A Training Manual for Training of Trainers on Integrated Soil Fertility Management for Field Crops production

Volume 4

By
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Training Organized by
Ministry of Agriculture and Livestock Resources (MoALR), Participatory Small-Scale Irrigation Development Program (PASIDP) and Ethiopian Institute of Agriculture Research,

Melkassa Agricultural Research Center

08–14 Oct 2018

Mekassa, Ethiopia

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Integrated Soil Fertility Management for Field Crop Production in Ethiopia

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Introduction

Substantial improvement in the productivity of agricultural systems is required to support growing rural and urban populations of Ethiopia. Because of strong pressure on land resources, agricultural intensification of existing production systems involving increasing cropping intensity and/or increased use of external inputs is often the only way to increase agricultural production. There is, however, a broad concern about the sustainability of agricultural production systems under increased external inputs. The Food and Agriculture Organization (FAO) defines sustainable agriculture as one that conserves land, water, and plant and animal genetic resources, does not degrade the environment, and is economically viable and socially acceptable. Thus, sustainable agriculture manages and uses natural resources to meet people's needs both for now and in the future.

The government of Ethiopia has given top priority to agricultural development and use of improved inputs (agro-chemicals, improved seed and irrigation water) and management for the enhancement of agricultural production and productivity in general to improve the food security situation. The use of improved crop production technology could sustain production with efficient and effective use of the available resources in order to primarily alleviate the problem of food insecurity, improve nutritional status of the rural population and in the long-run to achieve the bigger picture of alleviating poverty. Integrated soil fertility management (ISFM), which combines various soil fertility management techniques, is the key in raising productivity levels while maintaining the natural resource base. ISFM aims to replenish soil nutrient pools, maximize on-farm recycling of nutrients, reduce nutrient losses to the environment and improve the efficiency of external inputs.

This training manual will present ISFM strategies and practices that address these objectives. Its major focus is to give the trainees an understanding of participatory approach to designing and implementing effective ISFM programs. It will provide information and practices on ISFM program design as well as specific agronomic and non-agronomic components of an ISFM program. Agronomic components dealt with will include improved crop management practices, measures to improve soil organic matter maintenance and the combined use of organic materials and mineral fertilizers to replenish soil nutrient pools and improve the efficiency of external inputs. The approach pays particular attention to looking at ways to adapt ISFM options to the agronomic and socioeconomic needs and interests of farmers. It is based on the findings from works done by Soil Fertility Management Research in the country and in Sub-Saharan Africa.

This training manual on *"**Integrated Soil Fertility Management for Field Crop Production**"* is designed to improve participants' knowledge about various ISFM practices and give them the opportunity to apply this knowledge in the design of an effective ISFM program suitable for their local agricultural circumstances. The module is aimed to enable the trainees be able to:

- *Define ISFM in major field crops (maize, sorghum and lowland pulses) production*
- *Discuss the principle of ISFM practices and their application in major field crop production*
- *List and describe ISFM practices for major field crops*
- *Apply ISFM with in the irrigation schemes.*
- *Demonstrate manure and compost preparation and utilization practices for major field crops*
- *Demonstrate manure and compost preparation and utilization practices for major irrigated field crops*

1. Concepts of Soil Fertility and its Management

Soil fertility management is one of the major components to ensure food security and economic growth in a sustainable way. Poor soil fertility and nutrient depletion continue to represent huge obstacles to securing needed harvest unless more integrated problem-solving approaches are adopted with developing farmers' skill on how to benefit most from their application.

1.1 Plant Nutrition

It is well established fact that all plants are dependent on a favorable combination of five environmental factors: light, heat, air, nutrients and water which are also well understood by farmers. Studies have identified 20 nutrient elements that are essential for the growth and reproduction of plants. Three of them (carbon, hydrogen and oxygen) are obtained from the air and water. Although these elements are extremely important ($\geq$94 percent of most plants dry tissue is composed of these three elements), only minor adjustment can be done to improve their availability. The other elements constitute less than 6 percent of the plant dry matter; but crop production is frequently reduced and growth limited by a deficiency of one or more of them.

These essential elements are generally divided into two groups; macronutrients (present in at least 0.1% of the plant dry matter) and micronutrients (present in less than 0.1% of the plant dry matter). The macronutrients are nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), and magnesium (Mg). Unlike the macronutrients, micronutrients are required in small (micro) amounts by plants and hence sometimes called 'minor' or 'trace' elements. They include manganese (Mn), iron (Fe), boron (B), zinc (Zn), copper (Cu), molybdenum (Mo), chlorine (Cl), cobalt (Co), nickel (Ni), sodium (Na) and silicon (Si). Both groups of essential elements are equally important for normal growth and reproduction of plants.

1.1.1 Macronutrients

Nitrogen (N): Nitrogen is an important building block of proteins and enzymes in the plant. It promotes the growth of stalks and leaves. With sufficient nitrogen, the leaves become big and succulent. Nitrogen is a structural part of chlorophyll which is responsible for photosynthesis. It readily translocates from older tissue to younger tissue. If plants absorb too much nitrogen, the stems and leaves will grow bigger but also weaker.

Phosphorus (P): Like N, phosphorus is an essential part of the process of photosynthesis. Phosphorus plays an important role in breathing and in the energy supply. It promotes the development of roots in young plants. It has a positive effect on the number of grains per spike and the grain weight and for bulb crops on the bulb and root production.

Potassium (K): Potassium plays an essential role in the metabolic processes of plants and is required in adequate amounts in several enzymatic reactions. Potassium is needed for the firmness of the plant. Potassium makes the crop strong, and ensures that the root system is large and widely branched. It promotes the development of roots and bulbs, and it has a positive effect on the size of fruits and the weight of grains. K is involved in maintaining water balance and cold hardiness.

Sulfur (S): is another element essential for chlorophyll and is a constituent of the amino acids cystine, cysteine and methionine and hence in proteins that contain these amino acids. It is found in vitamins, enzymes and coenzymes. Sulfur is also present in glycosides which give characteristic odors and flavors to many vegetables. In legumes, it is required for nodulation and N fixation.

Magnesium (Mg): is part of the chlorophyll in all green plants and essential for photosynthesis. Similar to N, Mg is a relatively mobile element in the plant and can readily translocate from older to younger plant parts in the event of a deficiency.

Calcium (Ca): Calcium is an essential part of plant cell wall structure and important for normal transport and retention of other elements as well as strength in the plant. It influences water movement; cell growth and division and is required for uptake of nitrogen and other minerals.

1.1.2 Micronutrients

Iron (Fe): plays an important role in enzyme functions and is a catalyst for synthesis of chlorophyll.

Manganese (Mn): is necessary for enzyme activity for photosynthesis, respiration, and nitrogen metabolism.

Boron (B): regulates the metabolism of carbohydrates in plants. It affects at least 16 functions including flowering, pollen germination, fruiting, cell division, water relationships, movement of hormones, cell wall formation, membrane integrity, calcium uptake and movement of sugars.

Zinc (Zn): controls the synthesis of indoleacetic acid, which dramatically regulates plant growth. It is a functional part of enzymes including auxins (growth hormones), carbohydrate metabolism, protein synthesis and stem growth.

Copper (Cu): is necessary for nitrogen metabolism and an important component of many enzymes.

Molybdenum (Mo): is a structural part of the enzyme that reduces nitrates to ammonia. Without it, synthesis of proteins is blocked and plant growth ceases. This element is also required by nitrogen fixing bacteria.

Chlorine (Cl): is involved in osmosis (movement of water or solutes in cells) and important for maintaining ionic balance necessary to take up mineral elements. It also plays a role in photosynthesis.

Cobalt (Co): is required by nitrogen fixing bacteria and lack of this element may cause plants to exhibit nitrogen deficiency symptoms.

Nickel (Ni): has only recently been recognized as an essential element. It is required for the urease enzyme to break down urea into usable nitrogen and for iron absorption.

Sodium (Na): is important for the regulation of osmotic (water movement) and ionic balance in plants.

Silicon (Si): Silicon is a major component of cell walls and helps to create a mechanical barrier to piercing - sucking insects and fungi. It enhances improves heat and drought tolerance, and reduces transpiration.

1.2 Soil Fertility

Soil is the natural medium for the growth of plants for the production of the bulk of the food and fiber needed. For at least the foreseeable future the world will continue to rely on soil for agriculture. Some define soil fertility simply as the capacity/quality of the soil to ***supply essential nutrients in quantities and proportions*** for the growth and its successful production during plant life. This principle is probably best summed up by the **"*Law of the Minimum*"** proposed by Justus von Liebig in the mid 1800's. This law states that if one of the nutrient elements is deficient or lacking, plant growth will be poor even when all the other elements are abundant. Any deficiency of a nutrient, no matter how small an amount is needed, will hold back plant development. If the deficient element is supplied, growth will be increased up to the point where the supply of that element is no longer the limiting factor. Increasing the supply beyond this point is not helpful, as some other element would then be in a minimum supply and become the limiting factor.

A nutrient rich soil may not necessarily be a productive one. It must also provide a satisfactory environment for plant growth and the nutrients it contained must be available for use by the plants. In a broad view, soil fertility is a complex of soil chemical, physical and biological factors that affect land potential and the degree to which a soil is productive. Fertile soil is characterized by ongoing complex interactions involving organic matter decomposition, animals and microbes to form inorganic nutrient ions in soil water. Roots absorb these mineral ions if they are readily available and **not 'tied up'** by other elements or by alkaline or acidic soils. Soil microbes play a critical role in ion uptake and in the cycles that permit nutrients to flow from the soil to the plant. The microbiological community of the soil system around the roots breaks down the available organic material in the soil into a usable form that the plant root system can readily absorb. From this it clear that there are other soil components and characteristics (see below) that influence and determine soil fertility.

1.2.1 Soil Organic Matter (SOM)

Soil organic matter is defined as the soil fraction derived from materials of plant and animal origin. It includes these residues in various stages of decomposition, soil organisms and their synthesized by-products. Since SOM is derived mainly from plant residues, it contains all of the essential plant nutrients. Accumulated organic matter, therefore, is a storehouse of plant nutrients. Upon decomposition, the nutrients are released in a plant-available form. The stable organic fraction (humus) adsorbs and holds nutrients in a plant available form.

Organic matter content gives soils many of their desirable properties. It is important to soil structure and tilth. It provides energy for soil microorganisms, improves water infiltration and water holding capacity, reduces erosion potential and is an important element in the nutrient and carbon cycles. Organic matter can retain a lot of water, which means that in dry periods more water is available for the plants for a longer time or reduce frequency of irrigation. This is also especially important in sandy soils, which retain little water. Organic matter is the adhesive of the soil, binding together the soil components into stable aggregates. Organic matter can also bind H^+ and thus prevent soils from becoming acidic. Finally, organic matter supports the growth of soil organisms, which helps make the nutrients in the organic matter available to the plants.

Hence, soil organic matter plays a critical role in soil processes and is a key element of integrated soil management (ISFM). Almost all ISFM technologies are SOM dependent for their full success. Furthermore, SOM content can be used to set critical values that can help to make decisions when implementing ISFM programs. The SOM and ISFM relation is tricky, SOM build up is ISFM dependent and ISFM efficacy is SOM dependent.

1.2.2 Soil Organisms

Soil organisms are an important component of soil organic matter. Under a 1 m^2 soil surface, more than 10,000 bacterial and fungal types may be found, as well as 100 to 1,000 species of soil animals, such as protozoa, nematodes, mites, collembola and earthworms. These organisms form an integral part of the soil, as they contribute to the development of soil structure, the dynamics of organic matter and the availability of nutrients for plant growth.

One of the most important functions of soil microorganisms is the decomposition of organic matter that involves a variety of soil bacteria and fungi. A particularly important product of decomposition is humus (humic acid) which has a great influence on soil chemistry (cation exchange capacity) and water retention. Carbon dioxide, nitrogen and other essential plant nutrients are released and made available to growing crops and other micro-organisms through organic matter decomposition.

1.2.3 Soil Texture

Soil texture is a function of the mixture of the different particle size separates (soil separates) and refers to the relative proportions of the various size groups of individual particles or grains in a soil.

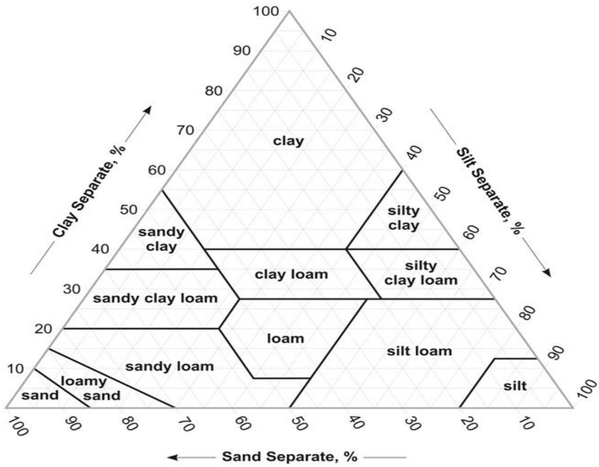


Figure 1. Soil textural class trainable

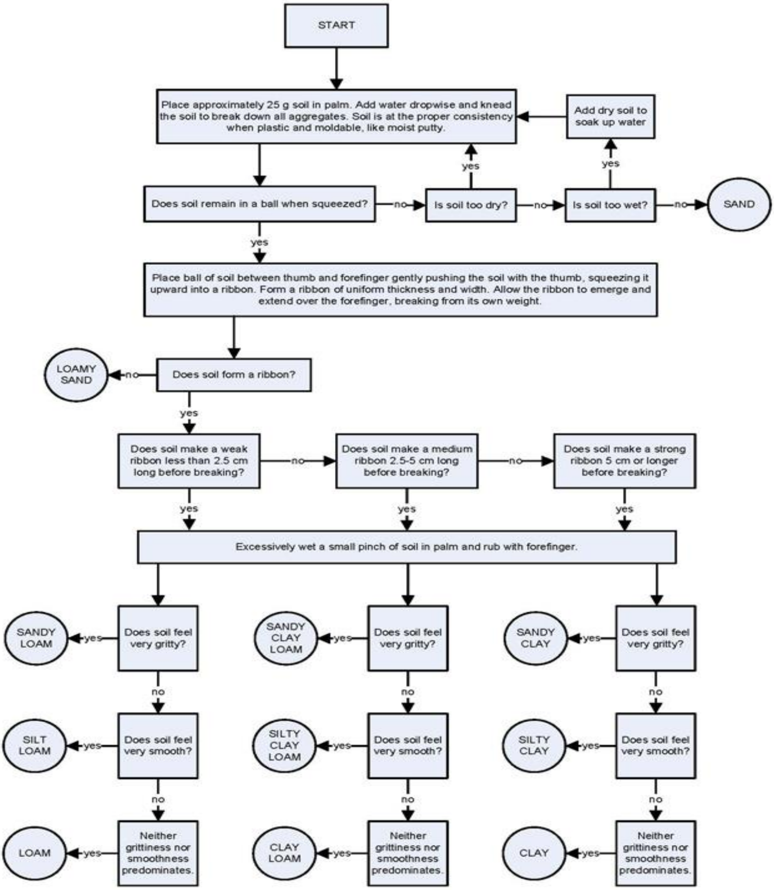


Figure 2 Guide to texture by feel

Soil texture is arguably the most important physical property of the soil in terms of soil fertility. This is because it affects and is related to several other soil properties such as soil structure, aeration, soil water holding capacity, nutrient storage and water movement. Soil water holding capacity is for instance is controlled primarily by the soil texture and the soil organic matter content. Soil texture reflects the particle size distribution of a soil.

1.2.4 Soil Structure

Soil structure refers to the arrangement of primary soil particles (sand, silt, and clay) and other soil materials, and how the individual soil particles clump or bind together.

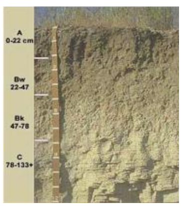
Granular Structure is commonly found in surface horizons where roots have been growing.

Prismatic Structure is usually found in lower horizons while **Columnar Structure** is found in soils of arid climates. **Platy Structure** is usually a characteristic of compacted soil.

Granular

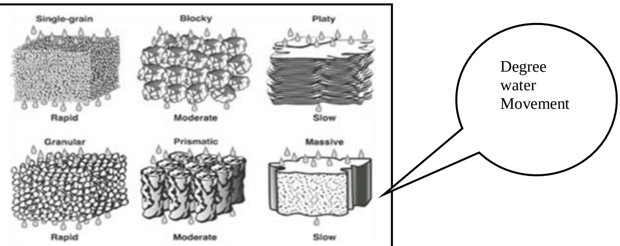

Prismatic


Blocky



Platty


Columnar



Figu

Soil structure is very important because the arrangement of soil particles plays the biggest role in determining the size and shape of the pores that conduct air and water. It also affects the plant's ability to send its roots through the soil.

1.2.5 Soil depth

Soil depth refers to the thickness of the soil materials which provide structural support, nutrients, and water for plants. The depth of soil in which to store satisfactory amounts of water should be given due emphasis. Shallow soils require frequent irrigation water to keep crops growing. Deep soils of medium texture and loose structure permit plants to root deeply, provide for storage of large volumes of /irrigation water in the soil, and consequently sustain satisfactory plant growth during relatively long periods between rain/irrigation.

The volume of water absorbed by the same plant roots and consumed to produce a crop may be practically the same for shallow and deep soils, provided the plants are grown under the same climatic condition. Under irrigated condition, more water is required during the crop growth season to irrigate a given crop on a shallow soil than is required for the same crop under a deep soil. The larger number of irrigations required for shallow soils and greater unavoidable water losses at each irrigation on shallow soils account for differences in practical water requirement for different soils during the season.

1.2.6 **Soil bulk density**

Bulk density refers to the soil overall density/compactness of a soil and should be distinguished from the soil density of the solid soil constituents, usually called the particle density. The bulk density is affected by structure of the soil, i.e., its looseness or degree of compaction, as well as by its swelling and shrinkage characteristics, which are dependent upon clay content and wetness. In sandy soil, soil bulk density can be as high as 1.6 gm/cm^3, where as in loams and clay soils, it can be as low as 1.0 gm/cm^3.

1.2.7 **Soil porosity**

Roots require oxygen for respiration and other metabolic activities. They also absorb water and dissolved nutrients from the soil, and produce carbon-dioxide, which has to be exchanged with oxygen from the atmosphere. This aeration process requires open pore space in the soil. If roots are to develop well, water plus nutrient and air must be available simultaneously. The soils contain small pores (micro-pores) and large pores (macro-pores). The small pores are used for the storage of water and the large pores are used as channels for the exchange of air and provide adequate drainage condition.

Course-textured soils (sandy soils) have a small percentage of total pore spaces, while fine textured soils (clays) have a greater percentage of total pore space.

1.2.8 Soil infiltration

Soil infiltration refers to the downward flow of water through the soil surface. It is one of the important soil properties having greater importance to irrigation. The infiltration rate depends on physical properties of the soil, such as texture, structure, porosity, moisture content of the soil, degree of compaction, organic matter etc. Knowledge of the soil infiltration rate is a prerequisite for efficient soil and water management. Typical infiltration rate for different soil texture is given in Table 1.

Table 1. Infiltration rates related to soil texture

Soil texture	Representative, I (mm hr^{-1})	Normal range of I (mm hr^{-1})	Category
Sandy	50	20 – 250	Rapid
Sandy loam	20	10 – 80	Moderate rapid
Loam	10	10 – 20	Moderate
Clay loam	8	2 – 15	Moderately slow
Silty clay	2	0.3 – 5	Slow
Clay	0.5	0.1 – 8	Very slow

1.2.9 Salinity

All soils and irrigation water contain a mixture of soluble salts, not all of which are essential for plants growth. Salts are toxic to plants when present in high concentration. Some plants are more tolerant to a high salt concentration than others. Table 2 provides salt tolerance level for some field crops.

Table 2. Salt tolerance of field crops

Crop	ECe threshold (dS/m)	Crop	ECe threshold (dS/m)
Barley	8.0	Pepper	1.5 – 1.7
Maize	1.7	Potato	1.7
Sorghum	6.8	Tomato	0.9 – 2.5
Wheat	5.9-8.5	Avocado	-
Cabbage	1.0 – 1.8	Mango	-
Carrot	1.0	Banana	1.0
Onion	1.2	Papaya	-

Most crops do not grow well on soils that contain salts. One reason is that salt causes a reduction in the rate and amount of water that the plant roots can take up from the soil. The salts concentration of the soil solution is usually higher than that of the applied water. This increase in salinity is the results from plant transpiration and soil surface evaporation which selectively remove water concentrating the salts in the remaining soil water.

A soil may be rich in salts. Salts in soil can develop from the weathering of primary minerals or be deposited by wind or water that carries salts. The most common source of salts in irrigated soils is the irrigation water itself. After irrigation, the water added to the soil is used by the plant or evaporates directly from the moist soil. The salt, however, is left behind in the soil. The salt affected soils can be classified under three classes as Saline, Saline-sodic and sodic based on general EC, SAR and pH. The salinity and sodicity are commonly occurring in arid and semi-arid climatic conditions. The USDA classification of salt-affected soils is given in Table 3.

Table 3 USDA classification of salt affected soils

Soils	ECe (dS m^{-1})	ESP	pH	Description
Saline soils	> 4	< 15	Usually < 8.5	Non-sodic soils containing sufficient soluble salts to interfere with plant growth of most crops
Saline-sodic soils	> 4	> 15	Usually < 8.5	Soils with sufficient exchangeable sodium to interfere with growth of most plants, and containing appreciable quantities of soluble salts
Sodic soils	< 4	> 15	Usually > 8.5	Soils with sufficient exchangeable sodium to interfere with growth of most plants, but without appreciable quantities of soluble salts

1.2.10 Soil pH

Soil pH, a measure of the acidity or alkalinity of the soil, is defined as the negative logarithm of the hydrogen ion concentration. The level of pH affects soil fertility and the availability of nutrients as well as microbial activities. Soil pH has a great effect on the solubility of minerals or nutrients. Most of the essential plant nutrients are obtained from the soil and are not available to the plant unless dissolved in the soil solution. If the pH is not close to what a plant requires, nutrients, such as phosphorus, calcium and magnesium, iron and manganese can't be dissolved in water and the plant can't absorb them.

Soil pH also influences plant growth by its effect on the activity of beneficial microorganisms. Bacteria that decompose soil organic matter are hindered in strongly acidic soils. This prevents organic matter from breaking down, resulting in an accumulation of organic matter and the tie up of nutrients, particularly nitrogen, that are held in the organic matter.

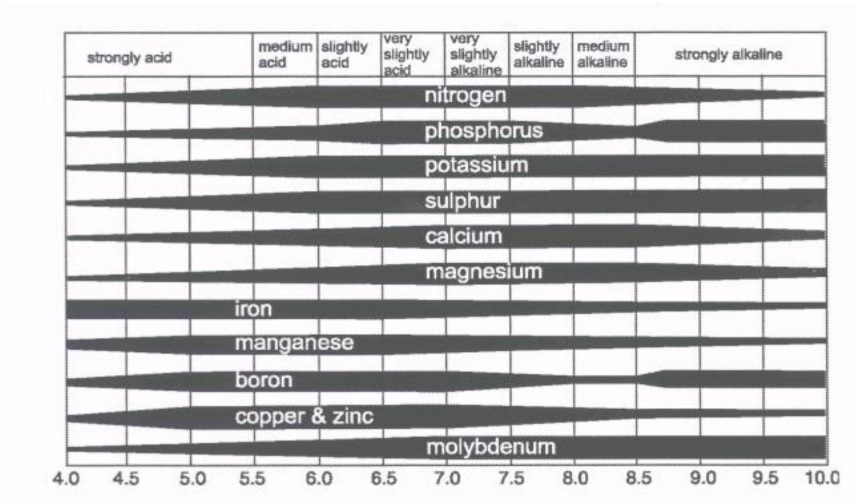


Figure 4. Chart on Effect of Soil pH on Nutrient Availability

1.2.11 Cation Exchange Capacity (CEC)

Cation exchange capacity is the ability of the soil to hold on nutrients (the amount of negative charge in soil that is available to bind positively charged ions, called cations) and prevent them from leaching beyond the roots. The higher the cation exchange capacity of soil, the more likely the soil will have a higher fertility level. This is because cations retained electrostatically are easily exchangeable with other cations in the soil solution and are thus readily available for plant uptake. When combined with other measures of soil fertility, CEC is a good indicator of soil quality and productivity.

Essential plant nutrients, K^+, Ca^{2+}, Mg^{2+}, ammonium ($NH4^+$) and other elements including Na^+, hydrogen (H^+), and aluminum (Al^{+3}) are cations. Cation exchange capacity buffers fluctuations in nutrient availability and soil pH.

Clay and organic matter are the main sources of CEC. The more clay and organic matter (humus) a soil contains, the higher its CEC. These materials act as centers of activity around which chemical reactions and nutrient exchanges occur. Their individual particles are characterized by extremely small size, large surface area per unit weight, and the presence of surface charges to which ions and water are attracted. This explains why sandy soils, which contain low percentages of clay and organic matter, have low exchange capacities and require more frequent applications of lime and fertilizer than soils containing more clay and organic matter.

2. Identifying Soil Nutrient problems and opportunities

Identifying problems is the first step in developing ISFM plan or program as it helps to set priorities for interventions and managing soil fertility. In order to make the diagnosis as valuable as possible, it is important to follow/apply a participatory learning and action research (PLA/R) approach: – an iterative cycle of working with farmers and other soil fertility stakeholders to highlight soil fertility problems and take informed action. The framework for this will be the Research-DATE that consists of four phases: D(iagnosis), A(ction planning), T(rying things out) and E(valuation). This is a bottom-up approach aiming at strengthening farmers' capacity in observing and analyzing soil fertility management practices, and taking decisions leading to improvements. The focus of the Research-DATE is on developing answers to site-specific nutrient problems, exploiting opportunities, making the best use of locally available resources and knowledge and decision making in combination with research-based understanding and analysis of the underlying principles.

2.1 Diagnosis

The diagnostic phase of the Research-**DATE** approach aims to get a common understanding of the local landscape and to identify different 'types' of farming systems. Village-level and beyond-village level factors that have influenced farmers' soil fertility strategies should be looked for and analyzed. Such beyond-village level factors may include infrastructure (roads), market development (inputs, credits), national- and regional-level policies related to land tenure and access to credits and inputs, the presence of rural development projects, strategies and focus of research and extension institutions etc.

The diagnostic phase should lay down the first ideas and options that can be used in the **'Action-planning'** phase to come later on. A number of learning and Decision-Support Tools (**DSTs**) can be used in this phase (Table 4). These tools range from simple rules of thumb (expert knowledge), to complex, crop growth simulation models.

Table 4. Overview of decision support tools that can be used during diagnostic phase

Goal	**Tools**	**Data requirement**	**Potential users**
Common understanding of the landscape	Discussion with farmers (current land use and history) Transect walk	Very limited	Farmers, extension & research
Spatial variability in soil fertility	Transect walk Mapping soils (land suitability) Soil and plant testing	Very limited	Farmers, extension & research

Goal	Tools	Data requirement	Potential users
	Pictures (Nutrient deficiency symptoms)		
Identification of yield gaps	Comparing yields among farmers and fields	Very limited	Farmers, extension & research
	Crop growth models	high	Research
Identification of yield limiting or reducing crop growth	Soil and plant testing	limited	Farmers, extension & research
	Cropping calendars, field observations, yield records	medium	Research
	Crop growth models	high	Research
Identification of leaks, losses & untapped resources	Resource flow map	medium	Farmers, extension & research
	Crop growth models	high	Research

While these tools can help to improve understanding of biophysical processes and interactions between soil, climate, animal and plant production systems; they mainly deal with nutrient aspects of soil fertility, mostly ignoring physical and biological aspects of ISFM. These non-nutritional effects are especially important when using organic amendments and in combination with inorganic fertilizer use, they may lead to important gains in fertilizer use efficiency. Knowing what changes have occurred over a longer time period can give insights into how knowledge is generated, which group of farmers have been most successful in adapting to changing circumstances and why. We will look into individual tools indicated in table 4.

Yield gap analysis

Majority of the farmers often achieve far less than 50% of the climatic and genetic yield potential for a given sowing date, cultivar choice and site. Figure 5 illustrates factors that define yield gaps at different levels. The potential yield or maximum yield (Y_{max}) is limited by climate and crop cultivar only, all other factors being optimal. Under irrigated conditions, water is assumed not to be limiting, but under rainfed conditions this assumption is often not true. Y_{max} is not constant but fluctuates from year to year and with sowing date because of climatic variability. The attainable yield (Y_{att}) is the 'nutrient-limited' yield that farmers can achieve with current soil fertility management practices, but with optimal water and crop management. The maximum attainable yield is often about 80% of Y_{max}. This is often referred to as the economic yield target (Y_{target}) as it is often not economical to close the remaining gap of about 20% of Y_{max}. In reality actual farmer yields ($Y_{farmers}$) are much lower because of a range of constraints to crop growth, including weed pressure, pests and diseases and sub-optimal soil fertility and water management practices.

A first approach to try to understand causes of low yields is to compare average yields in the village with the yields best farmers obtain. Discussions with farmers may give hints about what 'best farmers' do differently. This will help to identify the causes of the differences, e.g. weeds, pests or diseases (reducing factors), and will also provide the scope for short term improvement (yield gap 1 = best farmer yield – average yield). Crop growth simulation models can be applied to determine the attainable yield ceiling under given growth conditions (yield gap 2 = attainable yield ceiling - best farmer yield). This ceiling is limited by nutrients and/or water (the limiting factors). Finally, these models can also be used to determine potential yield, i.e. when sufficient water and nutrients are available. It should be realized that these yield gaps give indications about what is agronomically possible, not what would be economically optimal. Crop growth simulation models may also be helpful to analyze farmer management practices, and identify areas for improvement.

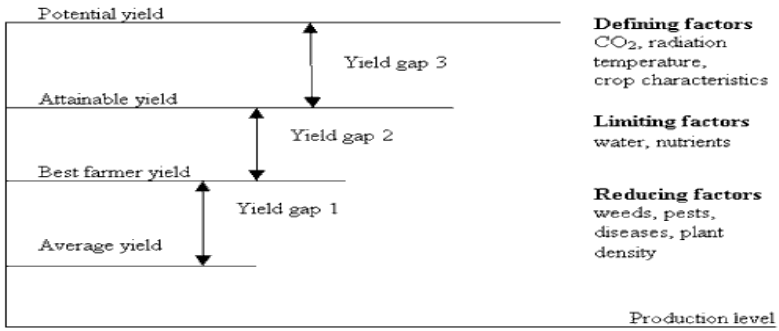


Figure 5. Effect of crop management on potential or maximum yield, attainable yield, best farmer yield and actual average farmer yield

When analyzing growth reducing and limiting factors, soil fertility will often be one of them. It should be realized, however, that crop growth in farmers' fields may also suffer from other factors, such as drought or excessive flooding or from incidence of pests, diseases and weeds. Current management practices that are preventing most farmers from obtaining better yields include choice of variety, plant population, sowing date and amount and type of fertilizer applied. In the latter case, crop response to fertilizer application may be disappointing due to the fact that the type of fertilizer applied does not address the limiting nutrient in the soil, e.g. soils that are low in K will not respond to large doses of N or P.

Soil Testing

Soil testing is any chemical or physical measurement that is made on a soil and it is done to:

- determine the relative ability of a soil to supply crop nutrients during a particular growing season,
- evaluate the fertility status of the soil as the basis for planning a nutrient management program
- provide a basis for fertilizer recommendations for a given crop
- predict the probability of obtaining a profitable response to fertilizer application,
- determine the need to adjust soil pH and

- diagnose problems such as excessive salinity or alkalinity

Soil tests are considered to be a helpful diagnostic tool but do not provide absolute recommendations. The information they provide must be interpreted using established critical values; otherwise on common sense considering the goals and circumstances of the grower. It is wise to consider that there are many other factors that may result in low yields even when nutrients are adequate. Furthermore, a soil analysis is only as good as the soil sample taken. If the sample submitted for testing is not representative of the actual status of the field, the results and recommendations will not be very valuable and will probably be misleading.

Plant Tissue Analysis

Plant tissue analysis is a way to measure the nutrients actually taken up by the plant and is another aid in diagnosing crop nutritional problems. Plant analysis is often used to complement soil test results and can indicate whether the cause of the problem is something other than a nutrient deficiency in the soil or not. For example, if the soil test level is adequate but the plants are deficient, some other factor is limiting the plant's ability to take up available nutrients. Possible explanations include the effects of crop management practices like tillage or pesticide use, pest injury, varietal characteristics and soil physico-chemical conditions.

Just as in soil testing, sample collection is very important. The nutrient concentration in a plant varies with the plant's age and the part of the plant sampled. If plant analyses are to be meaningful, the appropriate plant part must be collected for the age of the plant, and a number of plants must be included to obtain a representative sample. Samples should be taken from the problem area and a nearby "normal" area for comparison.

Field Observation

It is realized that laboratory testing of soil and plant tissue samples are not generally economic or even possible options for most farmers in the countries. Making timely and focused observations in the field has been a valuable way to diagnose problems since the dawn of agriculture and continues to be the most common and valuable way to identify deficiencies and the basis for interventions. Probably the simplest approach in observation is the **transect walk**. An agriculturalist can acquire a tremendous amount of information just by walking through a field or production area and noting what looks good and what doesn't (obvious differences that may be problems that need addressing. A bit more resource intensive but also more valuable is to prepare a more detailed resource map of the entire area. Resource maps are physical maps that identify land use systems and help to graphically illustrate the spatial relationships between different land use systems. Resource maps can be an aid in assessing (potential) conflict between land-use systems and available resources. It can include water sources for irrigation, organic matter source for soil amendment and nutrient source, and others.

Diagnostic Keys

Diagnostic keys provide a systematic approach to observing plant and crop systems and help to narrow down the possibilities. In order to use them effectively, however, you will need to be familiar with a few fundamental terms used to describe observed symptoms (Table 5).

Table 5. List of nutrient deficiency symptoms commonly used as diagnostic keys and their definitions

Terms	Definition and comments
Chlorosis	General yellowing of the leaf tissue. A very common deficiency symptom, since many nutrients affect the photosynthesis process directly or indirectly.
Firing	Yellowing, followed by rapid death of lower leaves, moving up the plant and giving the same appearance as if someone touched the bottom of the plants
Interveinal Chlorosis	Yellowing in between leaf veins, but with the veins themselves remaining green. In grasses, this is called striping.
Necrosis	Severe deficiencies result in death of the entire plant or parts of the plant first affected by the deficiency. The plant tissue browns and dies. The tissue which has already died on a still living plant is called necrotic tissue.
Stunting	Many deficiencies result in decreased growth. This can result in shorter height of the affected plants.
Abnormal coloration	Red, purple, brown colors caused by pigments

When using the keys, you will notice that many of them start by asking where the symptoms are most evident on the plant (Table 6). This is because different nutrients exhibit different patterns of nutrient mobility**.**

Mobile nutrients can be translocated from old tissue (bottom of the plant) to new tissue (top of the plant). Nutrients such as potassium and magnesium, which are highly mobile in the plant, show deficiency symptoms in the older leaves. Nutrients such as calcium, boron, copper, iron, manganese, molybdenum, and zinc, which have a low mobility in the plant, show deficiency symptoms in the younger leaves. Nutrients such as nitrogen, phosphorus and sulphur, which have a medium mobility in the plant, show deficiency symptoms evenly spread over the plant.

Table 6. Diagnostic decision support tools to nutrient deficiency symptoms in plant

I. Effects are general on whole plant or localized on older, lower leaves	2
2. Leaves light green. Uniform chlorosis of older leaves, which may die and turn brown. Abnormal production of anthocyanins in stems and leaves. Stems with greatly reduced terminal growth	Nitrogen
2. Leaves dark green. Stunted growth. Abnormal production of anthocyanins resulting in red and purple colors. Death of older leaves. Stems weak and spindly	Phosphorus
II. Effects mostly localized on older, lower leaves	3
3. Older leaves chlorotic, initially interveinal, beginning at tips of leaves. Margins and tips of leaves may turn or cup upward. If severe, all leaves become yellow or white. Older leaves may drop off.	Magnesium
3. Older leaves mottled, with necrosis of leaf tips and margins. Leaves may curl and crinkle. Internodes abnormally short and stems weak, sometimes with brown streaks.	Potassium
III. Effects localized on new leaves	4
4. Terminal bud dies. Tips and margins of youngest leaves necrotic and then buds. Initially young leaves pale green with hooked tips, as well as being deformed	Calcium
4. Terminal bud remains alive	5
5. Leaves light green (never yellow or white), beginning with younger ones. Veins lighter than interveinal areas. Necrotic spots may appear but not common.	Sulfur
5. Leaves chlorotic, beginning with younger ones. Veins remain green, except in case of prolonged, extreme deficiency.	Iron

Important factor to keep in mind when using keys or when observing symptoms are:

- deficiency symptoms can often be confused with other complex field events, such as high-water tables, salt damage, disease, drought, herbicide stress and varietal differences,
- appearance of a growth disorder based on visual symptoms does not absolutely mean a nutritional deficiency exists; it could be a result of other environmental factors and not to the absence of a particular nutrient in the soil, and
- in case of more than one nutrient deficiency is present, one can be more dominant in its symptoms, obscuring the symptoms of the other element.

Photographs

"A picture is worth than thousand words." Many people find it much more useful to be able to see what a particular deficiency symptom looks like rather than just reading a description. A good source for pictures of common local nutrient deficiency symptoms is the local extension office.

History and Record Keeping

Photographs and keys to nutrient deficiencies are useful in diagnosis, but field experience and knowledge of field history based on local experience is the best diagnostic aid particularly when there is a phenomenon of sub-clinical deficiency. Sub-clinical deficiency is said to occur when there is a reduction in yield or yield potential without the visual symptoms of deficiency being seen. Accurate accounting of nutrient removal and replacement, crop production statistics, and soil analysis results will help the producer manage fertilizer applications. Accurate historical records can be valuable but keeping such records is not all that common particularly for developing country farmers such as in Ethiopia.

Nutrient Flow Analysis

It is one way to get a handle on what is happening to the nutrient status of a field over time. It can be used to give insight into the impact of farmer management decisions on soil fertility in his or her farm. Farmers transport material that contains nutrients - be it harvested products, manure, fertilizer or

straw that is used to build roofs. Estimating nutrient flows is a useful way to find out if farmers' crop management practices are sustainable, i.e. are outputs of nutrients balanced by a sufficient level of inputs.
To compare flows, there is a need to express them in the same unit, e.g. kg of nitrogen, phosphorus or potassium. This means that one needs to know the concentration of specific nutrient element in e.g. manure, grains and straw of specific crop produced, etc. and the amount of dry matter (at 0% moisture) that is produced, transformed or transported. Nutrient flow analysis should enable a farmer to answer questions such as: 'What is happening to my soil if I do not apply any fertilizer to my maize field, and I sell both maize grain and maize straw?' It is important to realize that such analyses try to model a complex reality and should, therefore, used with care. Boundaries of the farming system that is analyzed and, boundaries of its subsystems (e.g. maize production system, vegetable production system, animal production system, and household system) should be clearly defined.

The nutrient balances include, major nutrient **inflows** from organic manure, mineral fertilizers, symbiotic N-fixation and sedimentation on one hand, whereas **outflows** include nutrient losses through harvested produce, erosion, leaching etc. Clearly some of these parameters are easier to measure or estimate than others. For a given soil nutrient (usually N, P or K) the equation reads:

Balance = [IN1 + IN2 + IN3+ IN4 + IN5 + IN6] – [OUT1 + OUT2 + OUT3 + OUT4 + OUT5 + OUT6]

Where: IN1 = mineral fertilizers; IN2 = animal manure; IN3 = atmospheric deposition; IN4 = biological nitrogen fixation; IN5 = sedimentation; IN6 = uptake by deep-rooted plants; and OUT1 = harvested production; OUT2 = crop residues; OUT3 = leaching; OUT4 = gaseous losses; OUT5 = soil erosion; OUT6 = losses in deep pit latrines.

Nutrient inflows from atmospheric deposition or losses as gases are invisible and not easy to comprehend by farmers. If nutrient flow analyses are done with farmers it is important to realize that farmers do not think in terms of kg per hectare, but rather in terms of head loads, bags, cans, hectares etc. and one should as much as possible use these terms as tools of analysis. Such discussions will, therefore, often be more qualitative than quantitative, but can still give important insights, pinpointing e.g. at '**leaks**' in the system (e.g. unused animal manure, burning of straw). The nutrient balance in the country are mostly negative (Table 7).

Table 7. Nutrient balances at farm level in relatively rich or poor households in Areka area

Farm units	Rich farmer		Poor farmer	
	N	P	N	P
Enset garden	12	11	-12	6
Midfield	-3	8	-5	4
Outfield	-95	7	-54	3

Source: Tilahun (2006)

Recently Average nitrogen (N), phosphorus (P) and potassium (K) balances were -23 ± 73, 9 ± 29 and -7 ± 64 kg ha-1, respectively. The situation was most severe for N, where average depletion rate average was 0.2 % of the soil total N stock per year, which equals about 4.2 % of the available soil N pool (van Beek et al., 2016).

Resource Flow Mapping

Resource flow mapping consists of making a simplified picture (map) of the farm system and its resource flow pattern, including elements that are crucial in soil fertility management. To make a resource flow map, first draw farm fields and other farm elements such as buildings, grazing areas and compost pits. Then for each field, both present and previous crops are noted and arrows are drawn representing resource flows between fields and other farm elements. Arrows indicate the use of crop products and residues leaving the fields and organic fertilizers produced on-farm, entering the fields. They are also used to show resources leaving and entering the farm such as products sold and mineral fertilizers purchased.

The resulting picture presents an overview of how the farmer actually manages the fertility of his lands, and depicts interactions (or absence of interaction) between farm elements and elements outside the farm. In this process, elements that initially were ‘invisible’ to the farmer are thus made more explicit and ‘visible’. Only the essential elements of the complex farm system are presented within an overall picture that is drawn on a single sheet of paper. This picture permits the analysis of strong and weak points in management, in view of identifying possible improvements.

These days computer-based diagnostic decision support tools with various software models and applications can also help to quantify, calculate and visualize nutrient flows, optimal fertilizer doses / ratio’s, simulate important aspects of an agricultural system etc.

2.2 Action Planning

Once promising improved soil fertility management options are identified, joint experimentation can be planned with farmers and change agents to test and verify potential interventions. During this phase, farmers should be encouraged to come up with their own ideas. Planning should take place during one or several joint meetings between farmers and change agents (DAs and experts as required) where the outcome of the Diagnosis phase is discussed and topics for experimentation of different ISFM options are debated. The results from the learning and decision-support tools developed in the Diagnosis phase can be used to guide the discussions. The outcome of this phase is a timetable for the next growing season(s). This Action plan calendar shows:

- when certain experiments or training sessions will be conducted,
- when field visits or monitoring tours will be made,
- clear division in responsibilities between farmers and change agents, and
- scheduled meetings with local input dealers or credit providers for certain ISFM options

2.3 Trying Things Out

Once the Action plan calendar is developed, ISFM ‘learning plots’ (i.e. fields that are proposed by farmers to be used for joint experimentation and learning) can be established around certain ISFM options. The ISFM learning plots should be followed frequently throughout the season. Field observations and participatory analysis (learning processes instead of comparing just one or two options) are key here. Farmers should be encouraged to make observations and take notes. Ideally farmers keep records of ISFM management practices, i.e. how things were done in practice and keep records of ‘observation indicators’ (e.g. plant height, weed infestation, quality of land preparation, etc.). Such forms need to be developed with farmers, and should be easy to fill in. Visual aids, like drawings and photographs can be useful. Such forms become important learning tools, give a record of cropping history and can be used in farmer discussions.

Farmers should try out new things for themselves. Successful ideas spread rapidly and never more so than when the ideas are developed by farmers themselves. ISFM learning plots will usually focus on a restricted set of management interventions and are farmer-led. Experimentation may deal only with soil fertility related issues, like a certain combination of mineral fertilizer and organic amendments, but may also address other issues that reduce the efficiency of external inputs, such as water and weed management.

ISFM learning plots can be complemented by more detailed analysis of what nutrient is limiting growth. In systems where farmers have the possibility and the means to apply fertilizer, **nutrient-omission trials** can be installed. Such trials deliberately omit one nutrient to investigate its importance. Through the yield obtained on the plot you get an idea of the supplying capacity of the soil for the nutrient that was omitted. Such trials are very useful, as soil tests are beyond the means of the average farmer and results of soil tests do not always correspond to crop performance, especially for N. The trick is to place the trials at representative sites, on different major soil types, and on sites with different cropping history, such as close to a village, far away etc. Nutrient omission trials are not repeated in one farmers’ field, but each participating farmer is one replication. Good management of such nutrient omission trials is important, to ensure that nutrients are determining crop growth, and no other factors, such as weeds, diseases, pests, water shortage etc.

2.4 Evaluation

Evaluation is a continuous process during the cropping cycle. ISFM learning plots should be regularly visited (ideally at least weekly), and compared with farmer practice. Farmer meetings and wrap-up sessions at the end of the season allow discussion of what worked and what didn't. If monitoring of the experiments is done well (i.e. frequent good observations and sound analysis) recommendation domains can be established for each ISFM option. This will allow certain ISFM options to be fed forward to the **DATE**-extension cycle. Gradually key villages may become knowledge centres in soil fertility management and may even take a lead role in farmer-to-farmer training.

3. History of approaches to soil fertility management in SSA

During the past three decades, the understanding that underpins nutrient management in cropping systems in SSA has undergone substantial change due to improved knowledge, based on extensive field research as well as changes in the overall social, economic and political environment in SSA (Table 8).

In the 1960s and 1970s major emphasis was placed on the use of mineral fertilizer to achieve proper crop nutrition and improved crop yields (Table 8). In the 1980s more emphasis was given to the use of organic resources, partly because of the problems with fertilizer access in SSA during that period. At present much research has shown the importance of combining the use of mineral fertilizers and organic resources in ways that are adapted to local conditions to achieve satisfactory crop yields and efficient fertilizer use.

Over the last few decades, there has been a gradual global shift of soil fertility management research focus towards an approach that improves soils health (sequesters carbon) such as to Integrated Soil Fertility Management (ISFM) (Table 8) which combines various soil fertility management techniques. This approach is based on a thorough scientific understanding of the underlying biophysical processes of ISFM and aims to promote options that make the best use of locally available inputs, and that are tailored to suit local agro-ecological conditions, and farmers' resources and interests.

It is a simple fact that plants use soil nutrients to grow and reproduce. If whole plants or major portions of them are continuously removed from the field and no nutrients are added, the soil's reserve of some or all of the elements will not be sufficient for economic agricultural production.

Table 8. Changes in tropical soil fertility management paradigms over the past five decades

Period	Approach	Role of fertilizer	Role of organic inputs	Experience
1960s to 1970s	External input use.	Use of fertilizer alone thought sufficient to improve and sustain yields.	Organic resources play a minimal role.	Limited success due to shortfalls in infrastructure, policy, and farming systems.
1980s	Organic input use.	Fertilizer plays a minimal role.	Organic resources are the main source of nutrients	Limited adoption. Organic matter production requires livestock ownership, excessive land and labour
1990s	Combined use of fertilizer and organic residues	Fertilizer use is essential to alleviate the main nutrient constraints	Organic resources are the major 'entry point' to soil fertility improvement and serve other functions besides nutrient supply.	Localized adoption around specific crops.
2000s	Integrated Soil Fertility Management	Fertilizer is a major entry point to increase yields and supply needed organic resources	Organic resources can improve the use efficiency of fertilizer	Goal of large-scope adoption

Source: Sanginga and Woomer (2009)

4. Principles of Integrated Soil Fertility Management

ISFM according to Sanginga and Woomer (2009) is defined as "application of soil fertility management **practices**, and the **knowledge to adapt these to local conditions**, which **maximize fertilizer and organic resource use efficiency and crop productivity**. The practices necessarily include appropriate fertilizer and organic input management in combination with the utilization of improved germplasms. All inputs need to be managed following sound agronomic and economic principles." Similarly, Soil Fertility Consortium for Southern Africa (SOFECSA), refers ISFM as combination of a proven set of concepts, principles and practices on the efficient use of available organic and inorganic resources, soil water and appropriate plant genotypes, according to farmer circumstances, in maintaining or improving soil fertility leading to sustainable crop production for household food and income security and enhanced livelihoods (Mapfumo, 2009). ISFM in general seeks to **(i)** encourage use and optimal combinations of locally available and externally added nutrient resources into cropping systems; **(ii)** promote appropriate choices of crop types and cultivars for given biophysical and socio-economic environments; **(iii)** employ mechanisms that minimise nutrient losses from the cropping system to enhance sustainability, and **(iv)** promote recycling of nutrients within cropping systems.

The local adaptation in ISFM allows adjustment for variability in soil fertility status and recognizes that substantial improvements in the Agronomic Efficiency (AE), defined as the amount of output (eg crop yield) obtained per unit of fertilizer applied, of the applied nutrients on more responsive soils **(A in Fig. 6).** On poor, less responsive soils, application of fertilizers alone may not result in improved nutrient use **(B Fig. 6)** and fertilizer is better applied in combination with organic resources (**C in Fig. 6**). Additions of organic materials to the soil provide several mechanisms for improved AE, particularly increased retention of soil nutrients and water and better synchronization of nutrient supply with crop demand, but it also improves soil health through increased soil biodiversity and carbon stocks.

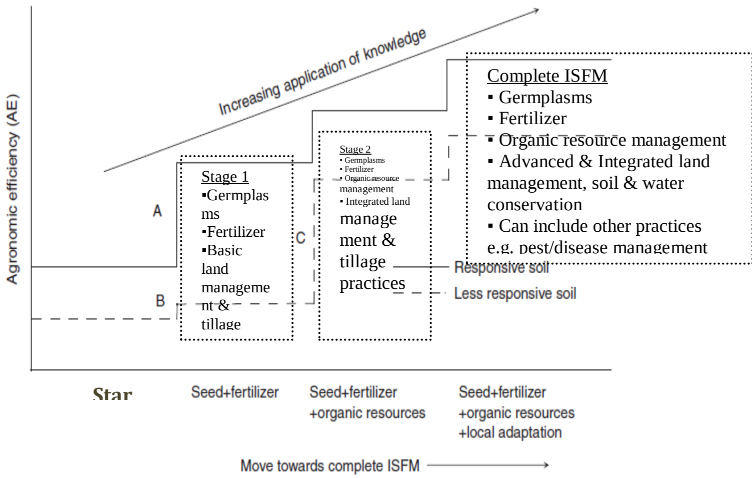


Figure 6. Conceptual relationship between the efficient uses of resources as one move from current starting towards more complete ISFM

Source: Sanginga, N. and Woomer, P.L. (2009)

ISFM approach therefore embraces the principles of plant production ecology where yield is a function of the interaction between genotype, environment and management:

Yield = G (genotype) x E (environment) x M (management)

where:

- Genotype is the seed or plants used in the farming system. They may be local or improved varieties;
- Environment refers to the soils (with variable response to inputs) and climate in the particular location; and
- Management refers to the farmer's ability and skill in managing crops and the farming system.

4.1 ISFM Strategies to Maximize Profits and Agronomic Use Efficiency

You have now come a long way towards your goal of developing a sound ISFM program strategy. You've selected a site where to do your work, identified potential problems and come up with a plan to verify your diagnosis. This section will deal with what can be done to address the problems identified. Although we focus on nutrient management in this framework with special emphasis on the macro-nutrients, it should be realized that soil fertility is more than nutrients alone. Certain interventions may improve the physical and biological properties of the soil, yielding important benefits, such as better water retention and improved recovery of mineral fertilizer by the plant.

ISFM is defined as a set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs and improved germplasm, combined with the knowledge of how to adapt these practices to local conditions, aimed at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic principles. The goal of ISFM is optimized crop productivity through maximizing interactions that occur when fertilizers, organic inputs and improved germplasm, along with the required associated knowledge, are integrated by farmers.

In this session we will consider 4 main options:

- adding nutrients to replenish stocks and flows in the soil,
- blocking nutrient flows leaving the farm ('leaks in the system'),
- doing a better job in recycling nutrients that are not optimally used within the farm,
- increasing the efficiency with which nutrients are used by the various production systems

4.1.1 Adding combination of Organic and Inorganic Fertilizers

While adding organic matter can contribute to maintaining soil fertility, organic sources of nutrients have low nutrient contents and are usually not abundantly available. Sustaining soil fertility and increasing productivity using organic resources alone is, therefore, often slow response. An enormous amount of organic fertilizer would be required to maintain soil fertility levels in each and every field. However, the opposite strategy, the unique use of inorganic fertilizers may lead to yield gains in the short term, but to serious damage to soil fertility (e.g. acidification) and yield decline in the long term. The best remedy for soil fertility is, therefore, a combination of both inorganic and organic fertilizers, where the inorganic fertilizer provides the nutrients and the organic fertilizer increases soil organic matter status, soil structure and buffering capacity of the soil in general. Use of both inorganic and organic fertilizers often results in synergism, improving efficiency of nutrient and water use.

Since the introduction of fertilizer to smallholder farming in the country under the Freedom from Hunger program in the late 1960s, national annual fertilizer use have continuously increased and the increase in the recent two decades was more substantial. Given the emphasis of increasing crop production through higher fertilizer use, import of chemical fertilizer have also considerably increased (IFPRI. 2013). The results from series of fertilizer experiments and demonstrations have depicted significant positive responses to nitrogen (N) and phosphorus (P) at almost all locations. The results further showed that the yield increase due to fertilizer for the improved varieties was found to be by far higher than for the local varieties (Tolessa et al., 2007).

Adding of organic matter can improve virtually almost all soil properties. It will result in looser and more porous soil, lower bulk density, higher water-holding capacity, greater aggregation, increased aggregate stability, lower erodibility, and greater soil fertility and increased CEC. Nevertheless, adding organic matter alone is not the complete answer to soil fertility problems. Soil organic matter contributes to soil productivity in several ways, but there is no direct quantitative relationship between soil productivity and total soil organic matter.

Soil organic matter cannot be increased quickly even when management practices that conserve soil organic matter are adopted. The increased addition of organic matter associated with continuous cropping, and the production of higher crop yields, are accompanied by an increase in the rate of decomposition. Moreover, only a small fraction of crop residues added to soil remains as soil organic matter. If the rate of addition is less than the rate of decomposition, soil organic matter will decline and, conversely if the rate of addition is greater than the rate of decomposition, soil organic matter will increase. Different sources of organic carbon or organic fertilizer have different nutrient level (Table 9 and 10)

Table 9. Nutrient content of dry manure of Ethiopian Cattle

Nutrient	Range (manure)	Average (manure/compost)
N (g/kg)	11.7 to 27.4	18.3 / 8.3
P (g/kg)	2.2 to 7.0	4.5 / 1.8
K (g/kg)	10.6 to 54.4	21.3 / 7.3
Ca (g/kg)	10.1 to 24.6	16.4
Mg (g/kg)	3.2 to 12.4	5.6
Fe (mg/kg)	3693 to 22477	10776
Mn (mg/kg)	271 to 1904	777
Cu (mg/kg)	8 to 86	24
Zn (mg/kg)	49 to 2127	92

Table 10. Nutrient content of different dry manures

Manures	**N**	**P_2O_5**	**K_2O**
	---------- g/kg (dry weight basis) -------		
Dairy manure	20.1	30.2	30.0
Beef manure	10.2	20.0	20.1
Poultry manure	30.0	50.0	20.0
Composted yard waste	10.3	4	4

Among the integrated soil fertility management practices, integrated use of chemical fertilizer with Farmyard manure; compost; green manure; and lime; were the common practices in most parts of Ethiopia. The approach is to increase the agricultural production while safeguarding the environment for future generations. Use of organic manure is more beneficial when combined

with inorganic fertilizers. Higher crop yields were achieved when the same amount of nutrients are used in combination (organic and inorganic) than use of either NP or FYM alone. The practice increased nutrient use efficiency of crops and soil fertility status; and hence the returns to farmers due to the positive interactions on soil biological, chemical and physical properties**.**
Sole application of FYM at the rates of 4-12 t ha^{-1} is encouraging for resource poor farmers on relatively fertile soils. Application of FYM every three years at the rate of 16 t ha^{-1} supplemented by NP fertilizer annually at the rate of 20/20 Kg N/P ha^{-1} was recommended for sustainable OPV maize production around Bako area (Tolessa, 1999a). The integrated use of coffee by-products and N fertilizer increased N uptake and grain yield of haricot bean and maize at Hawassa, southern Ethiopia. Coffee residue along with N fertilizer positively influenced soil moisture, soil nitrogen and organic matter, grain and water use efficiency of maize (Tenaw, 2006). The integrated use of 4.53 t FYM ha^{-1} and 37 kg N ha^{-1} were recommended for tef production on Vertisols of central highlands (Teklu et al., 2009). Integrated use of NP and Farmyard manure improves yield of maize intercropped with climbing beans and the physio-chemical properties of soils.

The integrated use of 5 tons ha^{-1} of compost either with 55/10 or 25/11 kg of N/P ha^{-1} is economical for maize production in Bako Tibe districts. Applications of the full-recommended doses of NP fertilizers integrated with 5 tons ha^{-1} crop residue are advised to improve the fertility of soils for sustainable maize production in Haramaya area.

The composting time linearly increased grain yield of tef up to 7.5 months, whereas extending the compositing period to 8.5 months started to decline tef grain yield. Increasing the proportion of legume plants in compost preparation, increased the quality of compost and shorten period of compositing to use for immediate soil amendment. Tef was most responsive to FYM and compost on Vertisols and Nitisols; mustard meal for both soil types (Balesh et al., 2007).
Integration of biogas slurry and NP fertilizer produced significantly higher grain yield of maize and improved soil properties. Biogas slurry at eight t ha^{-1} with 50 % recommended N/P kg ha^{-1}(100/50 kg ha^{-1} of Urea/DAP) or 12 t

biogas slurry ha^{-1} alone is recommended for maize production. Integration Vermicompost with NP fertilizer improved grain yield of different crops and soil properties.

Challenges and opportunities

- organic materials are required in bulk
- Most of the organic materials such as crop residues and FYM can be used as sources of energy and income instead of being used for soil amendment.
- Open grazing of animals
- Slow release of nutrients
- Little knowledge of farmers in integrating organic and inorganic fertilizer sources
- Little knowledge of farmers on preparing and keeping organic fertilizer sources

4.1.2 Adding Other Elements and Lime

While N and P are arguably the most commonly deficient elements, a deficiency of any of the other critical elements will adversely affect crop growth and the profitability and sustainability of a farm. If soils in your area are acidic, it might be necessary to add lime. According to Temesgen et al. (2017), about 43% of the cultivated land in Ethiopia is affected by soil acidity, of which about $2/3^{rd}$ is dominated by moderate to weak acid soil (4.5 < pH in KCl <5.5), and the remaining $1/3^{rd}$ by strong acid soil (pH in KCl < 4.5). Their occurrences are caused by natural processes (weathering) and/or man-made processes. Acid soils are infertile because of (i) Ca and/or P deficiencies and (ii) Al and/or Mn toxicities. Acid soils can be managed by liming based on appropriate lime requirement curves.

The combined use of lime with some type of organic matter is a superior treatment to increase pH and yield of crops. The reason for this is that organic matter has been shown to reduce Al toxicity, as well as enhance plant growth through the improvement of physical properties and the fertility of the soil. Addition of organic wastes and green manures to acid soil reduce Al toxicity

and increase crop yields; eg. by about 3.7 t ha^{-1} for barley.
Higher yield of crops including maize, finger millet, barley and soybean were obtained from integrated application of lime and phosphorous. Integrated use of 92/20 kg N/P ha^{-1} and 4 t lime ha^{-1} (according to the exchangeable acidity level of the soil) increased mean grain yields of maize intercropped with common bean by 23 and 10 %, respectively.

4.1.3 Reducing Nutrient Losses - Blocking Nutrient Flows Leaving the Farm

Nutrient losses can be reduced by controlling erosion, run-off and leaching. Erosion losses can be reduced through the construction of bunds, terraces, or stone lines. Multipurpose legume trees can be instrumental in re-capturing nutrients leached in to the subsoil in addition to fixation from atmosphere. Nitrogen losses through NH_3 volatilization during storage and handling of manure limit its effectiveness as a nutrient source. Anaerobic storage in pits with or without addition of crop residues can significantly reduce N losses.

4.1.4 Better Management of Available Resources – Managing Internal Flows of Nutrients

Better integration of crop and livestock management, use of household waste, composting and incorporating crop residues into the soil are promising ways to improve nutrient cycling within the farm. Bedding in stables absorbs urine and conserves nutrients.
Organic matter sources with a low C/N ratio mineralize very quickly and will supply nutrients for plant growth, but this will not lead to a rapid increase in soil organic matter in the soil. The effectiveness of an organic resource as fertilizer decreases with increasing C/N ratio. Chicken manure and vegetable residues have C/N ratios of about 10 and are most effective as an alternative to mineral fertilizer. Cattle and pig manure are intermediate (C/N ratios of about 20), and straw is least effective as fertilizer. The quality for its soil amendment increases with increasing C/N ratio, but decreases at extreme values. Soil N availability may even decrease if soil amendments are used with very high C/N ratios as the microorganisms that decompose the material temporarily block N otherwise available to the crop.

Composting is a process where material with a high C/N ratio (e.g. maize straw) is converted into material with a low C/N ratio. Farmers may improve the nutritional quality of compost by adding ashes and droppings of small ruminants. During composting, about 50% of the carbon in the initial material is typically lost but mineral nutrients are mostly conserved. Finished compost is therefore generally more concentrated in nutrients than the initial combination of raw materials used and can serve as an effective means of building soil fertility.

4.1.4.1 Improving the Efficiency of Nutrient Uptake

Improving input use efficiency is a key intervention as it results in reduced production costs and environmental risks. The more nutrients a crop converts to grain or fiber, the less opportunity for nutrients to reach streams, lakes or groundwater. Nutrient recovery may be enhanced in several ways. Perhaps the most effective of these is through improved crop management. It is important that ***nutrient addition be synchronized with plant demand*** for nutrients and fertilizer application may greatly enhance recovery. Better management of yield reducing factors like weeds, pests and diseases may greatly increase nutrient recovery from fertilizers.

Paying attention to ***placement of fertilizers*** is another important tactic. Plants take up nutrients more efficiently if fertilizers are applied close to the roots. It has been shown that micro-doses of growth-limiting nutrients placed near the roots may greatly enhance crop performance. Mulching (e.g. with maize straw or other plant residues) may conserve moisture and smother out weeds, enabling better crop establishment and nutrient uptake. It is common to see that farmers tend to wait with weed management until weeds are clearly visible and easy for uprooting, a period when most of the damage will already be done. It is also important to consider the value of balanced fertilization. When nutrient supply is unbalanced, yields and profits decline and, quite often, the quality of the crops are impaired.

4.1.4.2 Economic Considerations

It should be obvious that economics (Table 11) are the basis for farmer decision making and judging ISFM recommendations. Some of the key economic considerations in ISFM are highlighted below. In the majority of cases, farmers are not motivated to use ISFM technologies because they are not profitable. Soil fertility management can be strongly related to the degree of access to resources (e.g. land, cattle, labour, carts and cash). Land tenure is a very important issue. Farmers who do not own the land they cultivate may be hesitant to invest in soil fertility, as the pay-off is not always directly visible. Access to resources often differs among household members, e.g. women may have only limited access to certain resources.

Table 11. simple methods used for measuring profitability of fertilizer use

Method	It measures:	Profitability Decision Criteria
Value Cost Ratio (VCR)	The value of additional production due to fertilizer application. Estimated by dividing the value of the yield increase by the cost of fertilizer used in procuring the increased yield. It is a profit incentive.	Values must be equal to at least 2 in assured and less risky environments and at least 3 or 4 in more risky environments.

5. Promoting ISFM among Farmers

Recommendations that are not followed are not worth much. What can you do to see these adopted by farmers? What can you do to make a difference? In this section of the training, we will focus on information dissemination approaches and tools. We will again introduce the Extension-DATE approach and other approaches

5.1 Making an Extension DATE

Like the Research-DATE, the Extension-DATE is a participatory learning and action approach but focused on dissemination and adaptation of successful technological recommendations developed during the Research-DATE. The Extension-DATE involves working with farmers and other soil fertility experts and consists of the same four phases as the Research-**DATE** - **D**(iagnosis), **A** (ction planning), **T** (rying things out) and **E**(valuation).

5.2 Diagnosis

At this stage the recommendations developed during the Research-DATE should be verified for farmers at or close to the strategic site. Now, during the Extension-DATE, you need to assess their usefulness for more widely distributed farmers and their more diverse farming systems and circumstances. This is the main focus of the Diagnosis phase. Particular areas of interest during this phase include the identification of information and communication networks and key-actors that can play an active role in the dissemination of ISFM technologies identified.

Farmer organizations including **F**armers **R**esearch **G**roup (FRGs) and unions can often play a vital role in the process of extending ISFM strategies and also in helping to manage credit and inputs, storage and the marketing of agricultural products. Methods that can be used in this phase typically include village-level meetings, workshops bringing together the key-actors for ISFM extension (farmers, input dealers, local policy makers, traders, extensions and development workers), guided study tours of key-actors, innovative ways to exchange and/or diffuse information.

5.3 Action Planning

Once the interest for new and/or alternative ISFM strategies is established, meetings with farmers and other key-actors should be organized to discuss how to start with a dissemination and adaptation process for ISFM strategies. The action planning phase deals with determining what kind of ISFM strategies will be 'taken-up' by the farmers and by which farmers (the whole village, a sub-group of farmers first?) eg clustering. Other questions to answer include input provisioning (individually? farmers' group?), marketing of agricultural produce and the need for credit.

5.4 Trying Things Out

Action plans that have been decided upon in the action planning phase should be carefully implemented and monitored by the team of 'change agents' and the different stakeholders. In the extension cycle, farmers are implementing the adaptive trials. Input dealers and probably some farmer organizations are involved in providing inputs in time to the farmers. Farmers and 'change agents' are involved in setting-up rural knowledge centers. Farmers and traders may be involved in activities to improve storage and marketing of agricultural produce.

From the above, it should be clear that 'Change agents' have an important role to play in the promotion and institutionalization of participatory research and extension approaches. Dissemination of information within the region, between farmers and other stakeholders, is important. This helps to create awareness and to emphasize possibilities and favorable conditions for a sustainable intensification process, and the roles any actor can play.

5.5 Evaluation

The Evaluation phase aims to measure the progress being made in the extension cycle. To do this, a participatory monitoring and evaluation system should be set up, that enables the different stakeholders to analyze specific actions (were all the agreed activities executed? How many people were involved? What results?) as well as the larger 'Action plan' all together. Indicators that effectively measure the results of the different activities and that are comprehensible for a large audience should be decided. Specific analyses may be required. For instance, the functioning of input delivery and marketing of agricultural produce ma need to be judged for timely implementation of the activities and efficiencies.

5.6 'DATE ing' Considerations

When thinking about promoting ISFM strategies on a larger regional or national scale, it is critically important to consider the economic cost-benefit of recommendations. Extension strategies must, therefore, not only focus on promoting practices to farmers that are technologically sound but may have to work to improve the accessibility, both geographically and financially.

It is clear that bringing all this about will require the active participation of a range of other actors - all of which will have to be encouraged to invest time and money to make ISFM a reality. The question of farmer organization and empowerment is of particular importance. Significant economies of scale can be achieved when farmers come together and this leads to significant improvement in their access to marketing networks (bargaining power, credit, storage facilities, etc.) and to better access to information

- Farmers will have to invest in 'external' inputs and should (re-) allocate resources to adopt ISFM technologies. Moreover, farmer organization is not only an important means to increase access to markets and increase their bargaining power but will also be crucial to manage natural resources at community levels.
- Traders, transporters, and manufacturers should invest in local sale points of 'external' inputs, fabrication of agricultural equipment, processing of agricultural products, etc.
- Governments should invest in public infrastructure and in education and should stimulate and facilitate private sector actors (farmers, traders etc) to invest in the activities listed above.

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Appendixes

Appendix Table 1. General symptoms of nutrient deficiency in plants

Nitrogen: Plant light green, lower leaves yellow to light brown, stalks short and slender, plants stunted.	**Iron**: Young leaves are chlorotic, with principal veins typically green; stalks short and slender.
Phosphorus: Plants dark green, often developing red and purple pigments; lower leaves sometimes yellow; plants stunted.	**Zinc**: Leaf spots on older leaves, with spots rapidly enlarging and generally involving the area between the veins; thick leaves; stalks with shortened internodes.
Potassium: Spots of dead tissue, usually at the tips and between the veins; marked margins of leaves.	**Boron**: Young leaves of the terminal bud are light green at the base; the bud eventually dies.
Magnesium: Mottled or chlorotic leaves, which typically redden; leaf tips and margins turned or cupped upward.	**Copper**: Young leaves are permanently wilted, with spotty or marked chlorosis.
Calcium: Young leaves of terminal bud hooded; with severe deficiency, dying buds; dying back at the tips and margins of the leaf.	**Manganese**: Spots of dead tissue scattered over the leaf; smallest veins tend to remain green.
Sulfur: In young leaves, veins and tissue between veins are light green.	

Appendix Table 2. Nitrogen and Phosphorus fertilizer recommendations for major maize growing regions and soil types in Ethiopia

Region	**Locations and soil type**	**Soil Types**	**N/P (kg ha^{-1})**	**Variety**	**References**
Oromia	Bako	Alfisol	75/20; 92/20	OPV; BH 660	Tolessa et al. (2002)
	Bako, Jimma, Holetta	Alfisol, Vertisol, Nitisol	119/30	Maize Hybrid	Wakene et al. (2012).
	Melkassa,	Andosol	41/20	OPV	Tolessa et al. (2002); Wakene et al. (2012).
	Gimbi	NA	96/30	Hybrid	Wakene et al. (2012).
	West Showa (Gudar, Mutulu, Toke and Babichi area)	NA	75/22	Hybrid/OPV	Tolessa et al. (2002)
	West Wallega (Gimbi, Guliso and Jarso area)	NA	75/33	OPV	Tolessa et al. (2002)
	Haramaya	Vertisol	87/20	OPV	Wakene et al. (2012).
	Arsi highlands	NA	138/40, 92/30	(Argene, AMH 850)	Bayisa and Endale, 2013
	Jimma zone	Vertisol	69/20	Hybrid/OPV	Tolessa et al. (2002)

Region	Locations and soil type	Soil Types	N/P (kg ha^{-1})	Variety	References
	Ambo	Vertisol, Fluvisol	110/20	Hybrid	Wakene et al. (2012).
Gambella	Abobo	NA	23/20	OPV	Anon. (1999-2000)
	Gambella	Alisol	41/20	OPV	Tolessa et al. (2002); Wakene et al. (2012).
SNNPRS	Hawassa	Vertisol, Fluvisol	110/20	Hybrid	Wakene et al. (2012).
	Areka/Kokate	Alisol/Nitisol	46/20	Hybrid	
Amhara	Bure	NA	100/35	Hybrid	
	Pawe	Nitisol	69/0	Hybrid	Aseffa et al., 2009
	Adet	Vertisols	119/30	Hybrid	Wakene et al. (2012).
	Basoliben, Mecha and Yilmana, Densa and Ankesha, Jabi Tenan woredas	Nitisols	60/20	Hybrid	Tilahun et al., 2007a
	Bure and Huleteju Enebsie	Vertisol	120/20	Hybrid	
	Achefer	Nitisol	180/60	Hybrid	

NA= Data not available; Source: Mandefro et al. (2002); Worku et al. (2012).

Appendix Table 3. Optimum N and P fertilizer recommendations for sorghum growing areas in Ethiopia

Region	Locations	Soil type	NP (kg ha^{-1})	References
Amhara	Ambasel, Kalu, Habru	Black soil	46/23 - 69/46	Adet AR Center
Oromia	Melkassa, Welenchiti, Northern Ethiopia	Andosol	41/20	Worku et al., 2006; Tewodros et al., 2009

Appendix Table 4. Optimum N and P fertilizer recommendations for major common bean growing regions and soil types in Ethiopia

Region	Locations	Soil type	NP (kg ha^{-1})	References
Oromia	Rift valley of Ethiopia	Andosol	23/0 and 23/20	Birhan, 2006

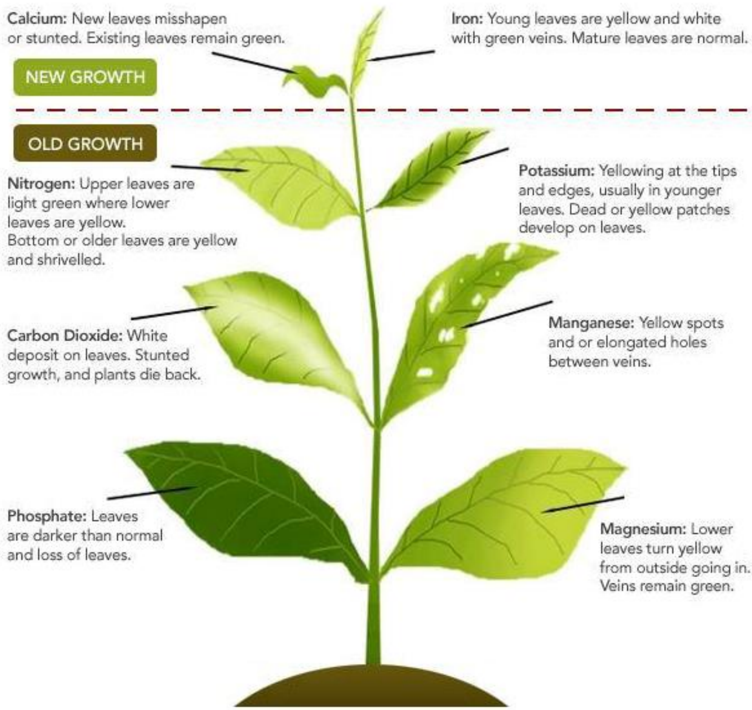
Appendix Table 5. Optimum N and P fertilizer recommendations for major tef growing regions and soil types in Ethiopia

Region	Location	Soil Type	N/P rates (kg ha^{-1})	Reference
Oromia	Ada'a, Akaki	Vertisols	60/10-15	Tekalign *et al*. (2001)
	Ada'a	Andosol	90/15	Teklu (2003)
	Melkassa	Andosol	23/10	Olani *et al*. (2005)
	Wolenchiti, Wonji	Andosol	23/10	Olani *et al*. (2005)
	Holetta	Nitisols	40/26	Balesh et al. (2008)
	Holetta	Vertisol	60/26	Balesh et al. (2008
	Arjo, Shambu	Nitisol	15/10	Abdenna *et al*. (2006)
SNNPRS	Humbo, Jinka	Nitisol	23/30	Abay *et al*. (2010) (unpublished)
	Areka	Nitisol	18/20	Kelsa (1998)
	Areka	Alisol	9-18/10-20	Abay (2011)
	Bobicho (Hossana)	Luvisol	9-27/10-30	Abay (2011)
Tigray	Tahtay Koraro and	Cambisol/Luvisol/ Vertisol	46/10	Abreha and Yesuf (2008)
	Asgede Tsimbela	Vertisol	46/46 (P from Orga fertilizer)	Fissehaye et al., 2009
Amhara	Yilmana Densa, Estie, Ebinat	Nitisol	40-41/18-26	Minale *et al*. (2004) Alemayehu *et al*. (2007)
	Achefer, Gozamin	Nitisol	60/26	Alemayehu *et al*. (2007)
	Dembecha, Dangila, Bure	Nitisol	20/18	Alemayehu *et al*. (2007)
	Dejen, Belesa	Vertisol	41/20	Alemayehu *et al*. (2007)
	Bichena	Vertisol	80/9-18	Minale *et al*. (2004)
	Huleteju-Enebssie, Awobel, Simada, Dembia	Vertisol	60-80/18-26	Alemayehu *et al*. (2007)
	Kelela, Tenta (Wata), Tehulederie, Habru, Wadla	Brown soil	46/0-20	Sirinka progress report (2007)
	Sayint, Kalu (Adamiya)	Red soil	46/10-30	Sirinka progress report (2007)
	Mekdela, Kobo Zuria, Sayint (Waro), Kalu (Harbu)	Black soil	46/0-30	Sirinka progress report (2007)

Source: Fissehaye et al. (2009); and Wakene and Yifru (2013).

Appendix Table 6. Optimum N and P fertilizer recommendations for major wheat growing regions and soil types in Ethiopia

Region	Location	Soil type	N/P rate (kg ha^{-1})	Source
SNNPRS	Hosanna, Kokate, Hagereselam	Nitisol	46/40	Abay et al., 2010 unpublished
	Chencha (Dokotsida and Gindogembela Kebeles)	N.A	78/20	Bekalu and Arega, 2016
Oromia	Debrezeit & Akaki	Vertisol	120 N	Bemnet et al, 2006
	Bekoji, Asasa	Nitisol	46 P_2O_5	KARC, 2004
	Kulumsa	Nitisol	90 N	Genene, 2003
	Central highlands (Holetta and Ginchi)	Nitisol & Vertisol	60/ 26	Amsal et al, 2000
	Akaki & Chefe Donsa	Pellic vertisol	92 to 115/15	Teklu et al, 2000
	Central highland Vertisols	Vertisol	60/10	Teklu, 2003
	Arjo and Shambu	Alfisol	23/23	
	Debre zeit & Akaki	Vertisol	64/20.9	Workneh and Mwangi, 1994
	Eteya-Gonde Bekoji	Nitisol	123 and 82; 0	Yesuf and Duga, 2000
	Central highlands		40- 64 N & 5-20 P	Getachew et al., 2015
Amhara	Farta & Lai-Gaint, NW Eth	Luvisol	123-138/30	Minale et al, 2006
	Bichena	Vertisol	138/20 with BBF	Minale et al, 1999
	East Gojam (Goncha Siso Enebssie and nebssie Sarmidir districts)	Nitisol	92 /20	Asmare et al, 1995
Tigray	Hawzen	Sandy soil	46/20	Bereket et al., 2014
Afar	Melka Werer, irrigated wheat	Cambisol	30/0	Kassahun, 1996


Calcium: New leaves misshapen or stunted. Existing leaves remain green.
Iron: Young leaves are yellow and white with green veins. Mature leaves are normal.
NEW GROWTH
OLD GROWTH
Nitrogen: Upper leaves are light green where lower leaves are yellow. Bottom or older leaves are yellow and shrivelled.
Potassium: Yellowing at the tips and edges, usually in younger leaves. Dead or yellow patches develop on leaves.
Carbon Dioxide: White deposit on leaves. Stunted growth, and plants die back.
Manganese: Yellow spots and or elongated holes between veins.
Phosphate: Leaves are darker than normal and loss of leaves.
Magnesium: Lower leaves turn yellow from outside going in. Veins remain green.