TRAINING PACKAGE ON SOIL FERTILITY MANAGEMENT TECHNOLOGIES

TECHNICAL MANUAL

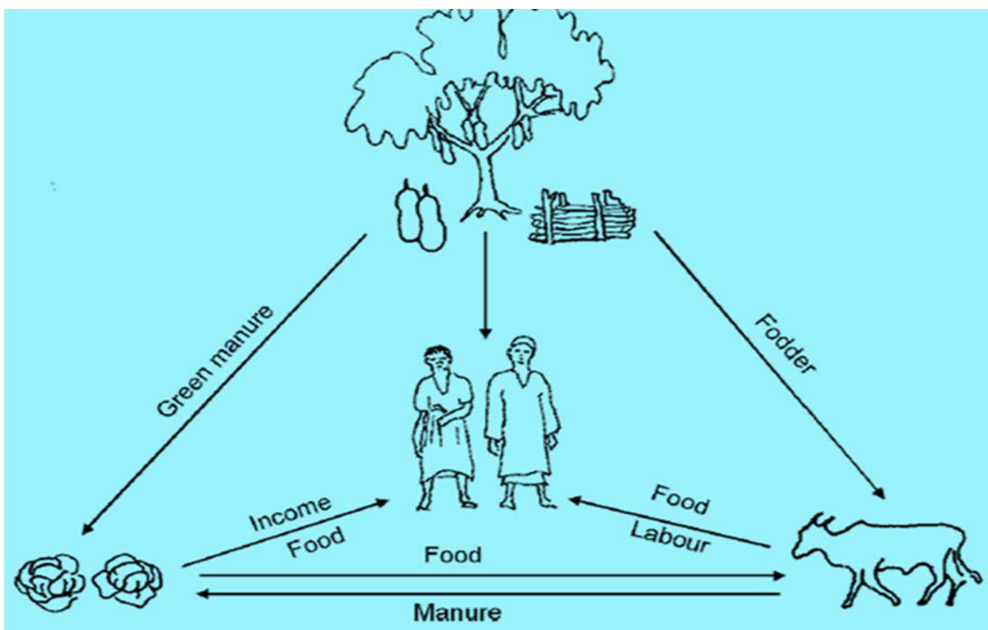

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TABLE OF CONTENTS

MODULE 1: COMPONENTS OF HEALTHY SOIL 3

1.1 MAJOR SOIL FERTILITY PROBLEMS IN ETHIOPIA 4
1.1.1 Acidity 4
1.1.2 Soil organic matter depletion 5

1.2 ROLE OF SOIL ORGANIC MATTER IN SOIL FERTILITY 7

1.3 SOIL ORGANIC MATTER MANAGEMENT 9

MODULE 2: BIOLOGICAL NITROGEN FIXATION (BNF) 10

2.1 PROMOTION OF RHIZOBIUM 16

2.2 INOCULATION METHODS 16
2.2.1 Seed-applied inoculation method 17
2.2.2 Direct-soil application method 18

2.3 CAUSES OF N-FIXATION FAILURE 19

MODULE 3: COMPOSTING AND COMPOST APPLICATION 20

3.1 CONCEPT AND PRINCIPLE OF COMPOSTING 20

3.2 GENERAL PRACTICES AND METHODS OF COMPOSTING 20

3.3 RAPID COMPOSTING METHODS 23

3.4 USING COMPOST 36

3.5 SOCIO-ECONOMIC CONSIDERATIONS AND WAYS OF INTRODUCING COMPOSTING 38

3.6 AGRO-CLIMATIC ASPECT OF COMPOSTING AND COMPOST APPLICATION 39
3.6.1 Agro-climatic aspect of composting 39
3.6.2 Compost Application 39

MODULE 4: MANURE AND ITS APPLICATION 40

4.1 CONCEPT 40

4.2 QUANTITY AND COMPOSITION OF MANURE 40

4.3 PRODUCING AND MANAGING FARM YARD MANURE (FYM) 41

4.4 QUALITY AND QUANTITY OF FARM YARD MANURE 42

4.5 SPREADING FYM: TECHNIQUES AND QUANTITIES 42

4.6 EFFECTS OF USING FYM 43

4.7 SOCIO-ECONOMIC CONSIDERATION 43

4.8 CLIMATIC ZONE CONSIDERATION 44

MODULE 5: USES OF AGRO-FORESTRY IN SOIL FERTILITY MANAGEMENT 45

5.1 CONCEPT OF AGRO-FORESTRY 45

5.2 ESTABLISHING SUSTAINABLE AGRO-FORESTRY SYSTEMS 46

5.3 EFFECTS OF AGRO-FORESTRY ON SOILS ... 48
5.4 ECONOMIC CONSIDERATIONS ... 50
MODULE 6: GREEN MANURE AND INTENSIVE FALLOWING ... 51
6.1 CONCEPT AND GENERAL PRINCIPLE ... 51
6.2 GREEN MANURING WITH LEAVES ... 51
6.3 GREEN MANURING WITH ROOTS AND STUBBLE ... 52
6.4 SUITABLE GREEN CROPS AND THEIR PRACTICAL APPLICATION ... 52
6.5 SOCIO-ECONOMIC ASPECT ... 53
6.6 AGRO-CLIMATIC ASPECT ... 54
MODULE 7: MULCH AND ITS APPLICATION ... 55
7.1 INTRODUCTION ... 55
7.2 PRINCIPLE OF MULCHING ... 55
7.3 MULCHING MATERIALS ... 56
7.4 TECHNIQUES OF MULCH APPLICATION ... 57
7.5 OPTIONS FOR PRODUCING MULCH ... 58
7.6 EFFECTS OF MULCH ... 58
7.7 ECONOMICS OF MULCHING ... 59
7.8 USE OF MULCH IN AGRO-CLIMATIC CONTEXT ... 59
MODULE 8: CROP ROTATION ... 60
MODULE 9: INTERCROPPING ... 62
MODULE 10: CROP RESIDUE MANAGEMENT ... 64
MODULE 11: BIO-INTENSIVE GARDENING IN THE HOME GARDEN ... 66
11.1 TECHNOLOGICAL PROFILE ... 67
11.2 IMPROVING COMPACTED SOIL ... 67
MODULE 12: COVER CROPS ... 70
MODULE 13: INTEGRATED NUTRIENT MANAGEMENT ... 72
13.1 BASIC CONCEPT ... 72
13.2 NUTRIENT BUDGET CALCULATION ... 73
MODULE 14: SOIL ACIDITY MANAGEMENT ... 77
MODULE 15: ECONOMIC ASPECTS OF SOIL FERTILITY MANAGEMENT ... 81
REFERENCES ... 83

INTRODUCTION

Though there are various soil types in Ethiopia, there are limiting factors especially in crop production. Core constraints include: topsoil erosion (According to the World Bank PER, 2008, Ethiopia is listed among the most severely erosion-affected countries in the world, along with Lesotho and Haiti; rates estimated at 10-13 mm p.a. on average (SCRP; Okigbo (1986); acidity-affected soils covering over 40 percent of the country; significantly depleted organic matter due to widespread use of biomass and dung as fuel; depleted macro and micro-nutrients, and; depletion of soil physical properties, and salinity.
The use of dung as fuel instead of soil amendment is estimated to reduce Ethiopia's agricultural GDP by 7 percent (Zenebe (2007).

Specific to fertilizer, there are a set of value-chain constraints:

- Chemical fertilizer poses significant constraints due to low availability of credit, and limited reach of distribution networks in contexts where appropriate application can enhance yields
- Bio-fertilizer currently only offers increased nitrogen (N) supply when rhizobium inoccula are used to enhance biological N fixation of legumes. The use of rhizobium inoccula is constrained by low demand, due to lack of awareness and understanding of the product, and limited production capacity. Extensive testing of benefits to identify appropriate products is needed—research efforts are currently limited. All other forms of bio-fertilizers would require thorough evaluation prior to commercialization.

Given this set of constraints, focusing on interventions separately does not work: despite a fivefold increase in fertilizer application, national cereal yields have only increased 10 percent since the 1980s, and relative benefits of chemical fertilizer application have decreased over time. Further, the set of interventions required varies greatly by Ethiopia's diverse agro-ecologies.

Therefore, it is essential to advocate that integrated soil fertility management (ISFM) as a framework for tackling multiple issues and accounting for varied local needs, using a range of interventions sequenced over time and tailored to the local situation. Examples from Ethiopia and other countries demonstrate this approach have more agronomic and economic impact than, for example, a focus on chemical fertilizer alone (World Bank PER (2008). Thus, sustainable measures which help to produce optimum production need to be taken to overcome these constraints. One of such key measures can be the integrated application of Organic and chemical fertilizers from different sources as one important aspect of sustainable land management practices. In addition to this, four priority areas of intervention can be recommended to improve the soil fertility situation in Ethiopia on the basis of multi stakeholders' research results by the International Food Policy Research Institute (IFPRI, 2010).

1. Implement soil fertility solutions appropriate to Ethiopia's extremely diverse agro-ecology and varied local soil fertility needs through Integrated Soil Fertility Management (ISFM).

2. Make effective use of organic carbon resources by increasing the amount of manure and crop residues produced and used as organic nutrient sources. This is central to achieving the long-term need for increased biomass production for food and soil fertility, and hence sustainably higher productivity, needed to break the poverty cycle. Specific actions include local supply of affordable fuel alternatives, increased fuel efficiency of major fuel-consuming household devices, availability of local, affordable feed and forage, and the scale-up of existing efforts to promote compost preparation and application. At the same time, it is recognized that the availability of crop residues is constrained by low yield and biomass production. Integrated soil fertility management including effective fertilizer use are key to high yield.

3. Mitigate severe topsoil erosion in cultivated highlands through interventions at the individual farm level as well as through large-scale community and regional projects in targeted areas. Suggested actions include soil and water conservation measures, scaling-up best practices (e.g. Tigray conservation program), and linking implementation with provision for other inputs or enablers like fertilizer or credit, inter alia.

4. **Reduce constraints on value chains for chemical and bio-fertilizers** (rhizobium inoccula for legumes) by improving distribution channels and reach, increasing supply of fertilizer credit, encouraging institutions to better tailor credit products to end-user needs (e.g. long-term payback and based on input packages rather than single inputs), and evaluating rhizobium inoccula to enhance nitrogen fixation of legumes and helping initiate demand, supply and distribution where needed. Opportunities exist to engage with international initiatives to evaluate other bio-fertilizers across a wide range of environments.

As part of these ISFM practices this training manual was developed to review various sustainable soil fertility management options that are believed to be proven agricultural technologies for smallholders across all program areas prioritized by the government. The manual is organized into 15 modules dealing with several intervention possibilities including the ones mentioned above.

MODULE 1: COMPONENTS OF HEALTHY SOIL

Healthy Soil is a state of soil meeting its range of ecosystem functions as appropriate to its environment. It is used to explain the situation of a soil in supporting plant and animal productivity and diversity, maintaining or enhancing water and air quality and supporting human health and environment. It is the condition of the soil in a defined space and at a defined scale relative to a set of benchmarks that encompass healthy functioning, (see Figure 1 below). The definition of soil health may vary between users of the term as alternative users may place differing priorities upon the multiple functions of a soil.

Therefore, the term soil health can only be understood within the context of the user of the term as 'the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, maintain the quality of air and water environments, and promote plant , animal and human health (Doran *et al*., 1996).

The underlying principle in the use of the term "soil health" is that soil is not just an inert, lifeless growing medium, which modern farming tends to represent, rather it is a living, dynamic and ever-so-subtly changing whole environment. It turns out that soils highly fertile from the point of view of crop productivity are also lively from a biological point of view. Some microbiologists now believe that 80% of soil nutrient functions are essentially controlled by microbes. Therefore, biological technology is one of the best approaches for managing soil fertility sustainably for the future. Here below illustrated are components of soil heath according to the European Journal of Soil Science (2003).

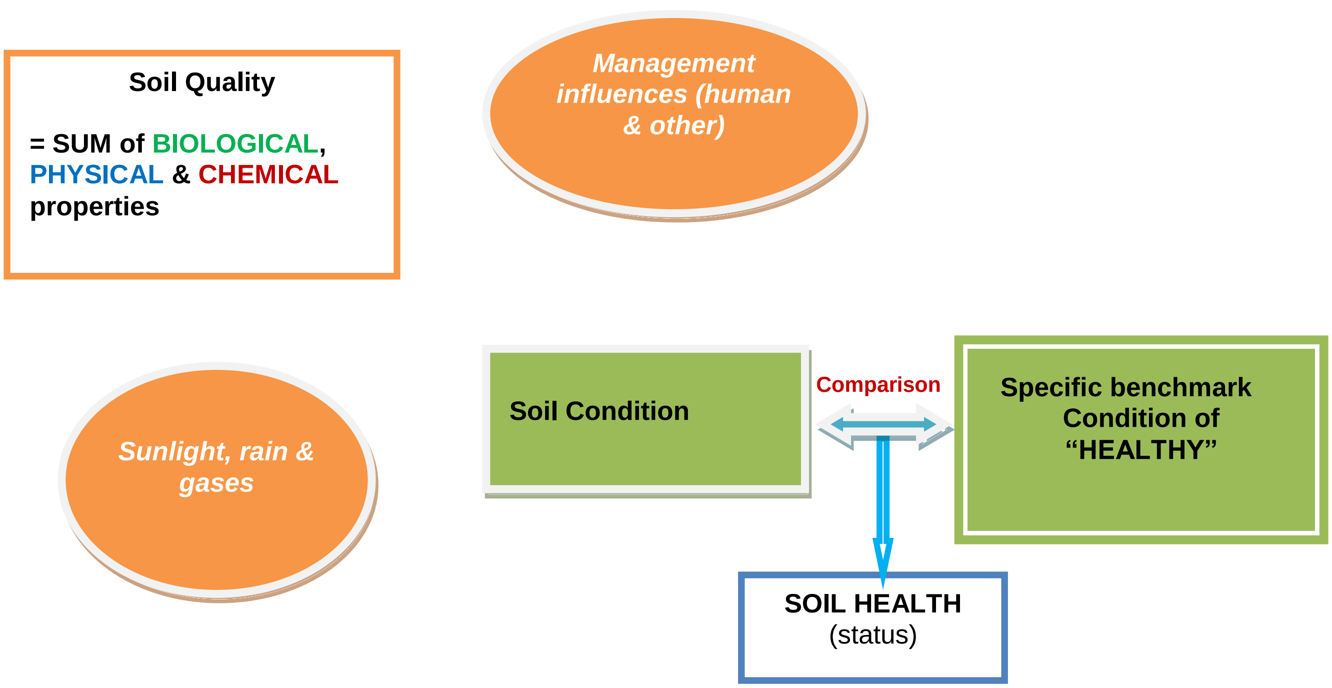


Figure 1: Component of soil health

1.1 Major Soil Fertility Problems in Ethiopia

Soil is the basis of production in agriculture, the nourisher of mankind and an important component of the human environment. One of the more critical aspects of soil uses and management is the maintenance of the capacity to produce plants that supply man with essential food and fiber. This capacity referred to as soil productivity, is measured in terms of yield and is a function of all factors of plant growth mainly light, heat, water and nutrients. Productivity of soils is also affected by negative factors such as disease and insect pests, salts and other toxic substance, as well as adverse climatic conditions. Maximum growth occurs only where all factors are as near the optimum as possible.
A factor much more under man`s control is the nutritional status, or fertility, of the soil. Indeed, the ease with which many nutritional problems can be corrected and the spectacular results that often follow such correction have made fertility one of the more readily accepted aspects of soil management. Fertility is the potential of a soil to supply nutrient elements in amount, forms, and proportion required for maximum plant growth. It is measured directly in terms of ions or compounds important to plant nutrition and indirectly in terms of the productive capacity of the soil.

Our country faces a wider set of soil fertility issues which has historically been the major focus for extension workers, researchers, policymakers, and donors. In addition, it has soil types with inherent characteristics which can be problematic for crop production and which need special management.

If left unchecked, this wider set of issues will limit future output and growth in agriculture across the country, in some areas; they already limit the effectiveness of chemical fertilizer. These chemical, physical, and biological issues interact and include loss of organic matter, macronutrient, and micronutrient depletion, topsoil erosion, acidity, salinity, and deterioration of other physical soil properties. In one way or another, the existing scenario perhaps may not help the country to meet placed development targets such as reaching middle income level countries by the year 2020. Major soil fertility problems, each with a brief description have been indicated below.

1.1.1 Acidity

Acidity: where soil pH is lower than optimal (5.5 and below) and reduces the solubility of nutrients needed for growth. Conditions also usually lead to Al and Mn toxicity plus deficiency in N, P, K, Mg, Ca and various micronutrients. This has multiple implications for plant growth and other soil fertility issues: can lead to lack of or reduced response to Ammonium Phosphate and Urea fertilizers, stunted root and plant growth due to nutrient deficiency (yields frequently reduced by 50 percent and can be reduced to 0), increased incidence of disease, and toxicity (e.g. for Mn: black spots and streaks on leaves).

- **Causes:** Acidification occurs with other conditions including eroded topsoil and depleted organic matter, depleted nutrients, alternating drought stress and high rainfall. In moisture-stressed areas, acidification can also be caused by continuous application of acid-forming fertilizers. Approximately 80 percent of acidic soils are expected to derive from Nitisols (Eyasu 2009).
- **Severity:** A1989 study by Schlede found 41% of land in Ethiopia is likely to be affected by soil acidity: 13 % is strongly acidic ($pH < 4.5$) and 28 % is moderately to weakly acidic (pH 4.5-5.5). Areas well-known to be severely affected by soil acidity include Ghimbi, Nedjo, Hossana, Sodo, Chencha, Hagere-Mariam, Endibir and Awi Zone of the Amahara regional state (MoARD 2007).

Despite these high-level statistics the situation is not well-understood in detail at the local level, or with more up-to-date estimates of severity

1.1.2 Soil organic matter depletion

Ethiopia faces a wider set of issues in soil fertility beyond chemical fertilizer use, which has historically been the major focus for extension workers, researchers, policymakers and donors. If left unchecked, this wider set of issues will limit future output and growth in agriculture across the country—and in some areas they already limit the effectiveness of chemical fertilizer. These chemical, physical and biological issues interact and include loss of organic matter, macronutrient, and micronutrient depletion; topsoil erosion; acidity; salinity; and deterioration of other soil physical properties. In addition Ethiopia has soil types with inherent characteristics which can be problematic for crop production and need special management. A summary of the issues is provided here:

a) **Organic matter depletion: this is** lack of replenishment of matter usually derived from plant, animal and microbial bodies in all stages of decay (organic carbon and other nutrients). Critical to ensuring long-term soil fertility providing a balanced medium for water and nutrients for growth plant growth.

- **Causes:** not returning animal dung and crop residues to soil, and excessive tillage, among others. Major drivers of this behaviour in Ethiopia include low availability of biomass overall due to low productivity, and competing uses for this biomass (dung used as fuel and crop residues used as feed).
- **Severity** has not been measured at national level, but the burning of dung as fuel instead of application as manure is estimated to reduce Ethiopia's agricultural GDP by seven percent (Zenebe 2007).

A 2005 study in the Bale highlands found organic Carbon levels in cultivated land of 2.5 % (Tilahun and Assefa (2009). Similarly Tegenu et al. (2009) found in north-west Ethiopia organic matter content was 7% in forest areas and 2.5% in cultivated areas.

- Organic matter depletion and nutrient depletion often occur together in the same area (see Table 1).

Table 1: Soil pH, Organic Carbon and total Nitrogen by area

Area	**pH**	**Organic Carbon**	**Total Nitrogen**
Melkassa	7.0 - 8.2	0.8 - 1.5	0.1 - 0.15
Miesso	7.3 -7.8	0.7 - 0.9	0.04 - 0.1
Arsi Negelle	6.5 - 7.9	1.3 - 2.1	0.1 -0.2
Wolenchiti	7.5 - 8.5	0.8 - 2.0	0.1 - 2.2
UAAIE *	8.2 - 8.5	>1	2.1 - 2.4
Adami Tulu	> 7.3	0.8 - 1.7	0.1 - 0.15

Source: MARC (2007) in IFPRI 2010; *Upper Awash Agro Industry

b) **Macronutrient depletion:** loss of Nitrates (N), Phosphates (P) and Potash (K) from the soil in available form for plants. Results in stunted growth and low crop yields.

- **Causes:** farming without replenishing nutrients over time, and/or chemical imbalance issues (e.g. acidity, salinity leading to fixation)—often driven by continuous cropping of cereals, removal of crop residues, leaching, low levels of fertilizer usage and unbalanced application of nutrients[xxxv]. In addition, inadequate runoff management can lead to leaching especially for N and K.
- **Data on severity** is very outdated: the most recent national study of macronutrient levels was in 1990 by Stoorvogel and Smaling, and indicated balances of -41kg/ha N, -6kg/ha P and -26kg/ha K in cultivated highland areas (see Table 2).

Table 2: National average macronutrient balances by country

	Nitrogen (kg/ha)	Phosphorus (kg/ha)	Potassium (kg/ha)	Nitrogen (kg/ha)	Phosphorus (kg/ha)	Potassium (kg/ha)
Country	1982-84	2000 projected	1982-84	2000 projected	1982-84	2000 projected
Ethiopia	-41	-47	-6	-7	-26	-32
Kenya	-42	-46	-3	-1	-29	-36
Malawi	-68	-67	-10	-10	-44	-48
Ruwanda	-54	-60	-9	-11	-47	-61
Tanzania	-27	-32	-4	-5	-18	-21
Zimbabwe	-31	-27	-2	2	-22	-26

SOURCE: Stoorvogel and Smaling (1990)

Field-level studies in the southern Ethiopian highlands by Eyasu (2002) reported N levels of -102kg/ha. Similarly, Amare et al. (2006) reported N, P and K balances in the central highlands showing N levels of up to -72 kg/ha in the study area, with highest nutrient depletion at foot slopes in Dega, and at the mid-slopes in Woina Dega.

The age of this data combined with low overall (but extremely varied) fertilizer application rates suggests the issue has most likely worsened significantly, and that nutrient balances are extremely varied from one area to the next and even at different altitudes within one area

c) **Micronutrient depletion:** Loss of nutrients required in small amounts for plant growth including Fe, Mn, Zn, Cu, B, Mo and Cl. If levels of these nutrients are too low, this can lead to too poor plant growth; reduced uptake and fixation of nutrients (e.g. P in cell roots); inhibited cell division, respiration, nitrogen mobilization and glucose phosphorylation; and inefficient water use by plants. If micronutrients are present in large amounts, these can become toxic and also limit growth (Fox et al. 1979).
   - **Causes** include farming without replenishing (including focusing only on high analysis fertilizers), although balances are related to soil pH (acidity issue), salinity, soil moisture content, and organic matter (Mesfin 1998).
   - **Severity:** Zn and Cu were found to be deficient in 65 % and 89 % of soil samples collected across the country, respectively (Desta Beyene (1983); AHI (1997). Similarly, in a separate study, over 75% of Vertisol, Cambisol, and Fluvisol soil samples analyzed were also reported to be Zn-deficient (Asgelil et. Al, 2007).

d) **Topsoil erosion:** the loss of fertile topsoil—meaning the base on which inputs applied and crops grown is increasingly depleted and thinly-spread. This leads to reduced water-holding capacity of soil (making it more susceptible to extreme conditions, e.g. drought) and limited crop emergence, growth, yield and rooting depth, which in turn contributes to a vicious cycle of increased rate of loss of organic matter –
   - **Caused** by a combination of cultivation of slopes with poor management, high rainfall and inappropriate drainage (water erosion), and significant loss of vegetation cover (deforestation, overstocking, overgrazing).
   - **Severity:** Average annual loss on agricultural land of 137t/ha/year, or an annual soil depth loss of 10-13mm. Under agricultural conditions 10mm lost topsoil takes approximately 200 years to replenish. Some sources list Ethiopia as one of the most severely erosion-affected countries in the world (FAO 1998).

e) **Salinity:** excessive accumulation of certain ions and salts impacts levels of other nutrients, limits the availability of water and disrupts the osmotic tension of soil, and can result in some excess accumulation of specific ions (B, Cl, Fl, Li, Na) and/or salts (e.g. HCO3-, CO32-). This leads to stunted plant growth.

- **Causes:** can be a side effect of pH imbalance (acidity problem), e.g. for each unit increase in pH, Fe levels decrease a thousand fold, and Mn, Cu and Zn decrease a hundredfold. Otherwise salinity tends to occur in the presence of conditions such as shallow ground water tables, inefficient irrigation practices and poor drainage (man-made or natural), natural saline seeps, and high evaporation surface moisture or insufficient annual rainfall leading to leaching of salts from plant rooting zone.
- **Severity:** salt-affected soils in Ethiopia cover at least 11m ha—nearly 10 percent of total land, although most of this is in low-lying areas. However given this data is from 1980s it is likely to underestimate current status.

f) **Inherently problematic soils:** Reddy and Kidane (1993) found crop production constraints in dry land areas covering close to half of total arable land mainly centre on moisture and nutrient stress, salinization and soil surface crusting. Overall, soils in these areas are known either to have highly degraded structural stability, or to be in the process of degradation due to largely-inappropriate land management combined with their natural tendency to surface seal leading to low infiltration and high erosion. As a result, typically nutrient levels and moisture storage capacities are low, and salinity and limited crop productivity are common. Vertisols are also known “problematic soil” type, covering 12.6 million ha (10.3 percent of the country). Numerous soil fertility issues have been reported in Vertisols is due to inherent soil properties and lack of adequate management practices. These include salinity issues, macro and micronutrient deficiencies, and very low efficiency of applied nitrogen fertilizers due to the tendency of Vertisols to become waterlogged.

1.2 Role of soil organic matter in soil fertility

A fertile and healthy soil is the basis for healthy plants, animals, and humans. And soil organic matter is the very foundation for healthy and productive soils, see figure 2 below. Organic fertilizer (animal manure, green manure, compost, mulch etc.) is assumed to be full fertilizer because it contains all macronutrients and micronutrients needed by plants. It gives soil its dark color and provides many plant nutrients, especially nitrogen and carbon, and significant quantities of many other nutrients. Organic matter also provides food for soil macro- and micro-organisms, which in turn decompose it and release the nutrients in forms that are available to plants. The soil organisms themselves decompose after they die, releasing nutrients to plants in a slow release form. Organic matter is a major contributor to forming and maintaining a stable, well-structured soil. A highly fertile soil will have high levels of organic matter and a reduced need for supplementary chemical fertilizers. A further benefit of organic matter in soil is to increase both the water infiltration rate and water holding capacity of the soil. This means that there is less runoff during a rainfall event, so more water is available in the soil for plants to use.

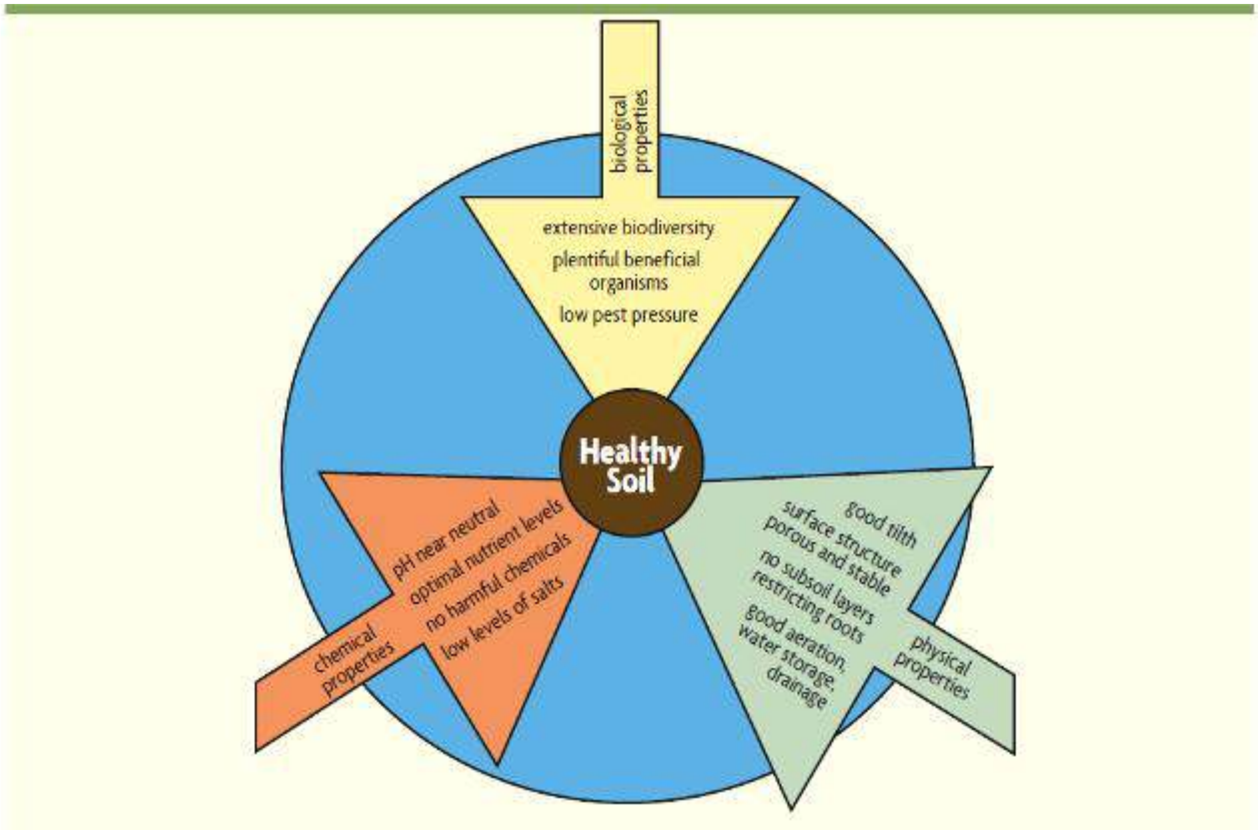


Figure 2: Optimal chemical, biological and physical properties promote healthy soils

Furthermore, carbon dioxide produced as a result of organic matter decomposing used by plants during photosynthesis. Humic acid /physiological active substance/ produced from organic matter decomposing in a soil solution influences positively the growth of root system / mass increments/. Organic matter serves as a source of energy for soil microorganisms and as a source of nutrients for plants. Organic matter holds the minerals absorbed from the soil against loss by leaching until they are released for plant uptake by the action of microorganisms. Bacteria thriving on the organic matter produce complex carbohydrates that cement soil particles into aggregates. Acids produced in the decomposition of organic matter may make available mineral nutrients of the soil to crop plants. It enhance good air and water relation for plant growth media and forms high water stable (resistance) soil aggregates that allow permanent percolation of water to the soil profiles (infiltration rate increases) and by this reduces losses of soil by erosion, see figure 3 below.

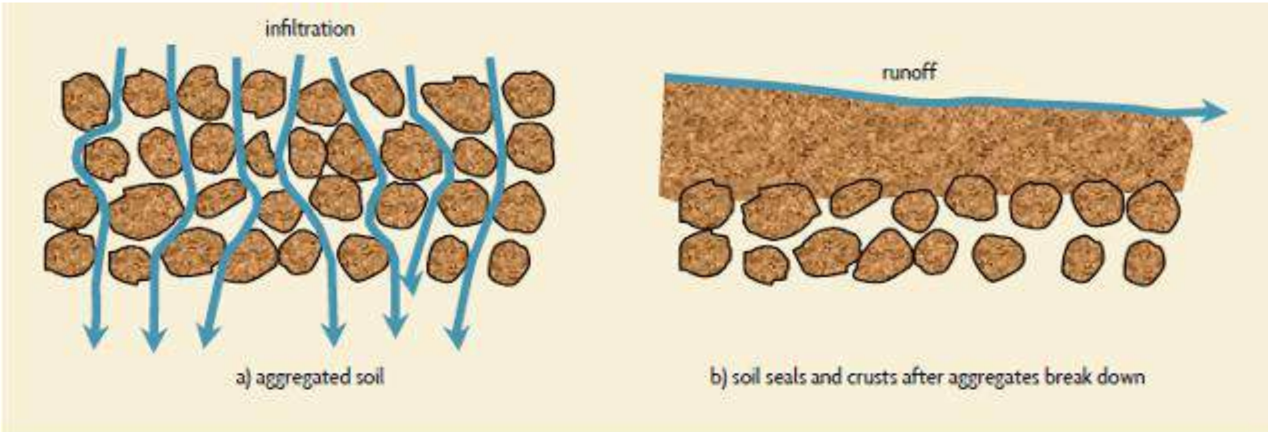


Figure 3: Water stable aggregate (a) and unstable aggregate (b). Changes in soil surface and water-flow pattern when seals and crusts develop

On the other hand, penetration of roots through the soil is improved by the good structure brought about by the decomposition of organic matter. The water-holding capacity of sands and sandy soils may be increased by the incorporation of organic matter. Aggregation in heavy soils may improve drainage. It is seldom possible to make a large permanent increase in the organic matter content of a soil. It decreases the soil pH by some degree if the soil is acidic. The mobility (toxicity level) of Aluminum, Iron and Manganese in acidic soil and others like pesticides negative action will be decreased. Application of organic matter in soil improves soil workability, as a result less traction power, time and money is needed for seed bed preparation. Generally, this improves soil productivity or alleviate problem of food security.

1.3 Soil organic matter management

In order to give soil productivity a sustainable basis i.e. maintaining optimal chemical, biological and physical properties, a continuous supply of active organic matter must be maintained, so that soil organisms have sufficient food so that humus can constantly accumulate.

There are four strategies for organic matter management.

1. Use crop residues more effectively and find new sources of residues to add to soils.
2. Try to use a number of different types of materials: manures, composts, cover crops, leaves, etc. to help develop and maintain a diverse group of soil organisms.
3. Try to use free nitrogen from the atmosphere by facilitating symbiotic and non symbiotic bacteria.
4. Implement practices that decrease the loss of organic matter from soils because of accelerated decomposition or erosion. All practices that help to build organic matter levels either add more organic materials than in the past or decrease the rate of organic matter loss from soils. Soil erosion must be controlled to keep organic matter–enriched topsoil in place. In addition, organic matter added to a soil must either match or exceed the rate of loss by decomposition. These additions can come from manures and composts brought from off the field, crop residues and mulches that remain following harvest, or cover crops. Reduced tillage lessens the rate of organic matter decomposition and also may result in less erosion. When reduced tillage increases crop growth and residues returned to soil, it is usually a result of better water infiltration and storage and less surface evaporation.

MODULE 2: BIOLOGICAL NITROGEN FIXATION (BNF)

Biological nitrogen fixation is a natural process whereby atmospheric nitrogen is reduced to ammonia. In legumes, this system operates in the root nodules formed by the nitrogen fixing Rhizobium spp. In most natural ecosystems, heavy losses of nitrogen occur due to crop uptake, leaching, erosion, denitrification etc. However, significant replenishment of nitrogen occurs in most soils mainly due to biological nitrogen fixation (Hardarson et al. 1987).

Nitrogen provided in this form is not only cheap but also does not impart other undesirable aspects such as pollution hazards due to heavy use of inorganic nitrogen fertilizers. In addition, inoculation of seeds, plants and soil with *Rhizobium* is even simpler than applying correct doses of inorganic nitrogen fertilizers such as urea or diammonium phosphate.

Rhizobium bacteria are found in soil, and are responsible for fixing nitrogen but different legumes need specific rhizobium strains to fix well. By adding the correct inoculum to legume seed before planting, farmers can further increase their yields.

Rhizobium spp. invades the root hairs of legumes and result in the formation of nodules, where free air nitrogen is fixed. These bacteria, although present in soils, vary in number, effectiveness in nodulation and N-fixation. It has been argued that usual native soil rhizobial populations are inadequate and are ineffective in biological nitrogen fixation. To ensure an optimum *rhizobial* population in the rhizosphere, seed inoculation of legumes with an efficient *rhizobial* strain is necessary. This helps improve nodulation, N2 -fixation solicit crop growth and yield of leguminous crops (Henzell, 1988). *Rhizobia* is one of the dominant symbiotic nitrogen fixing bacteria with legumes but a number of factor including low number of *Rhizobia* and ineffective native *Rhizobia* lead to poor nodulation and nitrogen fixation in legumes.

Nitrogen fixation is performed in the soil largely by two groups of bacteria. 1) The **free-living or non-symbiotic bacteria** 2) The root-nodule or **symbiotic bacteria**, lives in a mutually beneficial association with the roots of legume plants.

1) Non-symbiotic Fixation

Two heterotrophic bacteria are most influential in non-symbiotic nitrogen fixation. One is an aerobic, oval-shaped bacterium called *Azotobacter*. The other, *Clostridium*, is less important. The estimated quantity of nitrogen fixed non-symbiotically in soils is variable. The estimate is an amount up to 60 kg per hectare per year fixed by this means, but such a value is probably well above the average.

Figure 4: Azotobacter

2) Symbiotic Nitrogen Fixation

Our main interest in this technical manual centers on the legume-*Rhizobium* symbiosis. Leguminous plants fix atmospheric nitrogen by working symbiotically with special bacteria, rhizobia, which live in the root nodules. Rhizobia enter legume root system through root hair infection or through cracks in the epidermis and induce cortical cells to divide and form nodules (Kijne 1992). Within the root nodules, rhizobia transform Nitrogen between its abundant form as atmospheric gas (N_2) which is metabolically unavailable to plants and metabolically available combined N_2 and (NH_3).

This process is known as ***biological Nitrogen fixation***. After export from the nodule, the fixed Nitrogen can be used directly for growth by the crop or pasture legume. When a large proportion of fixed Nitrogen is removed as grain crop, Nitrogen fixation still improves the Nitrogen economy of soil (People et at. I995).

For the full Nitrogen benefit to be realized, legumes seeds must be nodulated by rhizobia strains that are effective in their Nitrogen fixing capacity.

The nodule bacteria (Rhizobium radiclcola), living symbiotically with legumes under favorable living conditions can accumulate 100-200 kg/ha of nitrogen, even more throughout the vegetative period if their yields are high (see table 3). The actual quantity of accumulated nitrogen depends on the type of legumes, the yielding capacity and soil properties. See also the annex (end pages) for more legumes and estimated accumulation of N.

Table 3: The amount of nitrogen accumulated by different legumes species in one cropping season

No	Legumes species	Accumulated nitrogen Kg/ha	Reference
1	Clover *(Trifolum pretense)*	150-160	B.B. Yagodina,1984
2	Lupine *(Lupines polyphyllus)*	160-170	B.B. Yagodina,1984
3	Alfalfa *(Medicago sativa)*	250-300	B.B. Yagodina,1984
4	Vetch *(lathyrus sativa),* kidney bean *(Phaseolus vulgaris)*	70-80	B.B. Yagodina,1984
5	Mug bean/green gram *(Phasoeolum aureus)*	63-342	Nutman 1976
6	Pigeon bean *(Cajanus Cajan)*	168	Cited in Hamdi 1982
7	Soya bean *(Glycine max)*	64-206	Aynaba and Dart1977
8	Centrose pubescens *(panicum maximum)*	126-395	Aynaba and Dart1977
9	Green leaf *(Desmodium intortum)*	406	Whitnen 1982
10	Leucaena *(Leucaena leucocephala)*	74	Nutman 1976

Knowing if the job is done

Check your nodules: Don't assume that by applying rhizobia to the crop that the job is over. It's important to see how effective the inoculum has been and what state of health the nodules are in. By checking the degree of nodulation you can assess the type of inoculum product you have used and the application technique employed to get the rhizobia where it needs to be- in the roots of the growing pulse.

If a root nodule is cut open and the inside is pink/red (Figure 5) the nodule is active and fixing lots of nitrogen for the plant. The colour is due to the presence of plenty of leghaemoglobin.

Figure 5: Heavily nodulated healthy root nodule actively converting nitrogen

Source: (retrieved from www.pulseaus.com.au)

The redder the nodule, the more active it is. Provided that you have used the appropriate product in your operations, and the season is favourable for strong early growth, you will have set up your pulse crop for a strong yield. The bonus will be seen in the following year in a healthy cereal crop, growing on the residual nitrogen from the pulse plant. When nodules are young and not yet fixing nitrogen they are white

or grey inside. Legume nodules that are no longer fixing nitrogen turn green and may be discarded by the plant. This may be the result of an inefficient *Rhizobium* strain or poor plant nutrition.
Break open the root nodules to check the colour (Picture 1). A strong pink colour indicates the rhizobia are actively converting nitrogen for use by the plant- and next year's cereal.

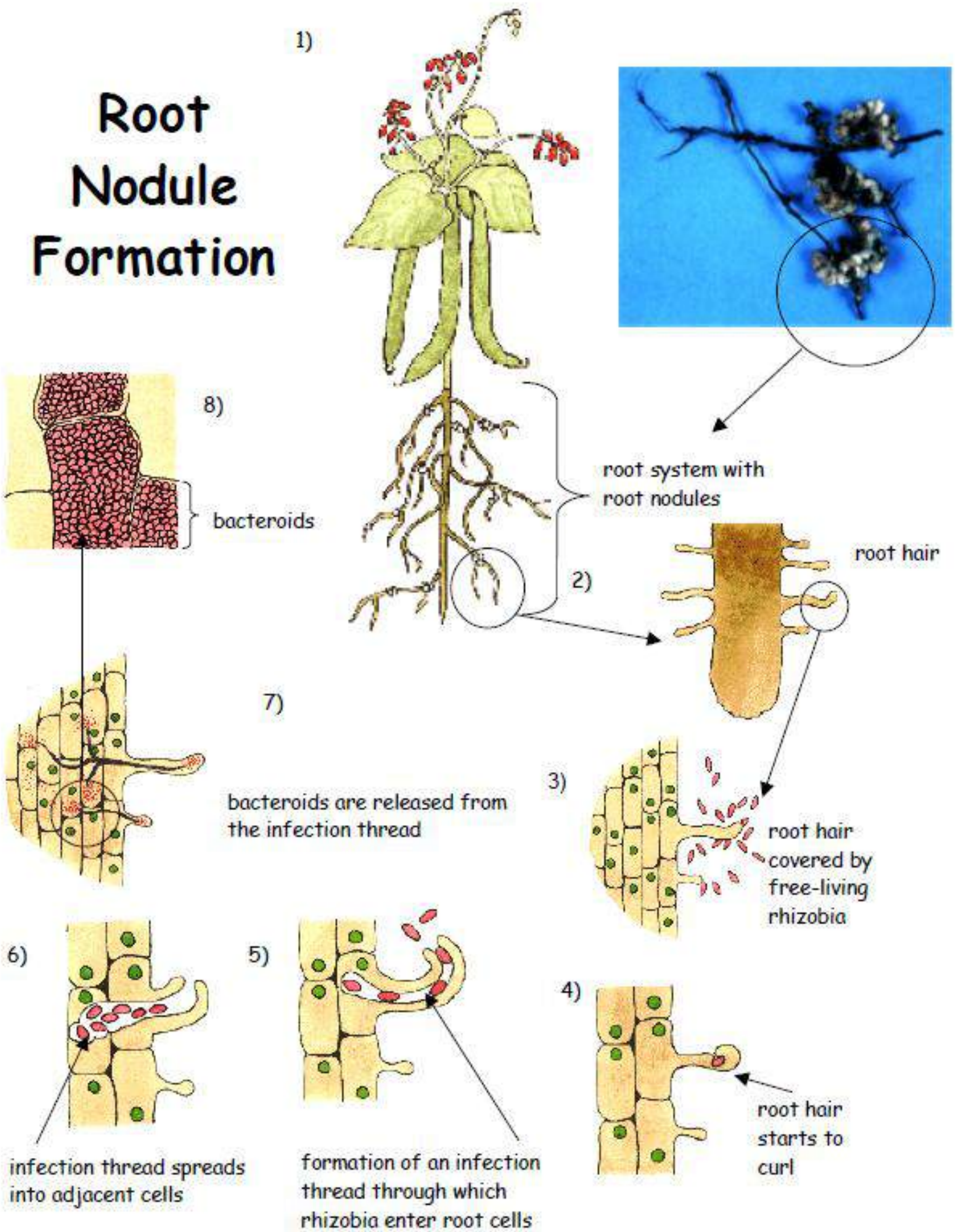


Figure 6: A cut and opened root nodule system showing a pink/red colour inside, i.e., is active in fixing lots of nitrogen
Source: Society for General Microbiology (2002)

Factors limiting biological nitrogen fixation

Interactions between the micro symbiont and the plant are complicated by edaphic, climatic, and management factors. A legume-*Rhizobium* symbiosis might perform well in a loamy soil but not in a sandy soil, in the sub-humid region but not in the Sahel, or under tillage but not in no-till plots. These factors affect the micro symbiont, the host-plant, or both.

A) Edaphic Factors: Edaphic factors relate to the soil. The six main edaphic factors limiting biological nitrogen fixation are:

- Excessive soil moisture,
- Drought,
- Soil acidity,
- P deficiency,
- Excess mineral N, and
- Deficiency of Ca, MO, CO and B.

Excessive moisture and water logging prevent the development of root hair and sites of nodulation, and interfere with a normal diffusion of O_2 in the root system of plants. *Sesbania rostrata* and *Aeschynomene* sp. can actively fix N_2 under these conditions because they are located on the plant stems, rather than on the roots.
Drought reduces the number of rhizobia in soils, and inhibits nodulation and N_2 fixation. Prolonged drought will promote nodule decay. Deep-rooted legumes exploiting moisture in lower soil layers can continue fixing N_2 when the soil is drying.

Soil acidity and related problems of Calcium deficiency and Aluminum and Manganese toxicity adversely affect nodulation, N_2 fixation and plant growth.

Phosphorus deficiency: reduces nodulation, N_2 fixation and plant growth. Identification of plant species adapted to low-P soils is a good strategy to overcome this soil constraint. The use of local rock phosphate has been recommended, particularly in acid soils, as an inexpensive source of P.

Mineral Nitrogen: inhibits the *Rhizobium* infection process and also inhibits N_2 fixation. The former problem probably results from impairment of the recognition mechanisms by nitrates, while the latter is probably due to diversion of photosynthesis toward assimilation of nitrates. Application of large quantities of fertilizer N inhibits N_2 fixation, but low doses (<30 kg N ha^{-1}) of fertilizer nitrogen can stimulate early growth of legumes and increase their overall N_2 fixation. The amount of this starter nitrogen must be defined in relation to available soil N.

Various microelements: (Cu, Mo, Co, B) are necessary for N_2 fixation. Some of these are components of nitrogenase for example Mo.

B) Climatic Factors: The two important climatic determinants affecting BNF are temperature and light.

Extreme temperatures affect N_2 fixation adversely. This is easy to understand because N_2 fixation is an enzymatic process. However, there are differences between symbiotic systems in their ability to tolerate high (>35°C) and low (<25°C) temperatures.

The **availability of light** regulates photosynthesis, upon which biological nitrogen fixation depends. This is demonstrated by diurnal variations in nitrogenase activity. A very few plants can grow and fix N_2 under shade. In alley farming if hedgerows are not weeded, or if trees are planted with food crops like cassava, their nitrogen fixation and growth will be reduced due to shading. Early growth of legume trees is slow and they cannot compete successfully for light.

C) Biotic Factors: Among biotic factors, the absence of the required rhizobia species constitutes the major constraint in the nitrogen fixation process. The other limiting biotic factors could be:

- Excessive defoliation of host plant,
- Crop competition, and
- Insects and nematodes

Defoliation, Crop Competition, and Pests: Defoliation (e.g., pruning and lopping) decreases the photosynthetic ability of legumes. It impairs N_2 fixation and can lead to nodule decay. For perennial legumes, nodule decay sheds a high number of rhizobia in the root zone. When new roots develop in subsequent vegetative cycles, nodulation of the legume is expected to improve.

Intercropping legumes with non-leguminous crops can result in competition for water and nutrients. This competition can affect N_2 fixation negatively. However, it has been shown that when mineral N is depleted in the root zone of the legume component by the non-leguminous intercrops, N_2 fixation of legumes may be promoted.

Insects and nematodes have also been reported to interfere with nodule formation development and functions.

Inoculation of Legumes seeds: If specific and effective rhizobia are absent in a soil, or if they are present in low numbers, it is necessary to introduce the rhizobia in that soil to ensure proper nodulation and nitrogen fixation. This is called *inoculation*. If specific and effective rhizobia are present in sufficient number, there will be no need to inoculate the legume. In agri-systems, whenever one is not sure of the presence and effectiveness of the native rhizobia, it could be necessary to inoculate the legume seeds with an adequate strain of rhizobia.

How can you determine the need for inoculation?

There are some simple tests: Are nodules absent or sparse on un-inoculated young plant growing in a low-N soil? (This is normally accompanied by N deficiencies). Or, are nodule sections white or green? (This is an indication of poor effectiveness).

Picture 2: *Rhizobium*

A more accurate relative effectiveness trial will provide more precise information. The trial, in a simple term, consists of growing the legume with and without fertilizer N while controlling all other limiting factors. The relative effectiveness ratio (RE) is then calculated. RE is defined as: dry weight of unfertilized plants x 100/dry weight of fertilized plants. If the value of RE is more than 5, the inoculation is not required.

The soil bacteria infect the roots of the plant and form structures known as nodules. The chemical reaction that is the process known as BNF, take place in the nodules (Picture 3a (left, & 3b above).

Figure 7a and 7b: Soil bacteria infected legume plant roots

Inoculant rhizobia usually persist in the soil for long periods, particularly when the host is cultivated frequently or is permanent. Persistence of a strain is desirable because it obviates the need for inoculation in subsequent years, assuming inoculant strains maintain their original effectiveness.

Inoculation with rhizobia is usually recommended for newly introduced legumes. Most positive responses to inoculation are confined to crops which have specific requirements for *Rhizobium*, (e.g., *Leucaena leucocephala,* American varieties of soybean). Indigenous legumes seldom respond to inoculation with introduced rhizobia because they nodulate with resident strains, even if these native rhizobia are not the most effective ones.

How to increase BNF and N_2 fixing ability

Biological N_2 fixed represents N gain and determines inorganic N fertilizer savings in cropping systems. Legumes can fix more than 250 kg N ha^{-1} (Bansh and Paul, (1992). However, the amounts of N_2 fixed can vary considerably in time and space. The nitrogen fixation process is influenced by factors such as:

- Presence and effectiveness of rhizobia, pest damage,
- Plant genotype and age,
- Plant and rhizobia interactions,
- Changes in soil physiochemical conditions, and
- Various management practices such as tree pruning or pesticide application that can affect both symbiotic partners.

Common approaches to enhance biological nitrogen fixation are:

- Inoculation with proven strains,
- Microbial screening for improved strains,
- host-plant screening and breeding, and
- Adoption of cropping systems and cultural practices.

a) Microbial Screening

There are collections of effective rhizobia located at centers around the world for most, if not all, legumes used in agriculture (Takishima et al, 1989). These strains may be screened to identify the most effective and competitive one(s) for a given agro-ecosystem. Once elite strains have been identified, the legume under consideration is inoculated. Instructions on inoculants use are usually given by the manufacturers. Seed inoculation using peat inoculants is the most commonly used method. However, studies are under way to assess the effectiveness of post planting inoculation as a corrective measure. Dual inoculation of rhizobia and mycorrhizal fungi has proven beneficial in some cases.

b) Host-plant Screening and Breeding

A screening of legume plants with high N_2-fixing components can be carried out. Breeders have developed plant varieties with promiscuous nodulation to obviate the need for inoculation with rhizobia. In some laboratories in the USA, plants that do not nodulate with indigenous rhizobia but only with introduced "super" strains are being developed

There are still many unexploited legume-*Rhizobium* symbioses in the world. The potential benefit of screening these symbioses is underscored by the fact that only about 0.5% of existing leguminous species are presently used for agricultural purposes.

c) Cropping Systems and Cultural Practices

It is evident that inclusion of N_2-fixing components in cropping systems will increase N inputs in agri-systems. Cultural practices can control some of the above-mentioned factors which limit BNF. Mulching, for instance, can control weeds and fluctuations of soil moisture and temperature. Liming can eliminate soil acidity, and Al and Mn toxicities.

2.1 *Promotion of Rhizobium* Inoculants

Cereal crops need a lot of nitrogen to grow well so a mixed cropping system of cereals and legumes is often a good idea. There are many different strains or species of Rhizobia present in leguminous crops. In some soils, Rhizobia bacteria are naturally present; in others they have to be artificially inoculated into the soil. Rhizobia have two main features that are relevant to food producers: They are specific to certain Genera or species of legumes. In other words, one strain of Rhizobium that is effective for soybeans may not also be effective for lima beans, for example. They can only survive for a short time when they are not in either seed or soil.

Rhizobium is the most well known species of a group of bacteria that acts as the primary symbiotic fixer of nitrogen. These bacteria can infect the roots of leguminous plants, leading to the formation of lumps or nodules where the nitrogen fixation takes place. The bacterium's enzyme system supplies a constant source of reduced nitrogen to the host plant and the plant furnishes nutrients and energy for the activities of the bacterium. About 90% of legumes can become nodulated. In the soil the bacteria are free living and motile, feeding on the remains of dead organisms. Free living rhizobia cannot fix nitrogen and they have a different shape from the bacteria found in root nodules.

Quick facts

- Legumes convert atmospheric nitrogen to usable ammonia nitrogen for the plant.
- Inoculation is the process of introducing commercially prepared rhizobia bacteria into the soil.
- Each legume species requires a specific species of rhizobia to form nodules and fix nitrogen.
- Store inoculum and pre-inoculated seed in a cool environment without exposure to sunlight with a temperature of about 4°C.
- Inoculum packages usually are labeled with an expiration date.
- The Rhizobium culture is contained in certain inert substances such as peat and used to inoculate the seed.
- Seed should be planted immediately after inoculation, and protected from direct sunlight.
- The recommended and certified inoculants for uses in Ethiopia are for crops such as Soya bean, Haricot bean, Chick pea, Fava bean, Lentil and Field pea can be purchased with full suggested appliance leaf lets from any licensed sources.

Some of the benefits of using inoculants

- ✓ Saving the use of chemical nitrogenous fertilizers by enhancing N fixation
- ✓ Low cost: one packet of inoculants can be used to plant (or about 20 kg) of bean seeds
- ✓ Easy to apply
- ✓ Gives increased yields of legumes
- ✓ Does not pollute the environment.

2.2 Inoculation methods

There are two ways of carrying out inoculation with the first one being the common method applied in Ethiopia. The first method is preferred because it is simple to carry out and is far cheaper to do. As the second method is not a common practice in the country, the focus will remain in the first inoculation method. However, sometimes it can be necessary to inoculate the soil; for example if the soil is very dry and acid (pH< 5), or contains many rhizobium that do not create active root nodules, or if the plant has been treated with chemicals such as fungicides or insecticides which rhizobia cannot tolerate. So far it is not yet known which chemicals rhizobia can tolerate and therefore, in such cases the second method might be the better option.

2.2.1Seed-applied inoculation method

Inoculum to be mixed with seed before planting is available on a variety of carriers; the most common carrier is peat. Peat has proven to be better than most other carriers in preserving live bacteria under unfavorable conditions (high temperature, late planting).

When inoculating seed, two conditions must be satisfied to get good nodulation:
1. The roots must be in contact with the *Rhizobia* bacteria, and
2. The *Rhizobia* must be alive and able to infect the plant root.

For the bacteria to be in contact with the roots of every plant, inoculum should cover each seed. To achieve the best distribution, the inoculum should be mixed with seed in a large space rather than in a planter seed box—on a tarp-covered floor, in a tub, in a cement mixer (paddles removed), or in the bed of a pickup.

Using an adhesive (also known as a sticker) helps the inoculant to adhere to each seed. This is especially important with small-seeded forage legumes, which need more inoculant per unit of seed-surface area. Both commercial and homemade stickers are effective. A homemade sticker can be prepared as a 1-in-10 dilution of syrup or molasses, diluted cola or milk also can be used.

The rate of inoculant to use depends on the amount of time elapsed since the legume was last grown in that field and on the conditions for bacteria survival at the time of planting. Start with the manufacturer's recommendations. If the soil is dry and germination of the seed is expected to be delayed, then a higher rate of inoculant is required to make up for loss of some Rhizobia. For soybeans being planted into a new field, three times the normal rate of inoculant is recommended. A good way to achieve this is to moisten the seed with liquid inoculant applied at the normal rate, then mix seed with twice the normal rate of peat-based inoculant.

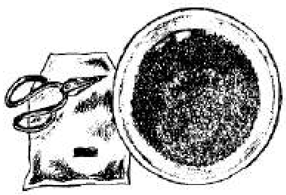
When buying inoculants you should check that the following things are listed on the packaging:

- The scientific (Latin) name of the rhizobium
- Instructions for use.
- How to store the product; not above 40°C because the rhizobium will die. At a temperature of about 20°C inoculants will remain good for about 6 months. At 4°C it will last even longer.
- The shelf life of the product must be given: the date after which the product can no longer be used.

Seed inoculation procedure and sowing

- Mix one part of inoculums with 2.5 parts of water to moisten the seeds.
- Pour this over the seed. Too much liquid may cause premature germination of the seed.
- Mix together so that every seed is covered.
- Wait until the seeds do not stick together, and then mix again.
- Sow as soon as possible, within three or four days if possible, though the inoculums may still be viable after seven days if the conditions are favorable (for detail Seed Inoculation techniques in figure 6 below).

the mixture is added to the seed



seed and inoculant mixture are mixed well so that all seeds are covered evenly with the mixture, but not soaked through. It is best to sow the seed immediately once this has been done

Figure 8: Seed inoculation techniques

items required to inoculate seed: seed in a mixing bowl, packet of inoculant, beaker of water

inoculant is mixed with water to form a pouring mixture (slurry)

2.2.2 Direct-soil application method

Application of inoculant directly to the soil has been quite effective. However, the greater surface area being covered by the inoculant required more of the material. This is especially the case when narrow-row soybean planting is practiced. Therefore, the method is more expensive than seed inoculation.

Granular forms of inoculum may be placed in the seed row via the insecticide box of a planter or through the fertilizer or grass seed box of a drill. (Clean the box before inoculum is placed in it.) The granules flow freely through field planting equipment and their flow should be calibrated and metered. Frozen or concentrated liquid cultures of inoculant may be diluted to slurry then added to a water-filled tank for spray application into the seed row. Broth or frozen concentrates usually are mixed with water and sprayed into the seed furrow at planting. Because liquid inoculants must be kept frozen or refrigerated during shipment and storage, their availability through normal distribution channels is limited.

Three basic forms of commercial inocula are solid, liquid and freeze-dried. Inoculant should not be mixed with either pesticide or fertilizer if applied to the seed row. When seeding forage legumes, it is recommended that fertilizer be applied separately.

2.3 Causes of N-fixation failure

Nitrogen fixation is a biological system that requires the plant and *Rhizobium* bacteria to work in balance. Conditions that cause nitrogen fixation failure include:

- Using the wrong species of *Rhizobium* for the crop seeded, or using inadequate rates of inoculant. Calibrate seeding equipment using inoculated seed as it may have slower flow rates than seed that has not been inoculated.
- Delays between inoculation and seeding. The bacteria die rapidly when exposed to temperature extremes and drying conditions. Ideally, inoculate only enough seed that can be planted within six hours. Under cool, dark storage conditions, bacteria can survive on seed for about one to two days, depending on the inoculant formulation. Any further delay will require retreating. Check product labels for manufacturer's instructions - some liquid products must be reapplied if the treated seed is held longer than six hours.
- Improper inoculant storage conditions. High temperatures or exposure to sunlight can kill the bacteria. This can occur in a short period of time, such as during transport or inside a warm vehicle. Inoculants should always be kept cool and out of direct sunlight.
- Environmental conditions (cool soil, waterlogged soil, drought stress or salt stress) that slow crop development and reduce the ability of the plant to supply energy and nutrients for nodule formation and fixation. Plant stress may result in delayed nodule formation and cause the fixation process to stop.
- Low available phosphate levels, deficiency of boron or molybdenum can slow seedling development and reduce the ability of the plant to fix nitrogen.
- Dry soil during the first two weeks after seeding can lead to desiccation (drying out) of the inoculant and death of the *Rhizobium*.
- Native *Rhizobium* bacteria can cause colonization of the roots; however, the native *Rhizobium* may be inefficient nitrogen fixers. In some cases, nodules form, but do not have the pink or red interior and are not effective.
- Shallow seeding into soil that dries out periodically after seeding may lead to the desiccation of the *Rhizobium*.
- Bridging of granular inoculants in the seeder tank can lead to uneven application. Follow manufacturer's label directions to avoid bridging.
- Soil too acid (especially when below about pH 5.5).
- High levels of available soil nitrogen (more than 55 kg/ha) cause the crop to preferentially use nitrogen from the soil (retrieved on August 27.2014 from www.agriculture.gov.sk.ca).

MODULE 3: COMPOSTING AND COMPOST APPLICATION

3.1 Concept and principle of composting

Compost is an organic fertilizer that can be made on the farm at very low cost. The most important input is the farmer's labour. Composting is a technology for recycling organic materials in order to achieve enhanced agricultural production. Biological and chemical processes accelerate the rate of decomposition and transform organic materials into a more stable humus form for application to the soil (Müller-Sämann, 1986).

To improve soil fertility in the long term, it is necessary to improve the soil structure and to increase the organic matter content of the soil. Compost is a good fertilizer because it contains nutrients as well as organic matter.

During the composting process, carbon dioxide and water are lost to the atmosphere and the size of the heap decreases by 30–60%. In addition, many weed seeds and disease-causing organisms may be killed by the high temperatures in the heap. Unpleasant odors are eliminated. There is evidence that compost application lowers the incidence of plant root and leaf diseases. In addition, the chelates and the direct hormone like chemicals present in compost stimulate the growth of healthy plants.

3.2 General practices and methods of composting

The natural decomposition process in the soil can be regulated and speeded up by man, however, the composting process happens due to the activity of micro-organisms and other larger organisms like worms and insects. These need certain conditions to live. To make the best possible compost, the micro-organisms must be able to work in optimum environment in terms of moisture, air temperature, organic matter etc. In general, for good compost quality the following conditions should be considered.

Moisture

The compost heap must be kept relatively moist. It should feel like a wet sponge but not too wet, because it will then rot rather than decompose. In a heap that is too dry, the bacteria and fungi cannot develop sufficiently. The right moisture level can usually be obtained by thoroughly wetting all the material before starting the heap. The heap should be placed in the shade or under a shed to prevent it from drying out. A shed is best because it also prevents nutrients from being leached by heavy rainfall. In dry areas, or in the dry season, the heap can be started in a hole that is 60-70 cm deep, which will help keep it moist. This does not work in wet areas or in the rainy season, because any excess water cannot run off and the compost can become too wet on the bottom.

Ventilation

The bacteria and fungi need oxygen to develop and to breathe. Proper ventilation can be achieved by mixing fine and rough materials. Every point in the heap should be within 70 cm of a ventilation point. Turning over also allows air to enter.

Temperature

The temperature in the middle of a well-built heap becomes 60-70°C in the first days after construction or turning over. To achieve this temperature, the heap has to be at least a meter wide and a meter high. However, the heap should not be higher than 1.5 m, or wider than 2.5 m, because the temperature can then become too high. It is also difficult to properly ventilate large heaps.

Hygiene

In theory, all organic material can be used for compost. However, human excrement requires careful treatment to ensure that any diseases and viruses that could be present are completely destroyed. To begin with, it is helpful to add some earth, old compost or another material that stimulates the growth of micro-organisms such as manure and molasses. Lime or ash can also help well, if they are very finely ground and added in small amounts.

Fresh moist material decomposes easily. Old and tough material like straw and wood is more difficult to break down. The greater the proportion of the latter material in the heap, the longer it will take for the compost heap to be ready. Animal manure also has a positive effect; without it, decomposition progresses much slower. The exact ratio of Carbon to Nitrogen (C: N) in the compost heap is very important. As a rule of thumb, a ratio of one part manure to three parts plant waste, or one part old plant material to one part young material is preferred.

Ideally the C: N ration will be 30: 1 to 35:1, to give a ratio in the final compost of between 15:1 and 20:1 some typical values are: Vegetable matter 24:1, Organic fraction of domestic waste 20:1, Night soil sludge 6:1, Higher final C: N rations can result in nitrogen levels in the soil being reduced as the carbonaceous substrate continues to decompose.

A C: N ratio that is too low results in a loss of Nitrogen in the form of Ammonia. If the C: N ratio is too high, the temperature in the heap will be low and decomposition will be very slow. If the cattle lay on it for one night it can also absorb urine which aids decomposition. In any case, the rough material has to be cut into small pieces (less than 20 cm) before it is added to the heap.

Traditional composting methods

Indore heap method

During rainy seasons or in regions with heavy rainfall, the compost may be prepared in heaps above ground and protected by a shed. The pile is about 2 m wide at the base, 1.5 m high and 2 m long. The sides taper so that the top is about 0.5 m narrower than the base. A small bund is sometimes built around the pile to protect it from wind, which tends to dry the heap.

Forming the heap - The heap is usually started with a 20 cm layer of carbonaceous material such as leaves, hay, straw, sawdust, wood chips and chopped corn stalks. This is covered with 10 cm of nitrogenous material such as fresh grass, weeds or garden plant residues, fresh or dry manure or digested sewage sludge. The pattern of 20 cm of carbonaceous material and 10 cm of nitrogenous material is repeated until the pile is 1.5 m high and the material is normally wetted until it feels damp but not soggy. The pile is sometimes covered with soil or hay to retain heat and it is turned at intervals of 6 and 12 weeks. In the Republic of Korea, the heaps are covered with thin plastic sheets to retain heat and prevent insect breeding.

Where materials are in short supply, the alternate layers can be added as they become available. Moreover, all the materials can be mixed together in the pile provided that the proper proportions are maintained. Shredding the material speeds up decomposition considerably. Most materials can be shredded by running a rotary mower over them several times. Where sufficient nitrogenous material is not available, a green manure or leguminous crop such as sun hemp is grown on the fermenting heap by sowing seeds after the first turning. The green matter is then turned in at the time of the second mixing. The process takes about four months to complete.

Indore Pit method

The pit method is a compost making process in pits, which is much better to be used in moisture stress and cold areas. This is because in moisture stress areas the pit keeps the available moisture for a longer time while in the cold, the pit keeps the inside temperature high enough for the decomposition process to continue.

This method involves digging a pit (e.g. 360 cm long × 180 cm wide × 90 cm deep) in a shaded area (length can vary according to the volume of waste materials available). The trenches should have sloping walls and a floor with a 90-cm slope to prevent waterlogging. Farm wastes such as straw, vegetable refuse, weeds and leaves are spread to a thickness of 15-20 cm. Wet animal dung is spread over this layer to a thickness of 5 cm. Water is sprinkled to moisten the material (50-60 percent of mass). This procedure is repeated until the whole mass reaches a height of 60 cm above ground. It is then plastered with mud, and anaerobic decomposition commences. In four weeks, the mass becomes reduced and the heap flattens. The mud plaster is removed and the entire mass is turned. Aerobic decomposition commences in at this stage. Water is sprinkled to keep the material moist. The compost is ready for use after four months.

Turning - The material is turned three times while in the pit during the whole period of composting: the first time 15 days after filling the pit; the second after another 15 days; and the third after another month. At each turning, the material is mixed thoroughly and moistened with water.

Bangalore method

This method of composting was developed at Bangalore in India in 1939 (FAO, 1980). It is recommended where night soil and refuse are used for preparing the compost. The method overcomes many of the disadvantages of the Indore methods (above), such as the problem of heap protection from adverse weather, nutrient losses from high winds and strong sun, frequent turning requirements, and fly nuisance. However, the time required for the production of finished compost is much longer. The method is suitable for areas with scanty rainfall.

Pit preparation - Trenches or pits about 1 m deep are dug; the breadth and length of the trenches can vary according to the availability of land and the type of material to be composted. Site selection is as per the Indore method. The trenches should have sloping walls and a floor with a 90-cm slope to prevent waterlogging.

Filling the pit - Organic residues and night soil are put in alternate layers. After filling, the pit is covered with a layer of refuse of 15-20 cm. The materials are allowed to remain in the pit without turning and watering for three months. During this period, the material settles owing to reduction in biomass volume. Additional night soil and refuse are placed on top in alternate layers and plastered or covered with mud or earth to prevent loss of moisture and breeding of flies. After the initial aerobic composting (about eight to ten days), the material undergoes anaerobic decomposition at a very slow rate. It takes about six to eight months to obtain the finished product.

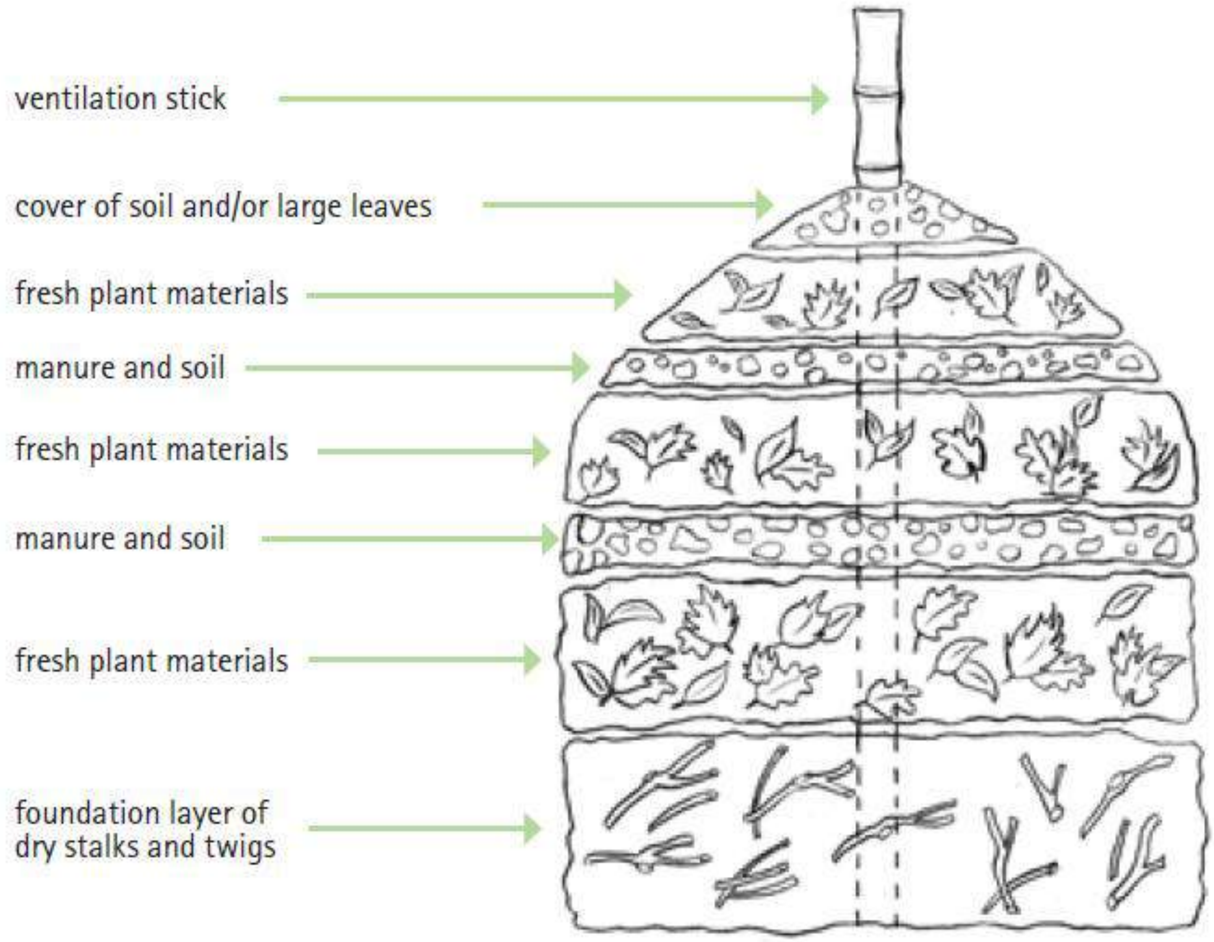


Figure 9*:* Showing the layers in bangalore compost heap

Passive composting of manure piles -Passive composting involves stacking the materials in piles to decompose over a long time with little agitation and management (NRAES, 1992). The process has been used for composting animal wastes. However, the simple placing of manure in a pile does not satisfy the requirements for continuous aerobic composting. Without considerable bedding material, the moisture content of manure exceeds the level that enables an open porous structure to exist in the pile. Little if any air passes through it. Under these circumstances, the anaerobic micro-organisms dominate the degradation. All of the undesirable effects associated with anaerobic degradation occur.

3.3 Rapid composting methods

Use of Effective Micro-organisms (EM)

Effective microorganisms refer to a cocktail of beneficial microorganisms that is used as a soil amendment (Woodward, 2003). EM contains selected species of microorganisms, including predominant populations of lactic acid bacteria and yeasts and smaller numbers of photosynthetic bacteria, actinomycetes and other types of organisms. All of these are claimed to be mutually compatible with one another and are able to coexist in liquid culture. Some microorganisms contained within EM are:

- **Phototropic Bacteria**
- **Lactic Acid Bacteria**
- **Yeast and**
- ***Actinomycetes***

Photosynthetic bacteria - The photosynthetic or phototropic bacteria are a group of independent, self-supporting microbes. These bacteria synthesize useful substances from secretions of roots, organic matter and/or harmful gases (e.g. hydrogen sulfide), by using sunlight and the heat of soil as sources of energy. Useful substances developed by these microbes include amino acids, nucleic acids, bioactive substances and sugars, all of which promote plant growth and development. The metabolites developed by these microorganisms are absorbed directly into plants and act as substrates for increasing beneficial populations (Prescot *et al*., 2002).

Lactic acid bacteria - Lactic acid bacteria produce lactic acid from sugars and other carbohydrates, developed by photosynthetic bacteria and yeast. Some foods and drinks such as yoghurt and pickles have been made with lactic acid bacteria for decades. However, lactic acid is a strong sterilizing compound, and suppresses harmful microorganisms and enhances decomposition of organic matter. Lactic acid bacteria promote the decomposition of materials such as lignin and cellulose and ferment these materials, thereby removing undesirable effects of un-decomposed organic matter (Prescott, Harley & Klein, 2002).

Yeasts - Yeasts synthesize antimicrobial and other useful substances required for plant growth from amino acids and sugars secreted by photosynthetic bacteria, organic matter and plant roots. The bioactive substances such as hormones and enzymes produced by yeasts promote active cell and root division. These secretions are also useful substrates for effective microbes such as lactic acid bacteria and actinomycetes (Prescot *et al*., 2002).

Actinomycetes - Actinomycetes are part of the microorganisms which make up EM and they disturb the life cycle of insects thereby reducing the reproduction rate. Actinomycetes feed on the chitin produced by the larvae to become pupae, henceforth the metamorphosis is hindered. Actinomycetes are aerobic and can be cultivated easily on simple growing media and are gram positive (Prescot *et al*., 2002).

Brands of EM

The use of EM as a broad-based organic material for crop production is an innovative model for use in organic agriculture, which is growing in popularity worldwide. The use of various brands of EM has been found to improve the growth and quality of crops (Daly and Stewart, 1999) and the brands of EM that helps to prepare compost discussed in detail in the succeeding sections.

EM-bokash - is a mixture of multiplied EM with fresh and quality organic materials like rice bran, wheat bran or fish meal. After the ingredients have been mixed, the resultant solution is kept for up to two weeks to ferment in sealed containers. The final product is used for:

1) Accelerating the fermentation and anaerobic decomposition of organic waste materials when making compost.
2) Adding to animal feed for improvements in general health and natural immunity (Anon., 2004b; 2005; Asia-Pacific Natural Agriculture Network, 1995).

EM-fermented fish (EM - F.F.): this **r**eleases nutrients like nitrogen and phosphorus slowly over a period of time, allowing plant growth from one season to the other. During preparation, the fish is crushed, making nutrients to be accessible to microorganisms. The product is then mixed with multiplied EM before spraying on plants (Anon., 2004b; 2005; Asia-Pacific Natural Agriculture Network, 1995).

EM-fermented chicken manure: EM-fermented chicken manure is similar to EM-fermented fish as it also provides nitrogen and phosphorus to the plants. Chicken manure, extended EM and an equivalent of 1% of bokash are the ingredients used (Anon., 2004a; 2005).

EM-fermented kitchen garbage: EM-fermented kitchen garbage is produced by fermenting organic waste generated in the kitchens using multiplied - EM to produce a nutrient-rich fertilizer for plants. The method for its production is similar to that of EM - F.P.E (Anon., 2004b; 2005).
According to Sangakkara (2004), EM is effective for crop production and is environmentally safe with different brands of EM being produced in about 40 countries across the globe using local microbial isolates. They find uses in different fields, ranging from crop agriculture, environmental management, animal production, and aquaculture. The different brands of EM are applied to the above mentioned environments in different ways and these are discussed fully in the succeeding sections.

Inoculation of EM into the soil

Brands of EM can either be applied as a soil drench or be spread to plants during crop production. When inoculating into the soil, a 1: 500 dilution of multiplied - EM in water or EM - FKG (kitchen garbage) is used. When using EM - F.F (fermented fish) or EM -F.C.M (fermented chicken manure), a 1: 300 dilution is advisable. An equivalent of 2.5 tones of bokash or less is applied to soil per hectare. Dosages above 2.5 t ha-1 are detrimental to the plants due to organic acids which can damage their roots. EM – bokash is usually applied between 10 to 14 days prior to planting and is placed at a distance of 10 cm to 15 cm away from roots (Anon., 2004b; 2005; Asia-Pacific Natural Agriculture Network, 1995).

Benefits of applying EM

The following are some of the beneficial influences of EM in agricultural production:

- Improvement of the physical, chemical and biological environments of the soil increases the efficacy of organic matter as fertilizers) and suppression of soil-borne pathogens and pests,
- Improvement of germination of seeds, flowering, fruiting and ripening in plants.
- Enhancement of the photosynthetic capacity of crops and,
- Increased crop yield.

As a result of the above-mentioned beneficial effects of EM, yields and quality of crops
are enhanced (Asia-Pacific Natural Agriculture Network, 1995).

Effects of EM on organic matter

Organic manures are a source of multiple nutrients and can improve soil physical, chemical and biological characteristics. However, the effects of organic manures on crop yield are long term and not immediate, therefore farmers prefer using mineral fertilizers in their cropping systems.
Addition of EM together with organic manures is thought to be an effective technique for stimulating supply and release of plant nutrients. Studies have shown that inoculating agro-ecosystems with EM can improve soil and crop quality (Higa and Parr, 1994; Hussain *et al*., 1999). Following EM application into the soil, there is an increase in soil microorganisms that are beneficial for the growth of the plant that result in rapid mineralization of organic materials (Asia-Pacific Natural Agriculture Network,1995). According to Khaliq, Kaleem & Hussain (2006), application of organic materials or EM alone did not significantly increase yield. However, their integrated use resulted in a 44% increase in yield over the control. Application of EM with mineral fertilizer in this case resulted in a slight increase in yield (14%) over the mineral fertilizer alone, demonstrating that EM is more effective when applied with organic manures. The relatively low response of mineral fertilizer compared to EM application was due to the fact that EM is made up of different microorganisms which can respond well only in the presence of sufficient

organic matter. Aryal, Xu & Fujita (2003) showed that *Rhizobia* and arbuscular mycorrhizal (AM) inoculation of bean plants significantly increased pod yield in plots with organic matter supplements compared to chemically treated plots.

The relative effects of EM were further observed in plant leaf N concentration where its co-application with organic materials increased leaf N concentration by 38% relative to the control compared to 16% increase due to organic materials application alone (Khaliq,et *al.*, 2006). EM enhances the degradation and stimulates mineralization of organic materials, releasing plant nutrients into the soil (Hussain *et al*., 1999). Application of EM into soil resulted in higher available phosphorus concentration 50 days after transplanting of tomato (Xu, 2000). However, 90 days after transplanting of tomato, both nitrogen and phosphorus concentration were low in EM treated soils and this was ascribed to more nutrients being taken up by plants that showed faster growth and subsequently higher yields. Piyadasa *et al.* (1995) studied the release of nitrogen and phosphorus from soils amended with organic matter over a 21 day incubation period at 60^{0}C. Application of EM increased both inorganic nitrogen and phosphorus compared to the control.

Effects of EM on photosynthetic capacity of crops

Extensive studies have been conducted on the effects of EM especially when applied with bokash on plant growth, photosynthesis and yield as compared with mineral fertilizers (Fujita *et al*., 1997; Arshad, 2006). Fujita *et al.* (1997), found that plants treated with mineral fertilizer had higher dry matter yields during the early stages of growth but lower dry matter yields at the later stages compared to EM treated plants. Plants treated with EM and bokash maintained vigorous growth with greater root mass and activity and a higher rate of photosynthesis until harvest time compared to plants treated with mineral fertilizer. According to Yamanda *et al.* (1996), well developed roots in EM – bokash treated plants play an important role in maintaining a higher rate of growth and photosynthetic activity. Higher growth rates are due to sustained availability of nutrients from bokash through mineralization by EM microorganisms (Kato *et al*., 1997). There is a possibility that EM contains growth regulators that could stimulate root activity and delay senescence of plants (Yamada *et al*., 1996). Plant hormones like auxins, gibberellins and abscisic acid play important roles in root growth and development (Schneider & Wightman, 1974). In addition, bacteria, fungi and actinomycetes produce some bioactive substances that can enhance plant growth and metabolism (Arshad & Frankenberger, 1992). However, it is not yet clear how EM stimulates growth or plant metabolic processes. Some researchers have been speculating that the beneficial effects of EM may be due to their ability to biosynthesize

Effects of EM on crop yield

Application of EM to soil also increases crop yield and quality due to an increase in plant nutrients and suppression of soil-borne pathogens (Asia-Pacific Natural Agriculture Network, 1995). In a study carried out by Daly & Stewart (1999), application of EM plus molasses caused a significant yield increase over the control and resulted in more first grade onions, peas and sweet corn.

The multiple Uses of EM

- To produce high quality humus in relatively short time.
- To boost crop production through improving soil fertility, moisture holding capacity and suppressing disease …
- To enhance livestock productivity through enriching feed and suppressing diseases.
- To purify and recycle waste water
- To compost household, city waste and produce odorless and usable substances
- To restore and improve the environment.

As in well known fermentation processes, EM accelerates the rupture of compounds such as proteins, sugars, fats and fibers, promoting the rapid decomposition of organic matter.

EM works in two main ways

1) by competitive exclusion from other harmful microorganisms and
2) through the production of beneficial by-products such as enzymes, organic acids, amino acids, hormones and antioxidants that promote the health of the environment

The facultative quality of EM allows it to extend its benefits to aerobic and anaerobic environments. As a result of the fermentation, the use of EM contributes to the elimination of foul odors.

Figure 10 & 11: Coffee husk piled as waste (left) and set on fire (right)

Controlling pollution from coffee waste in two steps using EM

1. Applying Activated EM and EM BALL to eliminate FOUL ODOR and improve BOD from the liquid waste
2. Preparing high EM COMPOST out of the solid waste

The solid waste contains high Nitrogen and free from Pathogens.

Figure 12 & 13: Spray EM, while heaping pulp, soil, weeds and any organic waste layer by layer

Figure 14: High quality compost in 45 days


Figure 15: Composting maize Stover with EM after 40 days (left) and Without EM applied (right)

EM Application Ratio for making 1 ton of compost

The ratio shall be adjusted according to the type of organic materials used for making compost. Very dry organic material will require more of the diluted solution.

Table 4: EM Application Ratio for making 1 ton of compost as r*ecommended by EMRO for warm tropics*

	1st week	3rd week (If the compost needs additional moisture, please add)
Water	96 liter	100 liter
Activated EM	2 liter	2iter
Molasses	2 liter	0 liter

Procedure

1. Sprinkle the diluted EM water at a rate of 20 liters on surface area of 2 x 4 m
2. Start with 20 cm layer of plant materials on an already moistened ground
3. Put a layer of animal waste or plant material as available
4. Sprinkle EM water
5. Place 5-10 cm layer of soil and sprinkle EM water
6. Place another layer of plant material
7. Continue until you have reached a height of 1 – 1.5 meters above ground

8. Cover with soil
9. Place a dry stick that should serve to measure the temperature. Heating will start in three to four days
10. Turn the composting layer after the temperature has reached about 50^0C (in about a week)
11. If white mold is seen on the stick, it is a sign that the compost is too dry. Apply water to bring the moisture to about 40% but not more
12. Cover with soil
13. The compost should be ready for use in about 5-6 weeks time

Figure 16: Spraying EM on landfill to Control odor and pathogens

Use of Vermicomposting and Vermiculture

Vermiculture

Vermiculture is the culture of earthworms. The ultimate goal is frequently increase the number of worms in order to attain a sustainable yield. The worms are either used to expand a Vermicomposting operation or sold to customers who use them for the same or other purposes.

Earthworms have been recognized as ecosystem engineers (Fonte et. al 2004) due to their influence on soil diverse types of soil processes (aggregation, decomposition, mineralization, aeration, infiltration).

There are an estimated number of 1800 species of earthworm worldwide. But the most commonly known and used ones are the Eiseniafetida (African worm). This worm is called as the “compost worm”, “manure worm”, “red worm”, and “red wiggler” Munroe (2007).Earth worms can be classified based on the way they behave and where they live.

Figure 17: Earth worms (Sherman, *et. al*, 2003)

Eiseniafetida is extremely tough and adaptable worm is indigenous to most parts of the world Munroe (2007) and can be found on most Ethiopian farm lands wherever there is a heap of manure have been left to age for more than a few weeks to months, under wood logs or under moist mulch with shade. They are 0.8 cm to 1.6 cm in length with varying physical characteristics (reddish/purple color to dark purple) but with yellow tail tip.

Reproduction of the earth worm: Earthworms are hermaphrodites. This means that they produce both eggs and sperm (*CSSWMD, 2010)* though they need another worm to mate. If the worm has a large swollen band (**clitellum**), it is a **mature** worm. The clitellum produces mucus that allows for two worms to join. Once joined, the worms pass sperm from each other to a sperm storage sac. After they detach, a cocoon (eggs) is formed on the clitellum. Baby worms will hatch from the cocoons in approximately 3 weeks. Baby worm can become adult in 3 to 5 months. Cocoons are lemon shaped and about the size of a match head (**Sherman, *et. al*, 2003)**. The ground rule is that 10 baby worms are produced per week from a mature worm (*CIWWB, 2004).*

Vermiculture procedures (Collecting worms, Indoor and outdoor method)

The term **vermiculture** is derived from Latin term. In latin "vermis" means worm. So vermiculture refers to culturing or rearing of worms. Vermiculture requires two methods of composting indoor and outdoor. The **indoor method** looks for a "worm bin" as an ideal condition. Worm bins are used in urban and pre-urban areas for people who live in condominiums and apartments. The outdoor method is good for composting in the field. Worm bins can be located inside or outside, depending on one's preferences and circumstances (Dickerson, 2001). Even in outdoor conditions, bins covered and placed under shade provide the environment that earthworms need as described in section 4.3.
Vermiculture needs worm bins be it in outdoor or indoor conditions. Worm bins are containers for rearing worms for small holder farmers. In the Ethiopian context wooden boxes, plastic (hard type plastic container or pots with holes or any material thrown away such as barrels or trunks can be used. In general wooden boxes are most preferred (because that they're more absorbent and provide better insulation). Transparent materials should not be used for constructing bins. Bins should have a lid (cover) and it is preferable if they are black in color.

The sizes of bins (length, width and height) depend on;

- Whether it is to be stationary or portable.
- on the amount of feed availability to feed worms and,
- On the total number of worms expected to be raised.

Although there are wide ranges of bins varying in size depending on feed availability and worms required to be produced, according to CSSWMD (2010) the minimum size of a bin is as small as 50 cm X 35 cm X25 cm.

Drilling air/drainage holes from 8 to 10 in number (0.5 cm - to 1cm diameter) at the bottom and sides of the bin will ensure good water drainage and air circulation. Cochran (2010) recommends a proportion of 50 cm length, 25 height and 50 cm width once you construct the bins, divide the bins in to compartments or sections. You can divide the bins in to 6 to 8 cells.

Figure 18: A plastic bin with air drainage holes
Source: Sherman, *et. al*, (2003)

STEP 1: *Construct bins for worms*

Construct a container (wooden, plastic or pot) with a size of 50 cm (length) X 50 cm (width) X 20 (height) cm with holes (0.5 cm diameter on top, bottom and sides of bins) and divide in at least three parts (compartments). Place bins where it does not keep it too cool and too hot.

Identifying and collecting worms for bins; Most of the time the red earthworm, *Eiseniafetida,* is found in moist, organic-rich environments, such as areas with spots of cattle manure or under wood logs. Earth worms live in agricultural mulch, consume the feed and survive near or in the soil. Earth worm cocoons will remain viable for long periods, waiting for the presence of manure to hatch and grow. In identifying the red earth worms it is good to notice the growth stages. Baby worms are transparent and whitish with a size less than 1.2 cm to 2.5 cm (Dickerson, 2001).

STEP2: *How do you identify red earthworms? Where to find and collect earthworms?*

Indigenous red earthworms which are used for vermicomposting can be collected from moist, organic rich environments (under wood logs, manure piles, in areas with wet animal droppings laid for days, rotten logs, under forest litters or decomposed mulch).

Note: If the worm goes deeper beyond bedding material, it may not be the right kind of earth worm , ie a "surface dweller".

Worm bins rearing environment: According to CSSWMD (2010) conditions that worms need are associated with **temperature, moisture, oxygen and light**.

Temperature for vermicomposting should vary between ***15^oC to 25^oC.*** (Maximum temperature is 35^oC). Always a thin layer (a few centimeters) of waste material keeps the temperature to minimum. Control temperature using bin cover (lid), add water with more moisture and keep under shade.

Moisture: earth worms require a moist environment. Therefore, we must keep a **moist** climate (maintain 75% water content in the bedding). This may mean approximately 50% water content by weight. With a limited composting experience, the level of moisture we want to keep in a bin is the level of water we use for a "wrung out sponge". The ground rule is that "worm bins should be moist not soaked all the time". Water to bedding material ratio is 3:1 by weight. Watering is much affected by the surrounding environment (temperature, humidity). In semi-arid areas (in a traditional agro-ecology like Kolla) where evapo-transpiration high and humidity is low watering is needed daily to control moisture). In humid and semi humid areas (in a traditional agro-ecology like Dega and Woynadega) where evapo-transpiration is low and humidity is high watering is needed once in two days or once in a week. Worms breathe in oxygen and produce carbon dioxide through their skin. Allowing for the flow of oxygen in the bin is crucial to the success of vermicompost. This requires proper bedding and adequate ventilation.

Worms do not like bright light due to their preference to dark places. This is why they stay in soil or bedding or under logs, to avoid light. Light is used for harvesting.

Worms do best if the (acidity) pH is around 7.0; however, they have the capacity to tolerate the levels from 4.2 to 8.0. Lime may be mixed with the bedding material to correct acidity or to maintain a more favorable pH. Evergreen (2010) suggest use of applying handful of crushed egg shells once a week in earth worms. Use of half quantity of ash from fire wood can also reduce acidity.

Feeding worms in vermiculture: There are categories of food which are not appropriate for earth worm (e.g. materials which are frozen or too hot or else highly acidic must be avoided). There are categories of food which are appropriate for earth worm (organic materials at room temperature, fresh leaves, materials chopped in to pieces…).

It is good to feed worms 1 to 2 times in a week rather than daily. Too much of uneaten food can attract insects and lack of food also enforce worms to move out. It is always good to know suitable food for worm and avoid what is not food. Bedding material should cover the worms (3 to 6 cm thick) while feeding worms. Feeding bedding material or worms food can be done by hand, by fork or with any tool that can be used to mix feeds.

STEP 3*: How to prepare bedding, add worm and feed the worms?*

Use various materials to prepare bedding (50% of the worm bin) using papers, hay and provide suitable worm food (manure). To add worms in the bin, just scatter them in it. Make 20 cm of bedding materials (5% peat /organic soil from nursery/, 80 % hay)

Note: Red earth worms are surface dwellers “Epigeic” and the pile of bedding material and feed should not exceed 50 cm.

Harvesting worms: According to Dickerson (2001), if we have as much as 500,000 earth worms in 0.4 ha of land it can recycle 5 tons of soil in a year. It means a small holder farmer in an Ethiopian context owns (0.4 to 1 ha of land) can have recycled 1 tons/0.4 ha/yr of organic matter with 100,000 earth worms. Approximately if a farmer can begin vermicomposting with 500 earth worms, recycled organic matter over 3-5 years can reach the desired target. Thus, the target set for vermiculture can be 500 earth worms. Farmers can start vermiculture with 100 earth worms.

If the bin environment is suitable, population of earth worms doubles every 60 to 90 days. Most common stocking densities are 5 to 10 Kg/m^2 (Munroe, 2007). Stocking density refers to the initial weight of worm biomass per unit area of bedding. High (> 5 Kg/m^2) and low (< 5 Kg/m^2) stocking densities have to be avoided.

The rule of thumb is to start Vermicomposting with 5 Kg/m^2 stocking density. The rule of thumb is to 1 Kg of worm can vermin-compost ½ Kg of garbage or organic matter in a day (Cochran, 2010). This will help to estimate the amount of worms we need.

The ground rule is that “1000 worms have a weight of 0.4 Kg (*CIWWB, 2004**)** the exact number of earthworms can vary according to the age and 0.4 Kg can have a number ranging from 500 to 2000.*

Bedding materials, feed stocks and feeding; Bedding is any material that provides the worms with a suitable habitat (Munroe, 2007). The materials in the bedding must be able to absorb and retain water fairly well (high absorbance) if the worms are to thrive. As opposed to feed stocks bedding materials have more Carbon (C) than feedstock. But bedding materials are used as feed stock when there is lack of food. Bedding material must not be too dense or packed too tightly. Porosity of the bedding material is need for water and air flow. It is good to consider particle size and shape, the texture, and the strength and rigidity of its structure which are provided as bedding materials. An important factor in selecting materials for bedding is the (Carbon: Nitrogen ratio).which affect the suitability of materials for worms. Commonly used bedding materials are peat, paper and in the context of Ethiopia crop residues can also be used.

Feeds must be given. Worms usually prefer feeds with high protein or nitrogen content, smaller particle size for a rapid degradation. According to Evergreen (2010) and Cochran (2010) meat, dairy, fish, bones, onion, oils, fresh manure, hot spices, vinegar and citrus, sauces are not suitable food for worms. Any processed food at home; raw materials with plastics, metals are not suitable too. Whereas fruit, plant leaves, crushed eggshell, papers, pre-fermented manures are suitable for worms. Manures are the most commonly used feedstock. Manure from cattle, sheep and goat and a small amount of poultry manure are generally considered the best natural food for red earth worms (Munroe, 2007). If manure contains excess urines it has to be drained before use.

Table 5: Characteristics of bedding materials

Bedding Material	Absorbency	C:N Ratio
Horse Manure	Medium-Good	22 - 56
Peat Moss	Good	58
Maize Silage	Medium-Good	38 - 43
Hay/straw – general	Poor	15 - 150
Paper, news paper	Medium-Good	127 - 178
Bark – soft and hard woods	Poor	131 - 1285
Sawdust	Poor-Medium	142 - 750
Shrub trimmings	Poor	53
Leaves (dry, loose)	Poor-Medium	40 - 80
Maize stalks	Poor	60 - 73

Source: Modified after Munroe, 2007

Review shows that a C:N ratio is in the range of 15-35:1 is suitable for Vermicomposting. In Vermicomposting or Vermiculture operations, the high-C materials are used as **bedding**, while the high-N materials are generally **feed stocks** (Munroe, 2007).

***STEP 4**: Identify right kind of food for earthworms? Feed the earthworms at regular interval?*

Feed once or twice in a week by looking at earthworms in the bin. Maintain moisture, aired and look of suitable bedding material. Feed them not at the top but at the pile of bedding material. How regular the intervals for feeding are depends on viability of scraps added.

If you want to get more vermicompost and previously existing compost exists, add worms in a compost pile in a batch. Compost heaps should be protected from heavy rains, strong sunshine which may lead to drought and predators (birds, rates, snakes, cock-roaches, ants). A cover could be banana leaves, corrugated iron sheet, wood, polyethylene.

Vermicomposting

Vermicomposting is a method of preparing enriched compost with the use of earthworms. It is one of the easiest methods to recycle agricultural wastes and to produce quality compost. Earthworms consume biomass and excrete it in digested form called worm casts. Worm casts are popularly called as Black gold. The casts are rich in nutrients, growth promoting substances, beneficial soil micro flora and have properties of inhibiting pathogenic microbes. Vermicompost is stable, fine granular organic manure, which enriches soil quality by improving its physicochemical and biological properties. It is highly useful in raising seedlings and for crop production. Vermicompost is becoming popular as a major component of organic farming systems.

Vermicomposting materials

Decomposable organic wastes such as animal excreta, kitchen waste, farm residues and forest litter are commonly used as composting materials. In general, animal dung mostly cow dung and dried chopped crop residues are the key raw materials. Mixtures of leguminous and non-leguminous crop residues enrich the quality of vermicompost.

Types of Vermicomposting

The types of Vermicomposting depend upon the amount of production and composting structures. Small-scale Vermicomposting is done to meet the personal requirement and the farmer can harvest 5-10 tones of vermicompost annually. While, large-scale Vermicomposting is done at commercial scale by recycling large quantity of organic waste with the production of more than 50 – 100 tons annually

Methods of Vermicomposting

Vermicomposting is done by various methods, among them bed and pit methods are more common:

The Pit Method: Composting is done in the cemented pits of size 5x5x3 feet. The unit is covered with thatch grass or any other locally available materials. This method is not preferred due to poor aeration, water logging at bottom, and more cost of production.

Figure 19: Bed composting

Figure 20 *:* Pit composting

Process of Vermicomposting

Following are the vermicompost preparation processes.

- Vermicomposting unit should be in cool, moist and shady site.
- Cow dung and chopped dried leafy materials are mixed in the proportion of 3: 1 and are kept for partial decomposition for 15 – 20 days.
- A layer of 15-20cm of chopped dried leaves/grasses should be kept as bedding material at the bottom of the bed.
- Beds of partially decomposed material of size 6x2x2 feet should be made (Picture 15). Each bed should contain 1.5-2.0q of raw material and the number of beds can be increased as per raw material availability and requirement.
- Red earthworms (1500-2000) should be released on the upper layer of bed (Picture 16).
- Water should be sprinkled immediately after the release of worms.
- Beds should be kept moist by sprinkling of water (daily) and by covering with gunny bags/polythene (Picture 15).
- Beds should be turned once after 30 days for maintaining aeration and for proper decomposition. Compost gets ready in 45-50 days, figure 19. The finished product is 3/4th of the raw materials used.

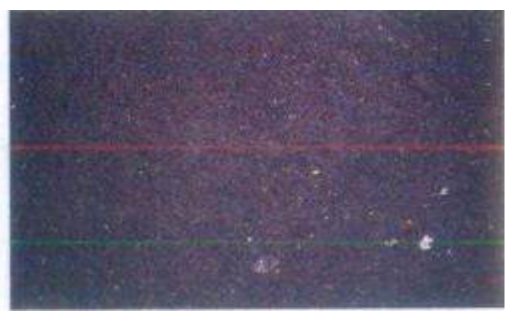
Harvesting

When raw material is completely decomposed it appears black and granular. Watering should be stopped as compost gets becomes. The compost should be kept over a heap of partially decomposed cow dung so that earthworms could migrate to cow dung from compost. After two days compost can be separated and sieved for use (Picture 17).

Figure 21: Beds covering with gunny bags & Watering of Beds


Figure 22: bed for raw material to use & Red Earth worms to use


Figure 23: harvested final product heaped after sieving

Preventive measures

- The floor of the unit should be compact to prevent earthworms' migration into the soil.
- 15-20 day's old cow dung should be used to avoid excess heat.
- The organic waste should be free from plastics, chemicals, pesticides & metals etc.
- Aeration should be maintained for proper growth and multiplication of earthworms.
- Optimum moisture level (30-40 %) should be maintained 18-25^{o}C temperature should be maintained for proper decomposition.

Nutrient content of vermicompost

The level of nutrients in compost depends upon the source of the raw material and the Species of earthworm. A fine worm cast is rich in N P K besides other nutrients. Nutrients in vermicompost are in readily available form and are released within a Month of application.

Table 6: Composition of Vermicompost

Nutrients	Contents
Organic carbon (%)	9.15-17.98
Total Nitrogen (%)	0.5-1.5
Available phosphorus (%)	0.1-0.3
Total phosphorus (%)	1.34-2.2
Available potassium (%)	0.15-0.56
Total potassium (%)	0.40-0.67
Available sodium (%)	0.06-0.30
Calcium and Magnesium(meq/100g)	22.67-70.00
Copper (ppm)	2.0-9.5
Iron (ppm)	2.0-9.3
Zinc (ppm)	5.7-11.5
Available sulphur (ppm)	128.1-546.0

Advantages

There are many advantages of vermicompost:

1) It provides efficient conversion of organic wastes/crop/animal residues
2) It is a stable and enriched soil conditioner.
3) It helps in reducing population of pathogenic microbes.
4) It helps in reducing the toxicity of heavy metals.
5) It is economically viable and environmentally safe nutrient supplement for Organic food production.
6) It is an easily adoptable low cost technology.

Doses

The doses of vermicompost application depend upon the type of crop grown in the field/nursery. For fruit crops, it is applied in the tree basin. It is added in the pot mixture for potted ornamental plants and for raising seedlings. Vermicompost should be used as a component of integrated nutrient supply system.

Table 7: Amount of Vermicompost to be applied

Crops	Dose/rate
Field crops	*5-6 t / ha*
Fruit crops	*3-5kg / plant*
Pots	*100-200g / pot*

3.4 Using Compost

Composts can be used for vegetable, potting soil, nursery soil, planting trees, Fish feed, erosion prevention and agronomic crops. Composts can be spread and left on the surface or incorporated into the soil by plowing. Composts also are used to grow greenhouse crops and form the basis of some potting soil mixes.

Composts should not be applied annually at high rates. That is a recipe for overloading the soil with nutrients.

Compost should never be left uncovered in the rain or in the sun. The rain washes out the nutrients and the sun can cause burning. The compost then loses its fertility. To reduce this loss the compost should be covered. Some useful covers are: banana leaves, intertwined palm leaves or a sheet of plastic. If the compost is left too long, it may also become a breeding place for unwanted insects, such as termites and the rhinoceros beetle (Oryctes rhinoceros).

Managing and application of composts

Mature compost is best stored in a pit or heap until it is needed. If it is kept dry and covered, mature compost can be stored for several weeks without deteriorating.

- The stored mature compost should be kept in a sheltered place, e.g. under the shade of a tree or in a shed, and covered with leaves and/or soil and sticks to prevent the nutrients escaping to the atmosphere, and animals trampling on and damaging the mature compost heap.
- Mature compost should be taken to the field early in the morning or late in the afternoon.
- For crops sown by broadcasting, the compost should be spread equally over the field, or the part of the field chosen to be treated with compost.
- The compost should be ploughed in immediately to mix it with the soil and prevent loss of nutrients from exposure to the sun and wind. For row planted crops, e.g. maize, sorghum and vegetables, the compost can be put along the row with the seeds or seedlings.
- For trees, compost is put in the bottom of the planting hole and covered by some soil when the seedling is planted out. It can also be dug into the soil around the bottom of a tree seedling after it has been planted.
- Time and effort are needed to make good compost, so it is worthwhile to also put in time and effort into using it properly in the field.

A rough estimate on amounts of compost applied per unit area

In Ethiopia, more research is needed to find out how much compost is needed to get good yields in the different agro-ecological zones. However, in Tigray, it is observed that compost added at the rate of 3.2–6 tons per hectare can give greatly improved yields, which are as good as, if not better than those from chemical fertilizer (see Edwards *et al.*, 2007). In wetter areas, farmers find that 5–8 tons per hectare can improve crop yields.

The following is a guide on the amount of compost to aim to produce under different environmental conditions:

- Mature compost to give a rate of 8–10 tons per hectare can be achieved in areas where there are plenty of composting materials, a good water supply and labour. Farmers working in groups are more likely to be able to produce large quantities of good quality compost than farmers working alone. These quantities have been achieved in Adi Abo Mossa village in Southern Tigray and Gimbichu district in Oromiya Regions.
- Mature compost to give a rate of around 6 tons per hectare can be achieved where there are medium amounts of composting materials, and water and labour are available. These quantities have been achieved by farmers working in Central Tigray near the town of Axum.
- Mature compost to give a rate of around 3.5 tons per hectare can bring improved yields. This can be achieved even in areas with low availability of composting materials, as long as there is enough water to moisten the composting materials. These rates have been achieved by farmers in the semi-arid eastern parts of Tigray.

- Where there are only small amounts of composting materials, e.g. for farmers who have very small plots of land and for women-headed households, working together to fill a common pit can make better quality compost than working alone.

3.5 Socio-economic considerations and ways of introducing composting

The current severe problems of soil fertility management in Ethiopia are:

- Increased population density with dominantly low income of smallholders, which depend heavily on soil nutrients for food and biomass for energy.
- Everything produced from the soil is used as much as possible and very little remains to re-invest in soil replenishment or inputs for the following year.
- Crop residues used for livestock feed and manure for fuel, respectively.
- In some cases, manure is used as a source of supplementary cash income.
- Supply of both dung and crop residues are scarce to begin with.
- Severe topsoil erosion, about137t/ha/year.
- Weak knowledge dissemination and limited enforcement of land management guidelines,

Ways of Introducing Composting

4 Prepare ground for awareness creation and field demonstration, technical and external financial support (revolving fund) for making compost and means of transportation if needed.

5 Introduce a rural energy source like Solar, Bio gas, hydro power, and fast growing energy wood where possible to make the animal manure and crop residues free to be used for soil fertility management and etc. to save the ecosystem from total failure.

6 Organizing Income Generation Groups and create job for resource poor member of communities in compost preparation, transporting and application actives.

Attention has to be given to unused animal manure and urine left unused in the barn during night time around home stead (Picture 18 below).

Figure 24: Accumulated animal manure-heap around homestead (Fentale, Oromia)

3.6 Agro-climatic aspect of composting and compost application

3.6.1 Agro-climatic aspect of composting

Composting is very suitable for dryer areas where crop residues decompose very slowly in the field. In this situation compost provides greater yields for the farmers. In very dry areas composting can be difficult because water and organic material are scarce. The organic material that is available is also often used as cooking fuel. Compost is still a good alternative to mulching, which is unpopular in these areas because it often results in an invasion of termites.

Compost also gives better results than chemical fertilizer due to its richer and chemically more balanced composition. Besides its chemical composition compost increases the water retention capacity of the soil and it improves the soil structure.

In areas with heavy rainfall, mulches and green manures are usually used together with permanent crops. Decomposition occurs fast enough on the field. So composting crop residues is not worthy.

If there are clearly defined rainy seasons and dry seasons, then composting can be done at the beginning of the rainy season in prepared composting sites. Spreading the material before composting allows it to get thoroughly wet first.

3.6.2 Compost Application

Agro climatic resource evaluation is very important for compost application. For application of compost sufficient soil moisture is needed for plant growth. If this is not met the chance for the soil to buffer even toxic substances will be jeopardized, which may result adverse effects on the plants.

MODULE 4: MANURE AND ITS APPLICATION

4.1 Concept

Manure consists of animal excrement, usually mixed with straw or leaves. The nutrients from animal feed are partly stored in the animals' bodies. By spreading their excrement and urine onto a field, these nutrients are made available to the plants. If cattle graze freely they can gather their own food, and their excrement is thus spread randomly over the field. A great deal of nitrogen is then leached or volatilized. Potassium is also partially leached. To use the excrement as manure it is thus better to keep the animals in a stable. The nutrients in the manure can then be protected from being leached and lost.
The goals of applying manure are to:

1. increase the level of organic matter;
2. increase the available nutrients;
3. Provide biological diversity in the soil.
4. Improve the structure (aggregate formation) and water retention capacity of the soil.
5. increase moisture holding capacity

4.2 Quantity and composition of manure

The quantity and quality of the excrement depends on the animals' feed, age of animal and animal species. Good manure contains more than just excrement and urine (table 5)

Animal manures can have very different properties depending on the animal species, feed, bedding, handling, and manure storage practices (see Table 5). The amounts of nutrients in the manure that become available to crops also depend on what time of year the manure is applied and how quickly it is worked into the soil. In addition, the influence of manure on soil organic matter and plant growth is influenced by soil type.

In addition to Nitrogen (N) phosphorus (P_2O_5) and potassium (K_2O), animal manure can be a good source of other macronutrients (Calcium, Magnesium, Sulfur)) and most essential micronutrients. Micronutrients present in manure and the chelation of these elements by various manure fractions help to prevent micronutrient deficiencies.

Table 8: Nutrient content (NPK) in some commonly used organic materials

Organic matter	Nitrogen (%)	Phosphorus (%)	Potassium (%)
Cow manure	0.4-0.6	0.2	0.2-0.5
Horse manure	0.5-0.7	0.3	0.6
Goat manure	1.4	0.2	0.3-1.0
Sheep manure	0.7	0.3	0.4
Human waste	2.0	1.0	0.2
Pig manure	0.5	0.3-0.4	0.5-0.8
Poultry manure	1.1-1.5	0.8-1.3	0.5-2.7
Rabbit manure	1.1-2.4	1.2-1.4	0.6
Boma (mixed animals)	0.7	0.1	0.7
Compost (households)	0.5	0.2	0.8
Gravillea leaves	1.37	0.06	0.64
Bean trash	0.80	0.07	1.57
Banana stalks	0.73	0.18	4.10
Sugar cane trash	0.47	0.06	1.23
Banana leaves	1.30	0.10	1.72
Coffee husks	1.63	0.14	4.45
Sweet potato vines	1.73	0.48	6.63
Leucaena leucocephala	3.74	0.26	3.37
Cajanus	3.62	0.21	n/a
Jack bean	3.45	0.16	n/a
Desmodium	3.44	0.15	n/a
Soybean	3.52	0.15	n/a
Lablab	4.02	0.18	n/a
Ground nut	3.25	0.18	n/a
Purple vetch	3.68	0.16	n/a

4.3 Producing and managing Farm Yard Manure (FYM)

The form in which nutrients occur in the manure is important not only because it determines the ease with which nutrients are released for plant use but also because it can affect the retention of nutrients in manure that must be stored for a period prior to its application to the land. Nutrient loss during manure storage can result either from leaching of soluble, mobile elements, such as potassium or boron, or from the volatilization loss of ammonia ($NH_{3)}$ gas. Fortunately, potassium and most micro nutrients are retained in relatively immobile form in manure and are therefore not susceptible to leaching or volatilization.

The nitrogen originally present as urea in manure is the most critical aspect of nutrient conservation. Good aeration encourages microbial activity that causes the heap to heat excessively and dry rapidly. Both heating and drying hasten the loss of ammonia.

From these considerations we may conclude the storage of manure in a compacted state is desirable. Keeping the manure moist aids in maintain anaerobic conditions within the heap. Stored manure should be protected from excess water that would cause nutrient loss by leaching.

Method of storage and stacking

As described above storage of manure has to be in a compacted state by keeping optimum moisture contents in anaerobic conditions within the heap. Hence the following techniques have to be followed.

1) Spread sufficient litter as bedding for animals to facilitate absorption of urine.
2) Use all cow dung without diverting any of the preparation of cow dung cake for fuel.
3) Conserve and mix all urine with dung and straw.
4) The Pit should be one meter in depth, two meters in width and of any convenient length. Floor should be sloping in one direction.
5) Fill the pit Systematically layer by layer each layer being 20-30 cm in height and cover each day`s with a thin layer of soil.
6) Enriching with phosphoric fertilizer is advisable.
7) Excess water should not get into the pit. Where this is difficult to avoid, it is better to adopt the heap method above the ground.

4.4 Quality and quantity of Farm Yard Manure

Farm animal excrete, dung and urine which are rich in plant nutrients, good quantity of straw and other plant material becomes available to farmers in some seasons of the year. Dung, urine and plant residues can be either incorporated directly in soil or systematically mixed and preserved in pits or heaps until converted into compost through a decomposition process. The final produce is known popularly as farmyard compost. It may contain about 1% nitrogen (N), 0.5 % phosphorus (P_2O_5) and 1% potassium (K_2O) depending upon the type and age of animals, the way they are fed, the quantity and quality of plant material mixed and the care taken in collecting, preserving and handling of materials.

4.5 Spreading FYM: Techniques and quantities

Spreading of farm yard manure in the field has to be done only in one day; otherwise, a great loss of nitrogen will be caused if left open in the field. The suitable time for FYM application is when there is sufficient soil moisture before planting time. Application of farm yard manure in dry soil can causes loss of nitrogen. After uniform distribution of FYM in the respective field by using simple hand tools (spade, fork), covering with soil by plowing to recommended depth has to be done in the same day. The depth of manure covering with soil depends upon soil types and climatic condition. In arid (dry) climate and sandy to loam soil texture class (light texture) the depth will be at least 20-22 cm, deeper. In heavy soil texture and moist to humid climatic condition the depth will be less and may vary from 12-14 cm.

The amount of FYM to be applied is based on crop type (variety) yield of crop, soil type, humus balance assumed to be maintained on the basis of agro ecological conditions whereby such data has to be released by research institutions. For field crops the doze of FYM should not be less than 5t/ ha; the remaining can be supplemented by chemical fertilizers. The optimum doze may vary between 8-10t/ha. However, the sole application of FYM at the rates of 4-12 t ha^{-1} is also encouraging for resource poor farmers on relatively fertile soils like Walda and Harato areas (Wakene Negassa, 2005).

Therefore, the exact doze of application should be referred from nearby Agricultural research station for specific locality.

4.6 Effects of using FYM

Using farm yard manure improves all agronomic soil property, soil physical, chemical and biological condition, by doing this sustainable land management will be achieved.

The effects of Farm Yard Manure are indicated as follows:

- The increase in the level of organic matter and humus
- The increase and availability of nutrients, macro and micro elements
- The provision of high level of biological diversity in the soil.
- Improves the structure (aggregate formation) and water retention capacity of the soil.
- Improves water availability and soil aggregates.
- Increases moisture holding capacity
- Improves level of soil acidity.
- Decreases mobility of aluminum and manganese
- Improves soil base saturation
- Improves soil buffer property
- Improves soil workability which means, less time, energy and lower cost of land preparation for the farmer
- Increases carbon dioxide (Co_2) concentration which improves plant nutrition
- Improves crop productivity and yield quality
- Improves plant and animal health.
- Alleviates problems of food security.
- Achieves Environmental Sustainability, and,
- Achieves Sustainable Land management Goal.

4.7 Socio-economic consideration

The socio economic conditions of manure management and application in specific agro ecology are specifically influenced by bio physical resources (soil types, rain fall, vegetation/land cover etc.) and socio economic situation (productivities of the land resources, house income, proximity to market, awareness etc) of the area.
The attitude of the community towards Farm Yard Manure preparation and utilization is influenced by diversity of agro climatic zone distribution, low income (self insufficiency), and access to market for cow dung cake sales etc.

In dry agro climatic area (low lands) the rain fall is very small and erratic with the way of life being dominated by pastoralists and agro-pastoralists. In this agro climatic condition, farm yard manure is commonly thrown around the homestead. Particularly in coffee and *Enset* growing areas the application of FYM is very important. However, due to lack of sufficient knowledge and competitiveness its utilization is limited. In predominantly cereal crops production areas, for example, in Shewa, Arsi, Bale, Hararghe and east Wellega, FYM is used as source of household energy and one source of income rather than used on farm. In addition, shortage of transportation of the farm yard manure from homestead area to farm lands as well as shortage of external funds to create awareness in management and applications FYM for Sustainable Soil Fertility Management is the major problem.

4.8 Climatic zone consideration

In Most of the areas with sufficient rainfall (the high and mid lands) farmers often do not have enough cattle to produce sufficient amounts of manure. However, good alternatives are available in the form of plant residues. In the semi-humid and humid area and acidic soil condition,conditions are better for raising cattle and less manure is needed for a substantial improvement of the soil fertility, because the organic matter decomposes slower.

In semi-arid and arid areas it is more difficult to keep the animals in a stable, because feed is scarce, and it is not possible to grow the feed. One option in this situation is to allow the animals to graze during the day, and to keep them in the stable at night. The manure is then kept in a manure cone to keep it from drying out too fast. On the other hand crop production in this area is highly limited by rain fall amount and distribution. Therefore, the above problem must be given due attention while promoting the technologies of FYM.

MODULE 5: USES OF AGRO-FORESTRY IN SOIL FERTILITY MANAGEMENT

5.1 Concept of agro-forestry

Agro forestry is a forestry agriculture integrated land use system whereby ecological (conservation) and economic (production) concerns of the farm owners are better addressed than mono culture farming on the same unit of land. The components of agro forestry are forestry, horticulture, range and agronomic crops. The arrangements of these various crops both in space and time form the different kinds of agro forestry systems.

The most important goals of agro forestry are to:

- maintain soil organic matter and physical properties;
- increase nutrient inputs, through nitrogen fixation and uptake from deep soil horizons;
- promote more closed nutrient cycling
- prevent the loss of nutrients;
- check runoff and soil erosion.

In many places in Africa, 30-250% higher yield was found on maize, millet, groundnut and sorghum crops grown beneath Faidherbia *albida* canopies (Charreau and Vidal, 1994). In Zambia, results of 15 sets of observations conducted by the conservation Farming Unit (CFU) in the 2008 growing season found that unfertilized maize yields in the vicinity of Faidherbia *albida* trees averaged 4.1 t/ha, compared to 1.3 t/ha nearby but beyond the tree canopy (Aagard 2009). An evaluation of the F. *albida*-based agro forestry practices was made in the Hareghe highlands of eastern Ethiopia by Peter Poschen in 1986 based on yield samples collected under the tree canopy and away from the trees. A statistically significant increase in crops yields by 56% on average was found for the crops under the tree canopies compared to those away from the trees.

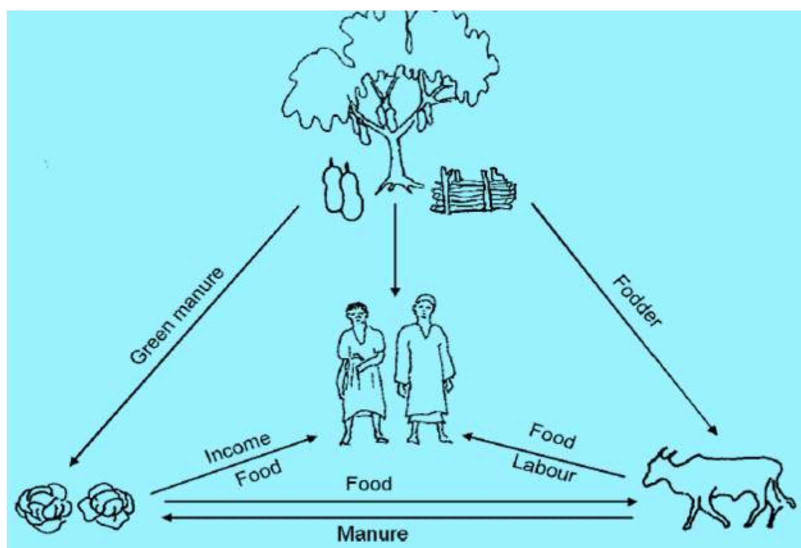


Figure 25: Interactions between trees, field crops, animals and people

This remarkable increase in crop production beneath F. *albida* canopies is referred to as the 'Albida effect'. The Albida effect results from both increase in soil fertility and improved soil water micro-climatic conditions below tree. Through leaf and pod fall, nitrogen fixation and association with soil micro-organisms, fertility accumulation under the canopy is reported as follows: 75kg N, 27kg P2O5, 183kg CaO, 39kg MgO, 19kg K2O, and 20kg S. This is equivalent to 300kg of complete fertilizer and 250kg of lime. This is equivalent to 300kg of complete fertilizer and 250kg of lime worth at least $165 today and provides the recommended nutrient requirement for a 4 ton maize crop (Peter Aagaard. 2007).

5.2 Establishing sustainable agro-forestry systems

Planning effective and sustainable agro forestry system that can be achieved by the optimum use of different land uses with the various agro forestry components, significantly achieves the purpose of *Sustainable Land Management*. Accordingly the following combinations of Agro-Forestry with different land use option are suggested for better uses.

a) **Agrisilvi-culture**; this is one of the agro forestry systems where agronomic crops are combined with bushes, shrubs/trees on the same unit of land for better and sustained production of annual crops and browse fodder and wood. The combination could be arranged in time sequence.

b) **Hedgerows inter-cropping** is an Agrisilvi-culture sub system by which trees/shrubs are grown in rows of hedged and agronomic crops are grown between the hedges in alleys. This cropping practice where by food crops are grown in alleys between the hedges is called **alley cropping**. There are two types of alleys, *intensive* and *wide alleys*.

1) *Intensive alleys* - have close spacing of *0.15-0.*25 meter between trees within rows and 2-4 meters between rows of tree (see e.g. picture 19).

- The distance between hedges in the situation of Ethiopian farmers (oxen-drawn wooden plough) have to be 10-15 meters. Here fast growing trees of shrubby and coppicing and nitrogen fixing should be planted. For this purpose *Sesbania sesban, Cajanus cajan* and *Leucaena leucocephala* are superior because of their fast growing, nitrogen fixing and producing more biomass for soil fertility improvements.

Figure 26: Legume crops sown in an alley cropping system

- In drier area *Cajanus Cajan* performs better. At the beginning of the rainy season the trees are pruned to a height of 0.5 to 1 m.
- The twigs and leaves are laid in the lines as mulch or incorporated to the soil. The branches are used as firewood or stakes. The crops are sown in the lines through the mulch layer. During the growing season the trees have to be pruned regularly, to prevent them from shading the crop.
- For trees that quickly produce shoots, a height of 0.5 m is best; trees that grow slower can be pruned higher. The leaves can be applied to the crop as ‘top-dressing’. After the crop has been harvested, the trees’ shoots can be allowed to grow, so that the trees can provide enough shade to inhibit weed growth. Trimming and pruning are common management practices. The advantages are mulching/green manuring, ground cover, root systems, and natural terraces.

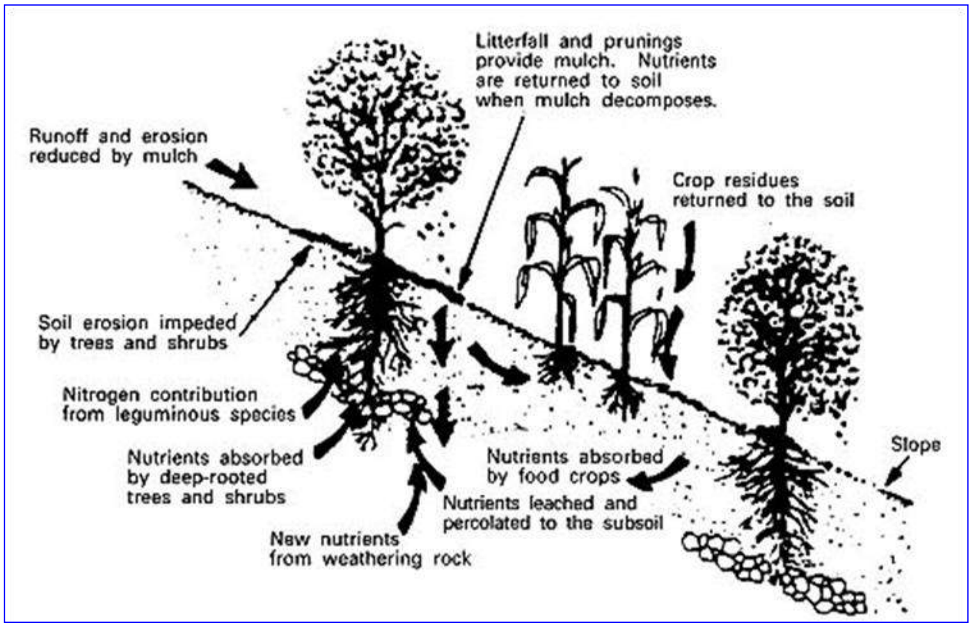


Figure 27: The alley cropping concept

2) *Wide Alleys* - rows of trees in wide spaced rows of 8-20 meter between rows and 0.5-1 meter between trees within rows. The objective here is to improve soil fertility and to get fruits, poles, seeds, firewood; timbers etc. for the purpose of soil fertility improvement species like *Sesbania sesban* and *Leucaena leucocephala are more preferred.* To minimize the shed effect alleys shall be oriented west to east. Management options are thinning, pruning, and pollarding.

- Bund stabilization planting: this can be done by grasses and leguminous fodder shrub. The leguminous shrub plants fix nitrogen to the soil from which the crops growing between the bunds can benefit. When rows are not required, trees would be grown in scattered form over a crop field. By then, 50-150 trees per hectare would be grown. The best tree species preferred for this purpose is: *Cajanus Cajan,* Sesbania sesban*, Faidherbia albida* and *Leucaena leucocephala*. The suggested grass legumes species to be grown in between rows of the trees are lablab, Disodium, siratro and clover etc.
- *Silvi-pasture*: is agro forestry sub system where ranges crops/ animal and trees are combined for better production of grasses browse fodder with trees of various utilities. The practices are carried out on rangelands from production of both feed and woody material is intended along with production of grasses. The subsystem would satisfy the farm owner from both feed and wood requirements point of view. The grazing area must be fenced first and compartmentalized by life fences. The improvement shall be done compartment by compartment.
- *Silvi-pastoral*: it is a growing of growing of grasses and tree, leguminous shrubs together on hillsides where conservation activities is conducted. Timber, local construction wood and fuel wood fuel wood may be produced. Cattle feed from the fodder shrubs and grasses may also be obtained. The same will apply on lands that are found sides of river gullies, cut of drains, waterways, and around lakes, ponds, reservoirs, and other important water bodies.

Choice factors for grasses to be used in a silivi-pasture subsystem are:

- Having fibrous or seminal rooting systems.
- Being perennials or biannuals.
- Being shade tolerant.
- Producing more leaf blade and less leaf sheath.
- Having less running and invader characteristics.

Choice factors for agro forestry tree/shrub species to be used in the *Agri-silvi-pasture* subsystems may be having:

- deep rooted and narrow root zone.
- good coppicing ability.
- nutritious and palatable leaves, pod, fruit, etc.
- good phonological for crop compatibility.
- enriching ability for soil nutrients.
- fast growth potential
- multipurpose quality
- ability to yield economic by products
- no self pruning or aggressive competitors' with compatible crop for shade, moisture, and soil nutrients.
- Have deep root systems (starting with seeds rather than cuttings is preferable, because the directly sown plants develop deeper root systems and are more resistant to termites).
- Significant known social acceptance in the locality.

Agri-silvi-pasture

It is an agro-Forestry practice by which food, pasture, and tree/shrub crops are combined on the same unit of land (constraints by slope) for the production of grass and browse feed as well as biomass for green manure. Alternative rows of hedgerows, grass strips, and crops in alley form such a system.

Home Garden Agro- Forestry Sub System

This is a mix of trees, horticultural crops, grasses, spices etc. close to residential areas.

A mix of vernonia, amigdilana, lemon, grass, and coffee, cordial at the back yard would be an example of this sub system.

5.3 Effects of agro-forestry on soils

Cultivating woody species together with other crops reduces nutrient loss. Trees and bushes generally have highly developed root systems, which can absorb many nutrients that are lost to crops with shallow root systems. The nutrients are 'stored' in the woody species. In this way they are protected from being leached in periods when no other crops are cultivated. After the leaves or cuttings fall to the ground, the nutrients once again become available to the crops via decomposition. This effect of woody species is sometimes called a 'nutrient pump'.

Trees and shrubs can form hedges that protect crops and soil from wind and the water of heavy rains running off over the surface of the soil.

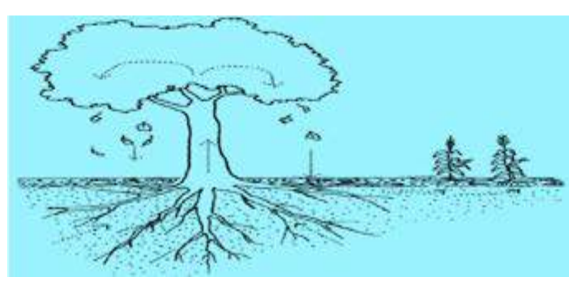


Figure 28*:* Trees act as nutrient pumps

Trees and shrubs play a role in modification of extremes of soil temperature through a combination of shading by canopy and litter cover, processes which affect soil chemical conditions.

Maintenance or improvement of soil physical properties (structure, porosity, moisture retention capacity and permeability) through a combination of maintenance of organic matter and effects of roots Modification of extremes of soil temperature through a combination of shading by canopy and litter cover. Processes which affect soil chemical conditions, reduction of acidity, through addition of bases in tree litter leaves and cuttings can serve as mulch.

The mulch obtained through the pruning of the trees and shrubs protects the soil surface from the impact of rain showers, thus there is less soil erosion. The soil becomes more fertile and the effect of fertilizers on production improves; the workability of the soil improves because the soil becomes softer, production of a range of different qualities of plant litter through supply of a mixture of woody and herbaceous material, including root residues.

How trees improve soils

- Increasing inputs (organic matter, nitrogen fixation, nutrient uptake)
- reducing losses (organic matter, recycling and checking erosion
- improving soil physical properties capacity
- Beneficial effects on soil biological nutrients) by promoting, including water-holding processes.

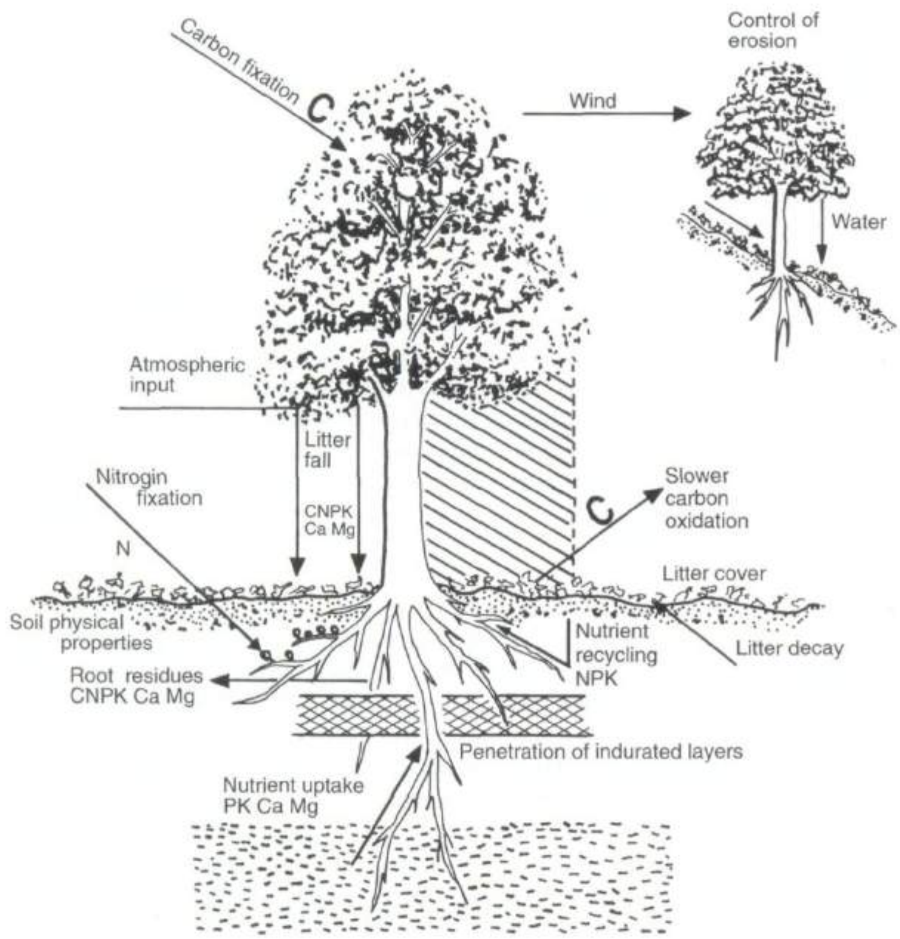


Figure 29: Processes by which trees improve soils

5.4 Economic considerations

Economic analysis revealed that, in situations where a farmer provides all labour from within the family, and does not involve hired labour, a maize yield increase of 65%, following a fallow, is required to break even. Where the farmer hires 50% of the labour, then only a 12% maize yield increase is required to break even. This is because labour costs saved by not cultivating during the fallow period are much higher in the latter scenario. It was also noted that profitability from fallows increases when base yields are low and when farmers use hired labour during cultivation.

Method of Implementation: there are many possible ways to combine woody species with crops or livestock. A number of possibilities have been discussed above. It is often not possible to implement an example exactly as described ever everyplace. Try to implement systems whose advantages best fit the circumstances. However, to prevent competition with the main crop, it is extremely important to regularly prune the trees or bushes and to thin out their roots by trimming them to one half meter around. Try to adapt the example by using trees that already grow in the area, and that provide the same advantages. Pay attention to climatic conditions; some systems work well only in certain climates.

MODULE 6: GREEN MANURE AND INTENSIVE FALLOWING

6.1 Concept and general principle

Green manure is a common practice to add leafy material to enrich the worn out soil. The material from certain kinds of trees especially that belonging to the legume family is preferred since it is rich in nitrogen. Green manuring consists of ploughing in green, not woody plants or plant parts. The plant material can come from a crop that was grown after or between the main crops, or from a weed that grew during a fallow period.
During their growth period, green manures provide the same benefits as mulch. They are therefore sometimes called ‘living mulch’. Their advantage over mulch is that they absorb nutrients, so these cannot be leached during a period in which no main crops are grown. After the green manures are ploughed under, these nutrients become available via decomposition.

Green manure enriches the soil with organic matter and Nitrogen. Depending on manuring conditions, one hectare of arable land often receives 35 to 45 tones fresh organic matter containing 150 to 200 kilogram of nitrogen fixed by nodule bacteria (when leguminous green crops are sown). Green manure contains almost the same (and even grater) amount of nitrogen as manure does, although its phosphorus and potassium contents are lower.

The factor of utilization green manure nitrogen by plants (during the first year of incorporation) is almost twice as high as that of manure nitrogen. Incorporation of green manure does not entail any losses of the nitrogen accumulated in it. Green manure decomposes much quicker than any other cellulose-rich organic fertilizers. Green manure can use in the area where organic fertilizers are in an extremely short supply or where the transportation is difficult.

Green manures also have a positive effect on the soil structure, because of the penetration of their root systems, they add organic matter, and they stimulate the growth of soil organisms. Organic matter nourishes the soil organisms, which also benefit from the higher moisture. Green manure protects the soil against rain and wind erosion, dehydration and extreme temperature fluctuations at a time when no other crops are present; and, when using leguminous plants as green manure.

6.2 Green manuring with Leaves

In this method, green leafy materials, are collected from other places and added to the soil to enrich with organic amendment. This practice is not very common in the existing farming systems of the country. However there are potential suitable green leaves that can be used for this purpose. There are potential areas such as homestead, road side, river side and miscellaneous lands that can be used to grow use full shrubs/trees such as pigeon peas, (Cajanus Cajan), Leucaena leucocephala, Sesbania sesban, Acacia albida, Cassia siamea, Albizia lebbek, Acacia abyssinica, Acacia deccurrens, and others shade plants or trees whose cuttings or fallen leaves are suitable for ploughing into the soil.

Therefore, if more attentions are given green manuring with leaves technique can be applied anywhere to improve the level soil organic matter.

6.3 Green manuring with roots and stubble

There is also a variety of ways to apply grown green manure crops. As a green manure either the entire plant material (including the above-ground parts and roots) or only part of it can be used. In this respect, three basic forms of green manure are distinguished: complete, mown, and aftermath.

Green manure is said to be complete when the entire plant material is ploughed down.

It is define as mown when incorporated into the soil are only the above ground parts of green manure crops grown elsewhere and brought to the field to be treated after they have been mown.

Aftermath green manure implies plowing down of stubble and root residues of plants after the aftermaths have reached a certain height (e.g. plow down of the stubble with after growth following mowing and utilization of the green material of annual fodder lupine, sweet clover, clover, or other legumes).

6.4 Suitable green crops and their practical application

For green manure agronomic crops have to be attractive and economically viable, the plants should possess the following characteristics:

- They should have profuse leaves and rapid growth early in their life cycle.
- They should have abundant and succulent tops and be capable of making good stands even on poor and exhausted soils.
- They should yield large quantities of green material in a short period. For example, *S. aculeata*.
- They should be leguminous with good nodular growth habit, which is indicative of rapid N fixation even under unfavorable soil conditions.
- They should have a deep root system which can open the subsoil compaction for the supply of plant nutrients.
- They should be easy to manage during the establishment and incorporation into the soil. They should be tender (more leafy than woody growth) so that their decomposition is rapid. For example, *T. alexandrinum*.
- They should be tolerant to drought, shade, adverse temperature, insect–pest attack, diseases, etc., so that they can be easily incorporated.
- They should have the capacity to recycle nutrients.
- They should have the ability to produce seeds in sufficient quantities to increase the areas under the crop.
- They should not invade and cause difficulties for the succeeding crop in the crop rotation.

Thus raising species like *Leucaena leucocephala, Cassia siamea, Cajanus cajan, Albizia lebbek, Acacia abyssinica, Acacia albida, Acacia deccurrens, Acacia saligna, Sesbania sesban* etc. Species of trees and shrubs on the boundaries of fields is being recommended to increase the supply of green leafy materials for green manure purpose. They contain about 3% N, 0.5% phosphorus (P_2O_5) and 3% potassium (K_2O). It is also possible to raise a short season crop like cowpea, vetch, lablab, Mung bean etc grown for Green manure yield large quantities of non woody green material in a short period of six to eight week with a view of incorporating it into the soil to increase its organic matter content. Such a practice, known as green manure can be adopted with advantage under specific situations.

Legumes are the most commonly used green manure crops as they provide the biggest increase in soil nitrogen. Two or more of these crops, or different varieties of the same crop, are often planted together. This spreads the risk of one failing. Sometimes these crops are planted together with a food crop, such as *siratro with millet*; Siratro can fix Nitrogen, which it passes on to the companion millet. *Oats with vetch* can be planted in the same way.

Instead of sacrificing the whole season for growing green manure crop it may be possible to raise an intercrop in broadly spread crops like maize, cotton, sugarcane, etc.
During application of green manuring consideration of its effectiveness is paramount.

The effectiveness of green manuring depends on the yield of the crop serves as its source. The higher the yield and the greater the quantity of the incorporated green manure, then, the stronger its effect and aftereffect.
The following aspects need to be borne in mind for ensuring maximum benefit:

- For faster decomposition rate green manure has to be incorporated to a shallower depth.
- Add small amount of horse manure or fecal matter to green manure (for enrichment with microorganisms) accelerates the decomposition.
- Apply phosphates fertilizer and potassium also if necessary to get a good harvest
- If needed add inoculants
- Sow with higher seed rate and closer spacing than usual.
- Harvest and incorporate when the crop reaches growing stage.
- Mix plant material with surface soil.

Green manure is possible only when there is adequate moisture supply for decomposition and for growing the next crop.

Establishing green manure cover crops

1) Select the species best adapted to the area.
2) Plant the green manure cover crop either as relay cropping, pure stand, under sow, mixed crop, or immediately after main crop is harvested depending on specific locality of agro ecological and socio economic situation.
3) Plant mixtures of cover crops where possible.
4) Weed when necessary.
5) Leave the green manure cover crop as mulch in the field after harvesting the food crop.

Incorporate the mulch into the soil before planting the next crop. In the field most species re-seed themselves and this will ensure a continuous cover with the subsequent seasons.

There are various niches on the farm for which different species can be used, for example as hedges along boundaries; live cover for riverbank protection; contour buffer strips for terrace embankment stability and fodder supply; as a cereal/legume intercrop; sole forage crop; relay fallow crop for soil improvement; live mulch for ground cover on steep slopes; and in grass/legume mixtures in improved pastures.

6.5 Socio-economic aspect

Green manuring for soil fertility management technology is almost a new innovation in Ethiopian farming systems. Before implementation this technology awareness creation among different stakeholders will be the main activity. The efficiency of this technology will be very high as the cost of establishment is not very high. It is very useful while establishing green manure in specific agro ecology to consider different forms of green manure combination with the main crops.

Integration of green manuring in to farming system does not affect the main crops growing seasons. It is possible to use the following green manure cropping forms for specific locality:

1) **Independent**; when green manure crops occupy a field from one to two season or even several years. These crops normally occupy for a relatively short period of time i.e. between harvest of one crop and sow of the next crop.
2) **Mixed cropping or inter cropping**: implies growing a main crop on a field together with a green manure crop or growing the latter between rows of another crop. The green manure crop is plowed down immediately or soon after the main crop has been harvested. Another distinction depending on whether green manure crops occupy the entire field or separate strips is between solid and strip cropping.
3) **Subordinate**; Green manure crop are sown under the preceding main crop.
4) **Stubble:** green manure crop are sown immediately after the main crop has been harvested.

6.6 Agro-climatic aspect

In Ethiopia, lablab and vetch are the most common crops used for green manuring in the highlands and lowlands respectively. Vetch is well adapted to altitudes ranging between 1800-2500 m.a.s.l (Yilma Seyoum and Cajuste, 1980), while lablab is grown in 'Kola' and 'Weinadega' agro-ecological zones. In addition to vetch, croletria, mucuna, canavalia, tefrosia and stylosanthus can also be used for green manures in the highland.

How green manure is used in the farming system is mainly influenced by agro climatic conditions. If the residual moisture status distribution is prolonged after the main crop harvest, it will be better to grow green manure crops as a pure stand. In this case green manuring crops with a longer length of growing period can grow. Green manure crops with longer growing periods can have better nutrient concentration, hence, better effectiveness at green manuring.

In area with a single and shorter growing period, the way to grow green manure crop is to under sow between rows of the crops or incorporated green manure from other outside-farm sources. If the moisture status of the soil is not sufficient, it is difficult to incorporate the green manure crop into the soil.

Therefore, for managing of green manure technologies, selection of type of green manure crops and forms of application the knowledge of the specific agro climatic zone is essential.

MODULE 7: MULCH AND ITS APPLICATION

7.1 Introduction

Mulch refers essentially all organic and inorganic materials that serve as soil covers. The main emphasis here, however, is on conventional mulches of organic materials, where the soil is usually completely covered to various depths by plant materials added from outside sources.

The mulch system provides many benefits to the crop and soil by keeping the soil surface protected for as much of the time as possible. As the crop residues are decomposed they pass gradually through the stage of active organic matter, and then to more resistant humus. If the mulched soil is left undisturbed, much of the organic matter tends to accumulate on the surface, as under virgin or forest conditions. Where annual crops are grown, the mulch and soil are disturbed and much of the mulch is mixed each year with the surface of soil. In either case, the, plant residues exert the various physical, chemical and biological effects that are so beneficial to growth of plants; i.e., they accelerate the rate of formation of good, highly-valued topsoil.

7.2 Principle of mulching

Mulches are materials placed on the soil surface to protect it against raindrop impact and erosion, and to enhance its fertility. Crop residue mulching is a system of maintaining a protective cover of vegetative residues such as straw, maize stalks, palm fronds and stubble on the soil surface. The system is particularly valuable where a satisfactory plant cover cannot be established rapidly when erosion risk is greatest .

Mulching ads organic matter to the soil, reduces weed growth, and virtually eliminates erosion during the period when the ground is covered with mulch.

There are two principal mulching systems:

1) *In situ* mulching systems - plant residues remain where they fall on the ground (Picture 20).
2) *Cut-and-carry* mulching systems - plant residues are brought from elsewhere and used as mulch.

Figure 30: Mulching in a banana plantation

Crop residue mulching has numerous positive effects on crop production. However, it may require a change in existing cropping practices. For example, farmers may conventionally burn crop residues instead of returning them to the soil. *In situ* mulching depends on the design of appropriate cropping systems and crop rotations, which have to be integrated with the farming system. The greater labour demands of cut-and-carry systems represent a major constraint. Mulch may be more relevant in home gardens or for valuable horticulture crops than in less intensive farming systems.

As the plantation matures the trash from harvested plants, de-sucking and de-leafing will provide additional soil protection and increase soil organic matter.

7.3 Mulching materials

The mulch itself can be almost any material, biodegradable or otherwise: crop Residues (stems, leaves, harvested pods etc.), grass cuttings, branches or young trees, pulled up or hoed weeds, leaves, sawdust and even jute, or plastic sheeting.

Figure 31: Soybeans grown under no-till with maize residue

The Pruning's of crops such as banana, tea and coffee can also be used as mulch. Old carpets work well, on a small scale, if they are made of natural material. Green manure crops can also act as mulch. They can be pulled up, hoed or cut down and then left on the soil surface to act as the mulch. They can be ploughed in after some time, and so complete their dual-purpose role of green manure and mulch.

Once the plantation is established, the soil should be managed to provide the best environment for the plant roots. This will involve the application of fertilisers and soil additives aimed at improving the physical, chemical and biological properties of the soil to benefit crop growth.

Figure 32: No-till maize under black oat mulch

7.4 Techniques of mulch application

(How to apply, minimum depth of mulching and when to apply mulch)

Using the right mulch can help to conserve water, protect your plants' roots from temperature extremes, improve the soil, and discourage the growth of weeds. Applying mulch is a simple enough process, but it helps to know a few details to make the most of its benefits.
Steps to be followed for mulch application:

- Choose appropriate mulching material.
- Factors to be considered include:
- Purpose: Mulch materials may need for weeds control or to reduce evaporation. Each of these is a viable reason and each way requires differences in application.
- Availability: Mulching materials may be something in the yard, such as grass clippings or fallen leaves, or mulch to be purchased.
- Permeability: A layer of plastic sheeting may discourage weeds, but it will also discourage watering.
- Biodegradability: Do you want the mulch to break down and become part of the soil (bark, leaves, wood chips) or not (rock, plastic).

Prepare the area

In advance of mulching, the following activities have to be accomplished.
Pull or cut weeds closely, if purpose of mulching is for weed control. While not strictly necessary, it will help the mulch, and anything under it, to lay flat, and it will slow down the weed growth. Remember, mulch prevents weed growth by excluding light. Enrich the soil and prepare the bed, if you plan to do so. Biodegradable mulch can break down into rich, loose soil without this preparation, but it will take time.

Obtain the mulch - You may be able to collect mulch for free in your area or you can produce from your own garden waste. Transport the mulch to wherever it's going. Locally possible means transportation or like wheelbarrow can be used to ship the mulch to where it will be applied.

The thickness of mulch to be applied

The depth of mulch is really important to retain moisture and prevent weed growth.

- Aim for at least 5-10cm of depth
- While placing the mulch don't mulch right up against plant stems and tree trunks.
- Leave at least a little margin 10-15cm for the plant to breathe, and to help prevent moisture-depletion or water logging problems
- Spread the mulch with a rake as needed for an even layer
- Pull back the mulch from an area when you wish to plant something new
- Renew organic mulches every few years, as they break down and get spread around. You can dig old mulch into the soil and let it finish decomposing, or you can simply spread new mulch over the old one.

Figure 33*: Mulching in the highlands of Northern Thailand*

FAO (Source: Van Keer et al., 1996)

Mulch Timing

The mulch has to be applied before the rainy season begins, because the soil is then most vulnerable. The seeds can be sown through the mulch layer by making small openings in the mulch through which the seeds are planted. After planting each seed the opening must be closed, otherwise birds will become aware of the presence of the seed. The mulch layer may not be too thick. A sufficient amount would almost completely cover the soil from sight. If the layer is too thick, it will be difficult for the sprouted plants to reach the surface.

Figure 34: Maize seedling directly drilled in residues of wheat

7.5 Options for producing mulch

Materials used as mulches vary and depend on a number of factors. Take into consideration availability, cost, appearance, the effect it has on the soil including chemical reactions and pH, durability, combustibility, rate of decomposition and how clean it is (some can contain weed seeds or plant pathogens).

A variety of materials are used as mulch:

1. Organic residues: grass clippings, leaves, hay, straw, kitchen scraps , shredded bark, whole bark nuggets, sawdust, shells, woodchips ,newspaper, cardboard, animal manure, etc. Many of these materials also act as a direct composting system, such as the mulched clippings of a mulching lawn mower, or other organics applied as sheet composting.
2. Compost: fully composted materials are used to avoid possible phytoxictity problems. Materials that are free of seeds are ideally used, to prevent weeds introduced by the mulch.
3. Rubber mulch: made from recycled tire rubber.
4. Plastic mulch: crops grow through slits or holes in thin plastic sheeting. This method is predominant in large-scale vegetable growing, with millions of acres cultivated under plastic mulch worldwide each year (disposal of plastic mulch is cited as an environmental problem).
5. Rock and gravel can also be used as mulch. In cooler climates the heat retained by rocks may extend the growing season.

7.6 Effects of mulch

Mulch has many effects on the soil properties. The following are the major effects that mulch has on the properties of the soil.

1) The soil is protected from drying out, and consequent loss by wind erosion, from heavy rain and loss by water erosion and from high temperatures;
2) As the mulch rots down into the soil it provides nutrients for subsequent crops;
3) More rain water is able to filter into the soil due to reduced evaporation and runoff;
4) Weed growth is reduced; this can compensate for the fact that mulching needs more Labour than burning;

5) The soil retains more moisture because evaporation is reduced;
6) It is claimed that nitrogen fixation can be increased by free-living soil bacteria, and also that the effect of fertilizers can be improved.

7.7 Economics of mulching

Obtaining the appropriate chemical fertilizer is very often a major problem facing food Producers. Even if it is available close enough to be transported to their farm, they often do not have enough cash or credit, but, there is always the possibility of using mulch as a source of plant nutrients i.e. fertilizer. On the negative side, the demands on labour may be very high, and there may only is a relatively small gain of nutrients.
Crop residues such as stems and leaves contain 40–90% of the nutrients which crops remove from the soil. These residues can contain the equivalent of 50 kg/ha or more of the major plant nutrients, which can be made available to crops which grow later on in that field if the crop residues are incorporated into the soil and become broken down.

7.8 Use of mulch in agro-climatic context

As well as using dead or inorganic material the mulch can consist of living, growing thick plants as a pure stand or under main crops can dramatically improve crop growth and may also lengthen the growth period of crops by conserving soil water, protecting soluble nutrients and not lost by leaching, oppress weeds and reducing soil temperature fluctuations.

The benefits of mulching are greatest in hot, dry regions, and unfortunately it is these very regions which have the least amount of available mulching material and where there are the most pressing needs for mulch material, stems in particular, to be used as building material, fuel, animal fodder and so on. In more humid regions where mulching material is more plentiful, increases in yield may not be so impressive, but the advantages of mulching the land such as reducing water erosion and stifling weed growth almost always outweigh the consequences of leaving the land bare and exposed to the elements. *Examples*: perennial peanuts (*Arachis prostrata*) under maize and *Desmodium* species plants, when they also act as a *cover crop*.

MODULE 8: CROP ROTATION

Rotation is the name given to a cropping system in which different kinds of crops are grown in more or less a fixed sequence on the same land. Rotations are of the greatest benefit when crops are grown as pure stands and are rarely used when crops are intercropped. Rotations are an important part of any sustainable agricultural system.

Benefit of forages as part of the rotation:

The rate of decomposition of soil organic matter decreases, because the soil is not continually being disturbed.

Grass and legume sods develop extensive root systems, part of which will naturally die each year, adding new organic matter to the soil. Crops with extensive root systems stimulate high levels of soil biological activity and soil aggregation. The roots of a healthy grass or legume-grass sod return more organic matter to the soil than roots of most other crops. Older roots of grasses die, even during the growing season, and provide sources of fresh, active organic matter.

As a result a wide variety of different types of organisms living in the soil, a good amount of active organic matter and high levels of well decomposed soil organic matter, or humus, due to, more residues from crops leave in the field, the greater the populations of soil microorganisms

Yields of crops grown in rotations are typically 10% higher than those of crops grown in monoculture in normal growing seasons, and as much as 25% higher in droughty growing seasons. Growing a grain or vegetable crop following a forage legume, the extra supply of nitrogen certainly helps.

Yields of crops grown in rotation are often higher than those of crops grown in monoculture, even when both are supplied with plentiful amounts of nitrogen.

The Benefits of Rotation

1) Maintains or improves soil fertility;
2) makes use of a greater depth of the topsoil because different crops occupy and use Different levels of the soil profile;
3) Ensures that fertilizers are used to the best advantage;
4) Avoids creating a sub-surface *pan* by not cultivating the soil to the same depth every year;
5) Reduces the accumulation of disease and insects ;
6) Reduces the accumulation of weeds;
7) Distributes labour requirements (for cultivations, planting, harvesting etc.) more evenly through the year, reducing labour, financial (paying for everything at once) and storage bottlenecks;
8) Avoids creating a sub-surface *pan* by not cultivating the soil to the same depth every year;

Principles of Crop Rotation

Planning a crop rotation, and adapting it when necessary, requires paying attention to a number of factors, including the following:

1. Legumes like alkaline soils or plenty of lime in more acid conditions, while Irish potatoes prefer more acidic soils;
2. Irish potatoes like a lot of manure, while other root crops such as carrots do not because manure can often cause their roots to become *forked* ie they split;
3. the Brassica family also like lime, but only after it has been in the soil for about a year;

4. Some crops should not be grown on the same land two years in succession, mainly to avoid the build-up of diseases. Ideally some years should elapse between, linseed (5–6);
5. If lime is put on the land for a crop such as soybeans, then the next year's crop can be one which likes some but not a lot of lime, such as maize or tobacco. The third year can be a crop which likes only a little lime, such as cereals or Irish potatoes;
6. In low rainfall areas more drought resistant crops such as millet may be the only ones to survive following a crop that takes a lot of water from the soil, such as Lucerne (alfalfa);
7. If grassland is ploughed in, even if it has only been established for a year or so, this will increase the soil organic matter and will also improve the tilth of soil which may have become compacted by heavy rain, machinery, trampling by animals etc.;
8. The type of soil some can successfully grow crops of sorghum, barley and so on for many years, while other soils would rapidly lose fertility or become infested with diseases and/or pests, and so need frequent break crops of legumes, root crops etc.;
9. The deep root penetration of some crops such as Lucerne and clover brings up nutrients from deep in the soil and also helps to increase soil aeration which can be highly beneficial to the following crop;
10. Market prices often have a greater influence on the choice of crop which is grown than the proper use of land;
11. Cultural and traditional beliefs, the need for food security and the availability of seed or planting material are some of the other factors which play a part in the use, or abuse, of crop rotations as an invaluable tool in the food producer's armory.

The specific selection of crop rotation depends on the climate and soils, the expertise of the farmer, whether there are livestock on the farm or nearby, equipment and labor availability, family quality of life considerations, and financial reality (potential price minus the cost of production). From an ecological view, longer and more complex rotations are preferred over shorter ones. It also makes a lot of sense, once equipment is in place, to stay flexible instead of having a rotation set in stone. If you're ready to adjust to rapid market changes, changes in labor availability, crop pest outbreaks, or unusual weather patterns, you'll be in a stronger position economically, while still maintaining a complex rotation.

MODULE 9: INTERCROPPING

Intercropping: is a multiple cropping system where two or more crops are grown simultaneously on the same field. The different crops can be planted in alternating rows or sections. Intercropping mixes different plant species with contrasting height, foliage, biomass, and other agronomic characteristics. It minimizes pest problems and improves soil fertility. Intercropping with legumes or deep-rooted plant species absorbs nutrients from deeper soil horizons and reduces N deficiencies among neighboring and succeeding non-legume crops. Fruit trees can be important components of the mosaic of multiple cropping. Intercropping with trees (agro forestry) allows planting annual crops between rows of trees and has multiple benefits.

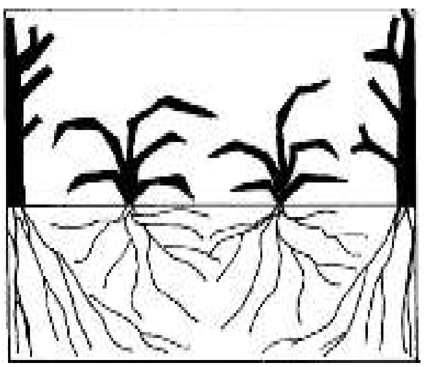


Figure 35 (left): Crops with various root systems

(Source: V. Oordwijk, (1990).

Figure 36: (right): An example of mixed intercropping with crops seeded at an angle to each other

There are four main types of intercropping:

1) ***Row intercropping****:* where the crops are grown in distinct rows; this practice is very common almost in all agro climatic zone (farming systems), for example coffee intercropped with Ginger, Maize with Haricot bean, Chat with maize etc.
2) ***Mixed intercropping***: where the crops are grown mixed together, without rows. This practice is common especially in semi arid area of our country, especially in eastern and southern parts of our country (Konso, Hareghe etc). The common crops selected to use for mixed crops have different root depth, contribution to soil fertility (leguminous, and non leguminous), have different length of growing periods etc.
3) ***Multistory intercropping***—where the crops which are grown are very different in height, such as peppers growing under bananas.
4) ***Relay intercropping***: where the crops are grown in sequence, one or more of them being planted before, during or after the harvest of the others. This system that can be applied in an area where there is residual moisture after main crop is harvested.

An important reason for intercropping is the improvement and maintenance of soil fertility. This is reached when a cereal crop such as sorghum or maize is intercropped with legumes (e.g., haricot bean, cow pea, mung bean and soybean). Leguminous crops fix nitrogen thereby reducing the fertilizer or compost demand of the companion crop. Cereal legume-intercropping is a widely applied traditional technique in Ethiopia. About 20% of the total sorghum production in Ethiopia and 85 % of the sorghum produced in eastern Ethiopia is intercropped with beans (Shimelis *et al*., 1990 and Yilma, 1977). Haricot bean, mung bean, cow pea and soybean are the most common legumes used for intercropping with maize and sorghum in Ethiopia.

In the highland, Fava bean is the feasible option for mixed cropping with Wheat and Barley. According to the study made by Getachew Agegnehu, Amare Ghizaw and Woldeyesus Sinebo, (2006) at Holetta Agricultural Research Centre (2001-2003), mixed intercropping of fava bean in normal barley and wheat culture at a density not less than less 37.5% of the sole fava bean density may give better overall yield and income than sole culture of both crops species

Why intercrop?

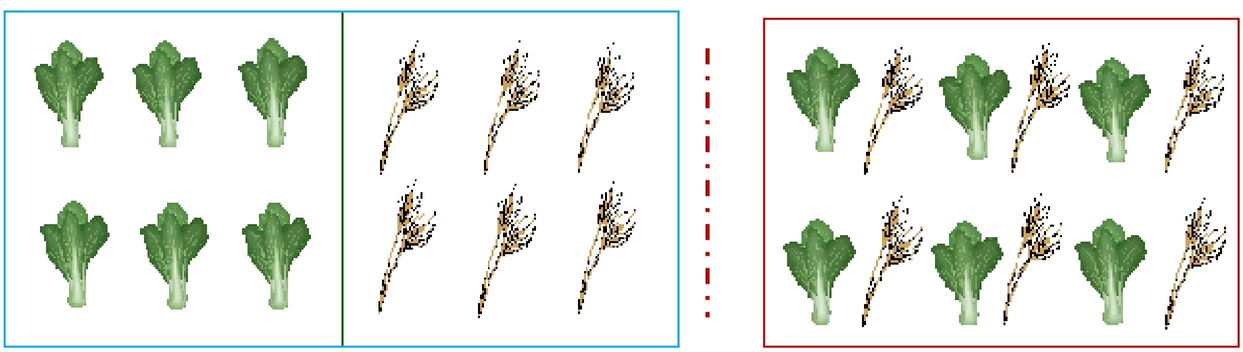
Benefits /Advantages of intercropping

- ✓ Intercropping gives higher income per unit area than sole cropping.
- ✓ It acts as an insurance against failure of crop in abnormal year.
- ✓ Intercrops maintain soil fertility as the nutrient uptake is made from both layers.
- ✓ Reduce soil runoff.
  Stability: Intercropping adds diversity to the cropping system and diversity tends to lead to stability.

Figure 37: Strip intercropping

- ✓ Reduced chemical use. Intercropping may allow for lower input levels in a cropping system by reducing fertilizer and pesticide requirements.
- ✓ Overyielding. Overyielding occurs when the yield produced by an intercrop is larger than the yield produced by the component crops grown in monoculture on the same total land area.

Overyielding is calculated using the Land Equivalency Ratio (LER). The LER is a measure of how much land would be required to achieve intercrop yields with crops grown as pure stands (See example fig.13).



When grown as sole crops, each of these crops yields 6 units per unit area

When grown as an intercrop, the same yield can be produced from a smaller area. In this case, the LER = 1.5.

Figure 38a & 38b**:** An Example of Land Equivalency Ratios

When the LER is greater than 1, overyielding is occurring and the intercrop is more productive than the component crops grown as sole crops. When the LER is less than 1, no overyielding is occurring and the sole crops are more productive than the intercrop.

Overyielding occurs for a variety of reasons, including the following:

- Weed suppression and lower susceptibility to insects and diseases probably help to increase yields of intercrops.
- Complementary resource use. A mix of different plants will use resources more efficiently than plants that are all of the same type. Plants of varying types may also provide benefits to each other, such as fixed nitrogen from legumes.

MODULE 10: CROP RESIDUE MANAGEMENT

Crop residues include any biomass left in the field after grains and other economic components have been harvested. Plant residues provide a renewable resource for incorporation into soil organic matter.
In a natural system, the production of plant residues is balanced by the return of dead plant material to the soil. In agricultural systems, however, as plants are harvested, only about 20 percent of production is accumulated in the soil as organic matter. Furthermore, in some farming systems, all above-ground production may be harvested, leaving only the root biomass. In cool climates, below-ground carbon inputs from roots alone can generally maintain soil organic carbon levels. In warmer or semi-arid regions, where residues decompose more swiftly and especially when continuous cropping is practiced in such areas, failure to return above-ground plant residue will inevitably lead to a reduction in soil organic matter.

Many of the resource-poor farmers and small land holders in our country usually remove crop residues for use as fodder, fuel, construction material and other competing uses. There are also areas (e.g. Konso and Raya areas) where leaving of crop residue on the surface is common. Crop residue of sorghum and maize are the most common types left on the surface.

Crop residues are usually the largest source of organic materials available to farmers. Residue return following harvest is important to improve soil biological, physical and chemical conditions, maintain a protective cover and reduce wind and water erosion and conserve moisture (very important in moisture stress area, arid and semiarid areas). Residue cover is insufficient in low rain fall area due to limited residue production and competing uses for residue. Returning crop residues and planting grass and legume trees can increase the amount of residue cover.

Do not use organic materials that contain seeds of serious weeds, disease, insects, or toxic materials; or materials with a large amount of carbon in relation to its nitrogen contents. Serious weed pests include Bermuda grass seed, stolons, and rhizomes. Parthenium weed residues leaves toxic effects on many crop plants. Diseases can be avoided by never using sickly plants.

Do not use wood products from toxic red cedar (Junipers species) Use only old hardwood sawdust. Always use organic residues with a carbon to nitrogen ration of 30:1 or narrower, unless a quick acting high nitrogen fertilizer is added to hasten decomposition. When an organic amendment with a wide C:N ratio is added to the soil, soil bacteria will utilize the scarce nitrogen and the plentiful carbon to grow and reproduce, thus crop plants will starve for nitrogen.

In most of the cereal production areas of our country after main crops are harvested, crop residues left in the farm lands are free grazed by livestock.

Figure 39: livestock free grazing on crop land aftermaths, Hetosa, Oromia (Ethiopia)

In this case it advisable to incorporate the residues to the soil immediately after harvest when there is still residual moisture in the field. During the dry season, especially in areas of heavy soil (vertisols) the field will completely dry and cracks, hence it is impossible to plow the land, see Picture 28 below.

In reality, the major problems for using crop residues are the shortage of grazing land, poor grazing land management, inadequate integration of pastures in to farming systems, and the sale of crop residues for income generation, for construction etc. Therefore, before crop residue management technology is applied other related problems in the area of application have to get due attention.

Figure 40: During dry season vertisols are completely dry and earth cracked, Gimbichu, Oromia (Ethiopia)

Crop residue is a tremendous natural resource in crop production. About 25% of nitrogen (N) and phosphorus (P), 50% of the sulfur and 75% of potassium (K) uptake by cereal crops are retained in crop residue making them a valuable nutrient source. Leaving residues stubble after harvesting the grain and incorporating this stubble into the soil can increased grain yield. Crop residue is also a source of organic matter. Soils with high organic carbon retain more plant nutrients, increasing crop yields and, thus, food security.

Crop residues contribute to adaptation to climate change. Especially, in areas of erratic and low rain fall coupled with increasing temperatures, crop residues can protect the soil, reducing the soil temperature and, hence, water loss due to evaporation, both are important factors for optimum plant growth. Retaining crop residues can also reduce the amount and speed of rainwater running off croplands reducing soil erosion, improving water infiltration and therefore moisture conservation and contributing to an improved hydrological regime. Depending on the amount of residue, soil erosion can be reduced up to 90 percent compared to intensively tilled fields. On a demonstration plot in central Wisconsin, for example, a maize plot with 0 percent residue lost 3910 kg of soil after a rain storm, a plot with 14 percent residue lost 1085 kg, and a plot with 54 percent residue lost only 9 kg of soil (University of Wisconsin, 2010).

Where plant residues accumulate in situ, the C fixed by plants in photosynthesis is available as a net gain to the soil. On average, crop residues contain about 40- 50% carbon. Cereals are better than legumes at sequestering carbon (a cereal crop adds 2-3 times more carbon annually). Maize and sorghum are the most common and recommended sources of crop residue.

MODULE 11: BIO-INTENSIVE GARDENING IN THE HOME GARDEN

Bio intensive gardening method is an alternative strategy for household level food production, using limited garden space and locally available materials. The method is a whole-system method developed especially for people who have little or no money or access to outside resources to begin a garden.

The Bio-intensive approach is a biological or organic (as opposed to chemical-based) form of agriculture in which a small area is intensively cultivated, using natural ingredients to re-establish and then sustain the soil's productivity. The method is built on low-cost and ecologically sound technologies i.e. on deep soil preparation; composting; intensive planting; companion planting; carbon farming; calorie farming; and open-pollinated seeds. It is all these factors working together that create a sustainable garden or farm.

The bio intensive method is especially good for people who want to raise substantial amounts of plant foods, foods that offer a lot of calories as well as foods that contain lots of vitamins and minerals. Salad crops and greens offer good nutrition, but little in the way of calories. In order for home-grown plant foods to become a large part of diet, and foods with a lot of caloric value will be needed to grow: root crops like potatoes or sweet potatoes, grain crops like corn or wheat, and dry beans or peas.

The method suggests allocating about 30% of garden space to these crops, compared to about 10% allocated to typical garden crops like lettuce, greens, peppers, tomatoes, carrots, and so forth. And this is calorie farming. Because the method is geared toward people who have little if any access to outside resources like fertilizers to help their gardens grow better and because bio intensive practices can quickly deplete the soil if efforts to build soil are neglected, crops that produce compostable material should make up about 60% of the garden area. These include grain crops for the compostable stems left behind after the grain has been harvested as well as soil-building legumes like clovers.

If one can grow the recommended area of carbon crops, the only additions to the garden after the first year will be the compost that one can make. Making the best compost is thus crucial to keeping a bio intensive garden fertile.

In the bio intensive method, slightly raised beds are created by the gardener's own labor and a shovel or locally available tools. Carefully applying the method means double-digging, or at least getting as close to double-digging as one's soil allows. While the labor is not beyond the ability of anyone in decent physical shape, it is physical labor and it takes a long time while one is learning the method. Expect at least 8 hours or more of work to dig a 100 square foot bed the first few times, you do it. It's best to start with a smaller area at first, say 50 square feet or less, and slowly expand as you learn the method. In order to garden in an actually sustainable way, produce your own seed for future plants from open-pollinated seeds and on-growing from seeds in the bio intensive method is important.

The major elements are as follows:

1. Deep Soil Preparation
2. Composting
3. Intensive Planting
4. Companion Planting
5. Carbon Farming
6. Calorie Farming
7. Open-Pollinated Seeds
8. Whole System Method

11.1 Technological profile

Deep Soil Preparation: the purpose is to build soil and soil structure. Deep soil preparation builds soil and soil structure by loosening the soil to a depth of 60 cm. Ideal soil structures has both pore space for air and water to move freely and soil particles that hold together nicely. Air supports plant roots and soil organisms that give life to the soil and enhance nutrient availability for the plants. Aerated soil holds water better than compacted soil, requiring less watering. It also facilitates root penetration, supporting healthy plants and minimizing erosion.

Digging procedure

Traditional tools for example, a long stick with two prolonged sharp metal end used by Chencha farmers (Gofa), and a tool used by Hararghe farmers which has a stone at one end and one prolonged sharp metal end on the other, are appropriate tools that can be used for the digging technique.

Procedures:

- Start by spreading compost over the soil where you will be tilling by hand.
- Next, dig a 10 deep ditch along one edge of the space. When you double dig the garden, you will be working from one end to the other.
- Then, start another ditch next to the first. Use the dirt from the second ditch to fill the second ditch.
- Continue hand tilling soil in this fashion across the whole area of the garden bed.
- Fill the last ditch with the soil from the first ditch you dug.
- After completing the steps above with this double digging technique, rake the soil smooth.

11.2 Improving compacted soil

The very best way to improve soil compaction is to make sure it does not happen in the first place. Avoid tilling the soil when it is too wet or too dry. Also, do not till the soil more than once a year and, if you can, avoid tilling the soil at all. Loosening compacted soil can be done a number of ways. For smaller areas, you can work in organic materials like compost, peat moss and other organic materials. Gypsum is another amendment that can be used for loosening compacted soil. Earthworms are another way to improve soil compaction. Earthworms can be added to garden beds that have problems with soil compaction and they will literally eat their way through compacted soil, leaving behind burrows and droppings that help to aerate and fertilize the ground. Improving compacted soil can make a world of difference in the garden. Taking the steps to improve soil compaction is well worth the extra effort.

Bed Preparation

The main characteristic is the preparation of deep dug narrow and raised beds. Such beds are considered permanent and are expected to be used throughout the year. Initially, it takes 2-8 hours (depending on the method chosen) to prepare a standard plot of 25 ft. x 4 ft. The plots may be double-dug and while this is undoubtedly the most productive and appropriate way,

The more popular plot preparation method is a single-dug, raised, narrow plot, deep using standard digging procedures and making use of locally available materials. The plots however are located in a permanent site with fixed pathways to eliminate stepping on the plots once they are dug. Of critical importance is the need to keep the plot constantly covered with crops or, if no water is available during some part of the year, to maintain a thick layer of dry straw/grass or other mulch materials. If the soil condition is conducive one can begin to practice minimum tillage within a single season.

Bed Fertilization

Every bio-intensive gardener attempts to maximize the use of plant and animal residues and waste.

- To put back into the soil much of what comes out of it, material is recycled back into the soil through compost, green leaf manure, ashes, etc.
- To each plot of 100 sq. feet 8 cubic feet of decomposed manure or compost or green leaf manure (green leaf manure as used in Bio-intensive gardens consists of leaves of any leguminous tree/ shrub/annual) or mud press (by-product of sugar mills) is given.
- If the soil is exceptionally poor or sandy three times that quantity is recommended (only) the first time the bed is prepared.
- These soil amendments are mixed into the top six inches (not shallower) of the soil and the plants/seeds are sown.

For areas where no compost or manure is available, green leaf manuring is recommended. This option based on an alley-cropping model proved to be an adequate alternative. The alternate rows of fast growing leguminous trees planted every 4-5 meters with two plots between them have been found effective. However, the trees may be cut half a meter above ground level 3-4 times a year (each cutting should yield 10 kg/row of green leaves) but only when the trees are at least one year old. Some potential tree species appropriate for this hedgerow species: Cajanus Cajan, Gliricidia sepium, Leucaena leucocephala, Sesbania, grandillora, Calliandra calothytsus. Flemengia species can be used for this purpose.

Intensive Planting

The purpose of intensive Planting is to create enhanced and uninterrupted root and plant growth. It creates enhanced and uninterrupted plant and root growth by transplanting seedlings in a close, off-set spacing pattern so their leaves are barely touching at maturity, creating living mulch over the soil.

A typical garden has four different crops per plot (legume, fruits, leafy and root). However, in practice gardeners tend to reduce this to 1-2 crops because of practical considerations. But diversity is an important factor in reducing the insect threat. This is achieved through relay cropping, intercropping and other mixed cropping systems preferred by gardeners. However, crop rotation (growing different crops on the same spot after each other) is considered critical.

The plots are intensively sown, so that when the plants are fully grown, the soil is kept completely covered by the plant canopy, thereby eliminating weeds and reducing water evaporation from plot surfaces.

Figure 41: Intensive Planting

To avoid weed growth and water losses when the plants are still young, the space in between is covered with an inch thick layer of dry mulch (e.g. straw). Additionally, the breakdown of this mulch contributes humus to the soil nurturing soil life.

Companion Planting

The purpose of Companion planting Focus on the whole garden to create a thriving mini-ecosystem with beneficial interrelationships. Companion planting draws a diverse insect population to the garden by using plants of many types and colors that flower all-season long. Additionally, a place for insects to drink water and to be protected at night can be helpful. These actions will support a balance of beneficial insects that prey on insect pests and pollinate the crops. Lastly, choosing strong-scented plants, like marigolds, will help repel unwanted insects.

Carbon Farming

The purpose of carbon (plant material) farming is to maximize seed production and quality and preserve genetic diversity. This helps create a self sufficient closed system by reducing dependence on large or small seed vendors, and by saving money the objective of carbon farming is to support closed system sustainable soil fertility. A farmer in tune with producing enough mature compost material will grow these crops in at least 60% of the cultivated area. By focusing on growing enough compost material through choosing carbon-producing crops, a farmer becomes more self-sufficient, relying on his/her own compost for soil fertility instead of buying resources from off of the farm. In addition, carbon farming has a diet element. The important cereal crops mentioned above also produce an edible seed. Emphasizing crops that produce compost material and a significant amount of calorie rich food sustains the soil and the farmer!

Figure 42: Carbon Farming

Calorie Farming

The objective of Calorie Farming is to grow a complete diet in the smallest area possible. Calorie farming produces a complete diet in the smallest space possible by focusing on special root crops that are calorie dense and yield well in a small area. A farm with 30% of its area in special root crops maximizes its area efficient production of calories and can grow a complete diet in the smallest space possible.

Open-pollinated Seeds

Whole System Approach (Principle 8): Integrate all the principles into the garden to create balance. Bio-Intensive Gardening requires farmers to act with thought and foresight, recognizing that the farm itself is part of a greater ecosystem that should be thriving. Keeping half of your land in the wild, if possible, nurtures the plant, insect, and animal diversity that surround the farm and provides a buffer that allows it to exist and succeed.

MODULE 12: COVER CROPS

Cover crops are plants that are sown in order to protect the soil and/or increase the soil fertility. They are usually creeping legumes that cover the ground surface between widely spaced perennial crops. They are planted between the rows of annual or perennial crops to cover the soil surface with a mat of vegetation.

Given the importance of agriculture in Ethiopia's economy, unsustainable land management practices pose a serious threat to crop and livestock productivity and thus to food security. A number of factors contribute to this. One of such factors is the increasing demand for cultivable land due to population pressure which leads not only to the extension of new cultivable and grazing areas, but also to overutilization of the existing farmlands thereby, affecting soil fertility and crop productivity. Therefore, an adequate supply of nutrients in the soil, particularly nitrogen, phosphorus, and potassium is essential to crop growth. Nutrients can be lost from the soil through intensive crop production (without possible fallow), leaching and soil erosion. These nutrients can be replenished through good farming practices such as planting cover crops particularly leguminous plants such as the ones mentioned below, and the use of green manure which is also handled in this training manual.

Legumes are used as cover crops because they capture nitrogen from the atmosphere and store it in their roots as well as their top growth. At the end of their growth period, cover crops are tilled into the soil. This not only adds organic matter to the soil but increases the available nitrogen level in the soil once the plants decompose.

Common legumes used as cover crops are:

Hairy vetch (Vicia *villosa*) - gets its name from the fine hairs that cover stems and small leaves. It is a sprawling ground cover that uses tendrils to cling to structures as high as 8 feet tall. It is suitable to cold areas since tolerates cold weather. Because hairy vetch is low growing and completely dies in warm weather, warm weather vegetable plants, such as tomatoes, can be planted directly into the ground while surrounded by the cover crop.

Cowpea (Vigna *unguiculata*) - is also known as the black-eyed pea or southern pea. It is an annual legume used as a summer cover crop since it is not cold tolerant. It produces broad leaves that shade out weeds and a deep taproot that seeks out moisture, which makes it tolerant of dry soils. The seeds, or peas, are produced in long pods that are often harvested before they dry and cooked in a variety of dishes.

Soybean (Glycine max) - is considered one of the highest biomass and nitrogen-producing cover crops for warm weather. The taproot can grow as long as 6 feet into the ground making the soybean more drought tolerant that other warm weather legumes used as cover crops. The broad leaves shade out weeds that compete for moisture and nutrition. Soybean plants are tolerant of a variety of soils.

Alfalfa (Medicago *sativa*) - is considered one of the highest quality forages for livestock. It has a deep taproot but must be planted in well-drained soils loosened to a depth of at least 3 feet. Alfalfa is capable of gathering nutrients, including nitrogen, from the soil and air with its extensive root system. When it is tilled under the soil, the concentrated nutrients are returned to the soil. Alfalfa is planted in the fall before cool weather arrives. Although drought tolerant, alfalfa grows best with supplemental moisture during dry periods.

Clover (Trifolium) - is one of the most widely used legumes for a cool weather cover crop. In areas with mild summers, it can be grown during the warmer months. There are many varieties of clover used as cover crops, but sweet clover, red clover and white clover are the most often used. These varieties can add as much as 100 pounds of nitrogen per acre into the soil when tilled under in the spring.

Application: Cover crops are usually sown where crops themselves have a wide spacing and are poor ground covers (trees for instance). Legumes used as a cover crop improve soil fertility even more because they can fix nitrogen from the air.

Figure 43: Cover crop on preventive plant

Through decomposition of the plants this nitrogen becomes available for the main crop

Implementation: Cover crops should be planted as soon as possible after tillage to be fully beneficial. This can be done at the same time as sowing the main crop, but also after harvesting it. In the last case the cover crops form fallow vegetation which serve as green manuring for the new season.

Some of the management goals for which farmers use cover crops include:

- Suppressing or preventing weed grows
- Protecting soil from erosion or runoff
- Improving soil aggregate stability
- Reducing surface crusting
- Adding active organic matter to soil and thus to improve the soil structure and fertility
- Breaking hardpan
- Fixing nitrogen
- Suppressing soil diseases and pests
- Reducing evaporation from the soil surface,
- Controlling plant diseases and
- Attracting beneficial insects to the garden.

In making a choice of cover crops, such as the ones mentioned above, the following points are important to consider

1. If possible choose a useful crop such as groundnut, beans or a fodder crop.
2. The crop should be a quick starter.
3. It should really be a ground covering crop that is low lying
4. Cover crops should compete with the main crop as little as possible.
5. The cover crop should not transmit disease to the main crop. The chance of this is very small if both crops belong to different families.

MODULE 13: INTEGRATED NUTRIENT MANAGEMENT

13.1 Basic concept

The continuous use of chemical fertilizers is adversely affecting the sustainability of agricultural production and causing environmental degradation. The major issue in designing a sustainable agricultural system will be the management of soil organic matter and the rational use of organic inputs such as animal manures, crop residues, green manures, sewage sludge and food industry wastes etc. However, organic manures cannot meet the total needs of modern agriculture; therefore, integrated use of nutrients from fertilizers and an organic resource seems to be the need of the time.

Management Approach
Integrated nutrient management (INM) is an approach to optimum combination Chemical fertilizers, farm yard manure, green manure, crop residues, compost, micro nutrients, and vermicompost and Bio fertilizers sources with soil and water conservation measures for specific crop, cropping system and climatic situation so as to achieve and sustain the optimum yield and to improve or maintain the soil's physical, biological and chemical properties. Integrated nutrient management adopts a holistic view of plant nutrient management by considering the totality of the farm resources that can be used as plant nutrients.

Advantages - The advantage INM is to enhance soil productivity and its sustainability, supplying plant nutrients in balanced form and lowering the dependency of chemical fertilizers.

The main advantages are as follows:

1) To maintain soil health status as well as environment for attaining food supply needs.
2) To improve soil quality by using all available organic sources which enhance the physical, chemical and biological properties of the soil
3) To alleviate soil degradation
4) To enhance soil micro organisms
5) To increase fertilizer use efficiency and to generate profit for the farmers through the judicious and efficient use of chemical fertilizers, organic manures, crop residues and bio-fertilizers

Basic principles of Integrated Nutrient Management explained as follows:

1. Nutrients removed by crops must be returned to the soil.
2. Soil physical conditions should be maintained and upgraded.
3. Organic content of soils should be maintained and enhanced.
4. Land degradation occurring due to soil erosion must be alleviated.
5. Continuous Soil quality upgrading should be enhanced.

System of fertilizers application

Systematic fertilizers applications focus on to get planned yield with desired quality whiling preserving the soil productivity. The balance method of fertilizers application in farming system that considers soil fertility level at farm level and yield size is better to use in our condition.

The method is driven to exploit high and very high levels fertility status for most soils, improves the level of very low and low, whereas maintain medium fertility level. This indicates that to have medium soil fertility status in farming system.

Procedures for fertilizer recommendation:

Selecting for each uniform land crops to be grown and yield to be attained. For this purpose utilize field experiment results or estimate from farmer's experience (field history data).

1) First estimate all organic sources so that the difference will be compensate by chemical fertilizers
2) Use fertilizer norm from field experiments or calculate using balance method table 5for planned yield.
3) Use correction factors to soil fertility status, table 7
4) Fertilizer alone cannot achieve better yield, therefore, apply recommend good agronomic practices package with fertilizer doze.
5) Fertilizer application at field has to combines the basal to the depth of 15-25cm with those applied at seeding to a depth of 3-10cm.
6) If there is no research data use for basal 60% and at seeding 40% (if the soil moister is sufficient it is possible to split and apply for top dressing 20% and with seeding 20%) of the recommended norm.
7) All organic amendment has to apply to the soil during basal application of chemical fertilizers at a depth of 15-25cm/28-32cm depending on the types of plant to be sown.

13.2 Nutrient budget calculation

Inorganic fertilizer

A maize farmer applied 100 kg ha-1 DAP (18:46:0) at planting, followed by 30 kg ha-1 UREA (46% N) for top-dressing; 100 kg of DAP would provide 18kg N (18% x 100), and 46 kg P_2O_5 (46% x 100), and zero K. To find out how much P (elemental) is in P_2O_5, multiply the P_2O_5 by a factor of 0.44. Therefore, the amount of P applied is 46 kg x 0.44 = 20 kg. The 30 kg UREA provides 13.8 kg N (46% x 30).

Organic fertilizer

The only available organic fertilizer is FYM, which the farmer applies to the maize crop at the rate of 1.5 t ha-1. Analysis of a sample of the same FYM shows that the manure contains 0.8% N, 0.2% P and 0.6% K. Thus, 1.5 t FYM contains 12 kg N, 3 kg P and 9 kg K. The total amount of nutrients (N, P and K) added to the soil is the sum of the organic and inorganic fertilizers applied during the crop season. Thus the amount of N applied (as shown above) is 18 + 13.8 + 12 = 43.8 kg ha-1; the amount of P is 20+ 3 = 23 kg ha-1; while the amount of K is 9 kg ha-1.It is known that some of the nutrients added to the soil are taken up by plants; some are lost through leaching or erosion, while some are retained in the soil. Therefore, not all the nutrients are recovered by the crop. The amount taken up by the crop is referred to as efficiency of nutrients utilization by plant. This is expressed as a percentage of the amount of nutrients applied. Efficiency of nutrients utilization by plant from organic, 30 for N, 40% for P, and 60% for K, and from mineral fertilizers, 65% for N, 25% for P, and 60% for K.

Nutrient removal with the maize harvest

Maize grain harvest takes away nutrients from the farm. Farmers also often remove maize Stover for feeding to livestock. One quintal of grain plus Stover contains 2.7 kg of N, 1.0 kg of P and 2.5 kg of K per ha. Assuming that 45 quintal ha-1 of maize were harvested, this would remove 121.5 kg N, 45 kg P and 112.5 kg of K from the farm. Deducting the lost nutrients from the added amounts would leave negative balances for N and K.

Results

The results summarized in table--- show that there is a net loss of N, and K due to the grain and Stover harvested and removed. The system requires sufficient replenishment of the nutrients lost otherwise the farm's production will continue to decline.

Table 9 : Nutrient budget calculation (kg ha-1)

Nutrient	Amount added	Material removed:	Net balance
N	44	121.5	-77.5
P	23	45	-22
K	9	112.5	-103.5

Therefore, fertilizers Norm required for planned yield can be calculated using the table 10 by considering all detail factors elaborated including soil fertility index.

Table 10: Correction factors to fertilizer rate, with account taken of the content of mobile phosphorus and potassium in the soil

Available forms of plant nutrients, according fertility mapping	Cereals crops, Grasses, Flax, Maize, Sorghum etc.	Vegetables
Nitrogen fertilizers		
Recommendation will be based on P_2O_5 fertility map for not light soils, light soils based on potassium (K)		
Very low	1.2	-
Low	1.1	1.2
Medium	1.0	1.1
High	0.9	1.0
Very high	0.8	0.9
P and K fertilizers		
Very low	1.5	-
Low	1.25	1.5
Medium	1	1.3
High	0.7	1
Very high	0.3	0.6

Source: adopted from B.A.YAGODIN (1984)

Table 11: Crop nutrients removal by main yields and related residues

No	Type of crop	Nutrients removal kg/Quintal		
		N	P_2O_5	K_2O
1	Wheat	2.6	1.3	3
2	Barley	2.2	1.2	5
3	Oats	3.0	1.3	2.9
4	Maize (Seed)	2.7	1.0	2.5
5	Maize (Silage)	0.3	0.1	0.2
6	Field pea	6.6	1.6	2.0
7	Lupine	6.8	1.9	4.7
	Soya	7.1	1.6	1.8
8	Line seed	1.9	1.22	3.22
9	Potato	0.5	0.2	0.8
10	Sugar Beet	0.45	0.14	0.63
11	Cotton	5	1.5	5
12	Millet	3	1.4	3.53
13	Rice	1.33	0.96	2.5
14	Buck Wheat	4.4	2.5	7.5
15	Field pea	4	1.5	3.0
16	Vetch	6	1.5	3.0
17	Haricot bean	5.5	1.5	4.5
18	Tomato	3.3	1.14	4.5
19	Onion	0.54	0.16	0.4
20	Sugar cane	0.11	0.063	0.315
21	Groundnut	4.12	1.18	2.4
22	Tobacco	6.46	3.92	6.23
23	Coffee	3.75	1.25	3.75

Source: adopted from B.A.YAGODIN (1984)

Table 12: Fertilizers norm required for planned yield ------- quintals (Seeds)

No	Items (parameters)	N	P_2O_5	K_2O
1	Nutrients removal by one quintal of main yield and related crop residues, kg			
2	Nutrients removal by planned yield' and related crop residues, kg			
3	Available forms of plant nutrients in the soil, mg/100g (ppm) of soil			
4	Available forms of plant nutrients in root depths (0-20cm), kg			
5	Efficiency of nutrients utilization by plant from soil, %	25	9	30
6	Amount of nutrients that will be utilized by plant from soil, kg			
7	Total amount of organic fertilizer applied under precursor crop, tone/ha			
8	Total amount of mineral fertilizer applied under precursor crop, kg			
9	Efficiency of nutrients utilization by plant from organic fertilizer in the second year after its application, %	10	15	10
10	Efficiency of nutrients utilization by plant from mineral fertilizer in the second year after its application, %	15	10	10
11	Crop will utilize nutrients from organic fertilizer in the second year after its application, kg			
12	Crop will utilize nutrients from mineral fertilizer in the second year after its application, kg			
13	Organic fertilizer that will be applied, tone			
14	Plant nutrients contented in organic fertilizers, %	0.5	0.25	0.6
15	Plant nutrients contented in organic fertilizers, kg			
16	Efficiency of nutrients utilization by plant from organic, %	30	40	60
17	Plant nutrients that will be utilized from organic fertilizer, kg/ha			
18	Total plant nutrients that will be utilized (6+11+12+17)			
19	Additional required plant nutrients for formation of planned yield, kg (2-18)			
20	Efficiency of nutrients utilization by plants from mineral fertilizers, %	65	25	60
21	Mineral fertilizers to be applied considering efficiency of utilization, kg/ha			
22	Fertilizer to be applied considering soil fertility index			

Source: Agricultural Chemistry B.A. YAGODIN, 1984; ; Fertilizer efficiency; N=50-70%, P=10-30%, K=50-60%

Table 13: Average utilization factors of nutrients from fertilizers (%)

Year	From organic fertilizers			From inorganic fertilizers		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
1st	20-25	25-30	50-60	50-60	15-20	50-60
2nd	20	10-15	10-15	5	10-15	20
3rd	10	5	-	5	5	-
Over a crop rotation cycle	50-55	40-50	60-75	60-70	30-40	70-80

Source: Agricultural Chemistry B.A. YAGODIN, 1984

MODULE 14: SOIL ACIDITY MANAGEMENT

The soil reaction produces a tangibles effect on the development of plants and soil microorganisms, on the rate and direction of the chemical and biochemical processes occurring in the soil. The uptake of nutrients by plants, the activity of soil microorganism, mineralization of organic substances, decomposition of soil mineral, and other physiochemical processes are strongly dependent on soil reaction. It also influences the effectiveness of applied fertilizers.

Soil pH can significantly influence plant growth by affecting the composition of the soil solution, and the availability (sufficiency or toxicity) of essential and nonessential elements as shown in Figure 1 and table12 for mineral soils,

Table 14: Effect of soil pH on element availability and/or soil solution composition

Element	P^H Decrease	P^H Increase
Aluminum	Increases	Decreases
Copper	Increases	Decreases
Iron	Increases	Decreases
Magnesium	Decreases	Increases
Manganese	Increases	Decreases
Zinc	Increases	Decreases

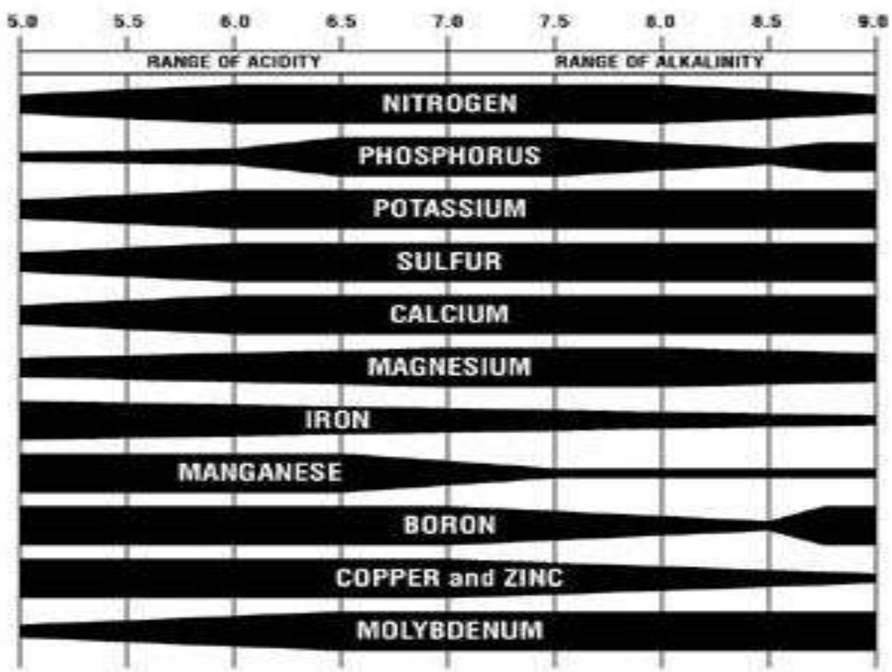


Figure 44: Availability of elements to plants at different pH levels for mineral soils

Source: University of Massachusetts Amherst at www. extension.umass.edu (last updated 8/2011)

Table 15: Fertilizer efficiency (%) at varying soil pH level

Soil Acidity	pH	Nitrogen	Phosphate	Potash
Extreme	4.5	30	23	33
Very Strong	5.0	33	34	52
Strong	5.5	77	46	77
Medium	6.0	89	52	100
Neutral	7.0	100	100	100

The main focuses of soil acidity management technologies aimed to correct problems of soil productivity such as low soil reaction, toxicity, imbalance and poor chemical status for plants growth and development, poor status of soil microorganisms and physical deterioration of soils.
During application of soil acidity management technology i.e. use of lime, attention has to be given not to distribute the ecosystem of certain plants while improve for others, Table 14 below. Therefore, before deciding liming the soil, land suitability evaluation for specific land utilization types has to be carry out in a detail scale of study by pertinent professionals.

Soil acidity management (reclamation) has three basic technologies that have been indicated as follows:

Liming: the first step and tough work is correction of soil reaction to desirable level for specific crop. Liming is the process of adding lime, dolomite, quicklime, slack lime, steel slag, or other materials to the soil to make the soil less acidic or to increase its pH level and to improve conditions for the growth of plants and microorganisms.

A serious problem faced by many farmers in the tropics is the extreme acidity of their soil. A pH level lower than 5 means the soil is so acidic that it inhibits healthy plant growth. Aluminum toxicity is especially problematic.

The soil can be made less acidic by adding lime. Factors that contribute acidic soils are: the use of chemical fertilizers, the removal of crop residues that contain basic elements such as calcium, magnesium, potassium, and sodium, washing away of basic elements from the soil, and the decomposition of fresh organic material into nutrients and others like acid rain etc.

The identification of lime requirement for specific soil type and crop needs special knowledge and soil testing activities, so the discussion here is limited to how lime is effectively applied to neutralize the acidity level of a soil and re-develop biological health of the soil.

Soil acidity management procedures:

1) Use limestone to raise the soil pH (if magnesium is also low, use a high magnesium or dolomite lime).

- ❖ Mix lime thoroughly into the plow layer.
- ❖ Spread lime well in advance of sensitive crops if at all possible.
- ❖ If the lime requirement is high consider splitting the application over two years.
- ❖ Reducing soil pH (making soil more acid) for acid loving crops is done best with elemental sulfur (S).
- ❖ If the pH is increased too much, phosphate is not released from slow working fertilizers. Lime must be reapplied regularly. This is labour-intensive and usually also prohibitively expensive. It is thus important to use acid tolerant crops or varieties, which can produce reasonable yields in

low pH soil table14. In most cases, this means that they can withstand high concentrations of aluminum.

2) **Increasing the soil organic matter**; acidic soils are poor in soil organic matter and soil micro organism, therefore, addition of organic matters like compost, FYM, Forest soil, as a fertilizer is very important activities to improve the soil Biological, chemical, physical i.e. soil health conditions for Sustainable Soil Fertility Management.

3) **Green manuring (inoculate**): leguminous crops rich in organic matter and nitrogen are the steps needed to increase soil biological fertility (Soil Health). Green manuring can improve all soil Health condition that soil lost due to increased acidity.

4) **Neutralizer acidity effects of mineral (synthetic) Nitrogen Fertilizers:** all nitrogen fertilizers **Urea,** Ammonium nitrate, Ammonium sulfate and Ammonium phosphate all of the accelerate soil acidification. Therefore to neutralize the acidity effect of one kilogram of urea 0.71 kg of lime is required to be added to the soil, one kilogram of Ammonium nitrate 0.62 kg, one kilogram of Ammonium sulfate 1.1 kg and one kilogram of Ammonium phosphate 0.37 kg, one kilogram of Mono ammonium phosphate 0.58 kilogram of lime is required to be adde4d to the soil, Hart (1998).

5) Fully replace mineral (synthetic) Nitrogen Fertilizers by organic nitrogen would eliminate the source of soil acidification.

6) During transition from chemical to organic, use house calcium sources such as wood ash, earth from termite mounds, alkaline nitrogen fertilizers (calcium Cyanamid, calcium ammonium nitrate and calcium nitrate).

Table 16: different field crops with their optimum ranges of soil reaction

No	Plant	Optimum P^H range	Plant	Optimum P^H range
1	Barley	6.5-8.0	Potato	4.8-6.9
2	Corn	5.5-7.5	Sugar cane	6.0-8.0
3	Oats	5.0-7.5	Strawberry	5.0-6.0
4	Rice	5.0-6.5	Eucalyptus	6.0-7.0
5	Rye	5.0-7.0	Ironwood	6.0-7.0
6	Wheat	5.5-7.5	Beets	6.0-7.0
7	Alfalfa	6.5-8.0	Bitter melon	5.5-6.5
8	Bean, field	6.0-7.5	Cabbage	6.0-7.0
9	Bean, Soy	6.0-7.0	Carrots	5.5-6.5
10	Clover	5.6-7.0	Celery	5.8-7.0
11	Clover, red	6.0-7.5	Chili pepper	5.5-6.5
12	Clover, sweet	6.5-7.5	Cowpea	5.5-7.0
13	Lupine	5.0-7.0	Cucumber	5.5-6.5
14	Peas	6.0-7.5	Ginger root	6.0-7.5
15	Vetch	5.2-7.0	Sunflower	6.0-7.0
16	Millet	5.0-6.5	Mustard	6.0-7.0
17	Sudan grass	5.0-6.5	Onion	6.0-6.5
18	Timothy	5.5-8.0	Peanut	5.5-6.5
19	Beets, red	6.0-7.5	Sweet potato	5.0-6.0
20	Cotton	5.0-6.0	Tomato	5.5-7.0
21	Water melon	5.0-6.5	Teff	5-8
22	Bread wheat	5-8.5	Maize	5.2-7.4
23	Sorghum	5.3-8.3	Triticale	5.2-7.8
24	Soya bean	5.5-7.8	Faba bean	6-7.7
25	Lentil	5.2-8.0	Chick pea	5.7-8.3
26	Fenugreek	5.7-8.3	Rape seed	5.2-7.8
28	Line seed	6-7.8	Niger seed	6.0-7.8
29	Garlic	5.5-7.5	Apple	5.5-7.3
30	Enset	5.2-7.7	Sesame	5.2-8.2
31	Tea	4.5-6.3	Ground nut	5.4-8.2
32	Banana	4.5-8.2	Coffee	4.6-6.3
33	Taro	4.7-7.6	Yam	5.0-7.0
34	Turmeric	5.5-7.5	Coriander	5.5-7.5
35	Oil palm	5.0-7.5		

MODULE 15: ECONOMIC ASPECTS OF SOIL FERTILITY MANAGEMENT

Factors Influencing Farmers' Decisions about Soil Fertility Management Practices

Soil fertility management technology transfer can be affected by different conditions such as Agro climatic, farming system, socio economic situations, political willingness, etc.

The decision to adopt a given soil fertility management technology made by an individual farmer or farmers, family or families on the specific farm plot varies significantly across the country. Hence for effective transfer of the practices of soil fertility management technologies, awareness of specific land user/users have to be investigated.

Decisions regarding a given field or a given practice, such as green manuring and agro forestry for soil fertility management are thus not made in isolation. These decisions are made within the context of the whole farm and of the totality of the resources and assets available to the farmer. These resources and assets include:

- labour (family labour plus hired labour if sufficient cash is available);
- cash to buy fertilizer and other chemicals;
- their entire landholding and the different fields comprising it;
- purchased assets such as implements, machinery, animal traction;
- access to water (either on farm or off farm); and
- Access to other off-farm assets (such as communal resources, forested lands and woodlots).

Farmers focus on the tradeoffs between the efforts they have to make to meet their production objectives (being able to produce enough food for the family, being able to produce a surplus and to sell it) and the payoffs they expect from these efforts. They consider the totality of their holding and its various current and potential uses *vis-à-vis* their production objectives and weigh these in terms of the outcomes they expect when combining their resources into different practices (including soil fertility management).
Farmers also have to factor into such decisions different groups of markets and different types of customs. They need to consider markets for agricultural commodities (local, regional, national and international if relevant), since the sale of their surplus production, over and above what they need to produce to feed their family, depends on these markets.
They also have to take into account markets for inputs. These determine the costs they will have to incur for their use of:

- Labour, be it hired or family labour
- Land, especially if they rent some of their fields;
- Capital, especially if they borrow money;
- Implements and machinery; and
- Water and other resources

The level of income of farmers is determined by these two groups of markets. Finally, the actual purchasing power of this income is dictated by markets for consumer goods (such as clothing and medicines) and by government policies regarding public infrastructure (such as means of transport and their costs, costs of education, health and electricity). Social customs and norms influence a number of the elements that farmers need to integrate in their decisions. These customs and norms determine farmers' access to many natural resources, as well as human labour, through the prevailing land and tree tenure system, and the regulations concerning access to off-farm resources (water, communal resources such as forests and woodlots), and access to non-family labour. It is important for the implementer who is undertaking studies on the growth of soil fertility management practices to be introduced to the farmer and understand his attitudes regarding the adoption of the measures.

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