

FARMER FIELD SCHOOL FACILTATOR'S MODULE

Integrated Soil Fertility Management (ISFM)

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A product of the Rwanda Soil Health Consortium

Please cite this publication as: Ruganzu et al. (2015) Farmer Field School Facilitators Module: Integrated soil fertility Management (ISFM). Rwanda Soil Health Consortium, RAB, Kigali-Rwanda

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July, 2015

Designed by Leo Brands

Acknowledgement

This module was developed by the Rwanda Soil Health Consortium (RWASHCO) through financial support from the Alliance for a Green Revolution in Africa (AGRA). The authors wish to express gratitude to the Rwanda Agricultural Board (RAB) for facilitating the process and the International Plant Nutrition Institute (IPNI) for backstopping the process of developing this module. Further, we thank all members of the Rwanda Soil Health Consortium and the Farmer Field School team for developing and organizing the content of this module.



List of Abbreviation and Acronyms

AF:	Agroforestry
AGRA:	Alliance for a Green Revolution in Africa
AESA:	Agro Eco-System Analyses
BTC:	Belgian Technical Cooperation/Belgian Development Agency
FAO:	Food and Agriculture Organization
FFS:	The Farmer Field School
IPNI:	International Plant Nutrition Institute
ISFM:	Integrated Soil Fertility Management
IPM:	Integrated Pest Management
IPPM:	Integrated Production and Pest Management
NPK:	Nitrogen, Phosphorus, Potassium
RAB:	Rwanda Agriculture Board
RWASHCO:	Rwanda Soil Health Consortium
TSP:	Triple Super-Phosphate
ToT:	Training of Trainers

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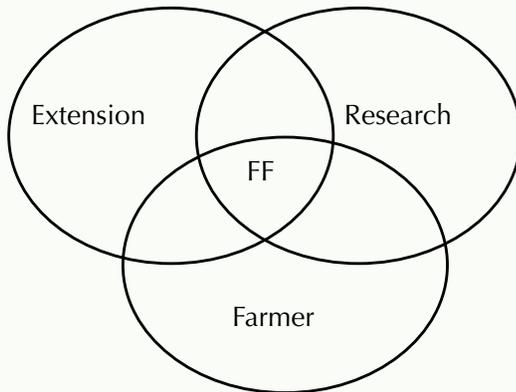


Part I: Introduction to Farmer Field School approach

The Farmer Field School (FFS) is a participatory agricultural extension approach, based on 'learning by discovery'. The FFS approach was developed in the 1980s by a FAO project in Southeast Asia as a way for small-scale rice farmers to learn for themselves the skills required for, and benefits to be obtained from, adopting integrated pest management (IPM) practices in their paddy fields. In Rwanda it was started very recently in 2009 by IPM Project funded by BTC-Rwanda. Farmer Field Schools are conducted for the purpose of creating a learning environment in which farmers can master and apply specific management skills. The emphasis is on empowering farmers to implement their own decisions in their own fields.

FFS: Forum For integration/Better Interaction

Extension-Research-Farmers



“Tell them and they will forget,
Show them and they may remember,
Involve them and they will
understand”

1.1 Characteristics of Farmer Field Schools

- Group of farmers: 25-30 farmers with common interest
- Field: The primary learning place based on the subject of study
- Competent facilitator: A trained person for offering help and guidance when required
- Learning curriculum: Topic/s should be chosen by the community; based on basic needs of farmers (demand driven); participants are involved in curriculum development
- Program leader: can support the training of facilitators, get materials organized for the field, solve problems in participatory way and nurture field staff facilitators. The program leader should also take charge of monitoring and evaluation.



Figure 1: Illustration of learning by doing

Conditions for FFS success and sustainability: non negotiable points

- (i) **Long training season: Training of Trainers (ToT) & FFS**
The long season training starts with land preparation to harvesting of the commodity under consideration.



Figure 2: Long training season sessions: Facilitators training on rice at Nyagatare

- (ii) **Agro Eco-System Analyses (AESA)**
AESA is a process done by observation of the interaction between a crop/livestock and other biotic and abiotic factors co-existing in the field. This involves regular observations of the crop/livestock. It is a way of assembling what we are studying and placing it into a useful process for decision making. It promotes learning by discovery. It guides farmers to critically analyze and make better decisions on their own fields.

AESA is the cornerstone of the FFS. FFS participants spend most of their time in the field. During AESA, the following activities have to be done:

- Observation
- Group discussion and analysis
- Conclusion and action plan

1.2 Steps for running the training on ISFM through FFS approach

Several steps are involved in training partners on ISFM through the FFS approach.

These include:

- Identification of farmers' problem and needs
- Presentation of integrated soil fertility management philosophy, components and objectives to the different farmers' associations and development of ToT curriculum
- Selection of participants to the training of trainers (ToT), ToT location, ToT plot and conducting the training
- Identification of FFS plot sites, establishment of FFS groups and implement season long training FFS activities in the fields
- Graduation
- Farmer run
- Monitoring and evaluation

Practically, the training sessions consist of the following categories of trainings:

- i. Theoretical presentations related to FFS approach and ISFM technologies and some related scientific data
- ii. Practical application in the common ToT plot for the whole group; field activities should be carried out by trainees themselves
- iii. Practical trainings in FFS group facilitation by implementing ISFM technologies in farmer environment: the work should be achieved by facilitators and farmers in FFS



Part II: Integrated Soil Fertility Management (ISFM)

Integrated Soil Fertility Management (ISFM) is a set of soil fertility management practices that necessarily include: The use of fertilizer, organic inputs, and improves germplasm combined with the knowledge on how to adapt these practices to local conditions, aimed at optimizing agronomic use efficiency of the applied nutrients and improving crop productivity.

ISFM involves a range of soil fertility enhancing methods, such as improved crop management practices, improvement of soil health, integration of livestock, measures to control erosion and leaching.

2. Description of ISFM technologies, their uses, advantages and disadvantages

2.1 Compost

Composting is the natural process of 'rotting' or decomposition of organic matter by micro-organisms under controlled conditions. Composting is an attractive proposition for turning on-farm organic waste materials into a farm resource. Composting enhanced soil fertility and soil health include increased agricultural productivity, improved soil biodiversity, reduced ecological risks and a better environment.

Materials needed to prepare compost are:

- Twigs (branches of trees)
- High carbon materials - includes dry vegetative matter such as maize stalk, seed husks, dry grass etc
- High nitrogen rich material – includes green vegetative materials such as weeds, grass, leguminous crop residues, hedge cuttings (e.g. tithonia, calliandra) or kitchen wastes such as fruit and vegetable peelings
- Animal dung, slurry or old compost
- Top soil - adds micro-organisms that are useful for decomposition of added organic resources
- Ash - provides minerals such as potash, phosphorous, calcium and magnesium. It also reduces the pH due to the higher bases cations in ash
- Sharp-pointed stick 2-3 m long (thermometer) - to detect heat and water requirements. Moisture is the lifeblood of the metabolic processes of the microbes. Water provides the medium for chemical reactions, transport nutrients and allows the microorganisms to move from place to place, biological activity is optimum when the materials are saturated. Activity ceases entirely below 15% moisture content. Heat accumulation in a compost pile can rise above 160° F (71°C) because of heat generated by microbial activity and the insulating qualities of the composting materials. When the temperature reaches this level, many of the microbes die or become dormant. The composting process effectively stops and does not recover until the population of the microorganisms recovers. The temperatures should be monitored and when the composting material becomes too hot, heat loss should be accelerated by forced aeration or by turning.
- Water - to soften materials and regulate heat in the heap
- Wheelbarrow, watering can, hoe, machete.

Composting methods

There are two basic methods of composting;

- i) Heap or pile composting
- ii) Pit method

How to build a compost heap (pile composting)

- This method is suitable for areas with high rainfall.
- Make a pit 30-45 cm deep and 2 meters wide with any convenient length. Loosen the ground and lay some coarse plant materials such as twigs. This will ensure good air circulation and drainage
- Put a layer of 30 cm of dry vegetative matter
- Chop them into small pieces. Small pieces decay faster
- Add a 10 cm layer of old compost, animal manure or slurry
- This will add extra bacterial and fungi to fasten decomposition. Add a 10 cm layer of green materials. Try to maintain a ratio of 1 part greens to 3 parts of dry matter.
- Kitchen wastes such as fruit and vegetable peelings decompose quickly.
- Add a sprinkling of top soil from the top 10 cm of cropped land
- Ash can then be sprinkled on to these layers. Water the whole pile well
- Repeat all these layers except the first layer of twigs until the heap reaches 1 to 1.5 m high
- The heap should be covered to protect it against evaporation due to volatilization of N compounds and heavy rain as this will leach away soluble nutrients. A 10 cm layer of top soil may be applied as this may reduce nitrogen volatilization of nutrients from the compost.
- Apply dry material on top of the top soil

Managing a compost heap

- Water the heap twice a week
- The pointed stick should be used to regulate temperature. Composting is most efficient when the temperature of the composting material is within the two ranges known as Mesophilic (26.6°-48.8°C) and Thermophilic (40.5°-65.5°C). Mesophilic temperatures allow effective composting, but most experts suggest maintaining temperatures between 43.3° and 70°C.
- Compost heap should be turned after every 3 weeks
- The heap should always be covered after turning

Duration of compost making varies depending on the quality of materials used. On average 6-8 weeks enable complete maturation of compost.



Figure 5: Transfer of compost manure from 1st to the 3rd step (maturing stage)

Pit method

The pit method of making compost conserves moisture, so it is useful in areas with low rainfall and a long dry season. Do not use it in wet areas, as the compost may become waterlogged.

How to build the compost pit

- Dig a pit 1.2 m (4 feet) wide and 0.6 m (2 feet) deep, and as long as you need for the amount of materials you have
- Build a pile in the pit, using the same method as in the pile method. Add water if necessary
- Push long poles into the pile to allow air to get into the layers beneath. Turn the pile every 2 weeks.

You can produce a regular supply of compost by digging three pits side by side. Every 2 weeks, turn the compost from one pit into the next one, and start a new compost pile with fresh vegetation in the empty pit.

Characteristics of mature compost

- Coarse materials become finer over time until a fine, loamy material is produced
- The different materials are no longer recognizable
- Has only a slight 'earthy' and inoffensive smell
- Temperature drops (10° - 15° C) and the compost is cool



Figure 6: Example of mature compost

Table 1: Do's and Don'ts of composting

Do's	Don'ts
Choose a sheltered site for the compost pile	Don't use materials that might contaminate the soil
Chop up long stems and big leaves	Don't use materials that might contaminate the soil Don't use waxy leaves (such as eucalyptus leaves)
Sprinkle some water on every layer, and ensure that the compost is moist all the time	Don't over-water the compost pile
Turn the pile every 3 weeks	Don't use materials that do not decompose e.g. Metal scraps or broken glasses or plastics
Protect the finished compost from sun, wind and rain	Avoid wastes that attract pests e.g. meat, dairy products

Field application

When delivered to the fields, compost manure should always be covered immediately. This will help to avoid loss of nutrients through evaporation or through leaching in case of heavy rainfall. Application of compost should be done during the planting period.

Application Rates

Well-decomposed compost should be applied at the rate of 20 t/ha (8 t/acre): about two large hoefuls per square meter, or enough to barely cover the ground with a layer 1 cm (0.4 inch) thick. For potatoes, use 1 tin (about 20 kg) for about 2 m (6 feet) of furrow. On wheelbarrow basis, apply 3 wheelbarrows of compost on 10 m² (100 square feet).

2.2 Legumes and other green manures

- Nitrogen (N) is the most limiting element in agricultural production,
- Its deficiency reduces the productivity of crops. There are several potential sources of nitrogen to overcome this shortfall, namely:
 - N from the mineralization (decomposition) of soil organic matter,
 - N from artificial fertilizers,
 - N from biological nitrogen fixation in legumes,

Legumes have a capacity to fix nitrogen. Key among the legumes that have a great potential for N fixation include:

Leucaena diversifolia

It is a fast growing shrub which can be grown in dry or wetland. It is used as fodder legume and yields up to 30-40 mt/ha/yr.

It has many uses such as forage, fire wood and timber, windbreak, shade and ornamental, charcoal, soil fertility improvement through nitrogen fixation, green manure and cover crop. *Leucaena* supply organic matter which improves soil structures and moisture retention in addition to reducing surface soil erosion on steep landscapes.



Figure 7: Leaves, flowers and pod of *Leucaena diversifolia*

Calliandra calothyrsus

Calliandra calothyrsus is used in agroforestry systems for fuelwood, reforestation, soil stabilization, plantation shade, soil improvement, as an intercrop hedgerow and as livestock forage.

As green manure, the relatively high levels of polyphenols (tannins) present in the leaves of calliandra slow the rate of microbial breakdown of the organic matter reducing its value as a soil ameliorant. In addition to fixing nitrogen its rooting structure has a capacity to recycle leached nutrients and act as a safety net for regulating further leaching losses. It is capable of fixing around 113 to 152 kg/ ha of N.

Methods of application of compost manure

Method of application 1: Dig holes according to the recommended spacing of the crop to be planted. Then apply two handfuls of the chopped material per hole and mix with the soil.



Figure 8: Leaves and flowers of *Calliandra calothyrsus*

Method of application 2: Spreading: Clear the area to be planted. Evenly spread the chopped material on the soil surface and dig in the material using a hoe. Apply four handfuls per square metre.

2.3 Biomass transfer using high N green manures: Example of *Tithonia*

Besides the nitrogen fixing legume trees, *Tithonia diversifolia* (*tithonia*) also known as false sun flower (wild sunflower) (English) has shown potential to improve soil fertility and crop yields. *Tithonia* is a succulent and soft shrub that grows to a height of 1-3 m. Its root structure allows it to scavenge for nutrients and makes them available for use as compost manure.

Why use *tithonia*?

- *Tithonia* is rich in plant nutrients, especially nitrogen, potassium and phosphorus.
- It decomposes rapidly releasing nearly all of its nitrogen into the soil within a period of less than 3 weeks.



Figure 9: *Tithonia diversifolia*

Use of *tithonia* for soil fertility improvement

- Harvest *tithonia* fresh from the hedges
- Chop into small pieces using a sharp panga
- Apply it at least one week before planting the crops

Two methods can be used to apply the chopped *tithonia*:

Method 1: Hole method: Dig holes about 15 cm deep with the recommended spacing of the crop to be planted. Apply about 4 handfuls of chopped *tithonia* leaves into the hole. Mix the *tithonia* with the soil and cover lightly with the soil.

Method 2: Spreading method: Select site for planting the crops and then spread the *tithonia* evenly on the soil surface (about 8 handfuls of chopped *tithonia* per square metre). Dig in the *tithonia* using a hoe while mixing and covering it with the soil.

Things to note:

- Use *tithonia* with phosphatic fertilizers to ensure adequate supplies of phosphorus to crops
- To reduce labour and increase economic benefits, plant *tithonia* near where crops will be planted and use the hole method
- Practice other recommended agricultural practices such as crop rotation, weeding and control of crop pests .



Figure 10: Application of *Tithonia* into soil by spreading method

Table 2: Do's and Don'ts for green manure

Do's	Don'ts
Choose the right type of green manure for your needs.	Don't plant if the soil is so dry or so wet that the crop will not germinate.
Make sure the planting materials do not contain seeds of weeds.	Don't allow livestock to graze directly on the green manure. Instead, cut the green manure crop and carry it to the animals.
If legume seeds are hard to find, grow a small plot to produce your own.	Don't harvest large amounts of the legumes as vegetables or fodder as it will deplete soil nutrients
Use normal spacing for the cereal even if you are intercropping it with a legume.	
Use inoculant with legume seeds to ensure they form large numbers of nodules for N fixation.	
Weed the green-manure crop.	
Reduce the canopy (for example to prevent an intercropped green manure from interfering with the main crop) by harvesting the crop for fodder.	

2.4 Animal manure

- Manure contains valuable plant nutrients for crop production eg nitrogen, phosphorus and potassium
- It provides valuable macro and micronutrients like Sulphar and Boron to the soil,
- Manure supplies organic matter to improve soil tilth, improves infiltration of water and retention of nutrients, and promotes growth of beneficial organisms.

Sources of animal manure

Sources of animal manure include cattle, goats, poultry, sheep, pigs, e.t.c. In general, manure from pigs and poultry is of better quality and should be applied in smaller amounts (eg: one handful per hole).

The amount of usable manure that can be obtained from cattle depends on factors like:

- The amount of feed,
- The method of feeding (pen rearing, kraaling the animals at night, or free range) and
- The efficiency of collection of the manure.

The quality of manure

- The quality of manure depends on what the animals have eaten.
- If they have been fed on good-quality feed, the manure will be rich in nutrients.
- Manure needs to mature for several weeks or months before it can be used as fertilizer.
- Keep it in a covered pit, structure or drum before spreading it on the field to avoid losses of nutrients through volatilization, leaching and erosion.
- Manure with urine (for instance, if it is collected in a lined slurry-pit) contains more nitrogen than manure without urine. But the nitrogen in urine is lost easily through volatilization. Cover the slurry-pit to prevent this.

In brief, the nutrient content of livestock manure is affected by;

- Quality of feed,
- Storage and handling,
- Ambient temperature and moisture levels, and,
- The length of open exposure

Table 3: Nutrient content in different animal manure

Manure	Moisture %	% N	% P ₂ O ₅	% K ₂ O	% CaO
Farmyard manure	38 - 54	0.5 – 2.0	0.4 –1.5	1.2 – 8.4	0.3 – 2.7
Cattle dung	34 - 40	1.7 – 2.0	0.5 –3.7	1.3 – 2.5	0.9 – 1.1
Sheep and goat drop-pings	40 - 52	1.5 – 1.8	0.9 – 1.0	1.4 – 1.7	0.9 – 1.0
Pig manure	35 -50	1.5 – 2.4	0.9 – 1.0	1.4 –3.8	1.3 –1.5
Poultry manure	10 - 13	2.3 – 2.5	2.3 – 3.9	1.0 – 3.7	0.6 – 4.0
Compost manure	49 – 52	0.5 – 1.66	0.3 –0.5	5.0 – 7.4	4.6 – 5.4

Source: Kaola Saidou, 2001

Manure preparation and management

- The raw materials in the cow shed include animal beddings, animal droppings, urine and feed leftovers. This is the mixture that makes manure when it is well cured and decomposed.
- The cattle shed should be roofed to avoid leaching of plant nutrients into the sub-soil during the rains
- Sufficient bedding to absorb the urine should also be provided. This is to avoid losses of nitrogen into the air through vaporization.
- Loss of nitrogen into the air is indicated by a strong choking smell of ammonia emitted from the urine around the cattle shed.
- It is advisable to use high quality bedding material such as Tithonia and legume stovers in order to get high quality manure.
- Cattle shed manure should be removed regularly and heaped outside. After removal of manure from the cattle shed, the manure should be stored while covered for about 2 to 3 months to facilitate maturity. This decomposition period will depend on the bedding material used. The longer the material takes to decompose, the longer the maturity period of the manure.
- Prepare a hole of 4.5 m depth and 1.0-1.2 m wide and length for convenience. The hole is meant to trap animal urine and water after cleaning the animal area.
- Cut some crooked sticks and put them into the hole for aeration and stabilize composting structure.
- Remove the un-decomposed manure from the shed bit by bit into a nearby hole while adding a bit of top soil and ashes.
- The top soil increases micro-organisms while ashes reduce the acidity in the manure. This is done in layers and after the last layer, the manure is covered to avoid direct contact with the sun, rain or wind
- Put a long straight stick diagonally into the heap for checking whether the manure is decomposing. The manure should remain for 21 days before turning into a neighbouring hole.

N.B: If the stick is white then it's a sign that the manure has fungal infection (fire fang which is an indication of poor decomposition). If the stick is cold then it indicates that the manure is not decomposing and there is need to apply some water. Manure should be ready for use after 6-8 weeks depending on the materials used to make the manure. The manure should always be covered to prevent loss of nutrients via evaporation or volatilization.

Illustrations of Good manure management practices



Figure 11: Roofed Cowshed



Figure 12: Covered manure prevent nutrients loss



Figure 13: Banana leaves covering manure



Figure 14: Open Cowshed

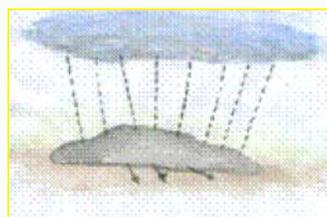


Figure 15: Nutrients are leached from uncovered manure

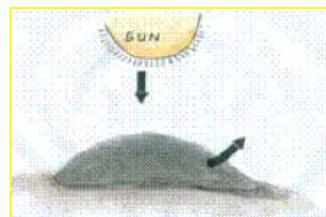


Figure 16: Nitrogen evaporates to the air from uncovered manure

Qualities of good mature manure can be determined by the absence of un-decomposed materials, smell and dryness. The characteristics of poor quality manure include: bad odour, whitish in colour, visibility of the materials that make the manure such as the leaves and stems, the manure is wet, has high temperatures.

Application/uses of animal manure

- Always use well decomposed manure, which is not hot, smelly and original bedding material used cannot be recognised
- When delivered to the fields, manure should always be incorporated immediately, since exposure to the rain or sunshine for long periods cause loss of nutrients.
- Avoid sowing the seeds in direct contact with the manure because they can get scorched.
- Apply in holes, in furrows and spread or incorporate into the soil. However, application in the holes or furrows is preferred to spreading since the manure is not usually enough and if applied in holes and furrows, the crop has the benefit of maximizing nutrient capture from localized application.

Rates of application of animal manure

Using maize as an example at a spacing of 75*50 cm, the recommended rate are two handfuls per hole when using manure alone or two handfuls per 1 metre length of furrow (7.5 tonnes of manure per hectare).

NB: For poultry manure put only one handful per hole when using manure alone.

2.5 Inorganic fertilizers

Mineral fertilizers are the quickest and surest way of supplying nutrients in known amounts, proportions and forms ready for uptake by plants.

Nitrogen fertilizers

Nitrogen deficiency has the potential to affect plant growth, development and

yield. N deficiency during the early stages of plant growth could interfere with initiation and development of leaves and flowers, hence the total yield could be reduced (Ma et al., 1996).

Nitrogen fertilizers are developed to supply nitrogen (N) either in the ammonium or nitrate form to plants. It is required by plants in large amounts as an essential component of proteins, nucleic acids and other cellular constituents. In cases of inadequate supplies the results are stunted growth, reduced yields, reduced water use efficiency and impaired crop quality. If N is taken up in excess amounts, vegetative growth is encouraged, delaying crop maturity (fruit and seed formation). Most N-fertilizers are applied as top-dressing when plants are actively growing and soils are moist.



Figure 17: Nitrogen deficiency symptoms on plant leaves

N use efficiency (maximizing the N taken by the crop for yield formation and minimizing losses) can be enhanced by:

- Matching crop need with nutrient availability.
- Application of the right type of N-fertilizer for specific crops and soils.
- Correct rates of application that are zone and crop specific.
- Correct mode and method of application for particular tillage system.
- Proper timing of fertilizer application for nutrient exploitation.
- Matching rates of application to the target yields.
- Proper control of soil acidity (Acidity limits crop response to applied nutrients)
- Availability of other nutrients in adequate amounts and balanced proportions in the soil.

Phosphatic fertilizers

Phosphorus (P) is vital to plant growth and is found in every living plant cell. It is involved in several key plant functions, including energy transfer, photosynthesis,

transformation of sugars and starches, nutrient movement within the plant and transfer of genetic characteristics from one generation to the next (PPI, 1999).

The major source of P is the phosphate rock deposits. It is mobile in plants and its deficiency symptoms are manifested in older leaves as purple discoloration in grain crops and cereals.

The total P content in fertilizer does not guarantee its availability for crop uptake. Some soils can fix P rendering it unavailable for crop growth. The utilization of P is only 16-22% in the first year of application and only 1-2% in each of subsequent years.

Triple super-phosphate (TSP) 0-46-0

- Made by reacting finely ground rock with concentrated phosphoric acid.
- TSP contains 44-52% P_2O_5 .
- TSP is fully water-soluble.
- TSP is most concentrated form of P-fertilizer and therefore, most cost effective.
- Suitable on most soil types and crops.



Figure 18: Phosphorus deficiency symptoms on leaves of maize and tomato

Potassium fertilizers

Potassium (K) increases crop yield and improves quality of produce. It is required for numerous plant growth processes (enzyme activation, stomatal activity, water use, photosynthesis, transport of sugar, starch synthesis, water and nutrient transport, protein synthesis and crop quality) (PPI, 1998).

All K-fertilizers are water soluble and quick acting. Common examples of K-fertilizers are Muriate of potash (MOP), sulphate of potash and potassium magnesium sulphate.

Complete and incomplete fertilizers.

Incomplete and complete fertilizers are classified as ammonium phosphates, nitro-phosphates and NPK fertilizers. They generally have high nutrient content.



Figure 19: Potassium deficiency symptoms on tomato leaves and fruits

Ammonium phosphates

- The common ones are mono-ammonium phosphates (MAP) and di-ammonium phosphates (DAP).
- Ammonium phosphates provides both N as NH_4^+ and water soluble P_2O_5 . DAP is suitable in areas and crops where P requirement is relatively higher than N.
- It has an acidifying effect requiring lime application.
- On the other hand MAP has a wide N: P_2O_5 ratio and may require additional nitrogen.

Nitro phosphates and NPK fertilizers

Examples are 23 - 23 - 0, 20 - 20 - 0, 20 - 10 - 10, 17 - 17 - 17 and 20 - 10 - 10.

- Agronomic performance of nitro-phosphates depends on solubility of the phosphate.
- Those that are at least 60% water-soluble are applicable to all crops and soils. The less water soluble ones are more suitable for acidic soils and long duration crops, e.g., tea and coffee.
- Nitro-phosphates are best applied as basal dressings.

What fertilizer to apply and when to apply

When choosing what fertilizer to use and how much, one needs to consider the following factors:

1. **Type of crop and its nutrient requirements:** some crops require a supply of certain nutrients more than others, e.g., fruit trees will require a lot of K while leafy vegetables require more of N. Maize crop, planted at a spacing of 75*50 will require 23:23:0 applied at a rate of 10g/hole (200 kg/ha).
2. **Plant stage:** At planting, plants require more of phosphorus for root development.
3. **Soil reaction:** Some fertilizers like DAP or Urea should not be used in highly acidic soils as this would make some nutrients unavailable for uptake by plants.
4. **Soil analysis results:** This is the best guide on what type and amount of fertilizer to use.
5. **Weather condition:** When it is very dry and crops are water stressed, foliar feed is the best option.

Timing of fertilizer applications

Basal application: Fertilizer is applied before planting, or shortly after planting but before crop emergence. Basal application gives plants the initial boost needed to achieve the crop's yield potential. Nutrients such as phosphorus are important for rapid root development and must be available during early plant growth. Therefore basal fertiliser should be rich in phosphorus.

Top dressing: Fertilizer is applied after seed emergence and establishment of a crop. Top dressing may be applied as late as the flowering stage of an annual crop. It should provide nutrients that can easily be lost from the soil before roots are well developed, e.g. nitrogen. Ammonium nitrate (AN) and Urea are widely used for top dressing cereals, field beans.

Split applications: done in several stages to reduce nutrient losses. This will also depend on soil type. Sandy soils require more frequent applications of nitrogen and some other nutrients, compared to clay-type soils eg: in case of Rwanda, in potato crop: they apply 300 kg/ha of NPK17-17-17 split into two applications (150 kg at planting and 150 kg/ha during soiling). Split application allows a farmer to apply nutrients as and when needed. This increases the efficiency with which nutrients are absorbed by the crop.

Environmental effects of fertilizer use

- Excess N in the soil can reduce crop quality, increase the effects of weed competition, and increase the crop's susceptibility to attack by plant diseases and insects.
- Leaching of excess nutrients can contaminate below ground water aquifers
- Water can wash excess nutrients into aboveground water bodies potentially contaminating it for use by humans and animals. Water bodies such as rivers, lakes, and oceans are subject to nutrient enrichment, which stimulates excessive growth of many aquatic organisms, often with disastrous consequences. Excess nitrogen can be released into the atmosphere as greenhouse gases like nitrous oxide (N_2O) and ammonia
- Algae usually are the first to respond to increased levels of N and P in water bodies, and their populations increase quickly, sometimes causing algal "blooms." When they grow and multiply rapidly, they exhaust the oxygen supply in the water often causing death of water organisms.
- Utilization of organic wastes, e.g., sewage sludge may contribute to the contamination of soils by harmful elements.

2.6 Organic and inorganic nutrient combinations

- There are challenges to reversing soil fertility decline and increasing crop yields with traditional organic materials such as compost, animal manure, green manure etc and they require high amount of labour for processing and application
- Technologies that combine mineral fertilizers with organic nutrient sources can be considered as a better option.
- They provide nutrients when required while building the long term soil health status.

2.7 Use of improved germplasm

It is important that the farmer uses the crop planting materials (usually seed but sometimes seedlings) best adapted to the particular farm in terms of:

- Responsiveness to nutrients (varieties differ in their responsiveness to added nutrients);
- Adaptation to the local environment (soils, climate); and
- Resistance to pests and diseases (unhealthy plants do not take up nutrients efficiently).



Figure 20: Germplasm of maize and Irish potato

2.8 Agroforestry

Agroforestry (AF) is a collective name for land-use systems in which woody perennials (trees, shrubs, etc.) are grown in association with herbaceous plants (crops, pastures) and/or livestock in a spatial arrangement, a rotation or both, and in which there are both ecological and economic interactions between the tree and non-tree components of the system. Beneficial effects of agroforestry on the environment, include:

- Ameliorate the (micro)climate, breaking the wind, moderating temperatures and raising humidity;
- Trees have deep roots to access nutrients and water unavailable to crops. When organic waste, in the form of leaves, crop wastes and animal manure, is mixed into the soil, this reduces the need for expensive fertilizers, saves money required for buying fertilizer
- Improve long term soil health by boosting the soil organic matter status through leaf fall, root decay and carbon release to the soil as exudates

- Protect the soil against erosion by wind and water, at the same time improving water infiltration;
- Support companion crops and animals by their effect on the climate and the soil, but also directly through providing shade and shelter or protection (live fences, hedges) and acting as nutrient pumps
- Diversify the landscape and enrich the environment

Choosing the right tree species for agroforestry interventions

- Choose multipurpose trees which not only help improve the soil, but also give you products that you need at home or can sell for cash: food, fruits, nuts, fuelwood, fodder, medicine, fibres, latex or construction materials.

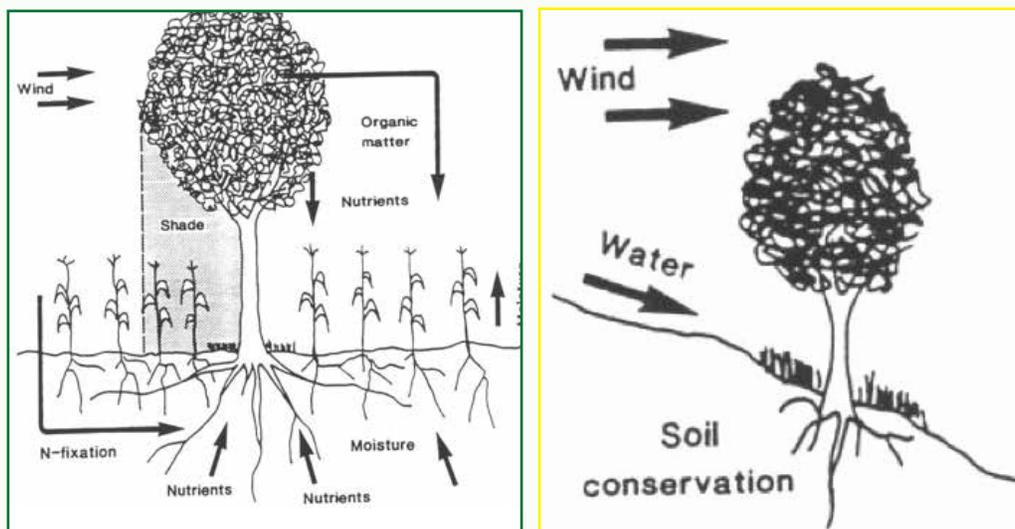
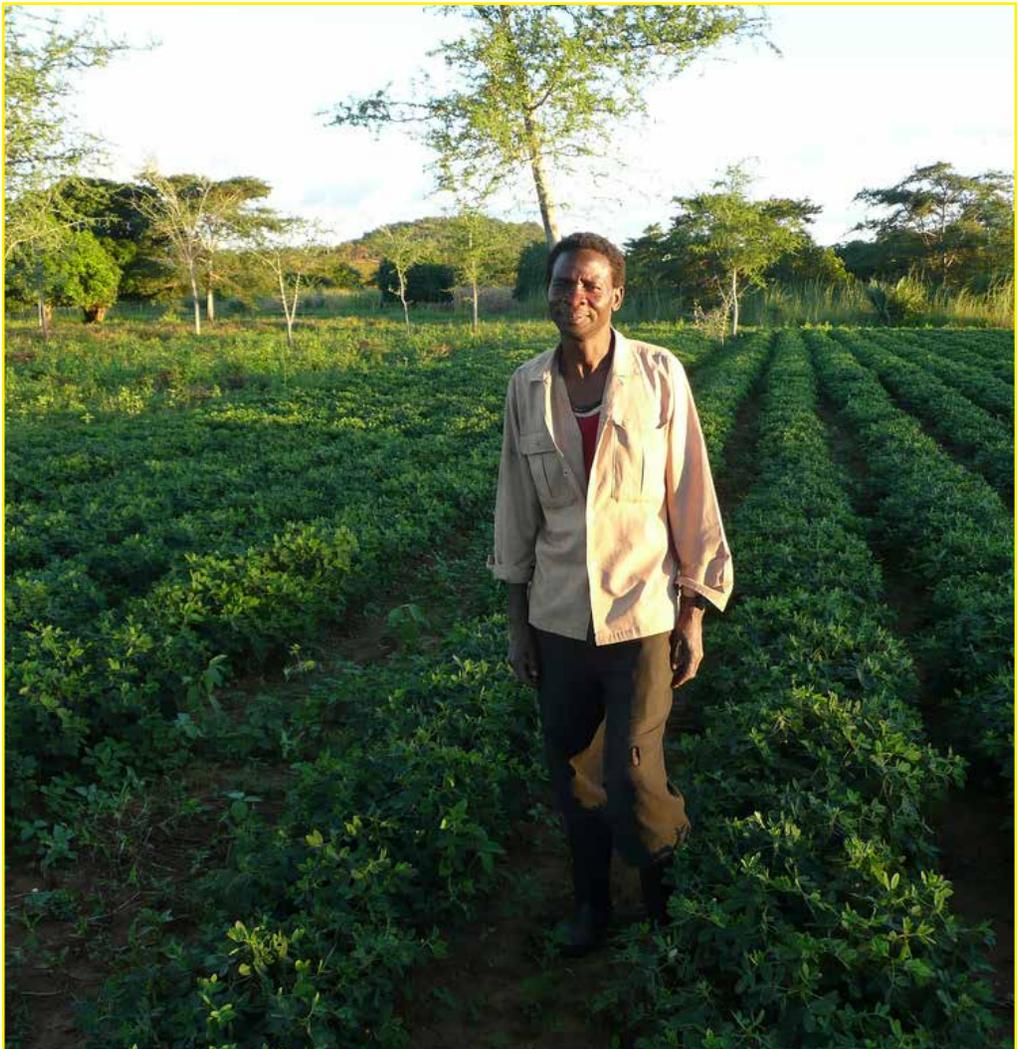


Figure 21: An illustration of agroforestry and its functions in agricultural landscapes



Figure 22: Agroforestry system





Part III. Soil conservation techniques and farming systems

Soil is the most important resource on which agriculture is based. Proper management of this valuable resource is vital to sustain long-term agricultural productivity. Unfortunately, soil erosion is usually only identified as a problem when it removes the top fertile soils hence reducing agricultural productivity. Soil erosion occurs at unsustainable levels when small rills are recognizable in a field. A loss of 1 cm of soil could imply loss of more than 100 tons of soil and associated nutrients. It decreases the crop rooting depth often exposing plant roots to subsoil that is difficult to penetrate and that is poor in nutrients.

Soil conservation practices are tools the farmers can use to prevent soil degradation and build soil organic matter. Agronomic or biological measures, soil management strategies and mechanical or physical methods are the three main techniques considered as effective for conservation (Mukankomeje, 2010).

3.1 Agronomic or biological measure

Agronomic or biological measures use vegetation to control or minimise soil erosion. They promote dense vegetation growth and improve soil structure to enhance its resistance to erosion. Agronomic measures include mulching, crop management (cover crops, improved fallows, intercropping, planting pattern/time and crop rotation) and agroforestry.

Mulching

- Mulch is a layer of plant residue placed on soil surface (between the soil surface and the atmosphere).
- Mulch is used to reduce the splash effect of the rain, control weeds, conserve moisture, increase water permeability, reduce run off, moderate soil temperatures and improve soil health.
- Practically the mulch should be applied at a rate of 3.3 to 4.5 t/ha to ensure at least 85% cover of the soil surface
- Ensure that the application of mulch is done across the slope of the field to avoid the effect of runoff flow
- Mulch can be ploughed under at the start of season to provide organic matter to the soil
- Mulch should be applied to fields after late season crops (i.e. potatoes and maize) are harvested



Figure 23: Illustration of mulched fields

Crop management

Diverse crop management practices have various beneficial effects; they improve soil properties (physical, chemical and biological) and reduce soil erosion. These practices include cover crops, improved fallows, intercropping, planting pattern/Time and crop rotation.

Cover Crops

- Cover cropping is effective at reducing soil erosion by leaving a cover over the soil which reduces soil displacement associated with the impact of raindrops hitting soil particles.
- It also reduces the volume and velocity of runoff over the soil.
- Cover crops such as the legumes or the grasses are plants that grow rapidly and close to the ground
- They increase the organic matter content, nitrogen (N) levels by N-fixing legumes, the cation exchange capacity, and hence crop yields (Mukankomeje, 2010).
- Cover crops should be seeded on time to produce a minimum of 10 cm of growth (tillering stage) before rainy season
- Cover crops can be seeded one to two weeks prior to a crop harvest. Normally, cover crops are planted after harvest of a grain crop and terminated before planting of the next crop



Figure 24: Cover crops

Improved fallows

- A fallow period is a period of time when farmers decide to let their land rest to regain fertility; it can be traditional or improved.
- Improved fallow consists of growing fast growing shrubs and nitrogen fixing trees. Improved fallow improves soil fertility faster than traditional fallow; the traditional fallows require 10 to 15 years for restoring soil fertility.
- The trees improve soil fertility by adding organic material, and through highly developed roots system, they capture and recycle the leached nutrients.

Practically, in improved fallows, the N-fixing trees (*sesbania*, pigeon pea, *tephrosia*,) and shrubs are grown for 1 to 3 years to restore soil fertility in a short period of time

Intercropping

- Intercropping is the practice of growing two or more crops together
- Intercropping systems generally contributes to erosion control.
- The increased coverage of the soil surface and the enhanced stability of soil aggregate reduce the erosivity of the rain and the erodibility of the soil (Mukankomeje, 2010).
- Mostly intercropping makes use of legumes in cereal growing farms to enable cereals to benefit from nitrogen that is fixed by legumes. Cereal yields can increase by more than 100% due to the soil fertility benefits from legumes.



Figure 25: Illustration of cereal-legume intercropping

Planting pattern/ time

Planting pattern, plant density, and time of planting also play an important role in soil conservation. Planting pattern and plant density influences radiation interception and utilization of moisture from the soil. Early sowing invites a large number of insect pest and diseases while late sowing fetches lesser grain yield due to short growing season and ultimately lesser accumulation of photosynthates. Timely sowing produces taller plants with better yield and yield components (Malik et al., 2006).

Crop rotation

- Crop rotation is the practice of growing a series of dissimilar types of crops in the same area in sequential seasons for various benefits such as to avoid the build up of pathogens and pests that often occurs when one species is continuously cropped.
- Crop rotation also seeks to balance the fertility demands of various crops to avoid excessive depletion of soil nutrients (Mukankomeje, 2010).

An example of crop rotation:

Season 1: Root crop

Season 2: Legumes

Season 3: Cereals

Season 4: Root crop

3.2 Soil management strategies

Conservation tillage

Conservation tillage involves aspects of reduced soil disturbance e.g zero tillage and reduced tillage and soil cultivation that leaves the previous year's crop residue on fields before and after planting the next crop, to reduce soil erosion and runoff.



Figure 26: Illustration of Conservation tillage

The practice could range from reduced or no-till to more intensive tillage depending on several factors, such as climate, soil properties, crop characteristics, and socio-economic factors etc...It could involve use of herbicides for weed control.

Practically, at least 30% of the soil surface must be covered with residue after planting the next crop (Alvarez, 2005). Some conservation tillage methods forego traditional tillage entirely and leave 70% residue or more. Conservation tillage is especially suitable for erosion-prone cropland. It leads to increased soil organic matter and improved soil moisture retention. This is crucial aspect that enables adaptation of plants to droughts due to soil moisture management.

Contour tillage

Contour tillage is the farming practice of ploughing across a slope following its elevation contour lines. The rows formed have the effect of slowing water runoff during rainstorms so that the soil is not washed away and allows infiltration of water into the soil. This can reduce soil and nutrient losses from sloping land by up to 50% compared with cultivated up-and-down the slope of the land. Practically, contour tillage is practiced by making perpendicular furrows to the slopes during cultivation (Mukankomeje, 2010).



Figure 27: Illustration of contour tillage

Strip farming

Strip farming is a method of farming used when a slope is too steep or too long, or when other types of farming may not prevent soil erosion. This is a method by which strips of row crops and closely growing crops, planted on the contour, are alternated. Erosion is largely limited to the row-crop strips and soil removed from these is trapped in the next strip down slope which is generally planted with a leguminous or grass crop.

Practically, the grass strips are about 2-4m wide and the cropped area about 15-45m wide depending on the slope. The slope will limit the strip size e.g., more sloping land requires a smaller strip width, while a rather flat land will necessitate a wider strip.



Figure 28: An illustration of strip farming

3.3 Mechanical or physical Strategies

Terraces

In agriculture, a terrace is a piece of sloped plane that has been cut into a series of successively receding flat surfaces or platforms, which resemble steps, for the purposes of more effective farming.

- It is designed as a method of soil conservation to slow or prevent the rapid surface runoff of rainwater and irrigation.
- There are two types of terraces: radical terraces or bench terraces and progressive terraces.
- Bench terraces are one of the most effective measures for erosion control and crop production.
- The design of terraces is done according to the needs of farmers, crops, climate, and tools to be used.
- Criteria for designing terraces include width of bench, slope, vertical intervals, height of riser, width of terraces, lengths of terraces, net area, volumes to be cut and filled and depths of cut.



Figure 29: An illustration of radical terraces

Contour bunds

Soil contour bunds are ridges and ditches made of soil, dug across the slope along the contour. They are used to prevent run-off and to conserve soil and water. Thus, they reduce soil erosion and increase the amount of water the soil can hold. Contour bunds can be used both on cultivated and uncultivated land. Fortunately, farmers can build contour bunds themselves without external assistance.

Practically, contour bunds are made on moderate slopes (5–10%) with light or medium soil texture and less than 700 mm of rain per year. Contour bunds are made in different steps:

- Use line-level to lay out a contour line across the slope and mark the contour with pegs or stones
- Move about 20 m up or down the slope, and mark another contour line. Repeat until you have marked enough contours.



Figure 30: An illustration of contour bunds

- Dig a ditch along the line, throwing the soil down-slope to build the bund wall.
- Compact the bund with your hands and feet and reinforce it with stones if possible
- Plant crops, grasses, shrubs or trees on the bund to stabilize it. If you plant trees, choose species that do not throw much shade, as you don't want to shade the crop too much.
- Plant crops on the land in between the bunds.
- During the first heavy shower, check for any breakages, and repair them immediately. One breakage may cause a whole series of breakages down slope.

NB: Do not build bunds on steep slopes (exceeding 30% slopes).



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