. LEISA technologies

LEISA stands for ***Low External-Input Sustainable Agriculture technologies.*** It is a broad term used to describe low-input farming systems which include; Alternative Agriculture, Low-Cost External Input Agriculture, Bio-Intensive Agriculture, Sustainable Agriculture and "Permaculture". In its most extreme form, low-input agriculture is known as organic farming.

6.6.1 Organic farming

Organic farming (or organic agriculture), is a farming system which utilizes natural products such as locally available biological material and natural methods to maintain soil fertility and to keep crops and livestock healthy. The approach keeps the land productive using materials found on the farm. Organic farming meant to promote environmentally sound means of production. Compared to conventional farming systems, where much effort goes into bringing chemical inputs and animal feeds from outside the farm, organic farming instead makes full use of what is found on the farm. In contrast, organic agriculture does not allow use of inorganic fertilizers, pesticides, vaccines and medicines. Instead, manures are used and organic pesticides made from plants and local materials. The organic farmer puts effort into improving soil fertility through composting, proper cultivation, rotation of crops, mixed planting, growing trees, proper care of crops and animals and the natural control of pests and diseases. Because of the better natural balance, agricultural products fetch a much higher price in niche markets than conventionally grown crops and, in general, ensure good health and environmental safety all around.

6.6.2 The case for LEISA

The main limitation with organic farming is that sometimes, locally made pesticides fail to work. Also, some farmers do not have manures or crop residues (the latter are fed to livestock) and thus soil fertility could be hampered unless mineral fertilizers are used. LEISA technologies offer a middle ground between puritanical organic farming and harmful effects of conventional agriculture. These technologies are more realistic and practicable by smallholder farmers. Nearly all the technologies and management practices described in this manual have some component of LEISA technologies.

7. CONSERVATION TILLAGE

7.1 What is conservation agriculture?

Conservation agriculture systems are systems that utilize soils and crops with the aim to reduce the excessive mixing-up of the soil and maintain the crop residues on the soil surface in order to minimize damage to the environment. CA is based on enhancing the natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agrochemicals and mineral fertilizers are reduced. Also, organic nutrients are applied in requisite quantities and in such a way as not to interfere with, or disrupt the biological processes.

CA is intended to provide and maintain optimum conditions for crop root-zone development by retaining maximum possible depth for crop roots to function effectively and in capturing high amounts of desired plant nutrients and water. CA also promotes beneficial biological activity in the soil in order to maintain and rebuild soil structure, contribute to soil organic matter and avoid physical or chemical damage to plant roots. CA is characterized by three principles which are linked to each other, namely:

(i) Permanent organic soil cover.

(ii) Diversified crop rotations in the case of annual crops or plant associations in case of perennial crops

(iii) Continuous minimum mechanical soil disturbance or conservation tillage.

Since permanent crop cover and crop rotations have been covered in Chapter 2 of this manual, this Chapter focuses on ***conservation tillage.***

7.2 What is conservation tillage

Conservation tillage, are land cultivation techniques which try to reduce labour, promote soil fertility and improve soil water conservation. It aims at reducing the negative effects of conventional tillage such as soil compaction, formation of pans, disturbance of soil fauna and moisture loss. The method tries to reduce labour in land preparation through tillage systems that promote soil fertility and soil and water conservation.

Conventionally, tillage is conducted to prepare a seed bed and also to control weeds. However, conventional tillage overworks the soil and can destroy the structure and cause compaction. This has negative effects on soil aeration, root development and water infiltration among other factors. More important, but less noticeable, is the destruction of soil microbiology by disturbance and turning over of soil, which is then exposed to drastic atmospheric and climatic conditions.

Conservation tillage, therefore, takes care of this by applying four main principles: 1) zero or minimum soil turning, 2) permanent soil cover, 3) stubble mulch tillage, and 4) crop selection and rotations. An important aspect of conservation tillage practice involves ripping the land with tined implements or sub-soiling the land immediately after crops are harvested, to break the plough pans using suitable equipment as described below.

7.3 Types of conservation tillage

Conservation tillage is a broad term encompassing a range of technologies and practices. Some of the more common methods used in smallholder agriculture are described bellow:.

7.3.1 Minimum tillage

Minimum tillage involves land cultivation in which soil turning operations are reduced from what is conventionally normal for a given crop or area. Thus, minimum tillage assumes many forms, from reduced tillage operations, strip cropping, spot tillage and even zero-tillage. Normally, special tined equipment are used to open the soil just enough to allow a seed to be planted. Weed control, a major function of minimum tillage, and is achieved through one of several options such as:

(i) applications of herbicides and growth regulators;

(ii) (ii) inter-cultivation based on secondary tillage;

(iii) (iii) manual hoeing/slashing; (

(iv) iv) smothering by cover crops and planted tallow, and

(v) (v) suppression by mulches.

The minimal cultivations reduce water losses because of a reduction in soil disturbance from tillage. In the long term the soil structure is improved. Less surface compaction and smearing at depth from the shares of the plough should increase rooting depth and therefore the drought tolerance of crops. There are many variations to minimum tillage as described below:

7.3.2 Zero tillage

Zero tillage, or no-till system, is minimum tillage at its most absolute. It involves growing a crop in a field which has had no tillage operations preceding the planting. The land is planted by direct seed drilling without opening any furrows or pits (figure 7.1). Old crop residues act as a mulch and weeds are controlled using herbicides. In the dry areas of Africa, zero tillage is hampered by poor infiltration, since most ASAL soils have surface-sealing problems. Moreover, the costs of herbicides can be prohibitive to small holder farmers whose agriculture is more labour based than capital based.

Figure 7.1 (a) Zero tillage planting with digging stick *(photos by A. Rakotondralambo)*

(b) The bean crop after establishment

7.3.3 Spot tillage

Spot tillage sometimes called pitting or auger hole cultivation**,** involves using special digging tools or augers, to excavate small holes just enough for one or two seeds of grain. The land is not tilled and the holes are dug over the old crop residues, while weeds are controlled with herbicides. The digging of small planting pits with hand-hoes can be quite efficient in concentrating surface water and plant nutrients as well as breaking hard plough pans. The technique is labour intensive, but simple and is an efficient way of assuring a crop survival even when rainfall is inadequate and resources such as fertilizers and manure are unavailable (figure 7.2).

Figure 7.2 Spot tillage (planting basins) with residue mulch covering *(Source: CFU Zambia, 2007)*

(b) Measuring depth of planting hole

7.3.4 Deep tillage

Deep tillage or sub-soiling is practiced on soils having surface crusting properties or those prone to developing hard pans. Special equipment known as sub-soilers, capable of digging down below the plow depth are used. Most sub-soilers require tractor-drawn power. However, manual sub-soilers have also been developed by innovative smallholder farmers The equipment comprises a long hoe that can cut into about 30 cm of soil. It is made from old car-springs cannibalized from junk cars and therefore, is quite durable and low-cost. Deep tillage may be required once every 3 years, to break soil crusts developed from prolonged use of the mold-board plow.

Manual sub-soilers have also been developed by innovative farmers. The equipment comprises a long hoe that can cut into about 30 cm of soil, which is made from old car-springs cannibalized from junk cars and, therefore, is quite durable and cost-effective. The sub-soiler is used once in 3 years, to break soil crusts developed from prolonged use of the mold-board plow.

7.3.5 Strip cultivation

Strip cultivation or No-till strip cropping, is a method of minimum tillage. It involves tilling the land in strips at the position of the crop rows, leaving the rest of the land untilled, to generate run-off and reduce labour (figure 7.3). Tined implements are usually used. The animal-drawn tined implements e.g. the "magoye ripper," can be used. It digs 25-30 cm into the soil breaking the plough hard pan. It can also be used to make furrows about 80 cm apart. Where access to equipment is possible, the operation can be advanced to simultaneously insert seeds (and even fertilizer) into the soil while breaking the hard pan in the same single pass.

Figure 7.3 (a) Strip cultivation using oxen (*Source: CFU Zambia, 2007*) **(b) Strip cultivation with stubble mulch**

7.3.6 Stubble mulch tillage

Stubble mulch tillage involves retaining the past season's crop residue by incorporating it into the soil during primary tillage. The residues are chopped and spread on the surface or incorporated during tillage with tined implements such as the chisel plough (figure 7.4). Stubble mulch tillage reduces labour and farm-power requirements, and as such, it is cost-effective. The system results in improved soil structure, thereby reducing direct impact of raindrops on bare soil, and thus minimizing soil erosion. Moisture retention capacity of the soil is also enhanced by the residues; hence crop survival is better during dry spells or drought.

Figure 7.4 (a) Stubble mulch tillage with tractor *(Source: CFU Zambia, 2007)* **(b) Stubble mulch tillage done with oxen** *(Photo by Bancy Mati)*

7.3.7 Ridging

Ridging, which is the construction of contour ridges (or contour furrows), involves making narrow earthen bunds along the contour at a spacing of about 1-2 m. The ridges may be on the contour with graded furrows draining into a grassed waterway or the ridges may have short cross-ties to create a series of basins to store water. In most smallholder farms, ridging is normally done for crops such as potatoes, tobacco, groundnuts and even for maize. Ridging for maize sometimes involves "earthing" up the maize rows during the weeding process, albeit the maize is first planted on the flat. Ridging systems are mostly suited for areas with an annual rainfall ranging from 350 to 750 mm. Ridging redirects surface runoff across the slope, improving infiltration and thus preventing soil erosion. In dry areas, the crop is planted at the side of the ridge so as to be closer to the water conserved, without the danger of water-logging (figure 7.5). Ridging is suited to deep soils and gentle topography. The ridges may be made every season. Alternatively, in a semi-permanent ridge-furrow system only the necessary repair is done at the onset of a new cropping cycle.

Figure 7.5 (a) Ridging with sweet potato crop **(b) Ridging with maize crop**
(Photos by Bancy Mati)

7.3.8 Tied Ridging

Tied ridges are a modification of the normal contour ridges. They are made in semi-arid areas especially for water conservation. The technique involves digging major ridges that run across the predominant slope, and then creating smaller sub-ridges (or cross-ties) within the main furrows (figure 7.6). The final effect is a series of small micro-basins that store rainwater in-situ, enhancing infiltration. Depending on the system, the crop is planted at the side of the main ridge, to be as close as possible to the harvested water while also avoiding water logging in case of prolonged rains. Tied ridges have been found to be very efficient in storing the rain water, which has resulted in substantial grain yield increase in some of the major dryland crops such as sorghum, maize, wheat, and beans.

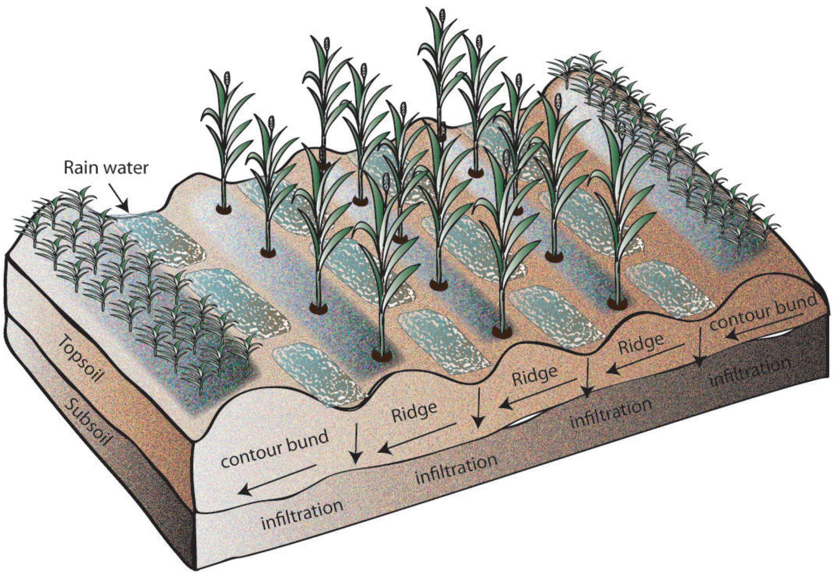


Figure 7.6 Sketch Illustration of tied ridging

7.4 Tools and equipment for conservation tillage

There is a wide range of equipment and tools used in smallholder agriculture in Africa, whether for conventional or conservation agriculture. The hand hoe, digging stick, pick axe, ox-drawn implements and other traditional tools can be used for conservation tillage, including planting and cultivation. However, African smallholder agriculture will not be upgraded with these rudimentary tools. They are slow, labour intensive, tiresome, inefficient and cause drudgery, which is a major reason youth shun agriculture. Even then, manual and animal drawn equipment are still necessary, and in some cases, quite effective and could be all that a farmer has. Therefore, this section will present tools and equipment used for conservation agriculture, including manual, animal-drawn and tractor drawn implements.

7.4.1 Special features of CA equipment

Equipments used in conservation tillage sometime differ to some extent from those used for conventional agriculture. The basic features are that these equipments should be able to dig deeply into the soil, while causing as little disturbance to the soil surface as possible. Tillage equipments such as the moldboard plough are not used in CA because they turn the soil. If possible the equipments should be capable of multiple functions. This could include ability to handle residues, open an appropriate slot, meter seed and perhaps fertilizer, distribute this to the openers, place it in the soil in an acceptable pattern, and cover and pack the seed and the fertilizer. There are many types of small-scale minimum tillage equipments available, each suited to different sources of power and field conditions. For instance, tined implements such as furrow openers used in minimum tillage which allow cutting into the soil to create a relatively deep and quite narrow furrows, without turning the soil. They are especially suitable for strip cultivation and stubble mulch tillage. Others include; tined cultivators, augers, hand jabbers, animal-drawn planters, rippers, sub-soilers, power tillers and powered tractors.

7.4.2 Hand-jab planters

Hand-jab planters (sometimes called dibblers) are normally used for sowing seeds under no-tillage systems. Hand-jabbers may have either separate hoppers for seed and fertilizer or one hopper for seed only. Figure 7.7 illustrates a typical double-hopper jab-planter. In design, a seed metering device is used on hand-jabbers in the form of a rectangular plate placed inside the hopper. When the handles are pulled apart, the seeds drop into the holes, which are delivered to the outlet and the discharge tube. Plates with different hole sizes are available according to the seed size. Seeding rates can be adjusted according to the number of holes in the seed plate that are exposed in the outlet. Fertilizer amounts can also be similarly adjusted.

Figure 7.7 (a). Sketch of a hand-jab planter with seed and fertilizer hoppers

(b) A hand-jab planter with seed and fertilizer hoppers *(photo by Bancy Mati)*

One of the advantages of hand-jab planters is that they do not require access to animal or tractor power, are low cost, light and easy to operate, although some skill is required. Thus, they are easy to use by a woman, which increases the available labour pool for small farmers, although no-tillage itself reduces labour demand. By planting seeds in pockets, there is minimal soil disturbance so weed seed germination is minimized, resulting in easy hand hoeing between plants. The small size of the devices makes them suitable for operation on hilly, stony and stumpy areas and for intercropping (e.g. sowing mucuna between maize rows) and for planting in fallow areas.

Hand-jab planters are suited to light soils since penetration can be difficult in harder soils in the absence of some form of tillage. Some clay soils may also stick to the blades when working in wet conditions and seed coverage may be affected by the V-shaped pockets and minimal disturbance. Hand-jab planters can also be adapted in conventional tilled agriculture as they reduce labour and introduce precision in planting of seeds.

7.4.3 Hoe openers

Openers are seed drills designed for manual planting. They can be attached with seed and fertilizer hoppers. Small-scale planters with tined openers have independent adjustment for the fertilizer opener so that fertilizer can be placed deeper than the seed. Although placing fertilizer beneath the seed in no-tillage does not always result in the best crop yield, with small-scale drills and planters it is a more realistic option than placing fertilizer alongside the seed because the latter option requires the fertilizer opener to be operating in new ground, which requires more energy than when both openers (seed and fertilizer) operate at different depths in a common slot. In any case, placed fertilizer within the seed zone is better than surface broadcasting causing slow crop access and increased weed growth.

Generally, tines require less force than double disc openers, which contributes to maintaining a uniform seeding depth if a suitable depth control mechanism is included. Tines are preferred in hard soils, although their drag force may become excessive for the power available. Tines are also more susceptible to blockage with residues and are unsuitable in stony areas.

7.4.4 Animal-drawn planters

Animal drawn planters for CA have the same basic design that allows seed placement in the soil with minimum disturbance (Figure 7.8). They are generally lighter, less expensive and more adaptable to hilly and stony areas. They also have a greater range of adjustments to allow for the diversity of small farms, seed types and animal pulling capacity. Residue handling is often easier with small scale machines as a result of fewer rows and openers.

Figure 7.8 (a) Tined openers for animal-drawn no-till planters *(source: Ribeiro et al, 2006)*

(b) Animal-drawn planter with fertilizer hopper *(photo by Bancy Mati)*

7.4.5 Magoye ripper

The Magoye ripper is a tined implement designed in Zambia especially for conservation tillage. The implement is basically a narrow tine (in this case a hexagonal-section 25 mm diameter carbon steel rod – probably from discarded rock drilling bits) with a low angle of attack (<15°). This configuration gives good penetration at low draft. The tine is reversible and moveable to compensate for wear. The tine and adjustment assembly are mounted on a steel plough frame.

The Magoye ripper has two variations, the sub-soiler and the ripper. The ripper is a tool for ripping and producing a weed-free seedbed along the line of planting. This obviates the need for ploughing, but does increase the level of management required to control the inter-row weeds (either mechanically or chemically). There is provision for attaching wings for ridging and the wing mounting plates alone produce a narrow weed-free furrow, suitable for hand planting with a stick or jab planter. The Magoye ripper is normally pulled by oxen and is quite popular with smallholder farmers engaged in conservation tillage

7.4.6 Tractor-drawn tined implements

There is a wide range of tractor pulled implements for CA adaptable to smallholder farming. These include small tractor tined cultivators and planters requiring up to 50 hp. The machines have the same straw-cutting (smooth disc) and slot forming (tine or double disc) openers as the single-row machines and most are capable of applying fertilizer at seeding time. Some models provide bulk seed and/or fertilizer hoppers in a similar manner to larger machines, while other models are set up as multi-row precision seeders (figure 7.9).

Figure 7.9 Small 4-wheeled tractor with planter *(photo by Bancy Mati)*

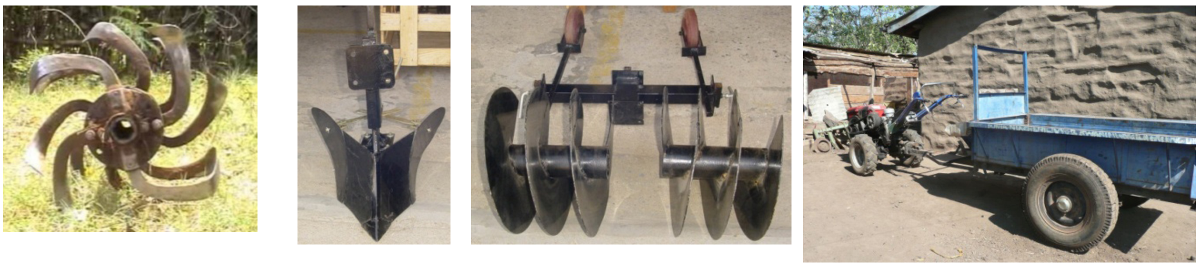
(b) 4-wheel tractor with chisel plow *(photo by Omar el Seed)*

7.4.7 Two wheeled tractors

Two-wheeled tractors, sometimes known as power tillers, provide an option to mechanise agriculture on small farms at less cost than conventional four wheeled tractors (figure 7.10). They can be used on land as small as 0.2 ha and utilize less energy. Two wheeled tractors can be used for both conventional and conservation agriculture, depending on the type of tools and attachments used. They offer versatile use and can be adapted as cultivators, planters, weeders, rotavators or attached to a trailer and sued to transport agricultural produce (figure 7.11).

Figure 7.10 Two-wheeled power tiller with tined cultivators *(photos by Bancy Mati)*

(b) Two-wheeled tractor mounted with sub-soiler



(a) **Weeding tyne** **(b) Ridger** **(c) Bund former** **(d) Trailer**

Figure 7.11 Accessories used with power tillers *(Source: Ribeiro et al, 2006)*

7.5 Advantages of conservation tillage

Labour saving: The substitution of conventional tillage by conservation agriculture allows a more even distribution of labour over the year, because of the elimination of ploughing and harrowing activities and the use of cover crops and herbicides.

Agronomic benefits: Adopting conservation agriculture leads to improvement of soil productivity: Organic matter increases, there is in-situ soil water conservation and improvement of soil structure, and thus rooting zone. Also, the reduced traffic by agricultural machinery reduces soil compaction, improving infiltration of water into the soil.

Improved soil fertility: The added crop residues increase of the organic matter content of the soil. In the beginning this is limited to the top layer of the soil, but with the years this will extend to deeper soil layers. Organic matter plays an important role in the soil: fertilizer use efficiency, water holding capacity, soil tilth, rooting environment and nutrient retention, all depend on organic matter.

Environmental benefits: There are improvements in water quality as there are less sediments eroded from land. Also, increased micro-biodiversity in the soil due to incorporation of crop residues on the soil surface and also reduced splash-effect of the raindrops. This results in higher infiltration and reduced runoff, leading to less erosion. The residues also form a physical barrier that reduces the speed of water and wind over the surface, of which the latter reduces evaporation.

Carbon sequestration: Conservation agriculture also has significant benefits at the global level, including: carbon sequestration in the organic matter accumulated in the soil from the crop residues and cover crops. There is also less leaching of soil nutrients or chemicals into groundwater, recharge of aquifers through better infiltration, less pollution of the water and less energy/fuel used during tillage.

7.6 Limitations of conservation tillage

Conservation tillage may carry high initial costs of purchasing the specialized equipment and the new management skills. In addition, conservation tillage may not work well in areas prone to flooding or soil with surface sealing properties. The need to use herbicides to control weeds is another limitation for smallholder farmers, where the cost of capital is higher than that of labour. In addition, smallholder farmer contain a multiplicity of crop enterprises for which herbicide use could pose a limitation. Sometimes, it takes several years before the advantages are realised so it should be considered a long-term project.

8. AGROFORESTRY

8.1 What is agroforestry?

Agroforestry refers to "a dynamic, ecologically based natural resources management system of trees in farms and in the landscape, diversifies and sustains far increased social, economic and environmental benefits for land use at all levels." It involves planting trees or shrubs in the farm, or keeping those that are already there. This can be in the form of interspaced trees, borders or shelterbelts. An agroforestry system should hold a diversity of plants with different root systems, drawing water from different soil layers with different growing periods (figure 8.1). Tree-roots are deeper than most agricultural crops and they can reach water & nutrients from deeper layers than crops. The idea is combine species with different properties in such a way that the resources are optimally used. Any negative interference or competition with crop should be minimal, such that the net productivity of land is increased compared with sole crops.

Figure 8.1 Agroforestry is growing trees, shrubs and crops *(photo by Bancy Mati)*

8.2 Benefits of agroforestry

- Agroforestry has the potential to increase the organic matter and nitrogen content of soils. The growing of multipurpose tree species compatible with existing farming systems is important in soil management.
- Agroforestry trees cushion the impact of raindrops on the soil, hence reducing the amount of rain-splash erosion. Their roots bind the soil together.
- Planted along contours, agroforestry trees interrupt the flow of water running off the surface. They prevent soil erosion, conserve soil water, and improve soil fertility and micro climate. The environmental benefits of trees include soil conservation, bio-diversity conservation, and conservation of terrestrial carbon.
- The trees shade the soil, reducing the soil temperature and cutting the amount of water that evaporates into the air. They also serve as a wind break, reducing incidence of wind

erosion.

- Agroforestry trees recycle nutrients from deep in the soil, and leguminous trees fix nitrogen that can benefit plants. They provide nutrient inputs to crops by capturing nutrients from atmospheric deposition, biological nitrogen fixation, availability of nutrients from deep in the subsoil (deep nitrate capture) and storing them in the bio-mass.
- In biomass transfer systems, the transfer of biomass from one site to another provides nutrient inputs which become available when the biomass is decomposed in the soil.
- Trees can also enhance nutrient cycling through conversion of soil organic matter into available nutrients (especially N and P). It is, therefore, possible to recycle nutrients through litter-fall, root decay, and green manure.
- Agroforestry has other environmental benefits such as improving water retention in a watershed, increasing biodiversity, greening the environment and supporting wildlife, and livestock.
- Apart from helping conserve water and soil, agroforestry can provide many other ecological, economic or social benefits. These include the provision of poles for building, fruits for sale and consumption, fuel wood, and fodder for livestock.

8.3 Limitations

The main limitation with agroforestry is that for some crops, the shading is undesirable and may lower yields. Also, there is some competition for nutrients and water especially in dry areas. Trees take up space on a farm and this may discourage farmers with very small plots of land to adopt agroforestry. The biggest limitation, however, is the lack of knowledge by farmers, on which tree species best suit their cropping systems, where to get them from, and how to manage them to optimize agricultural productivity on relatively small farms.

8.4 Types of agroforestry systems

Agroforestry systems are often complex systems, which allow the implementation of a number of water & soil conservation measures. Thus, there are many ways to practice agroforestry, and some of them e.g. hedge-row intercropping, grass-strips, vegetative buffers, improved fallows and strip cropping have been discussed in previous sections of this manual.

Other methods include the following

- Planting trees in woodlots, or farm forestry systems in which a part of the farm is set aside for pure stand of forest trees.
- Orchards are a variation of woodlots except that they carry fruit trees. This is an agroforestry system as much as it is a horticultural enterprise
- Interspersed planted with crops within the farm.
- Contour planting of hedges forms biological terraces naturally, stops the soil and water from washing downhill.
- Fodder trees and grass leys used for grazing add plant biomass to the farm and provide agroforestry benefits
- Multipurpose tree systems whereby trees have benefits e.g. *grevillea robusta* provides timber,

firewood from trimming its branches, shade and good leaf litter

- Indigenous trees could be retained on the farm, when new land is opened for cultivation,
- Natural bush hedges running across the slope which act as infiltration buffers
- Trees planted on farm boundaries
- Agroforestry trees planted to soil conservation structures e.g. terraces to stabilize them,
- Trees planted across the wind direction as wind breakers, and
- Sylvopastoral systems combine pasture and trees.

8.5 Characteristics of suitable agroforestry tree species

The important qualities of a good agroforestry tree species is one that has a light, open crown that lets sunlight through. The tree should have ability to fix nitrogen and good leaf litter which would easily convert into nutrients available at appropriate times in the crop cycle. It should have few and shallow lateral roots and a deep thrusting tap root system so that it draws most of its water from subsurface soil layers. The trees should have the ability to resprout quickly after pruning, coppicing or pollarding. A good agroforestry tree should be resistant to droughts, flooding, soil variability, and other climatic hazards. It should have a productive capacity that includes poles, wood, food, and fodder, medicinal and other products. It should not compete with crops for water or nutrients.

Tree species with all these characteristics are few to find. But a number of trees and shrubs have varying benefits and are commonly used for agroforestry in tropical zones. Typical species include trees such as Grevillea Robusta, and fruit trees such as papaya, mango, orange, avocado, guava, and other indigenous trees. Also, shrub species used in various soil and water conservation practices and for livestock feed are agroforestry trees. They include; *sesbania sesban, caliandra calothyrsus, Cassia siamea*, *Lantana camara, Tithonia diversifolia, Crotalaria grahamiana, Tephrosia vogelii, caliandra calothyrsus* and *leucena sp*. There are numerous other indigenous tree and shrubs which local people know are good for growing with crops.

8.6 Tree establishment and care

The establishment of agroforestry trees is an important step which requires much preparation and care. First suitable tree species are selected, their seeds collected and planted in a nursery. The seedlings are carefully tended in nursery beds during the dry season. The young seedlings should be kept under shade to protect them from the harsh conditions from the sun's heat. Later, when the seedlings are close to transplanting, they are removed from the shade and given enough time to grow and harden in the open (figure 8.2). Depending on tree species, the nursery seedlings are transplanted at the earliest opportunity, so that they take root in the field.

Figure 8.2 Young tree seedlings in a shaded nursery *(photo by Janvier Gassasira)*

(b) Hardening tree seedlings in the sun before transplanting *(photo by Bancy Mati)*

When ready, the seedlings are transplanted into large planting holes at the end of the dry season or at the onset of the rains. They are watered liberally at first in order to encourage the growth of deep roots in the planting hole and vigorous branch and leaf growth. Rapid leaf growth means that the roots will be well nourished; these will then increase in length and penetrate deep into the ground in search of the capillary fringe. When rainfall is inadequate, water application should be very limited, just enough to keep the tree alive. This avoids the formation of shallow rooting which is detrimental to of the growth of the deep thrusting tap roots. If the tap roots reach the capillary fringe by the end of the rainy season, the seedling will survive the dry season. Otherwise, it will need watering until the rains begin again**.**

As with all other agricultural enterprises, agroforestry trees should be tended with care. This could involve activities like pruning, watering, addition of fertilizers and manures where necessary, removal of unwanted vegetation and weeds, pest and disease control. Finally, trees are planted with a purpose. Therefore, harvesting of the tree products or the tree itself is part of agroforestry management.

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