World Agroforestry Centre

Conservation Agriculture With Trees: Principles and Practice

A simplified guide for Extension Staff and Farmers

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Acronyms

AF	Agroforestry
EC	European Commission
EGA	EverGreen Agriculture
CA	Conservation Agriculture
CO2	Carbon dioxide
CR	Crop residue
CAWT	Conservation Agriculture With Trees
ICRAF	World Agroforestry Centre
IFAD	International Fund for Agricultural Development
KATRESNO	Kenya Association of Tree Seed and Nursery Operators
KEFRI	Kenya Forestry Research Institute
KENDAT	Kenya Network for Dissemination of Agricultural Technologies
NGOs	Non-governmental Organizations
RAB	Rwanda Agricultural Board
RRC	Rural Resource Centre
SOC	Soil Organic Carbon
TAFORI	Tanzania Forestry Research Institute
WWF	World Wildlife Fund

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Background

This guide was prepared as a result of training sessions conducted between May and August 2012 in Kenya and Tanzania for extension agents from the Ministry of Agriculture, Landcare and World Vision in Kenya; and from the Ministry of Agriculture & Food Security, Division of Forestry & Bee keeping, Ministry of Natural resources and Tourism in Tanzania as well as those from WWF (World Wildlife Fund). These agents work in partnership with the IFAD funded EverGreen Agriculture (EGA)project areas of Machakos County in Kenya, and Mbarali District in Tanzania. It is expected that they will be able to stay in touch and support farmers with knowledge gained at these trainings, to increase the adoption of Conservation Agriculture (CA) and Agroforestry (AF) as well as participation in Landcare approaches.

The guide is intended to assist extension agents in the East African region conduct training events for farmers and other interested stakeholder in Conservation Agriculture With Trees (CAWT) specifically farmers and those wishing to practice Conservation Agriculture may also find this guide useful.

CAWT involves the integration of crop-friendly trees (mainly high value agroforestry tree species and nitrogen fixing trees) into the current suite of conservation agriculture practices. Conservation Agriculture encompasses three principles namely minimum tillage, maximum soil cover and crop rotation and association, applied concurrently or singly. The emphasis is the protection of the soil top layer which is responsible for sustaining crop life but is also the most vulnerable to erosion and degradation.

Although there is a lot of potential for the adoption of CAWT systems on farms, there are many internal and external circumstances that may hinder fast and widespread adoption processes. These may range from policy issues and support systems such as technology, cost and availability of inputs to arguments from different schools of thought, and cultural conditioning. This guide deals with technical issues and seeks to equip extension agents with appropriate information for farmer empowerment processes through information, skills and technology transfer.

As farmers acquire information and technology support at farm level to encourage the adoption of CAWT, it is hoped that the clearly discernible benefits realised will encourage more farmers to also adopt CAWT technologies.

It is anticipated that this will lead to a critical mass of CAWT practitioners, requiring central support for access to inputs, service infrastructure, equipment, markets, etc. Hence there is need to make a conscious effort towards capacity and opportunity to meet demands that might arise.

The guide is organized into five modules designed to provide learners with a step-by-step and logical progression from one topic to the next:

- Module one identifies the problem, by dealing with issues of soil health and soil degradation processes.
- Module two proposes CAWT as the solution and brings the principles of CA and its benefits into light and deals with the main challenges that must be addressed for the successful application/adoption of CAWT.
- Module three discusses the incorporation of trees into CA, thus CAWT.
- Module four explains how to implement CAWT.
- Module five deals with CA tools and equipment options to suit different categories of farmers.

Throughout the guide, discussion topics are provided to help solicit participation and provoke feedback from participants. Practical sessions are also provided to help reinforce the learning and transfer practical skills, which are essential to the application of CAWT in farmers' fields. The training guide also contains additional reading suggestions which the facilitators/extension agents may use to enrich their own knowledge of the subject matter.

How to use the guide

The guide provides the required information and materials to help extension officers conduct a basic training course in conservation agriculture with trees. This course is intended to help farmers and other interested parties get started in applying CAWT in practice. It is intended to be a guide for trainers, who are urged to provide additional information as required, by consulting the references given under each module. Suggestions for activities that can be used in delivering this information are included in text boxes.

Trainers using this guide are encouraged to use their ingenuity and creativity in designing an effective training program that may include these activities, to meet the unique needs of their specific trainees. Where possible we recommend the use of PowerPoint presentations, otherwise flip charts and other visual materials may be used.

Module One

Soil health and degradation processes

Learning objective

In this module participants will learn what constitutes a healthy soil. Important soil factors such as soil organic matter, soil carbon, soil organisms and soil pH will be presented and discussed. Participants will also learn about the process and impacts of soil erosion.

Soil health

Soil health refers to the capacity of soil to function as a living system. There are three main properties of a healthy soil – physical, chemical and biological.

The physical properties refer to the arrangement of soil particles and the movement of air and water in and out of the soil. For good physical soil health we need air and water to be in constant supply to promote plant growth.

The chemical properties deal with nutrient in the soil and the soils ability to supply the nutrients to the plant.

The biological properties of soil health refer to the living soil organisms. Soil organisms play a beneficial role in promoting plant growth by recycling nutrients, creating channels allowing movement of air and water, improving the soil structure and suppressing pests and diseases of plants.A healthy soil is one which is able to hold water and nutrients and supply them to plants when they need them, without the direct application of external nutrients such as chemical fertilizers.

Defining soil health. Ask participants to explain their own understanding of soil health. What are the characteristics of a healthy soil? What are the symptoms of unhealthy soils? Write down on a flip chart and encourage discussion on each listed point. Suggestions that can be used as prompts are made in the following section.

Properties of healthy soil

- Healthy soil accommodates active and diverse populations of beneficial organisms, with pests and plant pathogens in low numbers or controlled by beneficial organisms.
- It contains high levels of relatively fresh organic matter and residues that provide the beneficial organisms with food.

- It includes high levels of decomposed organic matter, which help it retain both water and available nutrients.
- It contains low levels of toxic compounds such as soluble aluminium and only low to moderate concentrations of salt.
- Its nutrient levels are adequate but not high enough to make the crop more attractive to insect pests or to increase the threat of surface or subsurface water pollution.

- Its surface is sufficiently porous, with many pores connected to subsoil and permit easy infiltration of rainfall or irrigation water.
- Its ample porosity and structure allow plant roots to easily penetrate large volumes of soil.

Soil organic matter (SOM)

Soil organic matter is a key soil component and plays a critical role in a range of physical, chemical and biological soils processes. Soil organic matter provides energy for biological processes, improves soil structural stability, influences water retention properties, and alters thermal properties, and contributes to the cation exchange capacity among other properties. Soil organic matter is the most important soil health parameter in terms of agricultural production and nutrient supply to plants. It is a key indicator of soil health. Its decline results in a soil that is degraded.

What is soil organic matter?

Soil organic matter refers to the fresh or partially decomposed plant, animal residues or humus that are present in the soil. Organic matter is mainly present in the top layer of the soil, which is subject to a continuous transformation a process. Organic matter is therefore important in determining the soil structure.

Soil organic matter (SOM) is the foundation for productive soil since it promotes healthy crops, supplies resources for microbes and other soil organisms, and regulates the supply of water, air and nutrients to plants.

When decomposed by soil organisms, Soil organic matter, recombines with mineral soil particles to form highly stable humus aggregates or crumbles which greatly improve the soil's overall structure. Organic matter is the glue that sticks soil particles together. The more soil organic matter the soil has, the more fertile it is likely to be.

The colour of the soil is usually a reflection of the amount of organic matter present in the soil hence darker soils with brown/black colour indicate the presence of high amounts of organic matter as compared to those with lighter coloured soils.The major sources of organic matter in soil include dead/decomposing plant materials such as grass, shrubs/trees and vegetable clippings, animal and green manures, compost and other organic materials. The quality of soil organic matter varies depending on the plant material and management practices.

Soil organic carbon (SOC)

Soil organic carbon is said to be the most important building component for a healthy soil. It is the single largest component of soil organic matter and a key factor in greenhouse gas mitigation.

Why is soil organic matter/carbon important?

Soil organic matter is the source of food for soil fauna and contributes to soil biodiversity by acting as reservoir of soil nutrients such as nitrogen, phosphorus and sulphur. Soil organic matter is the main contributor to soil fertility. Soil organic carbon supports the soil's structure, improving the physical environment for roots to penetrate through the soil. Organic matter absorbs water (can hold about six times its weight in water). Soils with organic matter have a better structure that improves water infiltration, and reduces the soil's susceptibility to compaction, erosion, desertification and landslides.

When soil organic matter decays, it releases carbon dioxide (CO_2) into the atmosphere; on the other hand when it is formed, CO_2 is removed from the atmosphere.

What causes organic matter decline?

Excessive tillage is one of the major causes of organic matter decline in the soil. Tillage accelerates the rate of decomposition of organic matter by bringing organic materials into contact with organisms and generally improves the environment for biological activity. Decomposition is desirable because it releases nutrients and feeds soil organisms. But if the rate of decomposition is faster than the rate at which organic matter is added, soil organic matter levels will decrease.

How can we manage soil organic matter?

There are two general approaches to increasing soil organic matter in the soil:

- Slowing down decomposition rates. This can be done by reducing tillage intensity. Reduced tillage or no-till practices reduce the amount of soil disturbance, and leave a surface cover of residues. The residue gradually breaks down into soil organic matter and CO_2.
- Increasing the amount of organic matter in the soil. This can be done through adding organic materials in the soil by using cover crops or compost amendments.

Soil living organisms

Soil living organisms are organisms that inhabit the soil during part or all of their life. They range in size from microscopic cells that digest organic material to small mammals that live primarily on other soil organisms.

What soil organic matter does:

Nutrient cycling:

- Increases the nutrient holding capacity of soil
- Acts as a pool of nutrient for plants
- Binds nutrients, preventing them from becoming unavailable to plants
- Provides food for soil organisms

Water dynamics:

- Improves water infiltration
- Decreases evaporation
- Increases water holding capacity, especially on sandy soils

Structure

- Reduces crusting, especially in fine-textured soils
- Encourages root development
- Improves aggregation, preventing erosion
- Prevents compaction

Soil organisms play an important role in maintaining fertility, structure, drainage, and aeration of soil. They also break down plant and animal tissues, releasing stored nutrients and converting them into forms usable by plants. Not all soil organisms are beneficial since some of them cause rot, some release substances that inhibit plant growth, and others are hosts for organisms that cause animal diseases.

Discussion point/activity: What are the factors that influence the presence and multiplication of soil living organisms? What are the most common soil living organisms?

However, most have beneficial functions. Soils with large numbers of organisms in them tend to be very fertile, for instance, one square metre of rich soil may contain as many as 1 trillion organisms. Large organisms such as earthworms are very important creatures living in the topsoil. Earthworms, for example, pass both soil and organic matter through their digestive systems, in the process aerating the soil, breaking up the litter of organic material on its surface, and moving material vertically from the surface to the subsoil.

This is extremely important to soil fertility as it develops the structure of the soil matrix for plants and other organisms. One of the most important roles of soil organisms is breaking up the complex substances in decaying plants and animals so that they can be used again by living plants.

Soil pH

Soil pH is a measurement of the alkalinity or acidity of soil and is measured on a scale of 1-14. A measure of 7 on the scale is neutral while anything below 7 is considered acidic and anything above 7 is considered alkaline.

Farmers should be interested in soil pH because it plays an important role in plant growth. Soil pH determines how easily nutrients become available to plants in the soil. This is known as solubility. Most soils are acidic, saline or alkaline. Most plants require a somewhat neutral pH of between 6.2 to 7. However, there are some plants that are more specific in their pH needs.

It is therefore important to test your soil to determine its pH level before deciding what corrective measure to undertake. For example, acidic soils may require the addition of lime. The modification of the soil pH and an increase in soil organic matter content can greatly improve nutrient availability and prevent nutrient toxicity.

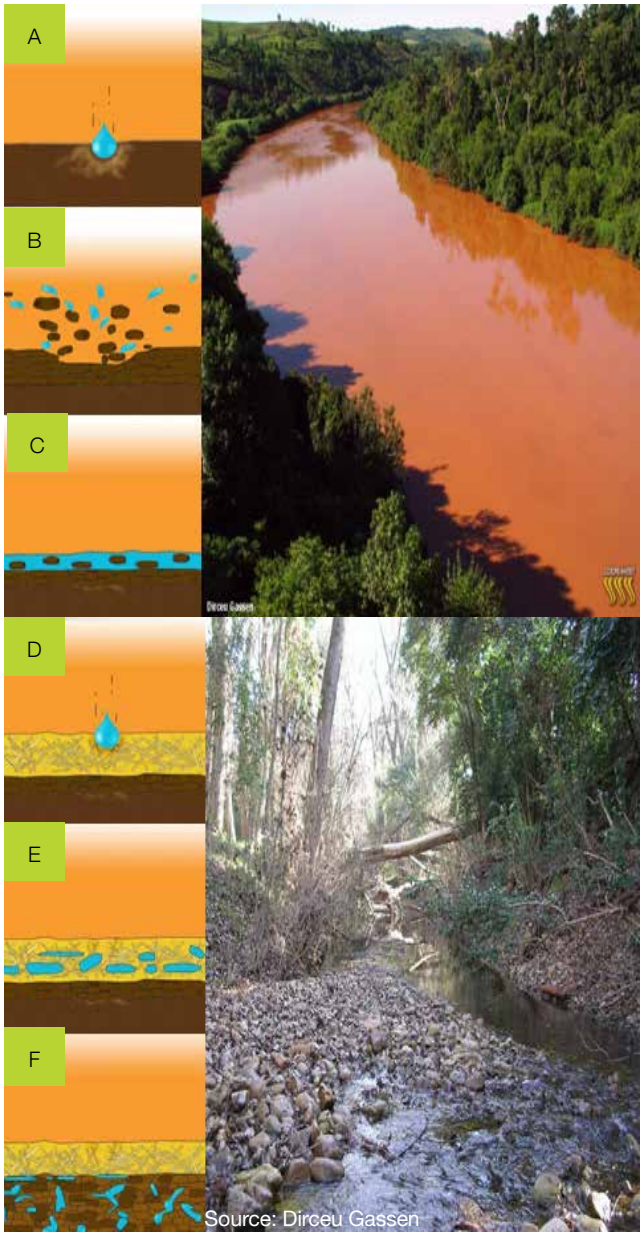
Soil erosion

Soil erosion is the removal topsoil due to natural, animal, and human activity. Natural activity includes the removal of soil by the action of water and wind. Human activities such as overgrazing, unsuitable cultivation practices, clearing land for construction of buildings, dams, roads etc. dramatically accelerate the rate at which erosion takes place. Accelerated erosion may affect both agricultural areas and the natural environment, and is one of the most widespread of today's environmental problems.

Soil erosion has impacts both at the point where soil is detached (on-site) and at the point where the soil is deposited (off-site). On-site impacts of soil erosion include the reduction in soil quality resulting in the loss of the nutrient-rich upper layers of the soil, and reduced water-holding capacity of many eroded soils.

On the other hand, water erosion's main off-site effect is the movement of sediment and agricultural pollutants into watercourses. This can lead to silting of dams, disruption of the ecosystems of lakes, as well as the contamination of drinking water.

In some cases increased downstream flooding may also occur due to the reduced capacity of eroded soils to absorb water on site.Naturally, the steeper the slope of a field is, the greater the amount of soil loss from erosion by water. Slope length also has an impact on soil loss due to greater accumulation of run-off along the slope.



The impact of raindrops on bare soil surfaces (A) detaches small soil particles (B) which are carried away by runoff (C). The soil particles are deposited down slope when the runoff velocity decreases. The brown colour of the water flowing in rivers is clear evidence of erosion.

Soil erosion's potential is increased if the soil has no or very little vegetative cover of plants and/or crop residue

Plant residue or cover protects the soil from raindrop impact and splash (D) and tends to slow down the movement of surface runoff (E) by allowing excessive surface water to infiltrate into the soil (F)

Impacts of soil erosion

On-site impacts

- Reduction of soil quality resulting from the loss of the nutrient-rich upper layer of the soil
- Reduced water-holding capacity of the eroded soils

Off-site impacts

- Movement of sediments and agricultural pollutants into water sources
- Silting of dams
- Disruption of the ecosystem of lakes
- Contamination of drinking water
- Flooding due to reduced capacity of eroded soils to absorb water

Field demo/Activity: Soil loss and run-off. See annex I for details

Further reading

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Module Two

CA as a viable and feasible option to farm sustainability

Learning objective

In this module, participants will learn how ploughing contributes to soil destruction leading to low yields and also gain an understanding of what Conservation Agriculture is and the underlying principles and benefits. The participants will also learn the key challenges hindering the adoption of CA and how these challenges can be overcome. In particular, issues of weed management and livestock integration are covered.

Why ploughing damages the soil

It is assumed that ploughing is necessary in order to loosen the soil and prepare a seedbed to encourage seed germination, control weeds and incorporate manure and plant material into the soil. Conventional ploughing/tillage as practised in many African countries involve turning the soil surface of the entire area of the field that is to be planted.

This type of cultivation leaves the soil bare, exposing it to erosion and water loss through evaporation which results in capping of the soil surface, accelerated decomposition of soil organic matter and contributes to the destruction of soil structure. Repeated ploughing and cultivation at the same depth increases the risk of soil compaction and creation of hardpans at the working depth.

Mixing of the soil layers can also severely harm soil organisms such as earthworms. Conventional ploughing is largely to blame for the extremely low yields and high labour input which characterize farming in most parts of Africa. There is urgent need to shift towards a more sustainable management of our soils.

CA, which has revolutionized the farming systems in Latin America within the last decade, is now being seen as a possible solution to Sub-Saharan Africa too. CA provides the means that can prevent further destruction of precious soils, ensures higher and more stable yields while reducing production costs (especially the energy input for tillage) and increases labour productivity.

Conventional farming practices, especially burning of crop residue and fallow vegetation, intensive ploughing, and the failure to replenish organic matter and plant nutrients, results in soil degradation and decline in soil fertility. The decline in soil fertility coupled with lower water infiltration and storage results in declining yields, increases the vulnerability of crops to droughts, leading to food insecurity and increased poverty.

Conservation Agriculture

In CA, ploughing is minimized to allow for seed and fertilizer placement. Usually this involves chiselling, ridging, sub-soiling, ripping and no-till.

In practising CA:

- The number of passes over the field for land preparation is greatly reduced.
- The surface residue is left on the surface to protect the soil and reduce water loss.

Conventional farming

In conventional farming, intensive ploughing is practiced. This involves a combination of primary and secondary tillage operations in preparing a seedbed for a given crop and area.

Usually the primary tillage is performed with a mouldboard plough followed by the secondary tillage, usually by disking once or twice with a disk harrow. Other implements such as a rotovator or spring tooth and spike tooth harrows are used. In practicing conventional farming:

- The soil is inverted and mixed thoroughly.
- Crop residue is buried in the soil leaving no surface mulch. This causes slow decay or the buried residue material.
- Bare soil is exposed to water and wind erosion.
- There is the possibility of compacting the soil beneath the plough.
- Soil surface is left relatively level with minimal ridging effect.
- System requires high tractor power (15 hp per plough bottom), leading to high cost per acre.

What is Conservation Agriculture (CA)?

CA is based on optimizing yields and profits, to achieve a balance of agricultural, economic and environmental benefits. It is the integration of ecological management with modern scientific agricultural production.

The Principles of CA

CA emphasizes that the soil is a living body, essential to sustain life on earth. It emphasizes the protection of the upper 0-20 cm of soil which is the most active zone but also the most vulnerable to erosion and degradation. Most of the environmental functions and services that are essential to support terrestrial life on the planet are concentrated in the micro, meso, and macro fauna and flora which live and interact in this zone. It is also the zone where human activities of land management have the most immediate, and potentially the greatest impact. By protecting this critical zone, we ensure the health, vitality and sustainability of life on this planet.The principles of Conservation Agriculture and the activities to be supported are described as follows:

Principle 1: Minimum soil disturbance

This principle advocates for minimal or little soil disturbance where the soil is not ploughed or turned. Continuous tillage destroys the soil structure, eventually forming a hard pan that prevents water infiltration and proper crop root development. Instead of ploughing and harrowing, the soil could be sub-soiled using a sub-soiler and then ripped using a ripper to make furrows for seedplacement.Alternatively, direct planting could be done using a hand operated jab planter, animal or tractor drawn direct planter. One can also plant through the soil cover using equipment such as the dibbler or muro, the hand hoe, jab planter, animal drawn direct seeder, and tractor drawn zero-till or direct planter. Such equipment can be used to plant with minimal disturbance of the soil. More on these equipment can be found in Module 6.

A sub soiled field during land preparation.

Principle 2: Crop rotation

Crop rotation is the practice of growing two (or more) dissimilar type of crops in the same space in sequence. Farmers should plant several crops in rotation or as intercrops (crop mixes) rather than planting a single crop in a season or year. Crop rotations should include legumes, deep-rooted crops and high-residue crops.

Benefits of crop rotation:

- Improves soil structure as some crops have strong deep roots which can penetrate deep into the soil breaking hard pans, and can tap moisture and nutrients from deep in the soil. Others have shallow roots and tap nutrients near the soil surface and also bind the soil together.
- When leguminous crops are part of the rotation, they fix nitrogen into the soil and their biomass adds nitrogen through decomposition.
- Crop rotation helps in control of some weeds, pests and diseases. Planting of the same crop season after season may encourage certain weeds, insects and diseases to thrive. Planting different crops season after season breaks their life cycle and prevents them from multiplying.
- Growing a mix of grain, beans, vegetables and fodder means a more varied diet and more types of produce to sell.
- Stimulates a diversity of soil organisms.
- Leads to balanced nutrient usage.
- Reduces erosion.
- Increases yields, hence profits.

Principle 3: Maximum soil cover

The aim is to have a protective layer above the soil surface. This is done by inclusion of live cover crops such as dolichos lablab, Mucuna, sweet potatoes and cow peas or spreading of dead vegetative material, mainly from crop residue. Agroforestry tree species can also be used to provide aerial soil cover. Covering the soil reduces its chances of being eroded by moving water or wind, conserves soil moisture, reduces weed growth, increases the rate of water infiltration into the soil while reducing the same from evaporation.

Good soil cover is the backbone of CA and is important since it:

- Protects the soil from erosion agents such as wind and water.
- Helps in suppressing weeds by smothering their growth and reducing the number of weed seeds hence reducing labour requirements for weeding.
- Increases the soil fertility and the organic matter content of the soil. When leguminous cover crop such as dolichos and mucuna are used they add nitrogen to the soil.
- Increases soil moisture by allowing more water to sink into the ground and reduces evaporation.
- Stimulates development of plant roots, which in turn improves soil structure, allowing more water to infiltrate into the soil reducing the amount that runs off.
- Decomposing vegetation and the roots of cover crops improves the soil structure and make the clumps and lumps in the soil more stable therefore making them harder to break and wash away.
- Soil organisms, earthworms and microorganisms can prosper in the soil cover as well as in the soil

The main types of soil cover used by farmers include:

- A range of living plant material which provide dense ground cover such as cowpeas, beans, soybeans, dolichos lab lab, mucuna etc and also aerial ground cover provided by trees
- Mulch or dead plant materials which include crop residues and prunings from trees and shrubs
- Crop residue, (CR), the fibrous by-products that result from the cultivation of cereals, pulses, oil plants, roots and tubers
- A range of tree species (crop friendly) which provide shade, soil cover and biomass.

NB: Examples and associated benefits of cover crops are illustrated in the subsequent pages:

Live cover crop: Dual purpose cowpea which provide ground cover as well as improving soil fertility : Photo by KENDAT

Dead vegetative material spread as surface mulch protecting the soil as well as increasing humus in the soil :Photo by KENDAT

Aerial cover: *Faidherbia albida*. Provides much needed nitrates. Creates micro climate for healthy crop growth and also provides fuel wood and timber. Also sequesters both above and below-ground carbon

Key features of Conservation Agriculture

- No burning of crop residue or fallow vegetation
- No ploughing, disking or soil cultivation to prevent loss of soil organic matter and nutrients
- Crop and cover crop residues stay on the surface
- Direct seeding or planting
- Permanent crop and weed residue mulch protects the soil
- No uncontrolled grazing
- Build-up of soil organic matter and reduced nutrient loss
- Lime and sometimes fertilizers are surface-applied where necessary. However, fertilizer usage should be minimal in CA
- Specialized equipment for seeding and mulch management

Benefits of CA

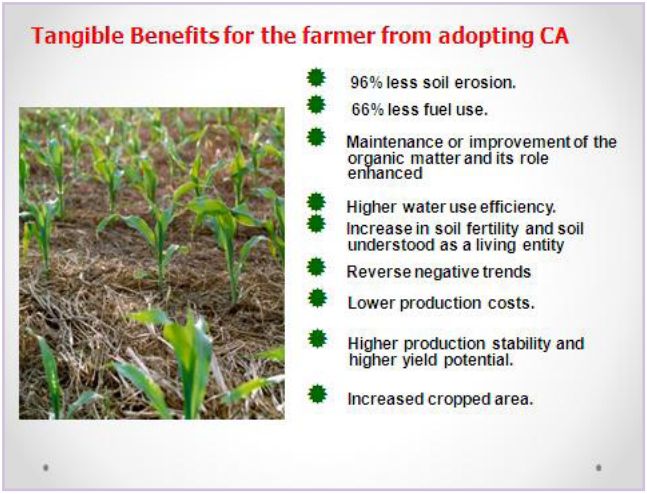
Some of the benefits associated with CA may include:

- Controlled weeds
- Carbon storage (global warming)
- Higher sustained yields (30-200%) at lower costs
- Environmental conservation
- Increases soil organic matter and nutrients, thus reducing the need for chemical fertilizers.
- Improves soil structure and its ability to absorb and hold more moisture for crop growth.
- Reduces time and labour requirement by up to 60% thereby allowing even the elderly farmers to still practise CA.
- Reduced time spent working on the farm hence creating an ample time for one to engage in social activities or other employment.

Challenges of CA

Despite the advantages of Conservation Agriculture in farming systems, its uptake by farmers, especially smallholders, has not been as anticipated. This is attributed to the fixed mind set of the farmers in their cultivation culture, coupled with other constraints associated with the technology such as availability and cost of inputs, competing use of crop residues, weeds and initial labour requirement.Under the smallholder integrated farming systems, crop residues are mainly burnt during land preparation or used as animal feed/bedding, construction material, cooking fuel and mulch.

However, if CA is to succeed, the competitive use of the residues must be minimized to allow for as much residue as possible to be left in the field as mulch or use Agroforestry tree species as a complimentary strategy.



Weeds pose a serious challenge in the initial stages of CA adoption. This is because thousands of seeds are already present in the soil waiting for the right conditions to germinate. This implies that the seeds will be the first to germinate at the onset of the rains thereby posing a serious competition with your crop. Farmers usually respond to this challenge by going back to conventional weed control method which involves too much soil disturbance, thereby negating the intent of CA. Thus, the issue of weed control must be dealt with appropriately for CA practice to succeed.

Key challenges hindering adoption of conservation agriculture

- Changing to CA involves a fundamental change in mind-set. Farmers are sceptical about trying new ideas due to the fear that a new way of doing things can put their food supply at risk.
- Keeping a permanent crop cover is difficult, especially in drier areas. Crop residue is a vital source of animal feed.
- Seed availability is a problem, particularly seeds for cover crops such as Mucuna.
- CA equipment is relatively new and unavailable locally. It is also expensive relative to conventional equipment.
- Limited access to information.

Weeds management and control in a CA system

What is a weed?

A weed is a plant that grows where it is not wanted or intended. Weeds have to be managed before they compete with the crop for water, light and nutrients and seriously affect yields. The longer they are left uncontrolled the harder they become to control, leading to higher costs of production and reduced yields. This translates to less income to the farmer. Weeds also host pests and diseases that attack the crop.

Knowing what type of weeds and the level of infestation one is dealing with is key to managing them effectively.The aim of practising weed control and management should be to reduce and maintain weed population at the lowest possible level (threshold) thereby making crop–weed competition minimal for the crop to attain its yield potential.

The first step is to understand the different types and characteristics of weeds as well as the extent or level of infestation, then devise a strategy for their control and management.

Weed identification exercise (to be done in the field): Ask participants/farmers to give names of the most difficult weeds in their area and how they control them. During the field practical session, conduct a weeds identification exercise and discuss their characteristics and control measures.

Characteristics of weeds

Weed seeds can remain dormant in the soil for a long period for example up to 20 years for stringa only to grow vigorously and rapidly once the conditions are right. Most weeds are very prolific and are capable of reproducing through seeds and stem parts. They have the ability to survive and reproduce under environmentally unfriendly conditions and have high seed scattering ability. Weeds also have high genetic diversity which makes them adapt to a wide range of conditions.

How can we control weeds?

There are several methods we can use to control weeds. First, we need to be sure we use clean seeds free from weed seeds infestation in order to minimize chances of importing weeds from other fields or areas. During the crop cycle, three main control methods can be applied:

1. Cultural methods: through crop rotations, good crop stand and row-spacing, intercropping, cover crops, mulches among others.
2. Physical control: mechanical and manual weeding
3. Chemical control: through the use of herbicides.

However, traditional weed control methods which include burning crop residue before ploughing and allowing cattle to graze in the fields are not recommended in a CA system.

Cultural/biological methods

Cover crops-Cover crops manage weeds by suppressing the growth of germinated weed seeds. The aim is to reduce space, cut out sunlight and deprive the weeds of nutrients and thus ensure the weed seedlings do not develop to maturity and therefore weed seeds are not added into the soil seed bank.

Cover crops can be planted at the same time with the main crop if soil moisture is limiting, or after the main crop has germinated where soil moisture is not limiting. Some cover crops produce certain compounds that inhibit the growth of certain weeds.

A good cover crop is one that establishes quickly and produces a lot of green matter to cover the ground quickly. Small-scale farmers prefer a cover crop which fits into their normal cropping system and has multiple purposes such as food, fodder, fuelwood among others. It is important to choose a cover crop which can grow well in the area. Some of the cover crops include:

- Dolichos
- Pigeon peas
- Mucuna
- Canavalia
- Stylothanses – in semi-arid areas
- Vetches
- Lupins,
- Peas,
- Black oats
- Wheat.

Characteristics of a good cover crop

- Grows quickly providing ground cover to protect the soil from direct sunlight and prevent erosion
- Produces heavy leaf biomass
- Aggressive enough to compete with weeds and has multiple uses such as being suitable for human food and as animal feed
- Has multiple uses e.g., edible seed for humans, animal feed
- Fixes Nitrogen in the soil

Mulch – Weed seed germinate easily if the soil is bare. Spreading crop residues on the soil surface in the right amount leaves little space and light for weeds to grow. If there is not enough crop residue consider bringing mulch from outside. Do not use mulch plants that have flowered and produced seeds as this will introduce new weed in the field. Mulch has the additional benefit of reducing soil temperature, reducing erosion, conserving moisture and adding organic matter into the soil.

Crop rotation – Rotating the main crop with other crops prevents the build-up of weed populations by breaking the life cycle of weeds. If unable to rotate the main crop, try to plant a different cover crop or an intercrop each season.

Crop spacing – Use recommended spacing to reduce space for weed growth.

Physical control (manual and mechanical weeding)

This may involve hand, animal or tractor powered tools/equipment. The underlying principle is to avoid excessive disturbance of the soil while removing the weeds. If using hand tools, sweepers or scrapers are recommended (shallow weeding) or one may simply pull out or slash the weeds. Hand weeding disturbs the soil less but is time consuming especially in the initial stages of CA adoption when weed densities tend to be high.

Weeding with animals involves the use of equipment such as cultivator sweeps. Some soil disturbance is evident and the method may be difficult in a CA system due to the presence of trash which the equipment would tend to drag along. Knife rollers are also examples of equipment that can also be used for both animals and tractors to manage both cover crops and weeds. The knife rollers are used to crush and flatten the cover crop and weeds leaving them to eventually die and break up into pieces.

Chemical control through the use of herbicides – Herbicides are quick and easy to apply. The soil is left undisturbed. However they are expensive, hard to find locally and require specialized equipment to apply. It is very important to use the right amount of chemicals mixed with clean water. Herbicides enter plants through roots, stems and leaves and exert their toxicity in many ways.

They are used during pre- or post-emergence. They can broadly be classified as soil-acting or leaf-acting herbicides. Soil-acting herbicides are mainly used in pre-emergence while leaf-acting are mainly used in post-emergence.

Pre-emergent herbicides

Pre-emergent herbicides act upon weed seeds in the soil or form a barrier in the soil to prevent weed seed germination or establishment. A properly timed application can provide control for several months.

Post-emergent herbicides

Post-emergent herbicides work on actively growing weeds and are further broken down into selective or non-selective categories.

- Selective herbicides can be applied to control either broadleaf or grasses. When herbicides for broadleaf weeds are applied, they will little effect on the grass weeds. Some products may require repeated applications for effective control.

- Non-selective herbicides kill all living plant material they come in contact with. Extra care must always be taken when handling non-selective herbicides to prevent spillage or accidents.
- The most popular non-selective herbicide is probably Round-Up (Glyphosate).

How and when to apply herbicides

Using herbicides properly is the key to their effectiveness. Anyone using herbicides should understand how they work.

Several options exist for applying herbicides. These options include the weed wiper (Zamwipe), ULV – micron sprayers, hand pulled sprayers, animal drawn sprayers and tractor mounted boom sprayers. Whichever method is used, calibration of spray equipment is essential for accurate delivery and mixing calculations.

Use of herbicides requires special skills to use effectively and therefore it is necessary for one to receive training on how to use herbicides correctly and safely.For specific instructions on chemical control methods e.g., rates of application, method of application and user responsibility and compliance with product, always refer to the instructions manual that come with different chemicals and keep in mind that the label is legally binding.

When and how to control weeds in a CA system

- Weeding should be carried out when the weeds are young before flowering so as to prevent them from producing seeds.
- To avoid soil disturbance, you may slash the weeds or spray them just before planting, and keep slashing them throughout the season whenever necessary. The strategy is to reduce and maintain the weed population at the lowest possible level (threshold) thereby making crop–weed competition minimal for the crop to attain its yield potential.
- After sowing the main crop, plant a cover crop between the rows of the main crop 2-3 weeks after. Regularly check for weeds and control them by pulling out, scraping the soil surface with a hoe, or using selective herbicides. This practice should continue even after harvesting the main crop.
- After harvesting the main crop allow the cover crop to establish itself well so as to provide soil cover and smother any emerging weeds. It is also important to manage weeds continuously in the coming season by using appropriate weed control measures depending on the one preferred.

Livestock integration in CA system

It is a common practice for small-scale farmers in tropical countries to practise both crop and livestock production from the same farm. There are obvious benefits of this practice such as nutrient cycling/transfer from one area to another, animal products (milk, meat, hides, skins, and manure) and animal power for the farm.

However, the fact that livestock also feed on crop residue causes conflict with the CA requirement that crop residues should be left or recycled back into the farm soon after harvesting. There is need, therefore, to include complementary livestock feeding strategies to avoid conflict between the two and ensure the success of both.

Complementary livestock feeding strategies

These strategies depend on the particular conditions for each location and range from:

- Establishment of plots of permanent forages for direct grazing or for cut-and-carry.

Sheep feeding on ***Senna spp*** tree leaves

If crop stubble is grazed, the herder must maintain control over the animals such that the needed residual is maintained.

- Controlling the grazing time permitted in a given area, e.g. 15 days per month.

Animals feeding on crop residues

- Reduction of herd size by culling out/destocking some animals to ensure the right density as per resources available
- Temporary displacement of animals to other areas especially among pastoralist communities
- On steep land, the use of living contour erosion barriers consisting of grasses and/or palatable leguminous trees
- Biomass transfer involves cutting, carrying and spreading bushy vegetation to make a mulch.
- The ability to conserve and transfer forage from periods of surplus to periods of deficit.
- Where fodder is being cut and carried to confined livestock in a zero grazing system. The non-edible parts can be returned either as such or as part of compost prepared by mixing with animal excreta.
- Zero grazing allows for precise amounts of feeds and nutrients, but it demands more labour.

As silage

As stored hay

Further reading

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Module Three

Conservation Agriculture With Trees (CAWT)

Learning objectives

In this module, participants will learn the underlying connection between CA and agroforestry, the benefits of integrating trees on-farm, agroforestry practices and technologies and the management of agroforestry tree species.

What is CAWT?

Conservation Agriculture With Trees (CAWT) is the inclusion of trees to support the CA system in order to combine the best of CA and the best of agroforestry leading to a working model under different social, economic, biophysical, institutional and policy conditions. CAWT is aimed at improving the uptake of CA through provision of fodder, fuel, construction materials, agricultural implements, biomass, nutrients, fencing, fruits, among other products and services. The CAWT model therefore introduces two more aspects to the three basic principles of CA explained in module 2 (minimum tillage, maximum soil cover and crop rotations/associations) as explained below.

Incorporating nitrogen fixing and high value trees

Gliricidia sepium intercropped with maize

Growing legume trees helps improve soil fertility through the fixation of atmospheric nitrogen, thus enriching the soil with nitrates. With appropriate selection of tree species and good management this can substantially reduce the requirement for inorganic fertilizers.

In addition to this, incorporating pruning materials (leaves and litters) of these nitrogen-fixing legumes in the soils adds carbon and enables better retention of water as well as increasing the content and efficiency of fertilizer use.

Pruning materials used as mulch also reduce the soil temperature, thereby enabling a better buildup of soil fauna that helps crop productivity. Therefore, the integration of tested trees into farming practices (agroforestry) has the potential to sustain land productivity in addition to providing useful tree products such as firewood, fruit and fodder.

Good management practices

Smallholder farmers are often skilled in crop management. However, they need quality seed and useful information on weather conditions. With appropriate timing of planting, weeding and overall efficiency of crop management, they can minimize crop failures. The spacing and management of trees is another important consideration. Trees spaced and managed optimally will provide the necessary nutrients to maximize crop productivity. The control of pests and weeds is crucial in minimizing production and post-harvest losses.

What is agroforestry?

Agroforestry is a farming system that integrates crops and livestock with trees and shrubs. The resulting biological interactions provide multiple benefits, including diversified income sources, increased biological production, better water quality, and improved habitat for both humans and wildlife. Farmers adopt agroforestry practices for two main reasons. They want to increase their economic stability and they want to improve the management of natural resources under their care. Agroforestry involves combining tree planting with another agricultural enterprise such as grazing animals or crop production or managing a woodlot for a diversity of special forest products while ensuring production of crops underneath the trees before the tree canopy is fully closed. For example, an agroforestry practice might produce firewood, biomass feedstock, pine straw mulch, fodder for grazing animals, and other traditional forest products. At the same time, the trees are sheltering livestock from wind or sun, providing wildlife habitat, controlling soil erosion, and in the case of most leguminous species fixing nitrogen to improve soil fertility.

Faidherbia albida growing in cropland

Common agroforestry practices and technologies with relevance to CAWT

Home/kitchen gardens

These are trees planted on home compound or near homesteads. They provide shade, shelter, fruits, fodder, beauty and other products. Examples include;

Ornamentals: *Ficus benjamina*, *Terminalia mentally*, *Araucaria angustifolia*,*Cupressus pyramindansis*, Ashok.

Fruit trees: Mangoes ***(****Mangifera indica*), avocado (*Persea americana*), cashewnuts (*Anacardium occidentale*), citrus (*Citrus spp*; oranges, lemons), macadamia (*Macadamia tetraphylla****)***, Jack fruits, mulberry, pawpaws, white supporter, *Annona sps. Syzigium sps****.***

High value medicinal trees: Neem, *Albizia coriara, Moringa oleifera.*

This home gardening practice does not have a direct CAWT application but if fodder trees are established in home gardens they can ease the competition for the use of crop residue as animal feed thus enabling the farmer to achieve CAWT in the cropland. Farmers are cautioned to plant big and shallow-lateral rooted trees away from buildings.

Trees planted in home garden

Woodlots

These are trees planted more often than not on the less fertile portion of the farm which is set aside for trees. They are mainly managed for firewood and timber production. Tree species commonly established as woodlots include; *Grevillea robusta, Markhamia lutea, Casuarina equissetifolia, Melia volkensii, Prunus africana, Gmelina alborea* and *Terminalia brownii.*

Trees planted in home garden

Depending on which tree species are planted (this calls for appropriate selection), food crops can be established underneath the trees and the tree canopy pruned to minimize shading the crops while the tree prunings can be used as mulch for soil cover or fodder.

Improved fallows and rotational fallows

A cropland left fallow with *Crotalaria* established for nitrogen fixation

A rotational fallow is a period of time when a field that has been under continuous cropping is left without cropping in order to regenerate. To hasten the regeneration process, woody species are planted with the last crop and left to grow during the fallow phase thus referred to as improved fallows.

Tree species for improved fallows include; *Gliricidia sepium*, *Tephrosia vogelii, Tephrosia candida Calliandra calothyrsus, Leucaena trichandria, Sesbania sesban* among others. This is a very important practice for CAWT as the biomass produced by the woody species can be used to cover the soil and suppress weeds and a farmer can use an improved fallow season to convert from convention to conservation agriculture with trees. Other selected tree species can also be established at the start of the fallow season so that they are left in the cropland as the fallow species is removed for the next cropping season.

Trees dispersed on cropland

In this case, multipurpose trees are scattered haphazardly or according to some systematic patterns in the field. Some of the tree species for this technology include; *Faidherbia albida, Tamarindus indica, Melia volkensii and Acacia spp.*

Proper tree species selection is needed to minimize adverse effects while enhancing beneficial interaction with crops. *Faidherbia albida* is particulary attractive in areas where it can grow well as it sheds leaves during the dry season and regains foliage as the season progresses thus shielding crops from adverse weather. Other species with positive effects on soil properties can also be planted and competition managed by appropriate spacing and pruning practices.

Acacia spp growing in a cropland

Boundary planting, shelter belts and life fences

These comprise trees and shrubs planted along and around the farm for protective purposes or boundary marking.

Trees planted along the fence in a farm (left) and live fence under established (right)

Some of the tree species for this technology include; *Hekea saligna, Markhamia lutea, Melia azadirach, Acacia sps, Jatropha curcas, Croton megalocarpus and Pithlobium dulce*. They are mainly used as boundary markers, live fences, sources of fodder or wind breaks. Trees that could have adverse effect on crops but give other beneficial tree products are better off established along boundaries. Live fences are useful for CAWT especially where free grazing of livestock prevails as they can keep livestock from feeding on cover crops and residue left in the farms for soil cover.

Hedgerow planting

This entails growing of food crops between hedgerows of planted shrubs and trees preferably leguminous or fertilizer and fodder trees. Some of the species for this technology include; *Gliricidia sepium, Calliandra calothyrsus* and *Leucaena spp*. The technology is useful for CAWT as the species fix nitrogen thus enriching the soil in-situ. Foliage harvested when the species are pruned can be applied as mulch or fed to the livestock in place of crop residue.

Gliricidia sepium (left) and *Calliandra calothyrsus* (right) established as hedgerows in a maize farm.

Benefits of agroforestry practices

1. **Provision of non-wood products**. Many useful products come from trees. Among these are medicines, fibres for making ropes, gums and resins, seeds for ornaments, bush meat, fruits and honey from tree flowers.

2. **Timber provision.** Trees in agroforestry practices produce wood and poles for houses, furniture, fences, telephone and electricity lines, paper, tools and works of art. Certain special trees are used to make products for religious or social ceremonies. Some indigenous trees produce very beautiful wood.

3. **Energy needs.** Water trapped, stored and released by trees flows to hydro-electric power plants, producing electricity. Trees produce wood, which may be used as fuel wood or charcoal.

4. **Water/hydrological cycle**. Trees in agroforestry practices catch, store and release water. Trees break the force of falling rain. In an area with trees, rainwater flows slowly into the ground where it is stored as groundwater. Later, the water flows out as springs and streams. By trapping and absorbing water, the trees reduce flooding. By storing and releasing water, the trees reduce the effects of drought.

5. **Soil conservation and fertility amelioration.** Trees in agroforestry practices break the force of rain and wind and protect the soil from erosion. Less erosion means richer soil for farming. It also means less silt in rivers, dams and the sea. Leaves from trees and micro-organisms from soils under trees enrich the soils around them by providing organic matter.

6. **Air quality and environmental services**. Trees in agroforestry practices help to moderate the climate. Near forests, hot days are less hot and cold nights less cold than in open areas. Trees absorb carbon dioxide, a gas that is produced by animals and burning fuels. By storing carbon dioxide, trees help to regulate the gases in the atmosphere around the earth.

CAWT benefits

In light of the above practices and benefits of agroforestry and, depending upon which woody species are used, and how they are managed, the incorporation of woody plants in conservation agriculture (thus CAWT) may contribute to:

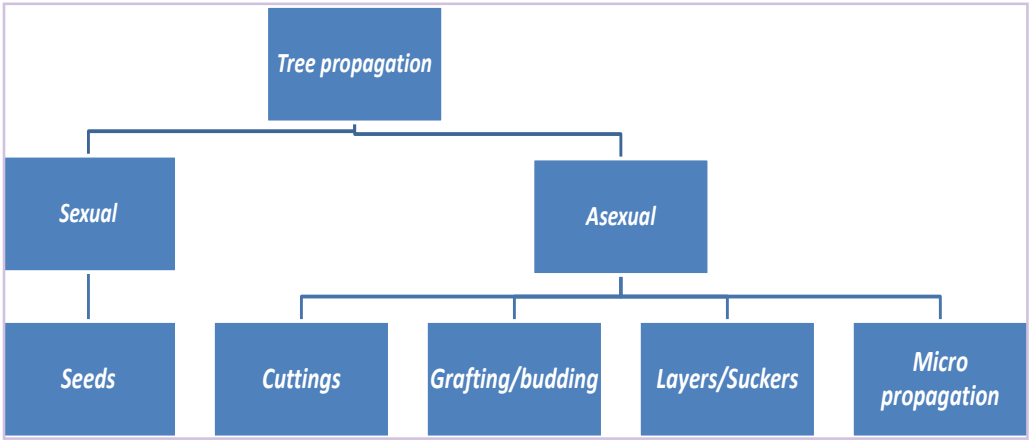
Soil improvement

- Enhancing soil structure and water infiltration and penetration through mulching and their rooting systems,
- Weed suppression through mulching and upper canopy cover.
- Nitrogen fixation and nutrient cycling through inclusion of deep rooted and leguminous trees and shrubs leading to improvement in crop yields for example an average of 3 to 4-fold yield increases maize intercropped with Gliricidia sepium, a nitrogen-fixing tree, while a mature Faidherbia albida tree supplies the equivalent of 300kg of complete fertilizer and 250kg of lime that can sustain a maize yield of 4000kg /ha with no supplementary fertilizers (Source: Garrity 2010, Creating an EverGreen Agriculture in Africa: for Food Security and Environmental Resilience)
- Carbon storage through tree biomass,
- Biodiversity conservation through leaves falling from the trees which are used as feed by soil micro-organisms.
- Maintaining vegetative soil cover through mulching and upper canopy thereby reducing soil erosion,
- Providing shelter belts against wind thereby controlling erosion.
- To achieve these benefits the appropriate tree propagation and management practices should be followed. Below we give some tips on these practices.

Fruits from trees in the market

Tree propagation

Tree propagation can either be sexual (through seeds/seedlings) or asexual (vegetative through cuttings or grating). Propagation through seeds is the most common practice and will be discussed in detail in this section including basic tree nursery management practices.



Types of tree propagation

Sexual propagation: In sexual propagation, seeds are used and provide opportunity for variation and genetic improvement which leads to production of varieties that perform better in the field and/or produce better quality of products.

Seed types

There are three main types of seeds based on their storage and viability characteristics. These are orthodox, recalcitrant and intermediate seeds.

- **Orthodox seeds**: Are those which do not lose viability quickly and hence can be stored at subzero temperatures without damage. Some of them stay dormant for some time hence there is a need to break their dormancy before sowing. Examples include *Tephrosia candida, Gliricidia sepium* and *Faidherbia albida.*

- **Recalcitrant seeds:** Are those which lose viability quickly (less than 1 month) and cannot be stored under conventional conditions. Some of these seeds even suffer chilling damage. Examples are seeds of cocoa, rubber, Warbugia, avocado and mango.

- **Intermediate seeds:** Are those which can be stored under sub-zero temperatures but for a period not exceeding 6 months. Examples include *Prunus africana, Azandirachta indica, Dovyalis caffra*.

Seed sources and collection

Quality seeds should be collected or purchased from trusted sources. Seeds ought to be collected from phenotypically superior plants for the desired end use and care should be taken to maintain broad genetic diversity. Thus, seeds should be collected from a population of at least 30 trees spaced over 10 m apart. This is especially critical for indigenous species that are growing in their natural environment because the trees growing together are likely to be very close relatives and would succumb easily to similar threats. Examples of trusted sources where one can purchase seeds include national tree seed centres such those managed by the Kenya Forestry Research Institute (KEFRI), Tanzania Forestry Research Institute (TAFORI) and Rwanda Agriculture Board (RAB). Others include reputable NGOs such as ICRAF (World Agroforestry Centre) and professional firms mainly ran by retired forestry professionals or farmers who have been trained on right procedures for seed collection. An example is the Kenya Association of Tree Seed and Nursery Operators (KATRESNO)

Sorting and cleaning - The poor quality seeds should be sorted out first. The rest should be extracted and cleaned.

Storage - Seeds can be stored in appropriate containers like plastic tins, gourds, sacks or baskets. Organic or commercial pesticides can be used to protect the stored seeds from insect attack. Recalcitrant seeds should be planted immediately. Stored seeds need to be labeled properly with species name, source (provenance), germination percentage, seeds per kg, and the weight.

Seed viability test

The procedure for testing seed viability is as follows;

- Open the seeds and check for pests and disease attack.
- Check also whether the embryo is alive. It should be firm, and mostly white. Grey, black or soft embryo is an indication that the seed is dead;
- Examine the shape of seeds. Deformed seeds and those with bad colouration are likely to be unviable.
- Floatation in water is also used to check for dead/unviable seeds which normally float. Note that only naturally heavy seeds can be used for this procedure because light seeds will all float.

Seed germination and seedling handling

Tephrosia candida, Gliricidia sepium and *Faidherbia albida* seeds are orthodox hence they remain dormant until they come into contact with sufficient moisture, warmth and air.

Points to note when handling seedlings

- The physical handling of seedlings should be reduced to a minimum during its time in the nursery.
- In addition, pricking out should be done as early as possible and very carefully so as not to damage the young seedlings and not to bend or expose its roots.
- Moving seedlings directly from the shade to the sun should be avoided. It is better to gradually reduce the shading, so that seedlings remain in the same place.
- Root pruning should be conducted, especially for seedlings which are placed on the ground. Use either a wire which is pulled through the nursery bed to sever the roots or a *panga* to cut between rows and columns.
- To avoid the task of root pruning it is recommendable to raise the seedlings in raised beds. These beds improve drainage and air circulation amongst the seedlings and reduce incidences of pests & diseases.

Asexual/vegetative propagation

In asexual propagation, an exact copy of the variety and genetic material of a mother plant is made and continued in new individuals. This is possible because, unlike animals or humans, plants have meristematic, undifferentiated cells that can differentiate to the various organs necessary to form a whole new plant. A piece of plant shoot, root or leaf can therefore, grow to form a new plant that contains the exact genetic information of its source plant.

Compared to trees planted from seed, trees from stem cuttings grow faster but develop a shallow root system that makes them more susceptible to moisture stress and wind damage. Obtain cuttings from branches of a tree that is at least one year old. Use hard wood and avoid using young green stem tissue. However the growth and performance of the cutting depends on what part of the tree it is collected from and shoots cut from near the base of the tree grow faster than those cut from the branches. Cuttings can be 45–150 cm long with diameters of 4–16 cm. Cuttings can be dried in the shade for three days before planting in the nursery or in the field.

This ensures drying of the sugary substances that otherwise attract pests. If the cuttings are to be planted immediately after cutting then apply insecticides to prevent insect attack. Cuttings are normally planted directly or in plastic pots/ bags in the nursery or greenhouse.

When planting directly, plant cuttings in light, sandy soil. Plant one-third of the length in the soil (i.e., if the cutting is 90 cm long, plant it 30 cm deep at an angle of 450 to maximize sunlight absorption). Ensure that the cutting is planted (up-side-up) so that the part that goes into the soil is the one that came from the bottom and not overturned. Add a balanced fertilizer or compost to infertile soils to encourage root development. Irrigate regularly to keep the soil moist but not wet. Cuttings planted in a nursery are ready for field planting after 2–3 months.

Nursery equipment & materials

They include:

- Wheelbarrow: for transporting materials including nursery soil
- Panga: For cutting and sharpening wooden materials
- Labels and book records: Proper labeling and record keeping are required in order to keep track of species and seedling batches produced. This is particularly important when several provenances or cultivars of the same species are raised in the nursery.
- Root pruning wire: To cut overgrown roots.Polythene tubes (containers): For holding seedlings after pricking out. They come in different sizes. The size of the container depends on the plants to be raised, purpose and size of the plant, substrate in use and fertilization schedule. It is important to note that polythene bags are the commonly used containers but have a disadvantage of roots coiling once they hit the smooth inner surface of the pots. A better alternative is to use Root Trainers which are rigid containers with internal vertical ribs that direct roots downwards avoiding the spiraling. They have a large drainage hole at the bottom. Allowing for air root pruning if containers are placed on frames above the ground.
- Dibbler: For uprooting seedlings during pricking out
- Pegs: For supporting nursery bench
- Jembe: For digging when making the nursery
- Rake: for leveling

Nursery establishment & management

Tree nurseries should be located in a site with constant supply of water. The nursery site should be cleared of weeds and fenced to avoid destruction of seedlings by animals. The raising of seedlings should be planned so that they are ready to set out in the field at the onset of the rains. Soil in the nursery should be fertile and well drained.

Seeds can either be sown directly on the nursery beds or in polythene bags (tubes) or improvised containers like those of banana fibre, used old tins, used milk packets etc.

The nursery seed bed should be oriented in a north-south direction so that the sun shines on the seedlings in the morning and in the evening when it is not too hot. The beds should have a small width of about 1 m and as long as possible. The smaller width is to facilitate easy weeding around the nursery bed. If there is more than 1 seedbed in the nursery, leave a path of about 0.6-0.9m (2-3ft) wide between the beds.

Factors to consider while raising seeds as bare-rooted or in containers

- The cost and availability of pots/tubes or recycled containers and whether the farmer can afford them
- The distance from the nursery to the planting site and the transportation available
- The likelihood of adequate and reliable rain after planting
- The value of the plants. If the seeds are scarce and/or expensive, it is more important to take every possible measure to maximize survival, including the use of containers

Substrate properties that influence seedling growth

- Physical properties: Water holding capacity (should hold sufficient but not too much water), porosity (should be porous enough to allow good gas exchange in the root zone), plasticity (should not contain too much clay otherwise it will become waterlogged, bulk density (to lighten the substrate add organic matter in form of decomposed manure, compost, rice husks or other plant residues or inorganic materials like sand or vermiculite)
- Biological properties: Availability of appropriate rhizobia and/ or mycorrhizae strains
- Chemical properties: Fertility (should be rich in plant nutrients: N, P, K, Ca, Mg, & S which are macronutrients or can use virgin forest soil or compost), acidity (pH), Buffer capacity or cation exchange capacity (CEC)

Seedling hardening

Before seedlings are taken out to be planted in the field (transplanting or planting out), they ought to be physiologically prepared for the harsh condition. It is like weaning a baby from mother's milk. The shade over the seedlings is thus, removed in the last week before transplanting. Watering is also done only once every 2 - 3 days.

Field preparation and transplanting

In CAWT, land tillage is avoided hence the trees are planted in holes of 0.30m x 0.30m x 0.30m (1ft x 1ft x 1ft). Holes of this size help in collection and preservation of rain water. Planting holes must be prepared prior to the transplanting exercise. Transplanting should be done during the rainy season and it should be done either in the morning or in the evening to minimize water loss (transpiration) from the seedling, which if severe, could lead to death of the seedlings. Tephrosia, Gliricidia and Faidherbia seedlings are transplanted when they reach 0.30m-0.45m (1-1.5ft). For Tephrosia and Gliricidia, this height can be attained within 2-3 months depending on growing environment/ conditions. Faidherbia seedlings may attain this height in 5-6 weeks.

It is important to note that:

The soil where the trees are to be planted should be light and sandy, not heavy with clay or water-logged.

- Dig a hole 0.30 m (1ft) square and 0.30m deep. Backfill with loose soil. Adding compost or manure mixed with ash will help the trees grow better.
- Water the planting holes one day before transplanting the seedlings.
- Plant seedlings in the late afternoon so that seedlings are not subjected to hot sun the first day.
- Make a hole in the pit to accept all soil in the bag. Carefully cut open the container and place the seedling in the planting hole. Be careful to keep the soil around the seedling's roots intact.
- Pack soil around the seedling base.
- Water only lightly for the first few days.

If the seedlings fall over, tie them to a stick for support. Protect young saplings from termites and nematodes.

Management of AF Tree Species

Tree management begins with selecting the right species for the right place. Even within a species trees that have grown in different areas develop different adaptation traits for the areas they grow in. It is therefore recommended that a farmer selects the best type (provenance and species) of the tree for the area he intends to plant. There are tools that have been developed to help farmers and development workers in this selection and can be a first hand support in selecting both the species and the category of the desired products. One very useful tool is the useful trees for Africa map developed by the World Agroforestry Centre. Annex 5 also contains information on some of tree species recommended for Machakos, Mbarali and Bugesera.

Watering/Irrigating

- This is crucial for young seedlings especially those that are newly transplanted.

Fertilizing/Manuring

- Fertilization is important for nursery seedlings or if plants are planted in infertile soils. This practice is however critical when the tree is young because mature trees have deep roots which can reach into the nutrients deposited deeper in the soil through leaching. However, for tree species where huge volumes of products are harvested annually such as fruit and fodder trees it is prudent to apply fertilizers or manures every once in a while even when mature to sustain the productivity

Controlling weeds

- This is done to reduce competition between the trees and other unwanted plants –through activities such as spot weeding, herbicides, mulching around the base of each young tree. For trees intercropped with annual crops, the weed control is done when weeding for the crops.

Mulching

- Placing dry leafy materials at the base of the trees to conserve soil moisture by reducing loss of water through evaporation. This is critical in the first few months after planting the trees in the field before full establishment if the rains are not adequate.

Gapping

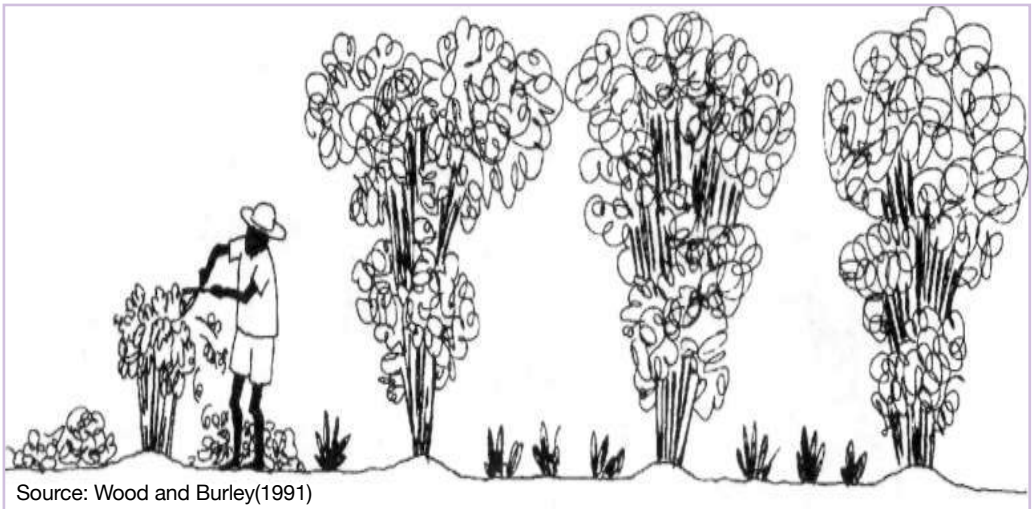
- Filling gaps of trees that do not establish well or those that age with others. This ensures that the available land is used effectively. There are three ways in which a farmer can do this. A farmer can either add trees of different species if the new species are more superior (substitution), or add more trees of the same species if the species is satisfactory (addition) and replace a poorer variety of the same species with a better variety (replacement).

Thinning

- This happens when the trees grow big in the farm and occupy too much space that they compete among themselves and other farm components. It involves removal of some trees that are too slender for the desired size/economic value and using the wood from the removed trees as building material, firewood or even sale.

Pruning

- This practice is conducted when the tree crowns are too huge and involves removal of branches from the lower part of the crown. In this practice, branches are cut near the stem to reduce shade for intercropped cereals, increase yield because lower branches respire more than they photosynthesize implying less productivity than branches in the upper parts of the crown. Pruning can also be conducted if the farmer is interested in getting early harvest for desired product such as fuelwood.



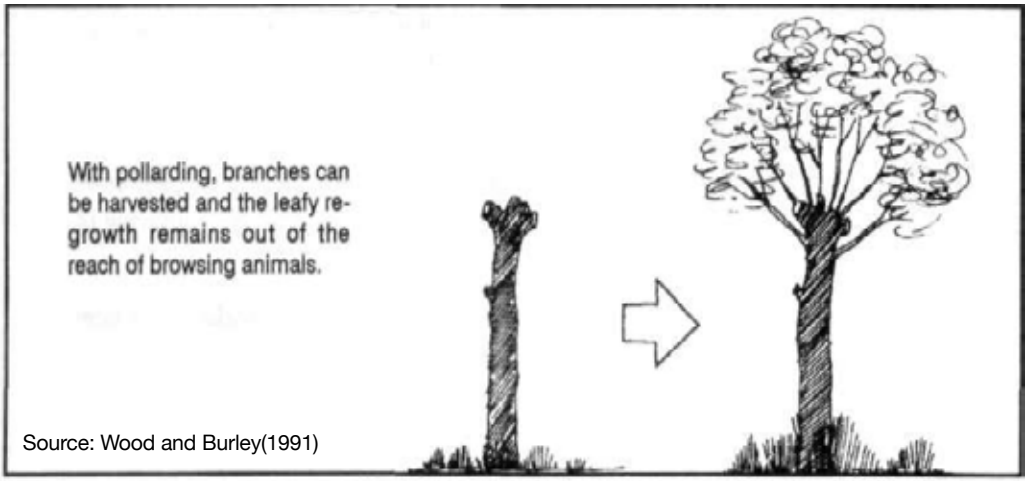
Source: Wood and Burley(1991)

Coppicing

- This is a practice that is desirable when trees are planted in alleys in cropland and competition with crops needs to be minimized. It works best with species that are able to grow back after cutting and involves cutting a tree at or near the base so that it grows new shoots. The practice is also done for trees planted away from crop alleys if the species has ability to re-establish after cutting because it substitutes the task of planting a new tree after a mature one is felled

Pollarding

- Cutting the tree at the top to control apical dominance and encourage lateral or side growth mainly for forage while reducing shading of underneath crops. The practice also works best with species that re-grow easily after cutting.



Source: Wood and Burley(1991)

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2. Albrecht J. (ed). 1993. Tree seed handbook of Kenya. Nairobi: Kenya Forestry Research Institute/ Deutsche Gesellschaft for Technische Zusammenarbeit

3. Tegnäs B. 1994. Agroforestry Extension Manual for Kenya. Nairobi: international Centre for Research in Agroforestry.

Module Four

Applying Conservation Agriculture

Learning objectives

In this module, participants will learn the steps followed in the conversion to a CA system and the different ways in which farmers may start practising CA based on draft power availability (animal/mechanized draft power).

Introduction

The adoption of Conservation Agriculture in Sub-Sahara Africa has been very slow in spite of successes experienced in some countries such as Brazil, Argentina and Australia among others. There are indeed concerns on whether Conservation Agriculture can work in smallholder set-up in Sub-Sahara Africa. Trials conducted so far in the region indicate that Conservation Agriculture has great potential in revolutionizing agriculture and building a more climate-resilient production system that is both sustainable and environmentally friendly. The main challenges in adapting CA in the SSA region have already been discussed in module three of this manual.

In moving forward, we recognise CA is the way to go in Sub-Saharan Africa but a set of strategies need to be put in place to accelerate the adoption process. This includes policy support and well defined pathways and entry points specific to the circumstances and contexts of the SSA region. Researchers, extension agents and other key development actors are now actively involved in defining appropriate entry points and the actual promotion of CA in SSA. National task forces have been appointed to tackle policy issues and develop workable business plans for CA uptake. So, assuming all relevant policies, strategies and government support will be sorted out, how do we move from conventional to CA at farmer level?

From conventional to Conservation Agriculture

To take up the challenge of changing the way we have been farming for decades, we need to see ourselves in a transitional journey that continuously challenges us to take on more and more CA practices around our farms.It is like going back to the forestry days or even an attempt at repairing all the damage caused in the past. This is why CA is viewed as a concept and a cocktail of many good practices good for our soil and environment.

The journey towards CA

- First there is need to recognise the pitfalls of conventional tillage and declare willingness to change the farming technology. This involves change in culture and is perhaps the most difficult part.
- If burning the bush, crop or weed residues, grasses or any other types of vegetation has been part of the farming practice, STOP doing this immediately. The material can be better used as a resource on your farm.
- Take stock of the soil and farm topography. Soils with low fertility or degradation must be improved with some special cover crop species, mainly legumes for periods, 1-3 years long. If resources are available, have the soil tested for its chemical content and acidity. This will offer guidelines on the correct fertilizers and soil amendments to use such as lime. Have soil conservation structures such as gabions and terraces put in place where necessary.
- Check the presence of hard pans and remove them by sub-soiling with an appropriate tool (see sections on CA equipment and hard pan identification process in the appendix).
- Plant more trees that fix nitrogen or produce plenty of biomass and place emphasis on foresting your land in every possible way. If you have any idle sections of the farm, plant a nitrogen fixing cover crop on them without having to till the soil.
- If there are terraces on the farm, plant on them live material such as vetiver grass, napier, lemon grass, pigeon pea, gliricidia sepium, tephrosia vogelli, and other strong-rooted crops to protect the structures.
- Reorganize the farm and graze animals in a controlled manner (refer to module two on livestock integration in CA).
- In all cases, plan for the whole farm but start the activities in small areas, and gradually introduce the conservation system to larger areas after learning what is good for the farm and positive results achieved.
- Plant with reduced tillage techniques and progress to no-tillage. If in a humid area, or have aggressive weeds like couch grass, use of herbicides will help until appropriate soil cover is established.
- When harvesting, use appropriate mulch management. Sowing can be done through the mulch with a direct seeder, or use the economical hand jab planter.

- In the first few years there will be a huge weed seed pool in the fields. Initially there may be need to use herbicides to control these high populations. To weed, use a herbicide or simply slash the weeds and lay them to suppress further growth. Gradually phase out herbicides by investing in cover-crop seed to suppress weeds.
- Try and establish a soil cover with native or improved exotic cover crop species (mainly legumes or plant cocktails). Preferably start in areas with less difficult weed infestations (few perennial species).
- Practice crop rotations, changing crop sequences or intercropping with cover crops (e.g. mucuna, lablab or pigeon pea intercropped with maize). This will decrease the occurrence of pests, diseases and weeds as well as protect the soil.

Conservation Agriculture with only a hoe!

If one does not have access to animal or tractor powered equipment, the common hand hoe is enough to practise CA.

What is important is to understand the principles and begin to apply them. Use the hand hoe to dig planting holes (pitting). If there is already trash in the field, one can push it aside to dig the planting holes. This practice saves up to 70 percent of the time that would otherwise have been spent digging the entire field and weeding, and drastically reduces the hazards of soil loss to rains.

At all costs leave the crop residues on the soil surface even if there is need to share a smaller portion with animals. Once the CA system is established the animals will have plenty to eat!

Conservation Agriculture with animal powered tools

Ranges of animal powered CA equipment are now available. There is the animal-drawn sub-soiler designed to break hard pans caused by many years of mould board ploughing. Sub soiling is a high draft power operation and should be done immediately after the current crop when the ground isn't too hard and the animals are strong from available feeds.

If sub-soiling with animals proves difficult due to high draft, make several passes consecutively, increasing depth until the desired depth is achieved. It will not be necessary to sub-soil every season. Include deep rooted crops such as pigeon peas in your rotations or inter-crop to help keep hard pans away. The Magoye ripper is used to make planting furrows, wide enough to allow for fertilizer, manure and seed placement without excessive soil disturbance. The seed, fertilizer or manure can be hand placed, or a jab planter can be used to plant inside the furrow.

Farmers in transition from conventional to conservation tillage will tend to prefer this process as it provides a gradual shift to direct seeding. Some chemical weed control will help in the early stages of shifting to CA, when weed infestation is likely to be heavy. Note that the equipment are designed to cause minimal soil disturbance. They must be used in the right soil conditions to avoid causing damage to the soil structure.

To accommodate animals in the CA system, feed them crop residue and use their waste to produce more manure. Also look for strategies to keep animals off protected farming sections and avoid over-grazing cordoned paddocks. Where there are roaming herds that cannot be controlled, build fences, use cover crops that are not edible by the cattle and develop special areas for high forage production (grasses and legumes to enhance animal feed availability).

Sub soiling with animal traction

Ripping allows fertlizer, manure and seeds to be placed inside the furrow manually. Direct seeding equipment such as the jab planter may be used to plant inside the ripped furows.

Final condition of a sub-soiled farm

Further reading

1. Goddard, T., Zoebisch, M.A., Gan, Y.T., Ellis, W., Watson, A. and Sombatpanit, S (eds) 2008. No-till farming systems. Special publication No.3, World Association of soil and water conservation. Bangkok

2. LI, R., 1986. Soil surface management in the tropics for intensive land use and high and sustained production. Adv. Soil Sci. 5, 1-109.

Module Five

Conservation Agriculture equipment

Learning objectives

In this module participants will learn about minimum and direct seeding equipment, utilization, care and maintenance.

Introduction

We have learned in earlier modules that excessive tillage is not good and should be avoided. The practice of CA requires things to be done differently including using different set of tools and equipment which may differ from what we have been used to. A variety of tools and equipment have been developed to suit different farm sizes, conditions and operations. This module focuses on CA equipment for smallholder farmers. This includes equipment for minimum tillage, direct seeding, cover crops and weed management equipment.

Most of the CA equipment are not widely available in local markets and some are still being used on a trial basis. The cost of CA equipment is also high compared with conventional equipment. This is primarily due to the present low demand for CA equipment. A critical mass of CA adopters is required to generate adequate demand to bring prices down. Recent efforts in the promotion of CA are expected to create demand for the equipment.

Minimum tillage equipment

The application of minimum tillage equipment is limited to the area where the crop is going to be planted leaving the rest of the area undisturbed. Note that most of the minimum tillage equipment are tine-based to avoid inversion and excessive soil disturbance.

The sub-soiler/chisel plough

Various parts of an animal drawn sub-soiler: Photo by KENDAT

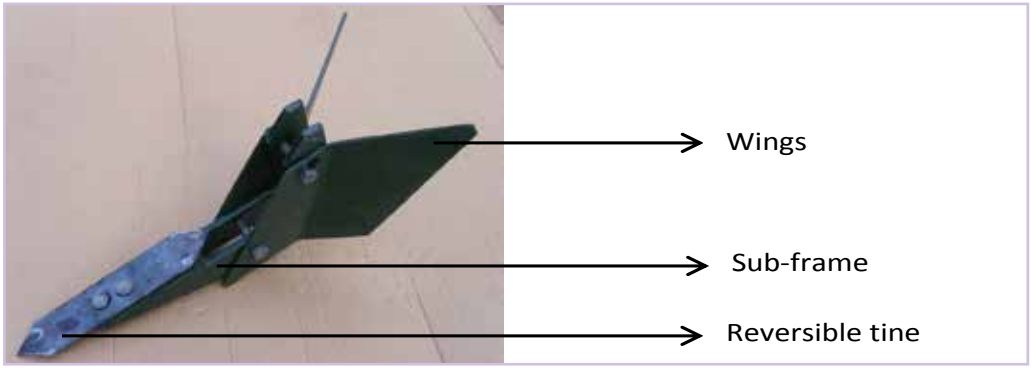
These tools have long tine(s), round, hexagonal or rectangular, designed to achieve deep penetration to break and loosen compacted soils. The animal drawn sub-soiler can penetrate up to a depth of 30cm. The tractor drawn chisel plough will loosen soil to a much greater depth. The tools are very effective, depending on how and when they are used, in breaking hard pans and loosening the soil without inverting it. They however have high draft requirement, especially on clay soils.

Tractor drawn chsel plough

Points to note when sub-soiling

- Usually done once every 3-4 years
- Only necessary if hardpans are detected
- Should never be done on wet soils otherwise serious damage to soil structure may occur
- The best time to subsoil is soon after harvesting when the soil is not too hard to reduce draft requirement.

The Ripper



Various parts of a ripper

The ripper is used to make planting furrows (called ripping) in un-ploughed fields. Ripping usually follows a sub-soiling operation (if hard pans were present). Some rippers are designed to achieve greater depths and therefore may also be used for breaking hardpans.

A trainer demonstrating the use of an animal drawn ripper: Photo by KENDAT

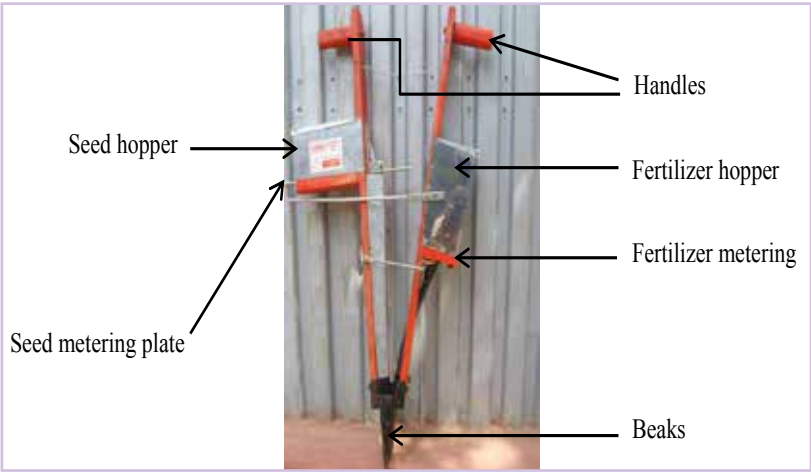
Direct seeding equipment

blogs.worldwatch.org

Direct seeding equipment refers to equipment capable of seeding directly into un-ploughed land. Under a CA system, this means the equipment should be able to plant through trash, mulch or a cover crop. The most common and basic of these include the dibble stick and the hand hoe. These are applicable where animal power is not available. They are also cheap, highly versatile and readily available. However they have low work rates and labour intensive.

The Jab planter

The Jab planter may have a single hopper (seed only), or double hoppers (seed and fertilizer). It has sharp beaks which penetrate into the soil through mulch, trash or other cover to place seed and fertilizer as desired. Both the seed and fertilizer hoppers have provision for adjusting the respective rates as desired.



Various parts of a jab planter

Operation of the Jab planter

The Jab planter is easy to use but requires practice to master its operation. The user puts the seeds in the seed hopper and fertilizers in the fertilizer hopper and uses the handles to push the equipment in the soil. Excessive force should not be used on the downward stroke to avoid placing seeds too deep in the soil. Some people prefer to use a marked line (string) to guide the planting stations on un-ploughed land.

This may however slow down the planting operation. Experienced operators are able to achieve fairly straight lines and consistency in both row and inter-row spacing without the use of the guiding line.

A trainer demonstartes to a farmer how to use a jab planter

Common problems in using the Jab planter

These include clogging of the beaks (hole openers), inconsistency in number of seeds dropped per station and failure to drop any seeds at all in some stations. Clogging of the beaks is caused by opening of the beaks on the downward stroke. The beaks should be in a fully closed position on the downward stroke.

This can only be overcome through practice. Inconsistency in number of seeds dropped and failure to drop seeds in some stations is a problem associated with variation in seed sizes. Most of the seeds on sale are not graded as they are meant for hand planting. Users are advised to repeat planting in the particular station where the seeds were not been dropped.

The animal-drawn direct seeder

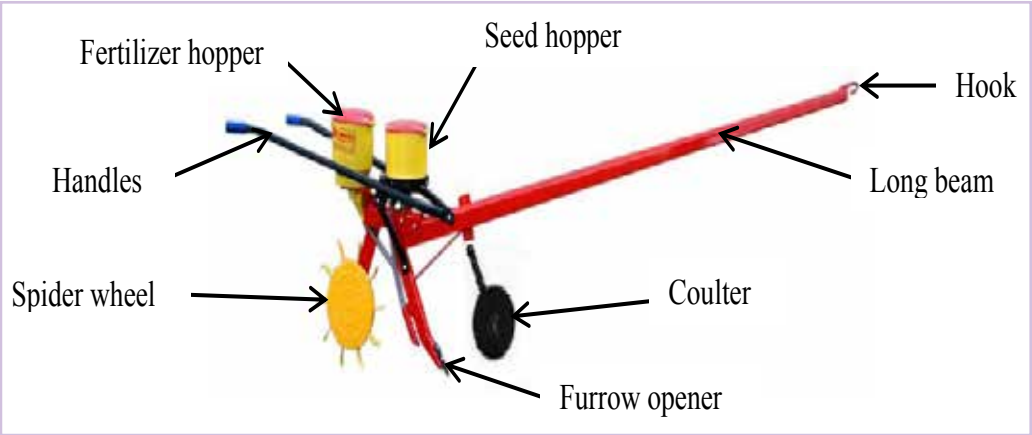
The animal-drawn direct planter is designed to plant into surface mulch in untilled soil with ease. The essential components of the planter are the coulter for cutting though the surface residue; two separate seed and fertilizer hoppers and a furrow opener. Each of these hoppers has mechanism for adjustments to give desired seed and fertilizer rates.

Wet soil clogging on jab planter beak

Operation of the animal-drawn direct seeder

Animals should be well trained and guided to walk in a straight line during planting operation. No force should be applied on the planter handles in an attempt to dig deeper. The coulter should be adjusted to exert adequate force for effective cutting of trash. If this is not done, trash will accumulate in front of the furrow opener and may hinder proper operation. The handles should be adjusted to suit operator height.

An animal drawn direct seeder



Various parts of an animal drwant direct seeder: Photo by KENDAT

Common problems in using the animal-drawn planter

Some of these problems include uneven spacing, seed breakage and trash accumulation at the front of the furrow opener. Uneven spacing and seed breakage is caused by seed size variation. If possible use graded seeds meant for machine use. For proper trash/residue cutting ensure coulter is sharp and is well adjusted.

Equipment for agro-chemicals application (spraying)

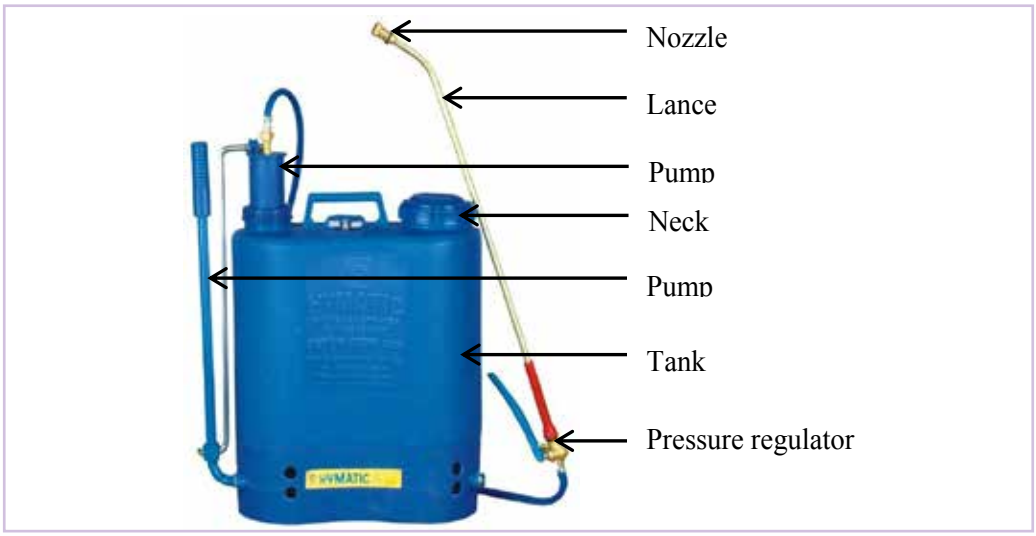
These are equipment used in the application of herbicides for weed control and pesticides in disease and pests control. The most common and readily available is the knap sack sprayer.

There are other new sprayers, generally modifications or variations of the knap sack meant to cover wider swathes for increased operator efficiency. These are not widely available and are expensive.

Irrespective of which sprayer is used, water for mixing with the chemicals should be of drinking quality (pH7) as some chemical e.g. round up are deactivated/ neutralized by contaminated water and should be passed through a sieve to avoid clogging of the discharge valves.

After use the tank and the whole discharge system should be cleaned. Moving parts should be oiled or greased regularly.

NB: Roundup works better in low pH or acidic conditions. You can lower water pH by adding lemon in the water.



Various parts of a knapsack sprayer: Photo by KENDAT

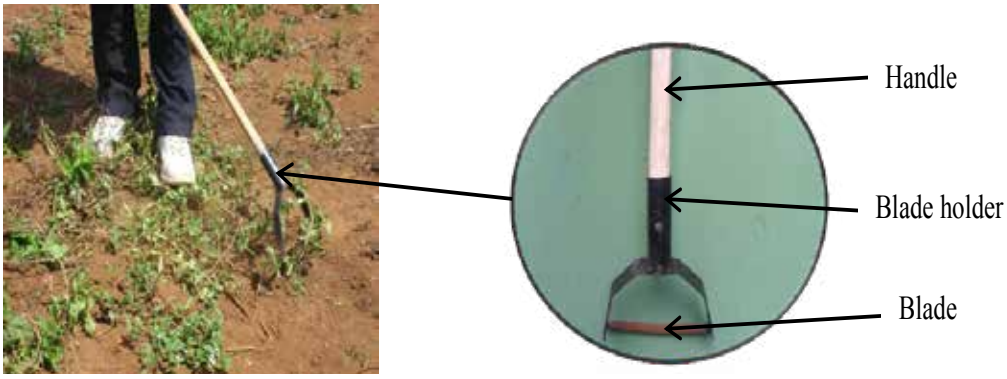
Caution in the use of chemicals

- Use protective clothing.
- Spray at the right time of the day. Early morning or later in the day when the wind is calm is recommended.
- The right chemical rate(s) must be applied for effectiveness
- Clean equipment thoroughly after use and wash your hands.
- Store chemicals in the right place as recommended by the supplier.
- Keep chemicals away from kids

Equipment for weed management

Manual weed control tools/equipment

A slasher or a sickle can be used to slash weeds above the ground. A push/pull hand weeder is another weed control tool which can be easily fabricated by local artisans. It is easy to use, effective and fast. Weeding by hand tools is hard work and takes a long time.



various parts of a weed scraper :Photo by KENDAT

Animal drawn weed control equipment

These include the duck-foot weeder which does not turn the soil over. Also included in this category are shallow sweepers with wide blades designed to make a single pass between crop rows. Weeding with animal drawn weeders is very fast requiring only one-fifth of the time needed for hand weeding. However, some animal-drawn weeders such as the duck-foot are expensive and may not be readily available locally. They also cause soil disturbance and can damage crop roots.

various parts of of an animal drawn weeder: Photo by KENDAT

Caution*:* Only equipment which does not cause excessive soil manipulation should be used for weed control in CA practice. Methods that turn the soil over should be avoided. Instead, slash or scrape the weeds with appropriate tools. A light hand hoe with a wide blade can be used to cut the weeds just below the soil surface.

Equipment operation and use

Before any equipment is taken out for use in the field, it is good practice to test and calibrate the equipment to ensure it meets both functional and design specifications. Before any equipment is released for circulation, it will have been subject to thorough testing by the manufacturer for both functionability and field performance. Our concern is to check equipment performance against the manufacturer's specifications and calibrate it for accuracy. See annex 3 for equipment calibration and work rates. Equipment should only be operated as specified by manufacturers.

Safety, care and maintenance of CA equipment

Observe manufacturers' guidelines on equipment use and operation and wear appropriate gear/clothing and observe all safety precautions when using equipment.

Tips on use and maintenance of CA equipment: Rippers and Sub-soilers

- Adjust the equipment to achieve desired depth by using chain length and the depth adjustment mechanism provided on the plough
- If you are struggling to achieve penetration, the adjustment is probably wrong
- Note both the sub-soiler and the ripper tines are usually double edged and can be reversed when one side is worn out.
- The sub-soiler tine can be adjusted to increase or reduce the shank part in contact with the soil
- Always clean your equipment after use by removing soil and dust from joints, bolts and nuts. Apply oil lightly on all bolts and nuts before storage.
- Ensure the tines are sharp at all times

Tips on use and maintenance of CA planting equipment: Jab planter and direct seed planter

- Remove seeds and fertilizer left-over after planting and clean the equipment
- Sharpen or replace cutting parts when worn out
- Joints, bolts and nuts should be kept lightly oiled or greased for storage
- Store equipment in a covered shade away from rain and sunshine
- Direct seeders must be calibrated for the desired seed/fertilizer rates before planting
- Keep children away from equipment.

CA equipment field exercise (to be done in the field)*:* A range of CA equipment should be provided for this exercise, especially those that are available in the market. The set up for the equipment should be done in advance of the exercise. Training should be done in a logical order to reflect the order of field operations. Each piece of equipment should be explained thoroughly and all participants allowed and encouraged to touch, adjust and practice its use and operation. All equipment calibrations should be done during this exercise

Further reading

1. Manual and Animal Traction Seeding Systems in Conservation Agriculture. Technical bulletin prepared by Christian Thierfelder and Patrick C. Wall for CIMMYT's BMZ and IFAD-funded projects on facilitating the Adoption of Conservation Agriculture in Eastern and Southern Africa.
2. Steiner, K., Derpsch, R., Koller, K. 1998. Sustainable management of soil resources through zero tillage. Agric. Rural Dev. 5. pg. 64-66.
3. Spray Sense. Information on pesticides issues No. 2. Calibrating hand operated sprayers. NSW department of primary industries.

Annex 1: Soil loss and run-off demonstration

Introduction

Inappropriate management practices (such as overgrazing, ploughing downhill, burning crop residues, bare soil, etc.) are important factors in causing erosion. Soil erosion is a serious problem as it removes the topsoil which is the most fertile layer. It is also the layer that provides the food for soil organisms. Usually the topsoil is a very thin layer and when removed the soil is left infertile. Soil loss and water runoff can be avoided by covering the soil with crops and crop residues.

Objectives

- To understand the function of soil cover
- To visualise the effect of rainfall on bare soil and covered soil
- To measure the difference in water loss through runoff and water infiltration
- Participants to understand the effect of soil cover on water infiltration and erosion

Preparation required

In advance, prepare an appropriate tray with soil, leaving one side bare and on the other one(s) put some type of soil cover, e.g. grass strips or leaves.

Materials required

- Two trays or one box that is divided into two parts
- Soil and cover material.
- Watering can or suitable dispenser
- Some support mechanism to adjust the slope of the tray
- Containers such as glasses to catch the run-off

Procedure

1. Place the trays or box at an angle, presenting the slope of a hill
2. Fill the watering can with water and start watering the box from about 50-100 cm above the box in a way that both "plots" receive the same amount of water
3. Ask the participants to observe the difference between the bare soil and the covered soil
4. Measure the difference in runoff and soil loss between the two "plots"
5. After watering, observe the soil surface of the two plots. Is there see any sign of erosion.

Questions to relate the topic to conservation agriculture

- What process took place on the bare soil?
- How was this avoided in the covered plot?
- What does this mean for growing a crop on the two plots, in relation to water efficiency?
- Can you think of other measures to avoid soil erosion and water loss?

Annex 2: Checking soil for hardpans

Introduction

A hard pan is a dense layer of compacted soil just below the plough zone. It is caused by continued use of conventional tillage tools such as the mouldboard plough. The hard pan restricts rain water from penetrating the ground leading to water logging, high levels of runoff and erosion. It also restricts plant root development, soil air and microorganism movement in the soil profile. The result is degraded soils which as a consequence leads to poor plant growth and low crop yields.

Methods for checking soil compaction

One can easily determine the presence of a hardpan by digging a soil profile from which the hardpan will be clearly visible. Another method is to push a metal rod about 8mm in diameter and 1.5m long, into the soil when the soil is moderately moist. The metal rod will bend if it is pushed beyond the compacted layer. Infiltration tests can also be used to determine the presence of a hard pan.

A quicker method is to uproot plants from the ground and observe the direction of root development. If the roots point sideways the field most likely has a hardpan.

Materials required

A hand hoe, a spade, and pocket knife (if digging a soil profile)

Metal rod: 1.5m long; 8mm diameter (if using the metal rod method)

Procedure

If using the metal rod method:

1. Push the rod down until the pressure makes it bend.
2. Measure how many centimeters the rod was able to penetrate the soil.
3. Take note of other soil characteristics: location, past history, types of vegetation, quality of vegetation growth, etc.
4. Discuss results with the group.

If using the soil profile method:

1. Dig a rectangular hole measuring 100 cm x 50 cm, and about 40 cm deep.
2. Using a pocket knife, push the knife against the exposed soil profile at different points (depths) on the soil profile. The compacted layer will require most effort in pushing the knife.
3. Discuss results with the group

Tap root in a soil profile

If using the root method:

1. Ask participants to pull different types of plants from the soil and observe root growth characteristics.
2. If the roots indicate the presence of a hard pan by pointing sideways, follow this up by digging a soil profile as described in the profile method above.

Tap root system deformed by hardpan

Soil erosion

Sometimes the most obvious sign of compacted soil is slow water infiltration following a storm. Slow infiltration is a major cause of erosion as the water will tend to move over the surface carrying soil with it and can't move into the soil quickly.

Annex 3: CA equipment calibration and work rates

Direct seeding equipment

a) Jab planter calibration:

Seed rates and plant population

Step 1: Determine the plant population per unit area (in this case per acre).

For the purpose of this calibration assume row spacing of 0.75 m and inter-row spacing of 0.35 m.

$$\text{Plant population} = \frac{4{,}000\text{m}^2 \times 2}{0.75\text{m} \times 0.35\text{m}} = 30{,}476 \text{ plants/acre}$$

Step 2: Determine planting stations (holes) per acre.

$$\text{Planting stations (holes)/acre} = \frac{4{,}000\text{m}^2}{0.75\text{m} \times 0.35\text{m}} = 15{,}238 \text{ holes}$$

Therefore, number of seeds/station (hole) = plant population / planting stations

= 30,476/15,238 = 2 seeds per hole

Step 3: Place seeds in the seed hopper and adjust the seed rate adjustment mechanism until a consistency of 2 seeds per each delivery is achieved. The seed rate calibration is ready.

Fertilizer rate

Step 1: Determine application rate per acre or ha. This can be obtained from recommended fertilizer rates for the particular fertilizer type. One can also ask farmers the rates they use.

Step 2: Determine the amount of fertilizer (in grams) delivered per application or per planting hole.

For the purpose of this calibration assume an application rate of 50kg/acre.

50kg/acre = 4,000m² (0.75x0.35) x (xg /1000), where x is number of grams delivered per application.

x = 50 x 1000 / 15,238 = 3.3grams

Step 3: Place adequate amount of fertilizer in the fertilizer hopper and adjust the fertilizer adjustment mechanism until the fertilizer delivery is 3.3 grams on average. You will need a clean floor or a piece of paper or cloth on which to collect the fertilizer during the calibration exercise. You will also need an appropriate weighing balance to weigh the fertilizer delivered from the fertilizer hopper.

b) Animal drawn seeder calibration:

Seed rate calibration

Step 1: Determine the plant population per unit area (in this case per acre). For the purpose of this calibration assume row spacing of 0.75 m and inter-row spacing of 0.35 m.

$$\text{Plant population} = \frac{4{,}000\text{m}^2 \times 2}{0.75\text{m} \times 0.35\text{m}} = 30{,}476 \text{ plants/acre}$$

Assume one seed per hole at the above spacing.

Step 2: Choose appropriate seed plate and place it in its place in the seed hopper. Place adequate seeds in the seed hopper and note which of the three bevel gears underneath the seed hopper is engaging the gear which in turn drives the seed metering mechanism.

Step 3: Find clear and clean stretch of ground, preferably with loose soil to reduce seed roll. Have someone to help to pull the planter along the selected ground while holding the planter handles.

During this exercise, the chisel-point tine furrow openers should run slightly above the ground but the rear spider wheel should be firmly on the ground to be able to drive the seed metering mechanism.

Step 4: Using a tape measure, measure the distance between the seeds on the ground and record.

Step 5: Make appropriate adjustments to achieve desired spacing. This is done by using the three bevel gears underneath the seed hopper. The smaller gear gives a longer spacing while the bigger gear gives a shorter spacing.

Fertilizer rate

Fertilizer calibration is done after the seed calibration has been satisfactorily done.

Step 1: Determine application rate per acre or ha. This can be obtained from recommended fertilizer rates for the particular fertilizer type. For this calibration we assume a fertilizer rate of 50kg/acre.

Step 2: Place some fertilizer in the fertilizer hopper and place the planter in such a way that the spider wheel can be rotated freely by hand and the fertilizer can be captured from the fertilizer deliver tube as it discharges from the fertilizer hopper.

Step 3: Measure spider wheel diameter and determine its circumference. For the purpose of this calibration assume a wheel diameter of 0.43m.

Circumference of the spider wheel = 3.14 x 0.43 = 1.35 m. For each complete rotation of the wheel, the planter will have travelled 1.35 m on the ground, assuming no wheel slippage/skidding occur.

Step 4: Based on the fertilizer application rate from step 1, determine the amount of fertilizer the planter should discharge, say in 10 rotations of the spider wheel, for calibration purposes.

Distance travelled to cover 1 acre = $\frac{4{,}000m^2}{0.75m}$ = 5,333m

Number of spider wheel revolutions = 3950 rev/acre

Amount of fertilizer to be discharged in 1acre = 50kg/acre

Amount of fertilizer discharged per 1 wheel rev = 50kg/acre/ 3,950 rev/acre = 0.0127kg

Fertilizer discharged in 10 wheel revolutions in gms = 0.0127kg x 10revs x 1000g/kg = 127gms

Step 5: Calibrate discharge rate for each fertilizer star wheel distributor and compare with the above rate. With the planter in the position described in step 2 above, for each star wheel, rotate the spider wheel 10 revs, collect and weigh the fertilizer discharged. Repeat at least 3 times for star wheel and get the average of the three measurements.

Step 6: Fit the star wheel fertilizer distributor that gives the correct rate (or close) as determined above. The planter is now calibrated for planting.

Note: Your fertilizer calibration options are limited by the sizes of the star wheel fertilizer distributors available. Essentially the planter should be supplied with several wheels of different sizes to allow for different fertilizer rates. However, it usually comes with 2 wheels of different sizes based on the most common fertilizer application rates.

c) Sprayers

Sprayers must be checked and calibrated to determine uniformity of discharge (spray distribution) and the rate of discharge before the actual spray exercise. It is important that the correct amount of herbicide or pesticide is applied per given area. Because sprayers may have different capacities, different nozzles with higher or lower outputs, a different operator, who may walk at different speed and may pump at higher or lower pressure, calibration is necessary.

Knapsack sprayers have a tank of up to 20 liter capacity, usually carried on the operator's back, a pressurizing system and a hand lance with a pressure regulator and one or more nozzles. The lance usually has a simple on-off valve (see figure for sprayer parts)

To check and calibrate a sprayer the following steps are followed:

A single nozzle sprayer and multiple nozzle sprayer: Photo by KENDAT

Step 1: Inspect the sprayer components physically and ensure they are in working order. Specifically check nozzle type and ensure it is the correct one for the intended job. Note that hollow cone nozzles are used for insecticides and fungicides and flat fan nozzles are used for herbicides.

Step 2: Put some clean water (say 5 liters) in the tank and check the discharge from the nozzle(s). If you notice any problem with the discharge, clean or replace suspect nozzle(s) before proceeding with the calibration.

Step 3: Find a dry surface and measure the spray width of the nozzle(s) on the surface (in meters). Be sure to hold the sprayer nozzle at the correct height above the ground surface (usually 0.4m)

Note: For the multiple nozzle boom sprayers, the spray width can simply be determined by multiplying the nozzle spacing with number of nozzles on the boom. For example, effective width of a boom with 4 nozzles spaced 0.5 m apart would be 0.5 m x 4 = 2m.

Step 4: Spray over a test area as if actually spraying the field, maintaining constant pressure and constant walking pace. Record the distance (in meters) covered in one minute (min).

Step 5: Measure the nozzle(s) output in liters over one minute in a measuring jug(s) (l/min.)

Step 6: Calculate the application rate per hectare (l/ha):

$$\text{Application rate (l/ha)} = \frac{\text{nozzle output (l/min)} \times 10{,}000}{\text{spray width (m)} \times \text{walking speed m/min)}}$$

Example: For the single nozzle sprayer, let us say the nozzle output in 1 minute is 4l, spray width is 1m and walking speed is 80m/min.

$$\text{Application rate (l/ha)} = \frac{4 \times 10{,}000}{1 \times 80} = \frac{40{,}000}{80}$$

$$= 500 \text{ l/ha}$$

Step 7: Calculate the amount of chemical to put in the tank

$$\text{Amount of chemical in one tank (l)} = \frac{\text{Recommended rate (l/ha)} \times \text{tank size (l)}}{\text{Application rate (l/ha)}}$$

Example: Assuming the recommended rate is 5l/ha and we are using a 20 liter tank. The application rate from above is 500 l/ha.

$$\text{Amount of chemical in one tank} = \frac{5 \times 20}{500} = 0.2 \text{ l or } 200 \text{ ml}$$

Thus 200 ml of chemical is added to a 20 liter knapsack sprayer to give the recommended rate of 5 l/ha.

Calibration of a pedestrian boom sprayer

Calibration

Step 1 and 2 are the same as in c) above.

Step 3: Determine effective boom width by multiplying the nozzle spacing with number of nozzles on the boom. In this case the effective boom width is 0.5 m x 4 = 2m.

Step 4: Determine discharge rate and spray distribution. The following items are required for this exercise:

Measuring cylinder

Water mugs for holding the discharge

Clock – to time the discharge from each nozzle per minute.

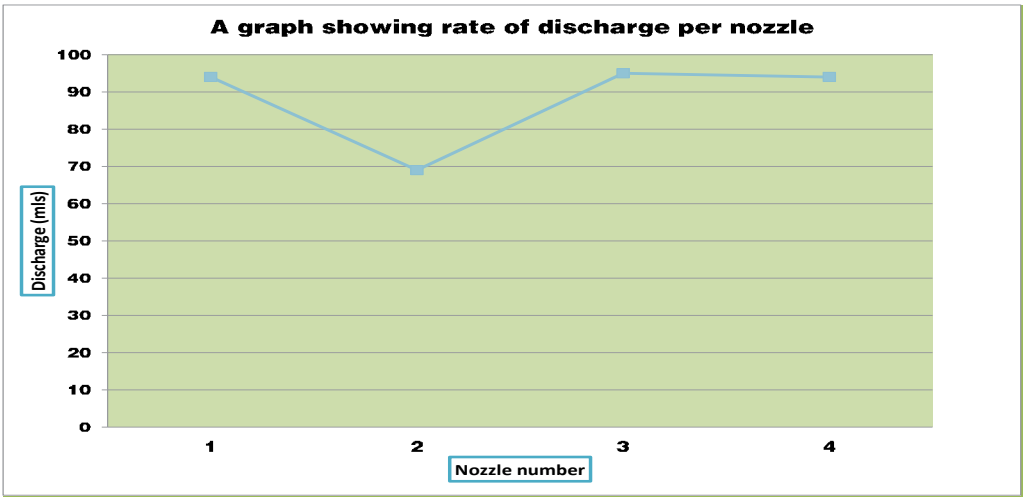
The pump of the pedestrian sprayer is operated by a pitman arm mechanism driven by one of the wheels as the sprayer is pulled along the ground. The sprayer will have to run the on the ground over a marked distance for calibration. As the sprayer has 4 nozzles there will be need to have 4 people to hold water mugs under the nozzles (1-4), as the sprayer is run over a marked distance, say 25m. Get someone to record the time taken over the 25m run. Measure the water from each nozzle and repeat exercise at least 3 times.

Step 5: Compare outputs across the nozzles. A table can be used but a graph will provide a better visualization of the discharge variations across the nozzles.

The table below shows the volume of discharge collected from the nozzles per minute.

Nozzle no.	Volume of discharge (output) collected over 25m run (ml)				Average discharge (ml)
1	125	75	100	75	94
2	75	50	75	75	69
3	100	80	100	100	95
4	95	80	100	100	94
Total discharge					352

From the above graph, it is clear nozzle number 2 has a much lower discharge implying it is either worn-out, clogged or of different type from the others. Check it out and take necessary action. The graph is a good tool to help determine when to replace nozzles.



Step 6: Determine water volume and amount of chemical needed to spray a unit area. The above graph is derived from an actual calibration exercise. Average time for four runs during the calibration exercise was 17 seconds over a 25 meters distance. Thus the speed of operation would be 1.5 meters per second. The width of the sprayer boom is 2 meters (see step 3 above).

Calculations

Area covered = 25m x 2m = 50m^2

Volume of water discharged in 50m^2 = 352mls

Which works out to: 352ml / 50m^2 = 7ml/m^2

In one acre: 7 ml x 4,300m^2 = 30,100mls (or 30.1 litres)

Assuming a dose of 350mls of glyphosate in 20 lts of water for normal weed control, this works out to 17.5 mls of roundup to 1 lt of water.

Amount of glyphosate required in one acre = 17.5mls x 30.1 litres = 527mls

1 acre = 4,300 m^2

Time taken to spray 1 acre: $\frac{17 \text{ secs}}{50\text{m}^2} \times 4{,}300\text{m}^2 \times \frac{1\text{min}}{60 \text{ secs}}$ = 24 minutes

Annex 4: Some species recommendations for incorporation with crops (EGA) in Machakos, Mbarali and Bugesera

Table 1: List of fertilizer and high value tree species recommended for Machakos County.

	Tree Species	Main use	Indigenous	Present on farm	Planted	Existing markets	Require domestication
Fertilizer trees	*Calliandra calothyrsus*	Fertility	-	x	x	na	-
	Faidherbia albida	Fertility	x	-	x	na	x
	Gliricidia sepium	Fertility	-	-	x	na	-
	Leucaena trichandra	Fertility	-	-	x	na	-
	Sesbania sesban	Fertility	x	x	x	na	x
High value trees	*Carica papaya*	Fruit	-	x	x	x	-
	Citrus sinensis	Fruit	-	x	x	x	-
	Mangifera indica	Fruit	-	x	x	x	-
	Psidium guajava	Fruit	-	x	x	x	-
	Persea americana	Fruit	-	x	x	x	-
	Tamarindus indica	Fruit	x	x	-	x	x
	Croton megalocarpus	Fuelwood	x	x	-	x	x
	Senna siamea	Fuelwood	-	x	x	x	-
	Grevillea robusta	Fuelwood	-	x	x	x	-
	Terminalia brownii	Fuelwood	x	x	-	x	x

Table 2: List of fertilizer and high value tree species recommended for Mbarali, Tanzania.

	Tree species	Main use	Indigenous	Present on farm	Planted	Existing markets	Require domestication
Fertilizer trees	*Faidherbia albida*	Fertilizer	x	x	-	na	x
	Gliricidia sepium	Fertilizer	-	-	-	na	-
	Sesbania sesban	Fertilizer	x	-	-	na	-
	Leucaena diversifolia	Fodder	-	-	X	na	-
	Acacia tortilis	Fuelwood	x	x	-	x	x
High value trees	*Adansonia digitata*	Fruit	x	x	-	x	x
	Azanza garckeana	Fruit	x	x	-	-	x
	Carica papaya	Fruit	-	x	X	x	-
	Mangifera indica	Fruit	-	x	X	x	-
	Moringa oleifera	Fruit	-	x	X	x	-
	Psidium guajava	Fruit	-	x	X	x	-
	Sclerocarya birrea	Fruit	x	x	-	x	x
	Tamarindus indica	Fruit	x	x	-	x	x
	Azadirachta indica	Fuelwood	-	x	X	x	-

Table 3: List of fertilizer and high value tree species recommended for Bugesera, Rwanda.

	Tree species	Main use	Indigenous	Present on farm	Planted	Existing markets	Require domestication
Fertilizer trees	*Faidherbia albida*	Fertilizer	x	-	-	na	x
	Gliricidia sepium	Fertilizer	-	-	-	na	-
	Sesbania sesban	Fertilizer	x	-	-	na	-
	Calliandra calothyrsus	Fodder	-	x	X	na	-
	Leucaena diversifolia	Fodder	-	x	X	na	-
High value trees	*Carica papaya*	Fruit	-	x	X	x	-
	Citrus limon	Fruit	-	x	X	x	-
	Citrus sinensis	Fruit	-	x	X	x	-
	Mangifera indica	Fruit	-	x	X	x	-
	Persea americana	Fruit	-	x	X	x	-
	Psidium guajava	Fruit	-	x	X	x	-
	Tamarindus indica	Fruit	x	-	-	x	x
	Markhamia lutea	Fuel	x	x	-	x	x
	Senna spectabilis	Fuel	-	x	X	x	-
	Grevillea robusta	Timber	-	x	X	x	-

Annex 5: Domestication status of some important tree species

1.Fertlizer Tree species

Acacia nilotica (L.) Willd. ex Del. – (Common name: Scented-pod acacia)

Agro-ecological value: *A. nilotica* is native to the drier areas of Africa, Middle East and Asia. Leaves and pods are high in protein, and the pods are available in the dry season. An edible gum, used in confectionery and as an adhesive, is obtained from the stem, while roasted pods have been used as flavouring.

The tree provides shade and provides superior timber, fuelwood, tanning, fodder, and medicine. It is nitrogen-fixing which improves soils; the development of perennial grasses under the canopy of the tree is dependent on its ability to provide shade, mulch, improve soil structure and infiltration and recycle nutrients.

Propagation: It is easily regenerated from seed which require pre-treatment before sowing. Mechanical scarification works best for small seed lots. Acid scarification from 60 - 120 minutes (depending on seed provenance or age), or pouring boiling water over the seeds and allowing them to cool are also effective. The species can be direct seeded or established by seedlings.

In the nursery long poly tubes (20 x 7 cm) should be used so as not to restrict rapid tap root growth. Frequent root pruning is advised. Nursery grown seedlings are usually outplanted after 6 months, but in some cases stay in the nursery up to a year. Inoculating the seed with improved rhizobia strains can increase early growth. Salt-tolerant Rhizobium isolates have also been tested which can nodulate and fix nitrogen in saline soils.

Pests and diseases: *Fusarium oxysporum* causes damping off in seedlings, and Fomes pappianus, a stem rot attacks unhealthy trees. Bruchid beetles attack seeds while powder post beetles (*Sibixylon anale* and *Lyctus africanus*) attack sapwood of felled timber.

Acacia senegal (L.) Willd. (Common name: gum arabic tree)

Agro-ecological value: *Acacia senegal* is widespread in Africa, Arabia and Asia. It is the main source of gum arabic, which is used as a stabilizer in food, cosmetics, pharmaceutical and chemical industries. Leaves and pods are important fodder for livestock while flowers are important bee forage. The wood is used for light construction, as fuelwood and for charcoal production while roots are used as twine and produce a fibre.

The edible gum is consumed locally and forms an important food source for herders while the fruits and seeds are also cooked as a vegetable.
Various parts of the tree are used in local medicine. It is nitrogen fixing tree and provides leaf mulch which contributes to soil fertility restoration.

Propagation: Seed storage behaviour is orthodox and seeds can remain viable for up to 7years under cool dry conditions. Fresh seed can be sown directly without pretreatment, but the hard seed coat develops within a season, and pretreatment is recommended to achieve high and uniform germination.

Mechanical scarification (nicking) works best for small lots, or soaking the seeds in cold water for 24 hours. Seed can be directly drilled 1 cm deep or planted in the nursery, preferably in long tubes (30 cm), 2 to 4 seeds per tube, thinned to one seedling after 4-6 weeks. There is rapid tap root growth, and frequent root pruning is required, if the seed is not directly sown. After 4 to 6 months seedlings are ready to be planted out.

Management: Spacing depends on the end use, for fuelwood and fodder production it can be grown at close spacing or wider spacings in agroforestry systems. It resprouts when coppiced.

Pests and diseases: Trees are susceptible to root knot nematodes and fungi while seeds are attacked by bruchids and the buffalo treehopper.

Acacia tortilis (Forsk.) Hayne: (Common name: umbrella thorn)

Agro-ecological value: *Acacia tortilis* is native to the dry zones of Africa, Middle East and Asia. It is used for timber and poles and is an excellent fuelwood and charcoal tree. Pods and leaves are an important source of fodder for animals. The ability to fix nitrogen and leaf fall improve and conserve soils under crop and livestock systems. Flowers provide a major source of good quality honey in some regions and the bark is used for tannin and medicine.

Propagation: *A. tortilis* is easily regenerated from seed. Seed pretreatment is necessary to achieve high and uniform germination. Mechanical scarification works best for small seed lots. Soaking seeds either in sulfuric acid for 20-30 minutes, or pouring boiling water and allowing cooling, are both effective treatments. Seeds are planted in the ground in 1 cm deep holes or in the nursery in 30 cm long tubes.

Seedlings exhibit rapid tap root growth requires frequent root pruning. Seedlings are ready to be planted out after 3-8 months. Propagation by cuttings, in vitro micropropogation and micrografting has been demonstrated, although regeneration by seed is not usually a problem.

Management: On marginal sites, initial seedling growth is often slow but quickens once roots have reached a water source. For best growth, plants should be weeded and protected from browsing animals for the first three years. *A. tortilis* forms mycorrhizal associations.

Pests and Diseases: *A. tortilis* is prone to attacks by caterpillars, bruchid and buprestid beetles. It is susceptible to nematodes, mistletoes (Loranthaceae) and galls.

Calliandra calothyrsus Meisn: (Common name: calliandra)

Calliandra calothyrsus planted on a hedge

Agro-ecological value: Calliandra calothyrsus is native to Mexico and Central America. Leaves are an excellent fodder source of supplementary protein for dairy cows and goats. The wood is used as fuelwood and can be converted to charcoal. It improves soil through biological nitrogen fixation and leaf mulch. The flowers are bee forage and produce a characteristic flavoured honey. When planted as a hedgerow, it reduces soil erosion on sloping land.

Propagation: Seed storage behaviour is orthodox. Propagation is by nursery raised seedlings, direct seeding or wildings. Two seeds are sown per pot and for bare root seedlings at a spacing of 15 X 15 cm or 10 x 30 cm. Fresh seed germinate readily in 4-8 days, however to achieve rapid and uniform germination, seed should be nicked or soaked in cool water for 24 hours. Germination rates of 75-90% are achieved. Seedlings are readily for planting out when they are about 20-50 cm tall. Inoculation of seeds or nursery soil with vesicular-arbuscular mycorrhizal fungi and Rhizobium enhances tree growth particularly for marginal sites.

Pests and Diseases: Information is available on pests and diseases of the genus Calliandra, but there has been little systematic study of pests or diseases of *C. calothyrsus*. However, it does not appear to suffer serious damage from pests or diseases in its native range or in areas where it has been introduced.

Faidherbia albida (Del.) A. Chev. (Common names: apple-ring acacia, mgunga)

Agro-ecological value: *Faidherbia albida* is native to most of the dryland regions of Africa and has been much valued in crop and livestock production systems. Its pods and leaves are an important fodder, marketed in the whole Sahelian region. The wood is valued for construction, handicraft, fuelwood and charcoal. Bark and roots are used as medicine and insecticide. As a member of the Fabaceae family, it is nitrogen-fixing and due to its reverse leaf phenology (shedding leaves during the rainy season) it does not compete much with crops for light, nutrients or water during the cropping season.

Propagation: *F. albida* reproduces by seed and suckers, under natural conditions. Seed storage behaviour is orthodox. Seed pretreatment is required for rapid uniform germination.Mechanical scarification works best for small lots.

Soaking with boiling water and leaving for 24 hours gives germination rates of 75-100% after 30 days. Seeds can be sown directly or planted in nurseries, using long plastic tubes (30 x 8 cm), with regular watering and frequent root pruning.

They should be transplanted 3-6 months later at 10 x 10 m spacing. Clonal propagation from both shoot and root cuttings, and from callus has been developed, although elite stock for propagation still require identification.

Management: In a trial in Burkina Faso, survival rate, plant height and root collar development of *F. albida* 7-month-old stem cuttings, 3-month-old bagged seedlings or direct sown seeds, mortality of seedlings was greater than that of cuttings after 7 months (15%), but after 42 months survival rate was greatest for seedlings (81%); height increments between 7 and 42 months were 146%, 60% and 48% for cuttings, direct sown plants, and bagged seedlings, respectively.

F. albida nodulates with Bradyrhizobium bacteria, commonly found in tropical soils, and also has vesicular-arbuscular mycorrhizal (VAM) associations.

Gliricidia sepium (Jacq.) Kunth ex Walp. (Common name: gliricidia)

Photo showing *Gliricidia sepium*

Agro-ecological value: *Gliricidia sepium* is native to seasonally dry regions of Mexico and Central America that has a pantropical distribution as a result of its incorporation in diverse smallholder farming systems. It improves soil fertility through biological nitrogen fixation and leaf mulch and is widely planted as live fences and for shade and erosion control. The tree provides a range of products including fuelwood, poles and fodder.

Propagation: Seed storage behaviour is orthodox. Direct sowing is sometimes used in alley farming or to establish other contour hedgerows, but container stock or bare-rooted seedlings are more frequently used. Potting mixtures are generally light textured and well-drained. Nursery stock can be out planted within 10-12 weeks. Vegetative propagation of shoot cuttings is easily achieved.

Large cuttings or branches, at least 6 months old, 3-6 cm thick and 0.5-2 m long with the bark incised to promote rooting are needed. Cuttings should be taken from mature branches and take root within 6 weeks allowing the tree to be readily established as living fence posts. However, trees established from cuttings have shallower roots and are less hardy than trees grown from seed. Seed or seedling inoculation with suitable strains of rhizobium is necessary where *G. sepium* is not naturalized.

Pests and diseases: There are no records of serious diseases and pests of *G. sepium*; however twig, stem and branch dieback have been reported as well as collar and root rot. Chocolate leaf spot has been identified as a problem in East and Southern Africa.

Leucaena trichandra (Urb.) (Common name: leucaena)

Agro-ecological value: *Leucaena diversifolia* is native to Mexico and Central America. Its leaves are high in protein and low in mimosine. The wood is used as fuelwood, charcoal, poles and timber. The tree is nitrogen fixing and can be used as green manure so contributes to soil fertility. When planted as a hedgerow, it helps in soil conservation on sloping land. The tree provides shade for perennial crops and pastures.

Propagation: Seed should be pretreated by soaking in warm water for 48 hours before sowing in the nursery. Germination takes place in about a week and seedlings are ready for transplanting in 8-12 weeks. Pretreated seeds can also be sown directly in the field.

Pests and Diseases: *L. trichandra* is generally resistant to insect pests in the field.

Sesbania sesban (L.) Merrill (Common name: sesbania)

Agro-ecological value: The geographical origin of Sesbania sesban is uncertain although it is widely distributed in tropical Africa and Asia. The species is capable of establishing in a wide range of environmental conditions. It is mainly grown as a short rotation tree or green manure on fallow and marginal lands to improve soil fertility, and for production of fodder, fuelwood, poles and pulp.

Propagation: *S. sesban* is propagated by seed. Scarification of seeds, using nicking, sandpaper, hot water, and sulphuric acid improves germination. Direct seeding can be relatively non-labour intensive with a probable high adoption potential. S. sesban has rapid early growth and therefore overcomes weed competition easily and usually requires little maintenance.

Vegetative propagation using stem cuttings is possible. Seedlings will normally form root nodules with native rhizobia within 3-4 weeks after planting. Where the effective rhizobia are absent and effective nodulation does not take place, inoculation with an appropriate Bradyrhizobium strain is necessary.

Phosphate fertilizer or manure application play an important role in nodulation, root and shoot dry matter and yield.

Pests and diseases: *S. sesban* is susceptible to root-knot nematodes which also affect production of susceptible crops. The defoliator beetle Mesoplatys ochroptera is a serious pest of S. sesban in Eastern and Southern Africa.

2.Fruit tree species

Adansonia digitata L. (Common name: Baobab)

Agro-ecological value: *Adansonia digitata* is indigenous to African dryland. The fruit pulp which is rich in vitamin C is used to make gruel and refreshing drinks. The dried pulp is used as a substitute for cream of tartar in baking and seeds are eaten raw or roasted and are used to thicken and flavour soup.

Seed kernels yield oil that can be used for cooking and in the cosmetics industry. Leaves are consumed as a leafy vegetable, or dried and powdered as an ingredient in soups and sauces. The trunk and root bark yield fibre which is used as string and for weaving ropes and baskets. Various parts of the tree are used in medicine. Leaves, flowers and fruits are use as dry season fodder.

Propagation: Natural regeneration of baobab is poor, mainly because of browsing animals and uncontrolled bush fires. Pre-treatment of seeds can be done by cracking or immersing in boiling water for 5–7 minutes, and should give a germination rate of 80–95%.
Sowing in bags is done 4–6 months before the expected start of the rainy season. Vegetative propagation by grafting is possible. For adult ortets, chip budding has been found to be the most successful technique. For grafting 3-month-old seedlings can be used with fresh scions. Stem cuttings can be easily rooted in nurseries.

Management: First flowering has been observed on an 8-year-old tree. Grafted trees start flowering after 3 years and do not become as tall as sown trees. The seeds take 8 months to mature and fruits are harvested from May to October in Kenya. Manure is recommended for intensive leaf production applied as top dressing per tree at the rate of 10-20 kg of manure at the beginning of the rainy season.

Due to their extensive root system, mature trees do not require fertilization. Regular pruning is recommended if grown for leaf production. Baobab can be intercropped with cereals, groundnuts and vegetables.

Pests and Diseases: It does not have any serious pests or diseases. Several insect pests, fungal and viral diseases have been recorded which attack the wood, fruit and shoots such as the cotton ball worms and strainer bugs, flea beetles and fungi that cause sooty mould, rotting and wilt.

Markets: Various products are sold in local markets such as fruits, seeds and craft products. Marketing involves intermediaries who collect the products from rural areas and transport them to urban markets. In Kenya, collectors sell directly to consumers or to middle men who process the raw material.

The major products which go through value addition are fruit pulp, seeds and bark fibre, which are sold commercially as juice, sweets and craft products. The international market is well established in West and Southern Africa particularly for products used in cosmetics and nutraceuticals.

Azanza garckeana (F.Hoffm.) Exell & Hillc. (Common name: tree hibiscus)

Agro-ecological value: *Azanza garckeana* is widely distributed in east and southern Africa. Ripe fruits are edible and can be processed to make jelly, boiled to make relish or made into porridge. Leaves are a source of fodder, bee forage and green manure. The wood is used as fuelwood, charcoal and to make farm implements, tool handles and domestic utensils.

Propagation: It regenerates naturally from seed, coppice and suckers. Seed germinate readily. Vegetative propagation using cuttings is possible. Coppice shoots have been observed to bear fruit after three months in field trials in Botswana (Mojeremane and Tshwenyane, 2004).

Pests and Diseases: The tree is susceptible to leaf defoliation by insects (Empoasca) and fungi (Phakopsora) and is a host to the cotton stainner and black beetle and therefore should not be planted in cotton producing areas.

Carica papaya L. (Common name: papaya)

Agro-ecological value: *Carica papaya* is a widely cultivated fruit tree in the tropics and subtropics. The fruit is consumed fresh and processed into fruit salads, refreshing drinks, jam and jelly. Unripe fruits are pickled or cooked as a vegetable. They are commercially used to produce papain, an enzyme that finds uses in the beverage, food and pharmaceutical industries. It is also used in treating hides, degumming silk and softening wool. Carpaine, an alkaloid present in papaya, can be used as a heart depressant, amoebicide and diuretic.

Propagation: Papaya is propagated by seed. To reproduce the desired characteristics seeds are produced through controlled pollination. The fleshy outer layer of the seed coat (sarcotesta) enveloping the seed is removed by rubbing the seed together against a fine-meshed screen under running water because it inhibits germination.

Dried seeds stored in air-tight containers remain viable for several years. Seeds are sown in small containers (tin cans, plastic bags or paper cups) at the rate of 3-4 seeds per container. Use of sterilised soil minimises losses resulting from nematodes and damping-off fungi. Germination takes 2-3 weeks. Another practice is to sow the seeds in sterilised nursery beds and to prick out at the 2-3-leaf stage, transferring 3-4 seedlings to each container.

Seedlings are transplanted about 2 months after sowing when they reach the 3-4 leaf stage or 20 cm height, preferably at the onset of the rainy season. Transplants must be watered regularly until they are established. Vegetative propagation of desirable clones is preferred while tissue culture is fast gaining popularity especially as it facilitates rapid production of disease free plants.

Management: Planting holes of 60 x 60 cm x 50 cm depth are prepared with 1 bucket of compost and a handful of rock phosphate is mixed in with the soil. It can be intercropped with coconut, other fruit trees such as mango or citrus or annual crops such as capsicums, beans, onions and cabbages. Irrigation is needed to minimise the abortion of flowers and maintain growth during the dry season.

Papaya requires a lot of nutrients for growth, use of manure and mulch balances the release of nutrients. Calcium deficiency depresses growth and fruit set and results in fruit drop hence liming is recommended to a pH of about 6. The tree can be productive for over 10 years but the economic period is only the first 3-4 years.

Pests and Diseases: Fruit flies have been recorded from papaya in East Africa, namely *Bactrocera invadens* and *Ceratitis rosa*. Spider mites and the broad mite, the cotton aphid and the green peach aphid are the most important aphids in papaya growing. The systates weevil is common in East Africa. Root-knot nematodes infestation reduces growth and yield while in nurseries severely infested seedlings wilt and die. Damping-off, root, stem and fruit rots, stem cankers, powdery mildew and papaya ringspot potyvirus are diseases that have been reported in East Africa.

Citrus sinensis (L.) Osbeck ^ Citrus limon (L.) Burm.f. (Common names: orange ^ lemon)

Agro-ecological value: Citrus species are native to the subtropical and tropical regions of Asia and have been cultivated since ancient times for their edible fruits, spreading to other regions of the world.

Propagation: The most common method of citrus propagation is by budding. When old trees are top-worked, bark grafting is used. Citrus varieties grown from seed have numerous problems like late bearing, uneven performance due to their genetic variability and susceptibility to drought, root invading fungi, nematodes and salinity.

Rootstocks are therefore used to meet all citrus requirements (tolerance / resistance to pests and diseases, suitability to soil and water conditions, as well as compatibility with scion variety selected). Rootstocks also improve the vigour and fruiting ability of the tree, as well as the quality, size, colour, flavour and rind-thickness of the fruit.

Pests and Diseases: Citrus spp. are susceptible to mites, insects and nematodes including citrus rust and bud mites, mealybugs, the citrus nematodes, woolly whitefly, blackflies, aphids, leafminer, African citrus psyllid, thrips, false codling moth and fruit flies. Citrus diseases caused by bacteria, mycoplasma, fungi and viruses include damping-off, greening disease, citrus tristeza virus (CTV), Phaeoramularia fruit and leaf spot, gummosis and anthracnose.

Mangifera indica L. (Common name: mango)

Agro-ecological value: *Mangifera indica* is an economically important horticultural tree native to India, but naturalized in the tropics. It is cultivated for its fruit that is consumed fresh or processed into various products such as juice, chutney, pickles, jam, jelly, canned and dried fruit. In addition to income opportunities, the mango is noted for nutritional and food provision especially during the dry season. The wood is used as timber, carving and fuelwood while various parts of the tree are used in medicine and as animal feed.

Propagation: Mangos are propagated either vegetatively or by seed. Seeds must be taken from ripe fruits and should be fresh at the time of planting. Freshly sown seeds should be protected from high temperatures and desiccation by providing shade.

Once seedlings emerge the shade is removed to harden the plants and produce a sturdy stem for grafting. Seedlings are grown sometimes to produce new cultivars but mainly for use as rootstocks or to reproduce known polyembryonic cultivars. Mono-embryonic types, however, require vegetative propagation to retain all of the desired characteristics.

Trees grafted on selected rootstocks remain smaller than the rootstock, and bear better and earlier. In the dry zones of Kenya, mango generally flowers from July to November and the fruit is harvested from December to March.Grafted mango trees can begin fruit production after 3-4 years though optimal yields are achieved between 10 and 15 years.

Management: Mango trees require pruning in order to shape young trees: in the first year, cap the seedling at 1 m height in order to produce a spreading framework of branches. In the second year, prune to leave 4 to 5 well-spaced branches to be the future main branches. Structural pruning should be done after fruit harvest so that the canopy is over one m above the ground and, to remove dead and sucker branches from the main structural branches.

Pests and Diseases: The worst pests for mangoes include fruit flies, cotton scales, mealybugs, cicadas and black flies that create honey dew. Diseases caused by fungi and bacteria include anthracnose, powdery mildew and leaf spot.

Moringa oleifera Lam. (Common name: moringa)

Agro-ecological value: *Moringa oleifera* is a native of India which is widely planted in the tropics. Its main use is the tender pods and leaves as a nutritious vegetable and fodder. Seeds have a high oil content which is used for cooking and in cosmetics; the press cake has flocculating compounds and is used to purify muddy water. Almost all parts are used in medicine; as an anodyne, anthelmintic, antispasmodic and disinfectant. It is used for living fences, in alley cropping and as a source of nectar for bees.

Propagation: *M. oleifera* is readily propagated from seeds and cuttings. Seed can be sown either directly or in containers. No seed pretreatment is required. Seeds should be planted 2 cm deep and germinate within 1-2 weeks. Germination rates are usually very good, but can drop to 0% after 2 years of storage.

The rapidly germinating seedlings can reach 5 m in one year if sheltered from drying winds and provided with enough water. Plants raised from 1 m cuttings bear pods from the second year of growth onwards, with maximum production at 4 to 5 years. In a favourable environment an individual tree can yield 50 to 70 kg of pods in one year.

Pests and Diseases: Moringa is resistant to most pests and diseases, but outbreaks may occur for example, diplodia root rot in waterlogged soils, causing severe wilting and death of plants. Insect pests include termites, aphids, leafminers, whiteflies, caterpillars and mites.

Persea americana Mill (Common name: avocado)

Agro-ecological value: *Persea americana* is native to tropical America and is an important horticultural crop in East Africa. The nutritious high protein and oil content edible fruit has multiple uses including cosmetics, healthcare products, lubricant or fuel oil. The wood is used as fuelwood while various parts are used as medicine.

Propagation: Avocado seed are recalcitrant; they germinate readily and can be raised in the nursery. Commercial planting is mostly based on high grafting high-yielding material onto hardy rootstock. Grafting should be carried out when the seedling reaches pencil thickness. Wedge grafting method is most successful. Grafting should be done at the point where rootstock is soft. The scion should be dormant at the time of grafting and should match the size of the stock.

Pests and Diseases: Major pests include fruit fly, thrips, aphids, mites, scales, false codling moth and the Mediterranean fruit fly. Diseases recorded include Phytophthora root rot, anthracnose, scab and Cercospora leaf spot.

Psidium guajava L. (Common name: guava)

Agro-ecological value: *Psidium guajava* origin is uncertain, though it is believed to originate in an area extending from southern Mexico into Central America. It is one of the most gregarious of fruit trees and has become naturalized in many parts of the world.

The fruit has the highest vitamin C of all fruits and is commonly eaten fresh or processed into sweets, preserves, jellies, jam and juices. Leaves, roots, bark and immature fruits are used as medicine, while wood is use as fuelwood, for charcoal production, in carpentry and turnery.

Propagation: Guava seeds remain viable for many months and germinate in 2-3 weeks. Pretreatment with sulfuric acid or boiling for 5 minutes, or soaking for 24 hours will hasten germination. Seedlings are transplanted when 5-75 cm high and set out in the field when 1 or 2 years old. Although seed may be used to propagate guava, commercial cultivars are vegetatively propagated by air layering, stem cuttings, grafting, budding and micro-propagation.

Management: Guava tree generally begin bearing 1 or 2 years after planting: grafted or budded trees may bear 1 year after planting and those from seed bear fruit 2 years after planting. Light pruning is recommended to develop a strong framework, and suckers should be eliminated around the base.

Thinning of branches is recommended and results in larger fruits. Trees live for 30-40 years although productivity declines after 15 years. Orchards may be rejuvenated by drastic pruning. Guava trees respond to a complete fertilizer mix applied once a month during the first year and every other month the second year at the rate of 227 g per tree initially with a gradual increase to 680 g by the end of the second year. Nutritional sprays providing copper and zinc are recommended thrice annually for the first 2 years and once a year thereafter.

Pests and Diseases: There is inadequate information on diseases and pests of guava in East Africa. In Kenya, the fruit fly has been reported as a major pest, other pests are the bollworm, aphids and caterpillars. Among diseases powdery mildew is a common problem.

Sclerocarya birrea (A. Rich.) Hoscht (Common name: marula)

Agro-ecological value: *Sclerocarya birrea* is indigenous to the dry areas of Africa. The vitamin C rich edible fruit is consumed fresh or processed into juice and fermented to produce an alcoholic beverage. The protein rich kernels extracted from fruits are consumed raw, crushed and used to make cakes or soup ingredient.

They are rich in oil which is extracted and used for cooking and skin care. Bark and leaves are used in medicine. Branches are lopped for animal fodder while leaves and fruits are browsed by wild herbivores. The wood is used for the production of mortars, bowls and carving, and as fuelwood while the bark yields dye and fibre.

Propagation: Seeds lose viability rapidly in open storage, but store well in air-dry storage at cool temperatures. Propagation by seed requires pretreatment to break dormancy. Stones immersed in boiling water then soaked for 24 hours gave 53% success while loosening the opercula of freshly cleaned stones gave 85% success after two weeks.

S. birrea is best propagated vegetatively by grafting and cuttings because it is dioecious. Grafting reduces time to first fruiting to about three years. Propagation using large branch or stem pieces (10 cm × 2 cm), root suckers and grafting is also possible.

Tamarindus indica L. (Common name: tamarind)

Agro-ecological value: *Tamarindus indica* is native to the Sahelian belt extending into East African drylands. The fruit is rich in minerals and vitamins. The wood has been traded internationally as Madeira mahogany timber; it is also used as firewood and for charcoal production. The trees provide shelter in dry areas and fodder. Leaves, roots and bark are used as medicine. The tree is nitrogen-fixing and the mulch improves soils.

Propagation: Seeds retain viability for about 6 months. Germination rates are about 65-75%. No seed pre-treatment is usually required. However, seed germination can be accelerated by nicking or soaking seeds in cold water for 12 hours gives germination rates of upto 90%. Fully-formed seeds are sown in polythene bags when containers are used for propagation. Seed germination begins within a week and may take a month to complete.

The seedlings can be field-planted after 14 months at which age they are about 30 cm tall. If growth is poor the seedlings should be retained in the nursery for another year although this may result in the taproot growing into the soil which then requires root pruning.

T. indica can be propagated vegetatively by shield and patch budding, cleft grafting, branch cuttings and layering. Patch budding and modified ring budding have achieved 96% and 94% success rates, respectively, and are reported as suitable for large-scale multiplication of *T. indica*. *T. indica* seed can be direct-sown for plantation establishment.

Management: Young trees are pruned to allow 3 to 5 well spaced branches to develop into the main scaffold structure of the tree. To control tree size and rejuvenate fruiting, regular pruning is required.

Pests and Diseases: *T. indica* is seldom affected by pests and diseases though ripe fruits in humid climates are attacked by beetles and fungi, so mature fruit should be harvested and stored.

The most serious pests are scale insects, mealy-bugs and bruchid beetles. Diseases reported include leaf spot, powdery mildews, sooty mould, stem disease, stem, root and wood rot, stem canker and bacterial leaf-spot.

Markets: Marketing involves intermediaries who collect the fruits from rural areas and transport them to urban markets. In Kenya, collectors sell directly to consumers or to middle men, tamarind is usually sold in major urban markets unprocessed. The major product processed from the fruit is tamarind juice.

3.Fuelwood tree species

Croton megalocarpus Hutch. (Common name: croton)

Photo showing branch of a *Croton megalocarpus* tree

Agro-ecological value: *Croton megalocarpus* is indigenous to East and Southern Africa. It is mostly used as firewood, timber and for charcoal production. Seed has high oil (30%) and protein content (50%) and has been used as poultry feed. The tree is used as medicine, leaves provide mulch and it is often planted as live fence.

Propagation: The tree is a prolific seeder and seed germination is abundant under the tree. It may be propagated by direct sowing, seedlings or wildings.

Pests and Diseases: Croton is susceptible to attacks by Ambrosia beetles and Scolytidae insects.

Delonix regia (Bojer ex Hook.) Raf. (Common name: flamboyant)

Agro-ecological value: *D. regia* is native to Madagascar but is widely planted in the tropics as an ornamental or avenue tree and for shade. It is planted on eroded sites for erosion control, and for soil rehabilitation and improvement through atmospheric nitrogen fixation. Leaves and pods are fodder and browse for livestock.

Propagation: *D. regia* seed storage behavior is orthodox. It is usually grown from seed, pre-treatment is necessary to hasten and improve germination. The seed is treated with sulfuric acid for about three hours, soaked in hot water for 24 hours or mechanically scarified before sowing to hasten germination.

Soaking in hot water at 90°C for 10 seconds, followed by soaking for 24 hours under controlled conditions of 28.2°C and 83% relative humidity, gave 80% germination. Seeds are sown in nursery beds, pots or polythene bags without shade and seedlings are ready for field planting in 4 months. Vegetative propagation by stem cuttings is advisable for propagating trees with uniform characteristics although rooting of cuttings is poor.

Pests and Diseases: *D. regia* plants are susceptible to attack from termites and shoot borers (Salman et al., 1987; Webb et al., 1984). Acanthopsyche reimeri larvae feed on leaves of ornamentals and has been reported to cause severe defoliation of D. regia in Kenya.

Senna siamea (Lam.) Irwin & Barneby (Common names: yellow cassia)

Agro-ecological value: *S. siamea* is native to Southeast Asia, but is widely cultivated and naturalised throughout the tropics. The tree is used for erosion control, windbreaks, shade and fuelwood. It produces quality timber used for marquetry and inlay work.

Propagation: *S. siame*a seeds are orthodox, and will keep for several years in dry storage at ambient temperature. Seed pretreatment is recommended; scarification with concentrated sulphuric acid for 10-30 minutes or with boiling water gives about 90% germination within 6 days. Seed can be direct sown with 55% survival rate. Nursery raised seedlings can reach 30 cm tall in 8 weeks at which time they are ready for out-planting.

Pests and Diseases: *S. siamea* is fairly resistant to termites but is susceptible to scale insects, caterpillars and defoliating insects. Among the fungal diseases, *Ganoderma lucidum* causes spongy-rot and butt rot. *Fomes lucidus* is a parasitic wound fungus that invades the tree through the roots, causing a white soft decay in the lower stem. *Phaeolus manihotis* is a root disease causing dieback. *Erianthemum ulugurense* is a mistletoe in Kenya that causes dieback.

Senna spectabilis (DC.) H.S.Irwin & Barneby. (Common names: spectacular senna)

Agro-ecological value: *Senna spectabilis* is native to native to Central and South America. It has been introduced and naturalized in many other parts of the humid tropics, particularly the East and southern Africa as an ornamental and a boundary marker. It produces quality firewood, and has been used for shade, windbreaks, soil fertility improvement, mulching.

Propagation: *S. spectabilis* can be grown vegetatively, from seedlings, direct sowing or by coppicing. Seeds can remain viable for several years in storage and should be pre-treated before sowing by pouring boiling water and allowing them to soak for 24 hours. A germination rate of up to 60-90% can be achieved.

Management: It is reported to be easier to raise, less susceptible to pests and diseases, and more drought-resistant than Senna siamea.

4.Timber tree species

Azadirachta indica A. Juss. (Common name: neem)

Agro-ecological value: The neem tree is native to India and Southeast Asia, but it is now grown in the warm lowland tropics as well as in arid and semi-arid areas of the world. Seeds, leaves and bark extracts are used in medical, cosmetic and insecticidal products. The wood is used as timber and when planted on slopes, the tree helps to combat erosion. It is planted for amenity, windbreak and shade.

Propagation: Neem is propagated by seed, fresh seed should be sown within two weeks while stored seed should be soaked in water for 24 hours. Fresh seed germinate readily at the rate of 85%.

Seed are commonly sown in polybags in the nursery, although direct sowing is successful where there is adequate rainfall. Vegetative propagation methods employed include grafting, root cuttings, stem cuttings and stump cuttings (Chamberlain, 2000).

Management: Lack of zinc or potassium drastically reduces growth. Trees affected by zinc deficiency show chlorosis of the leaf tips and leaf margins, shoots exude resin, and older leaves fall off. Those with potassium deficiency show leaf tip and marginal chlorosis and die back (necrosis).

Pests and Diseases: In some parts of Africa, scale insects, mistletoes and semi-parasitic plants have been reported to infest neem in Africa. Many diseases of neem are caused by fungi that affect its leaves, stems or roots, and are a particular problem for seedlings in plant nurseries.

Grevillea robusta A.Cunn. (Common name: silky oak)

Agro-ecological value: *Grevillea robusta* is native to Australia. It provides economically valuable products including timber, poles and firewood. The tree has been used shade for plantation crops and conserves soils through leaf mulch on sloping land. Leaves are used as fodder supplement for cattle in the dry season when other sources are scarce.

Propagation: Propagation is usually by seed. No pretreatment is required for germination. Seedlings are pricked out when their second leaf-pair starts to develop, into tubes or plastic bags filled with a fertile loamy potting mix. Seedlings are grown for around 4-6 months in the nursery until planting out at a height of 20–40 cm during the rainy season.

Management: The species is not known to form symbiotic associations with soil bacteria or mycorrhizal fungi. Fertilizer is seldom applied: 50 g per tree of an NPK fertilizer (12:12:12) applied shortly after planting would be appropriate for infertile soils. For soils deficient in boron, an application at planting of 10 g per tree of boron is recommended. When planted in woodlots and line plantings, thinning of inferior trees is often carried out at 4-5 years to yield poles and firewood for local use or sale. Pruning and pollarding every 3-4 years onwards is commonly practiced on farms to harvest high branches.

Pests and Diseases: Grevillea is susceptible to termites in semi-arid environments and is attacked by a dieback and canker disease leading to parts or entire trees being killed.

Melia volkensii Gürke. (Common name: mukau)

Agro-ecological value: ***Melia volkensii*** is indigenous to Eastern Africa, from southern Ethiopia through northern and eastern Kenya and into northern Tanzania. It produces high quality, termite resistant timber used in furniture and door making. Leaves and branches are used as livestock feed. Fallen ripe fruits are often fed to livestock during the dry season. Leaf extracts of *M. volkensii* are used against household and livestock insect and acarine pests. The tree is used as fuelwood and provides shade.

Propagation: *M. volkensii* seeds are difficult to germinate. The principal method of propagation is through seedlings. Propagation by seed requires the removal of the integument, perisperm and endosperm which results in 81% germination.

Seeds can also be nipped, soaked in 10% sodium hyperchloride (JIK) solution for 12 hours, slit and sown in sterilised pure river sand: a 69% germination rate has been recorded. Vegetative propagation by sucker and lateral root production has been found to be influenced by age of donor plants. Many farmers who have this species on their farms (especially observed in Kitui and Mbeere districts of Kenya) rely on natural regeneration of seedlings, transplanted saplings and root cuttings.

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