Lesson 1.1: Introduction to ISFM

This is a course on Integrated Soil Fertility Management (ISFM). We consider ISFM to be an approach to sustainable and cost-effective management of soil fertility. ISFM attempts to make the best use of inherent soil nutrient stocks, locally available soil amendments and mineral fertilizers to increase land productivity while maintaining or enhancing soil fertility. ISFM is a shift from traditional fertilizer response trials designed to come up with recommendations for simple production increases. The goal of ISFM is to develop comprehensive solutions that consider such diverse factors as weather, the presence of weeds, pests and diseases, inherent soil characteristics, history of land use and spatial differences in soil fertility. It involves a range of soil fertility enhancing methods, such as improved crop management practices, integration of livestock, measures to control erosion and leaching, and measures to improve soil organic matter maintenance. ISFM strategies include the combined use of soil amendments, organic materials, and mineral fertilizers to replenish soil nutrient pools and improve the efficiency of external inputs. A critical factor to keep in mind when thinking about ISFM strategies is that it is very important to consider the socio-economic aspects of technological interventions recommended. What technologies will be feasible and profitable for farmers to adopt? How long before farmers can expect a return on their investment in these technologies? What about input and output prices? Is labour available? What are the implications of existing agricultural policies and marketing practices?

Some of you may have heard of other terms used to identify this approach. As you look through the literature you will see Soil Fertility Management (SFM), Integrated Soil Nutrient Management (ISNM), Integrated Nutrient Management (INM) and some publications refer to Integrated Plant Nutrition Systems (IPNS). Whatever name is used, the underlying principles of all of these is the same – the integration of a range of actions that result in raising productivity levels while maintaining the natural resource base. Key aspects of the approach include:

- Replenishing soil nutrient pools
- Maximizing on-farm recycling of nutrients.
- Reducing nutrient losses to the environment.
- Improving the efficiency of external inputs

ISFM's basic focus is on sustainability. In our framework sustainability involves 3 essential components: (1) Adequate, affordable food, feed and fiber supplies; (2) A profitable system for the producer; and (3) Responsible safeguards for the environment. - http://www.back-to-basics.net/efu/pdfs/mey.pdf

In the following lessons we will be going into much more detail on this approach and what it involves. For those interested in a discussion of the major issues associated with ISFM and a history of human efforts to manage soil fertility we hope you will take the time to visit and read through the supplementary articles listed below.

Supplementary Reading

For some additional background on ISFM and a brief history of the ways farmers have tried to manage the fertility of their soils, interested participants should browse the following.

- Integrated Nutrient Management, Soil Fertility, and Sustainable Agriculture: Current Issues and Future Challenges -http://www.ifpri.org/2020/briefs/number67.htm
- Soil Fertility and Nutrient Management: Overview of the Debate - http://www.keysheets.org/green_7_soils.pdf
- Fertilizer Use: A Historical Perspective -http://www.back-to-basics.net/efu/pdfs/history.pdf

Lesson 1.2: Introduction to IFDC's Recommended Conceptual and Operational Framework for Implementing an ISFM Program

As explained earlier, this course is all about helping you to design, develop and implement an ISFM program suitable for your local situation. It is based on the experience of various individuals involved with the International Fertilizer Development Center (IFDC). Since 1974, IFDC has been working to increase agricultural productivity in a sustainable manner through the development and transfer of effective, environmentally sound plant nutrient technology and agricultural marketing expertise. You can learn more about IFDC by visiting its Website listed below.

In its long history, IFDC has learned a tremendous amount about how to achieve its goals and the remaining lessons and modules will focus on IFDC's approach to setting up programs for improving soil fertility management. Perhaps the most important lesson learned through this experience has been that client (farmer) participation is vital. This is because of several factors. One, soil fertility management is something that is done by farmers and farm communities and their actions and options are dependent on a range of complex biological, physical, social and their actions and options are dependent on a range of complex biological, physical, social and economic factors. Only by involving them in the process can you ensure that the resulting program will meet their needs and be acceptable. A second important reason is that farmers know a lot about their environment, the various types of land, crops and management methods, which are useful to adapt ISFM strategies to the local context. This means that, when promoting ISFM, it is best to focus on ISFM processes instead of packages or 'simple' recommendations. The last key consideration stems from what is known about the principles of adult learning. Experience and research has shown that adults learn best when going through a cycle of experiencing – processing – generalizing and applying. The experiencing phase is very important, and it is strongest when the new experiences, on ISFM, are closely linked to the experiences they already have. In addition to involving farmers it is also important to involve a wide range of stakeholders in the process.

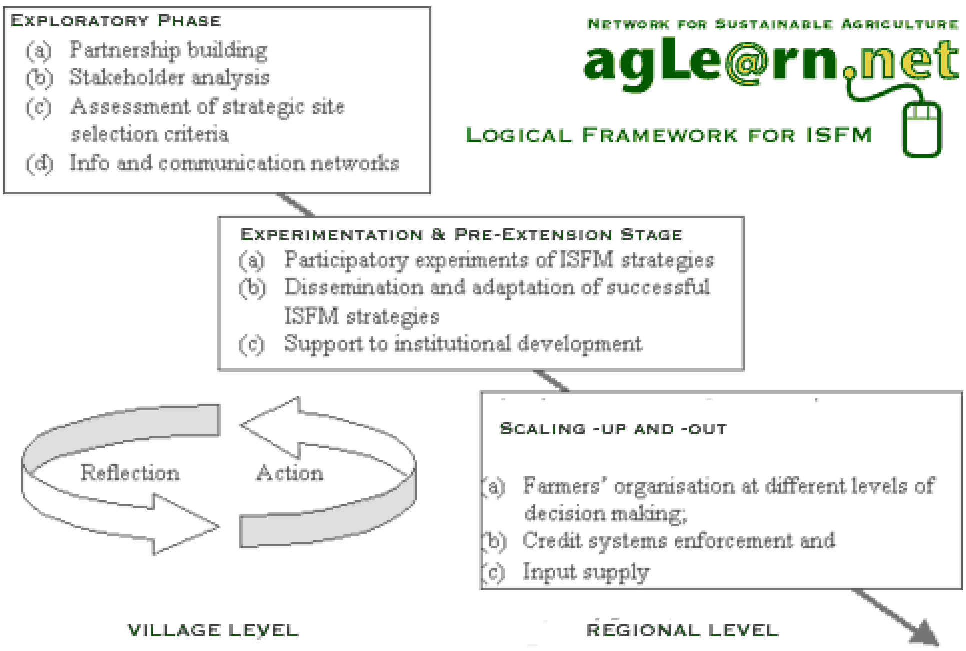
Like ISFM, this participatory approach goes by various names. You will often hear it referred to as PLAR (Participatory Learning and Action Research) or Farmer Participatory Research. Variants include PDCO (Participatory Diagnosis of Constraints and Opportunities) and Participatory Action Research. Again, the name we give it is less important than what it means.

Supplementary Reading

- International Fertilizer Development Center - http://www.ifdc.org/
- Participatory Research and Gender Analysis: Top Ten Resources http://www.prgaprogram.org/top_ten.htm
- Participatory Action Research for Improving Knowledge Systems' Performances in Africa - http://www.husdyr.kvl.dk/htm/php/tune97/12-groot.htm

Lesson 1.2.1: A Logical Framework for ISFM Programs

The approch advocated in this course for addressing soil fertility problems and improving soil fertility management practices consists of 3 stages. The logical framework presented here describes the longer-term program stages, the expected results within each stage, and a series of activities that should be considered for achieving the results. The framework is flexible enough to allow for the differences between partner institutions (skills and experiences) and pilot zones and to stimulate the development of locally relevant solutions. The following model may help you to understand the logical framework used.



The framework consists of three stages. An exploratory stage, an experimentation and pre-extension stage and a scaling up and out stage.

Exploratory stage

This stage is needed to build-up partnerships, to identify the different actors (other potential partners, 'integrated soil fertility management' stakeholders), to assess – in more detail – the strategic-site selection criteria with a key-group of partners and stakeholders, and to address core-activities (and entry-points!) of the program. Entry-points can be the development of innovative ISFM technologies with a selected group of partners and stakeholders (i.e. farmers), but also input-dealer training or institutional innovation, focusing directly on the linkages between farmers, bankers, input-dealers and traders. In most cases, technical innovation will be among the entry-points, and a choice of the pilot-villages from where the program might start its activities has to be made. Information and communication networks, interaction levels between different has to be made. Information and communication networks, interaction levels between different stakeholders, responsibilities and capacities of partner institutions to play their role as 'change agents' need to be explored.

Experimentation and pre-extension stage

Initially the program starts working in some pilot-villages, to come to grips with the reality farmers are facing and to start the process of mutual learning. Researchers and extension workers promoting ISFM techniques must be able to translate their ideas and recommendations in a way understandable and convincing enough for farmers. Moreover experience shows that top-down transfers of technologies rarely succeed. Every initiative should start from farmers' perceptions on soil fertility problems. In this phase, the primary objective is to develop an efficient dialogue between researchers, extension agents and farmers. Farmers' knowledge plays a crucial role in such a dialogue. Researchers and extension workers, however, participate actively in the development of ISFM management techniques and strategies appropriate for the specific circumstances of different groups of farmers. It is only through such a process of mutual learning that farmers' decision-making capacities with respect to ISFM techniques will be enhanced. Gradually, the program focuses on a pilot area instead of some pilot villages. The experimentation and pre-extension stage is the most intensive stage of an ISFM program. Two iterative, and partly overlapping participatory learning cycles (**DATE cycles**) can be used during this stage and will be covered in more detail in the next lesson.

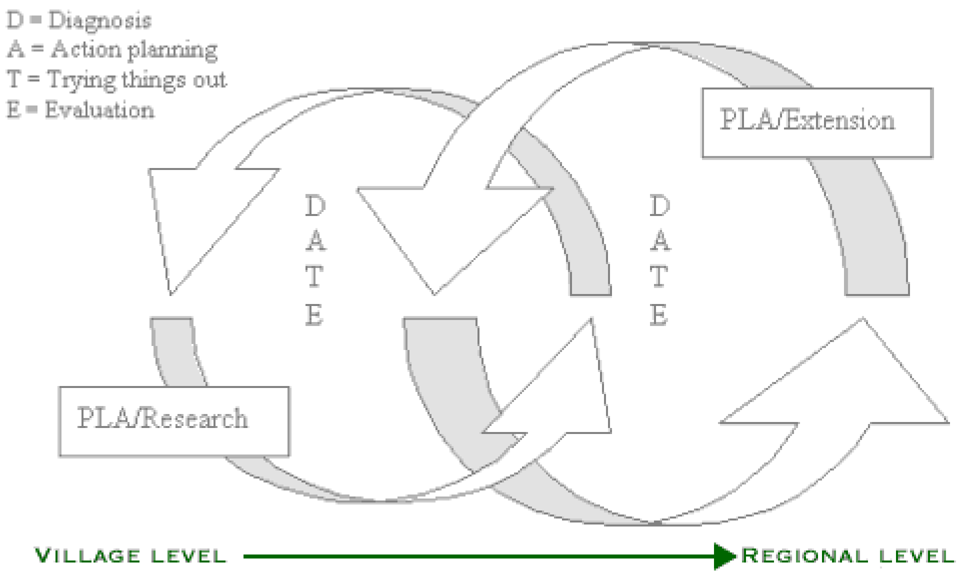
Scaling-up and -out stage

In this stage, the institutionalization of key project results is the most important issue. The involvement of partner institutions will be less intense, and targeted to the facilitation of further institutional change and improvement that is needed to keep-up the process of technological innovation, input-distribution, access to finance for both farmers (or farmer-groups) and input-dealers, and the search for marketing facilities that maintain the competitiveness of the agricultural sector in the pilot-region.

Lesson 1.2.2: 'DATEing'

In the previous lesson we mentioned two related participatory learning cycles that have been shown to be effective change models. Each cycle consists of a **D**(iagnosing), **A**(ction planning), **T**(rying things out), and **E**(valuating) phase. The first DATE cycle is conducted at field to village level and focuses mainly on participatory learning and action research, involving a limited number of farmers (**research-DATE**). The research-DATE emphasizes farmer experimentation and participatory learning, and building of partnerships between soil fertility management stakeholders (farmers, credit providers, input dealers, research and extension agencies, government) from field to village level. The second DATE cycle is a participatory learning and action extension cycle (**extension-DATE**) with an emphasis on the dissemination and adaptation of successful technologies from the research-DATE from village to regional level, and support to institutional change that reinforces linkages between farmers, bankers, input-dealers and traders.

The following figure may help you understand these cycles and their relationship.



Lesson 1.3.3: Strategic Site Selection

You will have noticed in this introduction to IFDC's approach that the first step in setting up an

ISFM program is to select a strategic site where initial research will focus and participatory approaches developed. As we mentioned, this is a major goal of the exploratory stage and helps to ensure that farmers become effective partners in the research and development activities to come. The selection of a strategic site is crucial. ISFM projects will be successful to the extent that they target production systems that are – or have considerable potential to become – intensive, market-oriented systems and have comparative advantages for ISFM-based intensification. The guiding principle for site-selection (both for the zone as well as for the villages within each zone) is the 'potential' for sustainable agricultural intensification based on ISFM strategies.

Locations that have such high potential are characterized by such factors as:

- Relatively good agro-ecological conditions (i.e. high potential for intensive crop or animal production);
- High pressure on the land in relation to the carrying capacity of natural resources;
- Proximity of important markets with a relatively high purchasing power (large – industrial - cities; ports);
- Comparative advantage in the production of certain crops having prices that are relatively high and stable (cotton, sugarcane, rice, fodder farming/animal husbandry, etc.);
- Relatively high degree of farmer investment in agriculture (e.g., soil and water conservation methods, experimenting with alternative uses of local resources) and of rural organisation (management of natural resources, economic interest groups, etc.);
- Relatively good infrastructure;
- Encouraging policies (availability of inputs, credits, extension and research etc.).

The process of strategic site selection provides an excellent opportunity to lay the foundations for the entire ISFM program. It should involve identifying the different actors and potential partners, analyzing their capacities and establishing partnerships. Partners should be encouraged to modify and comment on the strategic-site selection criteria. If done well, this initial activity will result in a team of so-called 'change agents' of researchers, development workers and local stakeholder. All team members will have the opportunity to discuss the objectives of the project and the way of 'working together'. Village-meetings in the strategic site will help to validate the objectives and the approach of the project and to mobilize farmers and other stakeholders to become involved.

Criticisms

Athough this approach has proven itself it must be recognized that it is not universally accepted. Critics maintain that under this model:

- Only regions with a high actual and medium term potential for ISFM profit and the low potential areas are further marginalized;
- Only well endowed farm-households profit from the ISFM-projects, while poor farmers and women do not have the capacities to participate.

IFDC's views are that ISFM-projects should result in independent, farmer-led agricultural intensifications - with limited support and short-term subsidies. A focus on comparatively lower potential zones will probably increase financial outlays of the project and will make long-term dependency on the project very likely. We also believe that economic growth in high potential areas will have influence on production systems and economic development perspectives in low potential areas. Some of the ways this can happen are through labour migrations and increased levels of food supply, at lower prices.

Also, ISFM is – in principal – not more profitable for larger and richer farmers than for smaller farmers. The prerequisite for benefiting from ISFM is access to such factors as credit and labour. If measures are taken to provide these, then poor farmers can indeed be considered high potential.

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Module 2: Principles and Concepts of Soil Fertility

Module Overview

As we explained in the introductory module, this course is focused on how to set up and implement an ISFM program. In the last module we introduced a suggested framework for doing this. Later on we will come back to this approach but would first like to make sure that everyone in the class has a common understanding of the important technical considerations that underlie the approach. These are related to soil and the key principles and concepts underlying soil fertility.

In this module we will cover some of the most important factors associated with soil fertility. We will talk about the important nutrients that plants require to grow and reproduce as well as the ways in which soils provide (or fail to provide) these nutrients. We will talk about how soil is formed, what it is made of and the role of the various soil components.

Lesson 2.1: Plant Nutrition

No course on soil fertility management would be complete without some discussion of the fundamental reason why we are so interested in managing soil fertility – providing adequate nutrition for plants. It is very important to understand the basic nutritional needs of plants before going on to discuss the best ways to provide these requirements.

All plants are dependent on a favorable combination of five environmental factors; light, heat, air, nutrients, and water.Since the dawn of agriculture, farmers have well understood this general concept. They sow their crops in locations with sufficient sunlight and at the time of the year when temperatures allow growth to maturity. They try to ensure adequate water availability either through irrigation or by predicting rainfall. As you may have learned in the historical overview of fertilizer use linked to in the last lesson, they have also been aware of the importance of nutritional supplements.

Through modern science, we now have a fairly sophisticated understanding of the nutrient requirements of plants. Science has identified some 20 nutrient elements that are essential for the growth and reproduction of plants. Plants obtain 3 of these elements - carbon, hydrogen, and oxygen - from the air and water. Although these elements are extremely important, (for most plants, 94 percent or more of their dry tissue is composed of these three elements) there is really not much that can be done to improve or manage their availability. The other elements combined represent 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 these.

These essential elements are generally divided into two groups. The **macronutrients** are nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), and magnesium (Mg). The second group of essential elements is called **micronutrients** (or sometimes 'minor' or 'trace' elements) because those elements are required in small (micro) amounts by plants. 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).

For additional information on these key elemental nutrients and their functions in plant growth, development and reproduction interested participants may want to access the following supplementary pages.

- Macronutrients
- Micronutrients

Macronutrients

(N)-Nitrogen: Nitrogen is a constituent of all living cells and is a necessary part of all proteins, enzymes and metabolic processes involved in the synthesis and transfer of energy. Nitrogen is a structural part of chlorophyll which is responsible for photosynthesis. Photosynthesis is a process which involves combining the energy of light with water and carbon dioxide to form simple carbohydrates essential for plant growth. Other functions of N include stimulating plants into rapid, vigorous growth, increasing seed and fruit yield and improving the quality of leaf and forage crops. Too much can delay fruiting. Too little and yields are reduced, leaves yellow (reduced photosynthesis) and plant growth is stunted.

(P)-Phosphorus: Like N, phosphorus (P) is an essential part of the process of photosynthesis. It is readily translocated from of the process of photosynthesis. It is readily translocated from older tissue to younger tissue, and as plants mature, most of the element moves into the seeds and/or fruits. P is important for overall growth and metabolism including utilization of starch and sugar, cell nucleus formation, cell division and multiplication, fat and albumin formation, cell organization, and transfer of heredity. When P is deficient, plants exhibit purple stems and leaves, retarded growth and maturity; poor flowering and fruiting. Too much can result in zinc deficiency.

(K)-Potassium: Potassium, unlike N and P, is not found in organic combination with plant tissues. Potassium plays an essential role in the metabolic processes of plants and is required in adequate amounts in several enzymatic reactions, particularly those involving the adenosine phosphates (ATP and ADP), which are the energy carriers in the metabolic processes of both plants and animals. Potassium also is essential in carbohydrate metabolism, a process by which energy is obtained from sugar. There is evidence that K also plays a role in photosynthesis and protein synthesis. K is involved in maintaining water balance and cold hardiness. Plants deficient in K exhibit spotted, curled or burnt looking leaves.

(S)-Sulfur: Sulfer is another element essential for chlorophyll and is a constituent of the amino acids cystine, cysteine, and methionine and, hence, 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. Deficient plants exhibit light green leaves.

(Mg)-Magnesium: Magnesium is part of the chlorophyll in all green plants and essential for photosynthesis. It also helps activate many plant enzymes needed for growth and the formation of fruits, nuts and seed germination. Magnesium is a relatively mobile element in the plant and can be readily translocated from older to younger plant parts in the event of a deficiency. Plants deficient in Mg may show yellowing between the veins of older leaves; chlorosis and drooping leaves.

(Ca)-Calcium: Calcium is an essential part of plant cell wall structure and provides 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. Symptoms associated with Ca deficiency include stunting of new growth in stems, flowers and roots; black spots on leaves and fruit and yellow leaf margins.

Micronutrients

(Fe)-Iron: Iron plays an important role in enzyme functions and is a catalyst for synthesis of chlorophyll. Plants deficient in Fe may exhibit pale leaves and/or yellowing of leaves and veins.

(Mn)-Manganese: Manganese is necessary for enzyme activity for photosynthesis, respiration, and nitrogen metabolism. When limiting the symptoms are similar to Fe deficiency with pale young leaves pale and green veins. Sometimes brown, black, or gray spots are observed next to veins.

(B)-Boron: The primarily function of Boron is in regulating 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. When deficient, the terminal bud may die, causing rosette of thick, curled, brittle leaves or brown, discolored, cracked, fruits, tubers and roots.

(Zn)-Zinc: Zinc is essential for plant growth because it 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. Zinc deficient plants often show mottled leaves and irregular yellow areas.

(Cu)-Copper: Copper is necessary for nitrogen metabolism and an important component of many enzymes. It is believed that copper is part of the enzyme system that uses carbohydrates and proteins. Copper deficient plants may show die back of shoot tips and terminal leaves develop brown spots.

(Mo)- Molybdenum: Molybdenum 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. When molybdenum is deficient plants have pale leaves with rolled, cupped margins and seeds may not form. Plants may also show nitrogen deficiency symptoms when plants lack molybdenum.

(CI)-Chlorine: Chlorine 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. When limited, plans may show wilting, stubby roots, yellowing and bronzing.

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

(Ni)-Nickel: Nickel 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.

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

(Si)-Silicon: Silicon is a major component of cell walls and helps to create a mechanical barrier to piercing - sucking insects and fungi. It enhances leaf presentation; improves heat and drought tolerance, and reduces transpiration. Deficiency symptoms include wilting, poor fruit and flower set and increased susceptibility to insects and disease.

Lesson 2.2: Soil Fertility

It is possible for plants to develop and mature quite well without soil if they are provided with suitable combinations of the five essential environmental factors; light, heat, air, nutrients, and water. This concept is the basis of “hydroponics” and it is not uncommon for plants to be grown commercially in production systems that do not involve soil.

However, soil is still the natural medium for the growth of plants and it is doubtful that soilless agriculture will ever be a cost effective alternative 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.

We’ve already learned that much of the world’s soils are becoming less fertile. But what exactly does soil fertility mean? Some define soil fertility simply as the capacity of the soil to supply nutrients to the plant and then only with macronutrients, usually nitrogen (N) and phosphorus (P) and sometimes potassium (K). Using this definition, a fertile soil is one that contains an adequate supply of all the nutrients required for the successful production of plant life.

This principle is probably best summed up by the “Law of the Minimum” propounded by Justus von Liebig in the mid-1800’s. This law states that if one of the nutritive 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.

But, a nutrient rich soil is not necessarily a productive one. To be productive, soil must also provide a satisfactory environment for plant growth and the nutrients it contains must be available for use by the plants. In this course we take a broad view of soil fertility and see it as 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 decomposition of rocks, organic matter, 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.

In the following lessons, we will provide some basic specific information on these soil components and soil characteristics that influence and determine soil fertility.

Supplementary Reading

- Home Hydroponics - http://www.ext.vt.edu/pubs/envirohort/426-084/426-084.html
- About Hydroponics - http://www.nzhydroponics.com/
- What is Soil Fertility? - http://www.dnagardens.com/what_is_soil_fertility.htm

Lesson 2.2.1: Soil Formation and Taxonomy

Soil is a relatively thin layer of unconsolidated mineral and organic material on the immediate surface of the earth. Fertile soil contains approximately 25% of both air and water, about 5% organic matter and about 45% mineral matter. It is important to understand something about how soils are formed to determine the best use of available soils and how to manage their fertility.

In general, soil formation starts with rocks that are pushed to the surface of the earth by geological or climactic forces. These rocks then undergo **weathering** - the chemical alteration and physical breakdown of rock during exposure to the atmosphere, hydrosphere, and biosphere. Through the weathering process, eventually enough essential elements become available to support lichens and other lower forms of plant life. As continuing generations of lichens grow, die, and decay, they leave increasing amounts of organic matter. Naturally-occurring organic acids further hasten decay of the rock. An increasing build-up of organic matter and formation of fine rock fragments result in more water retention in the soil and more water available for use by larger numbers of plants and animals.

Four factors determine what type of soils are formed. These are Climate, Organisms, Topography and Parent Material.

Climate has two major components for soil formation. The first is the temperature. As the mean annual soil temperature increases, the weathering of the rocks and minerals in the soil will be faster. Along with temperature is the climate factor of precipitation or rainfall. In general, areas with more rainfall will have greater weathering and greater leaching.

Organisms include animals living in the soil that contribute to soil development by their mixing activities. The mixing of the soil by organisms is called **bioturbation**. Humans also influence the soil with their activities of agriculture, urbanization, grazing, and forestry.

Topography as a soil forming factor is related to the soil's position on the landscape elevation, direction and depth to the water table. Topography will have a great deal to do with the soils character as different topographic locations vary in respect to water runoff, erosion, leaching and temperature.

Parent material refers to the primary material from which the soil is formed. The type of soil that forms depends on the type of rocks available, the minerals in rocks, and how minerals react to temperature, pressure, and erosive forces. Soil parent material could be bedrock, organic material, an old soil surface, or a deposit from water, wind, glaciers, volcanoes, or material moving down a slope.

The length of **time** required for a soil to form depends on the intensity of the other active soil forming factors of climate and organisms, and how topography and parent material modify their affect.

Each of the world's soils is assigned to one of twelve taxonomic soil orders, largely on the basis of soil properties that result from the five soil forming factors acting on the parent material over time**.**

Supplementary Reading

- Changing Rocks into Soil: Weathering - http://www.soils.agri.umn.edu/academics/classes/soil2125/doc/s1chap3.htm
- Soil Forming Processes & The Pedon - http://www.soils.agri.umn.edu/academics/classes/soil2125/doc/s2chap1.htm
- Classifying Soils Using Soil Taxonomy: The Twelve Soil Orders - http://www.soils.agri.umn.edu/academics/classes/soil2125/doc/s4chap2.htm

Lesson 2.2.2: 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 soil organic matter 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.

While there is not yet a consensus on exactly how to measure soil quality, there is little disagreement that organic matter content gives soils many of their desirable properties. Organic matter 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 is the adhesive of the soil, binding together the soil components into stable aggregates. It is widely considered to be the single most important indicator of soil quality and productivity

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.

Supplementary Reading

- Soil organic matter - http://www.agric.gov.ab.ca/agdex/500/536-1.html
- Soil organic matter - http://www.umext.maine.edu/onlinepubs/htmpubs/2288.htm
- Soil organic matter - http://www.agric.uwa.edu.au/soils/soilhealth/organic/

Lesson 2.2.3: Soil Organisms

Soil organisms are an important component of soil organic matter. Although soil is often considered (and treated as) a lifeless substance, it is not. Healthy soils teem with life, and would not exist without the organisms inhabiting it. Under a 1-meter-square 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 and decomposition is performed by 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. Other products formed when organic matter is decomposed include carbon dioxide and nitrogen and other essential plant nutrients are released and made available to growing crops and other micro-organisms.

A particularly important soil organism is **Rhizobium**. This is a genus of soil bacteria that is responsible for symbiotic nitrogen fixation in legume plants. These organisms penetrate plant roots causing the formation of small nodules on the roots. They then live in symbiotic relation with the host plant.

Supplementary Reading

- Soil Animals - http://www.agric.uwa.edu.au/soils/soilhealth/animals/index.htm
- Soil Fungi - http://www.agric.uwa.edu.au/soils/soilhealth/fungi/index.htm
- Soil Bacteria - http://www.agric.uwa.edu.au/soils/soilhealth/bacteria/index.htm

Lesson 2.2.4: Soil Texture

Soil texture is arguably the single 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, water holding capacity, nutrient storage and water movement.

Soil texture is dependent on 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. From largest to smallest the soil separates are:

- **Stones and cobbles** are bigger than 64 mm (diameter)
- **Gravel** is from 2 mm to 64 mm
- **Sand** is from .05 to 2 mm
- **Silt** is from .002 to .05 mm
- **Clay** is less than .002 mm.

Clay is less than .002 mm.

Texture is used to define a range of soil classes. It is important that participants in this class understand these terms as they will be used in future lessons. The table below lists the recognized soil textural classes and their makeup.

Soil Classes	% Sand	% Silt	% Clay
SANDS	85+		0-10
LOAMY SANDS	70-90		0-15
SANDY LOAMS	43-85		0-20
SILT		80+	0-12
SILT LOAMS		50-88	0-27
LOAMS	0-52	0-50	7-27
SANDY CLAY LOAMS	45+	0-28	20-35
CLAY LOAMS	0-45	0-53	27-40
SILTY CLAY LOAMS	0-20	40 +	27-40
SANDY CLAYS	45+	0-20	35-55
SILTY CLAYS		40 +	40 +
CLAYS	0-45	0-40	40 +

http://www.back-to-basics.net/efu/pdfs/soil.pdf

In talking about texture it is important to note that the term "clay" is used in two different ways when describing soils. The term "clay" is a description of particle size and is also used to identify a particular kind of silicate mineral found in soils - a chemical recombination of the base elements of silicon, aluminum, and oxygen into a silicate clay mineral.

Supplementary Readings

- Soil Texture - http://interactive.usask.ca/ski/agriculture/soils/soilphys/soilphys_tex.html
- Soil Texture & Mechanical Analysis - http://www.soils.agri.umn.edu/academics/classes/soil2125/doc/s6chap1.htm

Lesson 2.2.5: Soil Structure

Soil structure refers to the arrangement of particles in a soil and how the individual soil particles clump or bind together. 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. Soil scientists have developed a classification systems to describe soil structure that involves **5 major structural classes - granular, blocky, platy, prismatic and structureless**.

For more information on soil structure, participants should refer to the supplementary resources listed below.

Supplementary Reading

- Soil Structure - http://interactive.usask.ca/ski/agriculture/soils/soilphys/soilphys_struct.html http://interactive.usask.ca/ski/agriculture/soils/soilphys/soilphys_struct.html

- Soil Structure - http://www.irim.com/ssm/ssm00090.htm
- Soil Structure -http://ltpwww.gsfc.nasa.gov/globe/pvg/prop1.htm

Lesson 2.2.6: Soil pH

Another important soil property that affects soil fertility and the availability of nutrients is soil pH, a measure of the acidity or alkalinity of the soil. This property also has considerable effect on microbial activity. Soil pH is defined as the negative logarithm of the hydrogen ion concentration. The pH scale goes from 0 to 14 with pH 7 as the neutral point. As the amount of hydrogen ions in the soil increases the soil pH decreases thus becoming more acidic.

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. Most minerals and nutrients are more soluble or available in acid soils than in neutral or slightly alkaline soils. If the pH isn't close to what a plant requires, some nutrients, such as phosphorus, calcium and magnesium, can't be dissolved in water. And, if the nutrients aren't dissolved, the plant can't absorb them. The plants won't grow or produce to their full potential.

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.

For more on soil pH, participants should review the supplementary resources below.

Supplementary Reading

- Soil pH - http://www.back-to-basics.net/efu/pdfs/ph.pdf
- Soil pH: What it Means - http://www.esf.edu/pubprog/brochure/soilph/soilph.htm
- Some Thoughts About Soil pH, Fertilizers and Lime - http://www.ncw.wsu.edu/lime.htm
- THE EFFECT OF SOIL PH ON NUTRIENT AVAILABILITY - http://www.micromixsolutions.com/diag-effectph.html

Lesson 2.2.7: Cation Exchange Capacity (CEC)

Cation exchange capacity(CEC) is the ability of the soil to hold onto nutrients and prevent them from leaching beyond the roots. The more cation exchange capacity a soil has, 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. Knowledge of this phenomenon is basic to understanding how much and how frequently lime and fertilizers should be applied for optimum crop production.

Cation exchange capacity (CEC) is the amount of negative charge in soil that is available to bind positively charged ions (cations). Essential plant nutrients, potassium (K+), calcium (Ca2+), magnesium (Mg2+), and ammonium (NH4+) and detrimental elements, sodium (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 cation exchange capacity. These materials act as centers of activity around which chemical reactions and nutrient exchanges occur. The individual particles of each 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.

Supplementary Reading

- Cation Exchange & Cation Exchange Capacity - http://www.soils.agri.umn.edu/academics/classes/soil2125/doc/s12chap1.htm
- Cation Exchange Capacity – Everything You Want to Know and Much More - http://virtual.clemson.edu/groups/turfornamental/tmi/fertlime/Cation%20exchange%20capacity.pdf
- Clay Minerals - http://www.soils.agri.umn.edu/academics/classes/soil2125/doc/s12chap2.htm
- Humus: Still a Mystery - http://users.ids.net/~nofari/tnf_hums.htm

Module Overview

You should now be well on your way to designing an effective ISFM program. You are familiar with a conceptual and operational framework to implement ISFM and have learned about key principles and concepts of soil fertility. You have also selected and characterized a target area for your efforts. In the last module you have taken a close look at the soils you expect to be dealing with and described their predominant characteristics. This information will provide a good basis for the work you are expected to do in this module - identifying soil fertility problems you will need to deal with in the area you have selected. Identifying problems is an important first step in developing an integrated soil fertility management plan or program. Identification helps you to set priorities for interventions and managing soil fertility.

In order to make the diagnosis as valuable as possible, we will suggest and describe 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** described earlier. As you remember, DATE 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.

This module will focus primarily on the **D** of DATE. In the following lessons you will find descriptions of a range of diagnostic techniques including testing, field observations, mapping and experimentation. The potential contribution of computer-based decision support tools in the diagnostic process will also be highlighted. We will then go on to talk about the role of participatory action planning, research and evaluation in the validation of the diagnosis leading to preliminary recommendations for a limited area.

Lesson 3.1: Diagnosis

The diagnostic phase of the Research-DATE approach aims to get a common understanding of the local landscape, how soil fertility has been transformed over time, and what initiatives farmers have taken in the past. An important aspect of the diagnostic phase is 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 typically 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. These tools range from simple rules of thumb (expert knowledge), to complex, crop growth simulation models and the table below gives an overview of decision support tools that can be used during this phase.

Goal	Tools	Data Requirements	Potential Users
Common understanding of the landscape	Discussions with farmers (current land use and history) Transect walks	Very limited	Farmers, extension, research
Spatial variability in soil fertility	Transect walks Mapping (soils, land suitability) Soil and plant testing Pictures (nutrient deficiency symptoms)	Very limited	Farmers, extension, research
Identification of yield gaps	Comparing yields between among farmers and fields	Very limited	Farmers, extension, research
	Crop growth models	High	Research
Identification of factors 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, un-tapped resources	Resource flow maps	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 and 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. Also, these diagnostic tools presented tend to give only 'pictures' of today's reality and do not give an idea of the evolution and changes that have occurred in the farming-system(s). 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. A comprehensive discussion about analyzing diversity can be accessed in the Supplementary Reading section below.

These tools are also currently weak in terms of capturing the socio-economic aspects of a plot or farm. Farmers may have much more opportunities off-farm for improving livelihoods and this often means that adopting more labor intensive agricultural technologies (as many ISFM options are) is counter productive.

The following lessons will provide additional information on the individual tools.

Lesson 3.1.1: Yield Gap Analysis

Farmers often achieve far less than 50% of the climatic and genetic yield potential for a given sowing date, cultivar choice and site. Figure 1 illustrates factors that define yield gaps at different levels. The potential yield or maximum yield (Ymax) 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. Ymax is not constant but fluctuates from year to year and with sowing date because of climatic variability. The attainable yield (Ya) is the 'nutrient-limited' yield that farmers can achieve with current soil fertility management practices, but with optimal water and crop management. The maximum Ya is often about 80% of Ymax. This is often referred to as the economic yield target (Ytarget) as it is often not economical to close the remaining gap of about 20% of Ymax. In reality actual farmer yields (Yf) 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.

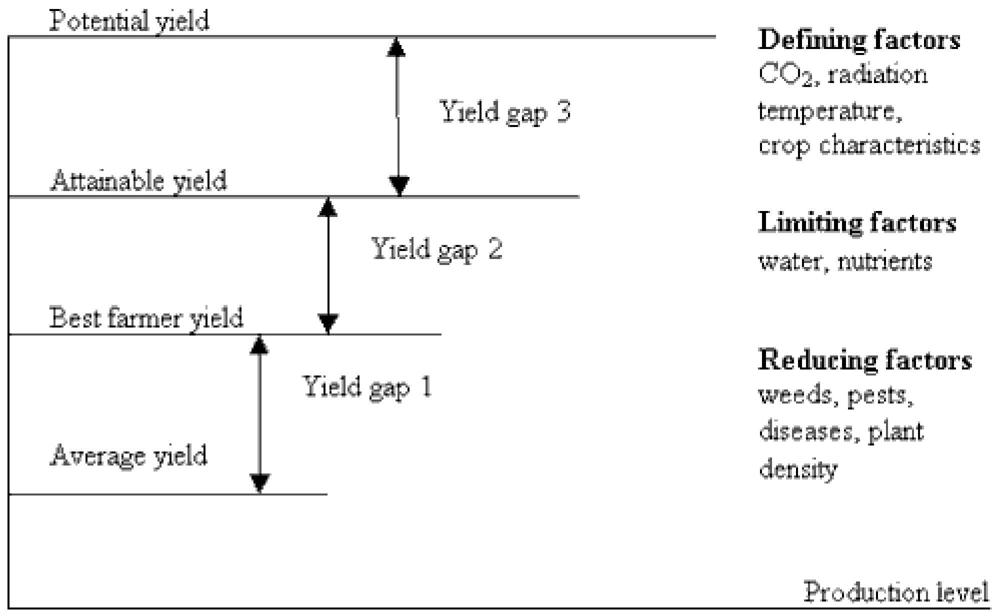


Figure 1: Effect of crop management on potential or maximum yield, attainable yield, best farmer yield and actual average farmer yield.

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 may prevent the farmer from obtaining better yields, such as choice of variety, plant population, sowing data and the 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 match the requirements of the soil, e.g. soils that are low in K will not respond to large doses of N or P.

Supplementary Reading

- Strategies for bridging the yield gap in rice: A regional perspective - http://www.fao.org/DOCREP/003/X6905E/x6905e0h.htm

Lesson 3.1.2: Soil Testing

Soil testing is any chemical or physical measurement that is made on a soil. Soil tests are done to:

- Determine the relative ability of a soil to supply crop nutrients during a particular growing season,
- Predict the probability of obtaining a profitable response to fertilizer application,
- Determine the need to adjust soil pH,
- Diagnose problems such as excessive salinity or alkalinity,
- Provide a basis for fertilizer recommendations for a given crop,
- Evaluate the fertility status of the soil as the basis for planning a nutrient management program.

A soil test report will give basic information about deficiencies and problems and suggest measures that should be taken to correct problems and specific nutrients that are needed to obtain better yields. Soil tests are considered to be a helpful diagnostic tool but do not provide absolute recommendations. The information they provide must be interpreted using common sense and consider the goals and circumstances of the grower. A key point to remember is that the test only provides information about the fertility level and chemical properties of the soil. Correcting these is only one part of a growers crop management program. There are many other factors that may result in low yields even when nutrients are adequate.

Remember, 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. It is therefore important that you know proper procedures to follow when collecting soil samples.

Participants should review the supplementary readings below for more information on soil testing and soil sampling. For some examples of calculating and interpreting N, P, K soil test results in terms of nutrient availability for the crop see the insets below.

See:

- Nitrogen
- Phosphorus
- Potassium

Nitrogen

Nitrogen is vital for plant growth, and is an important component of plant proteins. It is a very mobile nutrient and can move relatively quickly by infiltrating rainwater or by changing from a soluble form in soil solution to gaseous forms that eventually escape into the air. Because it is so mobile nitrogen moves rapidly to the growing part of the plant, and often produces a green 'flush' at the start of the wet season. After a dry period soil life regains momentum, and rapidly decomposing organic material generates a sudden increase in available N. If there are no roots to capture the flush, significant quantities may be leached and eventually lost. Plants lacking in nitrogen turn a light green/yellow, especially the older leaves.
Nitrogen is unstable, and when it is applied in mineral fertilisers it can easily be lost through leaching and N-carrying gases. Such losses can be reduced by applying nitrogen fertilisers at several intervals during the wet season, particularly after rain

or during rainy periods, when there is less risk of it burning the crop. Sources of organic matter which increase nitrogen levels in the soil include animal manure, compost and green manure. For nitrogen, the fertility status of a soil can be estimated by observing its surface colour, texture and structure. A dark, clayey and well-structured soil with plenty of active soil fauna (especially worms) indicates good levels of nitrogen.
Table 3.4 gives an idea of the quantities of nitrogen in different kinds of soil. The total reserve of nitrogen in the soil can be estimated by measuring the percentage of soil nitrogen. About half of this reserve will always be available as it is stored in the relatively active form of organic matter. This part is called the **dynamic reserve,** and it will give an indication of the length of time that crop production is potentially possible. As reserves diminish it becomes increasingly difficult for a crop's roots to find the nitrogen they need, and consequently yields decline. The other half of the total nitrogen reserve, a fraction of organic matter that does not easily release its nutrients is called the **inert reserve**. It should be noted that only about 1-4% of the dynamic reserve is directly available for crop production, and this is subject to losses.

How to estimate soil's nitrogen reserves?
For light, sandy soils one can assume that 1 litre of soil weighs 1.5 kg. Soils with a higher clay content tend to be heavier, weighing about 1.7 kg/l.

If we take the top 20cm of soil the volume of one hectare will be:
10,000 m2 x 0.2 m depth = 2,000 m3 of soil; or
2,000 x 1,000 litres = 2,000,000 litres.

This equals 2,000,000 x 1.5 kg of soil = 3,000,000 kg.

A soil with a good supply of nitrogen contains about 0.1% nitrogen (see Table above), so one hectare will contain 3,000,000 kg x 0.1/100 = 3,000 kg of nitrogen. Of this, 1500 kg (50%) represents the 'dynamic reserve'. Only about 1-4% of this is directly available for crop production, and is subject to losses of between 15-90 kg.

This estimate of available N shows the relative importance of nutrient recycling during crop production. The ratio of nitrogen exported (through removing crops) : the dynamic reserve indicates how long a farmer can afford to continue extracting N without replacing it. If, for example, the dynamic reserve is less than 750 kg/ha and a crop annually exports 75 kg/ha, crop yields will soon drop.

Phosphorus:

Phosphorus is a basic nutrient which, like nitrogen, contributes to essential proteins in the plant. As it is not a mobile nutrient and cannot easily be lost through leaching, applying P-fertiliser can be a good investment that will bring returns over many years. However, when organic matter is added to the soil phosphorus may become more mobile and erosion can also cause substantial losses when it removes the more fertile topsoil.

Plants that suffer from phosphorus deficiency tend to be stunted and often have dark green leaves and reddish-purple leaf tips.

Phosphorus can be applied in less soluble forms such as rock phosphate (which is especially recommended for acid soils), and is also present in organic fertilisers such as animal manure. Farmers using phosphorus fertiliser need to take account of the soil's nitrogen status, as it is only economical to apply large quantities of phosphorus when there is enough N in the soil. Red soils tend to contain significant amounts of iron, and when phosphorous is added to such soils it may become fixed to the iron compounds. This means that the farmer will have to use large quantities of phosphorus fertiliser to ensure some phosphorous remains available for the plants.

In general there is not much phosphorus available in soils unless they are regularly fertilised. The P-reserve is mainly found in organic matter, and is fixed in barely soluble aluminum- and iron-compounds in the soil. In areas where the soil is aluminum-saturated, large amounts of phosphorus may slowly become available, keeping the P-reserve well supplied. In other areas, such as the Sahel, P reserves are more reliant on the SOM content, as is the case with nitrogen.

There are several ways of extracting phosphorus. The Bray method is used for more acid soils, while the Olsen method is more generally applicable. P-Bray gives an estimate of the phosphorus that is **immediately available** for crop growth. As a rule of the thumb, 6 or more mg/kg P-Bray shows that there is enough phosphorous for the coming cropping season; less than 6 mg/kg indicates a possible deficiency.

P-Olsen gives an indication of the **total P reserve**. A concentration of less than 200 mg/kg P-Olson shows a poor phosphorus reserve, while more than 800 mg/kg indicates a good P reserve. Sandy soils usually contain less phosphorus than soils with a high clay content, and a pH of less than 5.0 (acid soils) often means that very limited amounts of P are available.

The **dynamic reserve** of phosphorous is roughly 80% of the total reserve, of which 50% is found in the SOM. So a soil with a total P reserve of 2,500 kg/ha will contain a dynamic phosphorus reserve of about 2,000 kg/ha, of which 1,000 kg/ha is found in the SOM.

How to estimate soil's phosphorus reserves?

This estimate assumes that we are looking at a soil whose top layer weighs 3,000,000 kg per hectare. In that weight of soil we could expect to find about 6 ppm (parts per million or mg/kg) P-Bray, which amounts to 18,000,000 mg or 18 kg of available P per hectare (see Table above). To gauge the significance of P extraction we compare the amount of available P per hectare with the amount of P exported in crops and residues removed from the field. A cotton crop yielding 2,000kg of fibre and 3,000kg of straw exports about 11 kg of P, which means that more than half of the immediately available P in the soil is removed with the crop.

Potassium

Potassium is essential to plants for the formation and transfer of carbohydrates in photosynthesis, and also for protein synthesis. It is particularly important for fruits, leaves and stems, and is needed to strengthen the plant's structure. Potassium deficiency in plants can be quite difficult to detect, but indicators are yellowing leaf tips and margins, and increased lodging.

Potassium promotes high crop yields, particularly in root and tuber crops. Farmers aiming to maintain maize yields of over 2 tons per hectare will need to apply extra potassium, as well as large amounts of nitrogen and phosphorus. Crop residues often contain considerable quantities of this nutrient, so it is important to recycle them to maintain the soil's potassium levels. Mineral fertilisers do not always contain potassium, so that mining can take place.

Potassium reserves are largely dependent on the type of soil minerals present. Soil potassium may be classified according to its availability to plants, and falls into three categories: (1) the inert reserve or slowly available K; (2) the dynamic reserve and (3) the readily available reserve.

The **inert reserve** or **slowly available potassium** constitutes about 95% of the soil reserve, and is mainly contained in primary minerals and clays such as *vermiculite* or *illite*. These minerals release K very slowly, and the amount released over a single growing season is negligible.

The **readily available potassium** is measured by the exchangeable K (expressed as cmol(+)/kg) absorbed in the clay-SOM complex and found in the soil solution. Normal (kaolinitic) soils contain about twice as much K in their **dynamic reserve** as in their readily available reserve.

When plants take up potassium the equilibrium between the dynamic and readily available reserves is temporarily disrupted. Some of the exchangeable K must then be immediately released into the soil solution to re-establish this equilibrium. Clayey soils contain more potassium than sandy soils, so that a soil containing about 40 % clay has four times more exchangeable K available than a soil with only 10 % clay.

How to estimate the availability of potassium
This estimate assumes that we are looking at a soil whose top layer weighs 3,000,000 kg/ha.
Exchangeable potassium is expressed in cmol(+)/kg, which originates from the atomic weight of the element, 39. One cmol(+) corresponds to 39 ¸ 100= 0.39g. This weight is always expressed per kg soil.
So, if a soil contains 0.10 cmol(+)/kg soil of exchangeable K, the total amount of readily available potassium for the given soil layer will be:

3,000,000 kg x 0.1 x 0.39/1,000 = 117 kg/ha.

The ratio of potassium exported through crop removal : exchangeable K indicates how long a farmer can afford to continue extract K without adding fertiliser.

Supplementary Reading

- Soil Testing For High-Yield Agriculture - http://www.back-to-basics.net/efu/pdfs/testing.pdf
- Soil Analysis - http://www.agroservicesinternational.com/Soil%20Analysis/Soil.html
- Soil Analysis: A key to soil nutrient management - http://www.cahe.nmsu.edu/pubs/_a/a-137.html
- Soil test interpretation guide -
- Soil Test Interpretations - http://www.cahe.nmsu.edu/pubs/_a/a-122.html
- Soil Sampling for High Yield Agriculture - http://www.back-to-basics.net/efu/pdfs/sampling.pdf
- Guidelines for Soil Sampling - http://www.ianr.unl.edu/pubs/soil/g1000.htm
- Soil Sampling as a Basis forFertilizer Application - http://www.sbreb.org/brochures/soilsampling/soilsamp.htm

Lesson 3.1.3: 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 confirm soil test results and can indicate when the cause of the problem is something other than a nutrient deficiency in the soil. 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 physical conditions. Plant nutrient content represents the effects soil nutrient status and all the other factors controlling plant growth.

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. Specific directions on plant sampling generally are available with each sampling kit from the plant analysis laboratory.

For more information on plant tissue analysis and tissue sampling, please read through the supplementary references below.

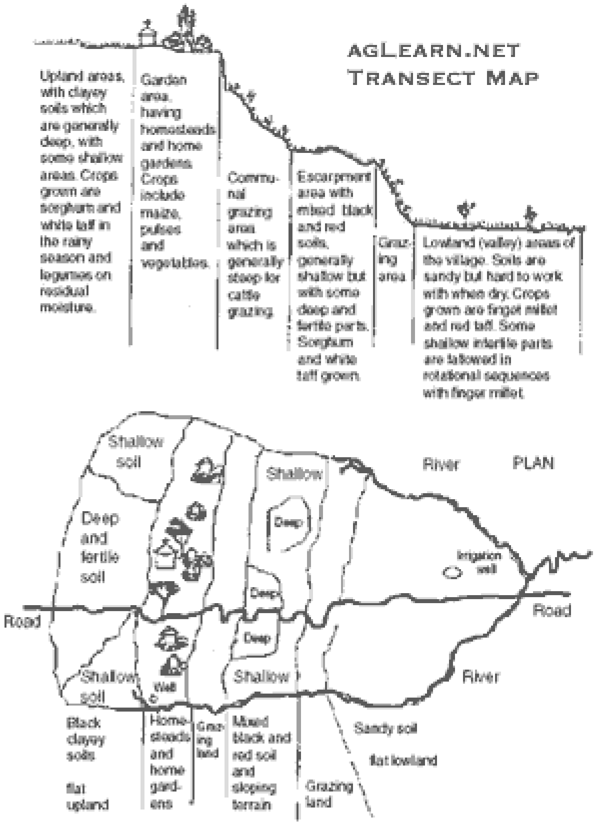
Supplementary Reading

- Plant tissue analysis - http://agguide.agronomy.psu.edu/sect2/sec26a.htm
- Plant tissue analysis - http://www.lpes.org/Lessons/Lesson35/35_4_Plant_Tissue.pdf
- Sampling for Plant Tissue Analysis - http://www.cahe.nmsu.edu/pubs/_a/a-123.html

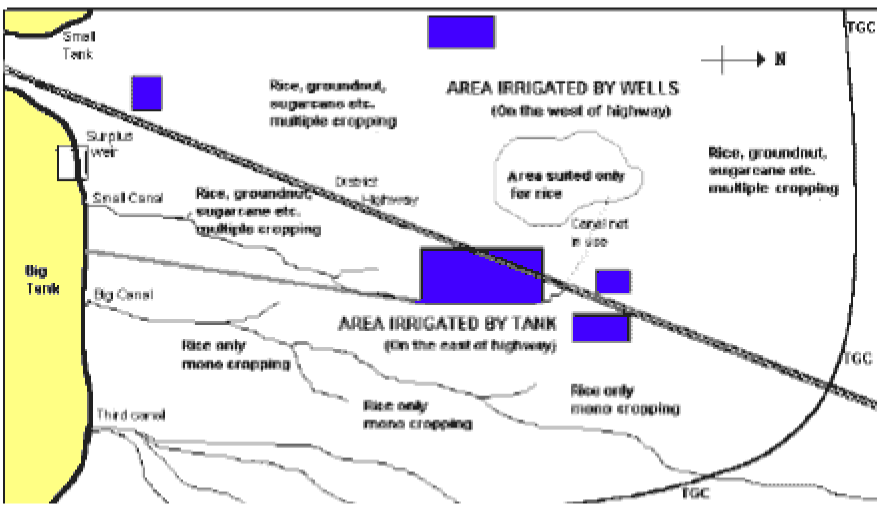
Lesson 3.1.4: Field Observation

Of course, it is realized that laboratory testing of soil and plant tissue samples are not generally economic or even possible options for most farmers in developing countries. But there are many other tools. 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**. A grower or 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. In a transect walk, the diagnostician walks from one edge of the field or area to the other and makes notes on what is observed including the types of landscape, plants and animals and obvious differences that may be problems that need addressing. Many find it helpful to draw the walk on paper in what is known as a **transect map**. Such maps show a topographical cross-sections of the territory and are made more useful if notes are made below each portion of the cross-section. See below for an example of a transect map:



A bit more resource intensive but also more valuable is to prepare a more detailed **resource map** of the entire area in which you are interested. 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.



AGLEARN.NET - RESOURCE MAP FOR SAMPLE VILLAGE IN INDIA

Lesson 3.1.5: Diagnostic Keys

Of course, it helps if you can recognize problems as you observe fields and areas. **Keys** are an excellent tool for helping you do this. 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.

Some of the most common nutrient deficiency symptoms used in keys are listed and defined in the table below:

Term	**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

See our guide to Plant Nutrient-Deficiency Symptoms

I. Effects 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

Source: http://scidiv.bcc.ctc.edu/rkr/Botany110/labs/pdfs/MineralNutrition.pdf

When using the keys you will notice that many of them start by asking where the symptoms are most evident on the plant. 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.

Another important factor to keep in mind when using keys or when observing symptoms is that 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. The appearance of a growth disorder based on visual symptoms does not absolutely mean a nutritional deficiency exists. The observation of a symptom could also be a result of nutrient unavailability or other environmental factors and not to the absence of a particular nutrient in the soil. If more than one deficiency is present, one can be more dominant in its symptoms, obscuring the symptoms of the other element.

For more information on using keys and some examples, we suggest you visit the sites and resources listed below.

Supplementary Reading

- Plant Nutrient Deficiency Decision Key (small grains) - http://www.smallgrains.org/Techfile/Franzen2.htm
- A Key to Nutrient-Deficiency Symptoms http://www.aces.edu/department/ipm/avgnutdef.htm
- Impact of Mineral Deficiency Stress (flow chart) - http://www.plantstress.com/Articles/min_deficiency_i/impact.htm
- Nutrient Deficiency Symptoms - http://www.back-to-basics.net/nds/index.htm
- RECOGNIZING PLANT NUTRIENT DEFICIENCIES - http://www.unce.unr.edu/publications/FS02/FS0265.pdf
- Key to Nutrient Deficiency Symptoms ~ Wheat - http://www.cropsoil.uga.edu/~oplank/diagnostics70/Symptoms_/Wheat/wheat.html
- Key to Nutrient Deficiency Symptoms ~ Corn - http://www.cropsoil.uga.edu/~oplank/diagnostics70/Symptoms_/Corn/corn.html

Lesson 3.1.6: Photographs

We are sure that you have all heard the old saying, "A picture is worth a 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 your local extension office. Also, as more and more organizations take advantage of the Internet for disseminating information, it is becoming easier to access quality pictures online.

- The Diagnosis of Mineral Deficiencies in Plants by Visual Symptoms - http://www.luminet.net/~wenonah/min-def/index.html
- Nutrient Problems - http://www.ehs.calpoly.edu/ehs/ehs327/pages/nutbd.html
- Plant Nutrient Deficiency Symptoms - http://agri.atu.edu/people/Hodgson/FieldCrops/Mirror/Nutrient%20Def.htm
- DIAGNOSIS OF MICRONUTRIENT DEFICIENCIES IN CROPS - http://www.agnet.org/library/article/pt2001023.html#0
- NUTDEF - http://hort.ifas.ufl.edu/nutdef/
- Fertilizer deficiencies - http://www.msue.msu.edu/msue/imp/modf1/modf1d.html

Lesson 3.1.7: History and Record Keeping

Photographs of 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. Good records can provide valuable insights into potential nutrient deficiency problems even when there are no obvious symptoms. Probably more common than acute deficiencies associated with a particular nutrient is the 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. Many crops fail to live up to expectations without obvious cause, and a high proportion of these cases can be put down to sub-clinical nutrient deficiencies. Accurate accounting of nutrient removal and replacement, crop production statistics, and soil analysis results will help the producer manage fertilizer applications.

Lesson 3.1.8: Nutrient Flow Analysis

Accurate historical records can be valuable but keeping such records is not all that common, particularly for developing country farmers. One way to get a handle on what is happening to the nutrient status of a field over time is to analyze and map nutrient flows.

Nutrient flow analysis 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. Some processes may lead to a loss in nutrients, e.g. burning of straw will result in complete loss of carbon and nitrogen. 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 nitrogen in e.g. manure, millet grains and millet straw, 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 rice field, and I sell both rice grain and rice 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. rice production system, vegetable production system, animal production system, and household system) should be clearly defined. A wealth of literature is now available demonstrating the nutrient budgeting approach and there are links to some good references in the Supplementary Reading section below.

The nutrient balances include, on one hand, major nutrient inflows from rainfall, organic manure, mineral fertilizers, symbiotic N-fixation and sedimentation; on the other hand, nutrient outflows through harvested produce and losses due to erosion, leaching etc. 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.

Clearly some of these parameters are easier to measure or estimate than others. Nutrient inflows from atmospheric deposition, or losses as gases are invisible and not easy to comprehend by farmers. Often, estimations are combined with actual measurements, which may lead to considerable errors. A simple method to get an idea of nutrient flows associated with a farm or larger area is to develop **resource maps**.

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, acres, carrés, 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).

Supplementary Reading

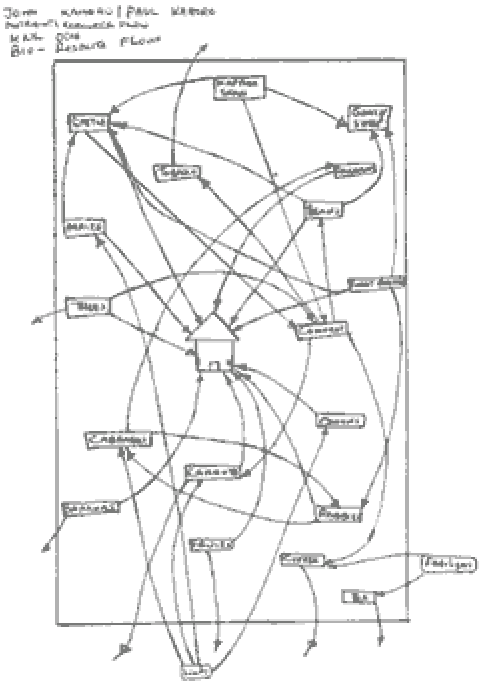
- Chapter 3. Sources and flows of nutrients in farming. Toon Defoer, Arnoud Budelmann, Camilla Toulmin, Simon E. Carter
- Chapter 4. Nutrient flow analysis. Toon Defoer, Arnoud Budelmann, Camilla Toulmin, Simon E. Carter
- Soil nutrient budgets and balances: What use for policy? - http://www.iied.org/pdf/soils_6.pdf

Lesson 3.1.9: 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.

Below are examples of resource flow maps prepared by farmers.



http://www.nutmon.org/files/6d2413cec969e35b850c104fe40deb9e.pdf

Supplementary Reading

- Nutrient Flow Worksheet - http://whatcom.wsu.edu/ag/nutrient/Appendix_A.PDF
- Land Quality Indicators for Sustainable Land Management: Yield Gap - http://www.ciesin.org/lw-kmn/yldgap/yldgap.html

Lesson 3.1.10: Computer-based Diagnostic Tools

No discussion of diagnostic decision support tools would be complete without some reference to the now available computer based tools. Various software models and applications can help to quantify, calculate and visualize nutrient flows (NUTMON), calculate optimal fertilizer doses / ratio's (NuMaSS, QUEFTS), simulate important aspects of an agricultural system (e.g. a model that simulates the development of soil carbon over a number of years: the Rothamsted Carbon model), and dynamic models that mimic the most important processes of the system of interest (e,g, models that simulate the effects of weather, soil, crop characteristics and crop management on yield, such as DSSAT, COTONS, APSIM and RIDEV)

To learn more about these tools, click on their names below to popup a window containing additional information. Below you will also find a link to an article describing how one of these tools was used in an ISFM program.

- DSSAT **-** Decision Support for Agrotechnology Transfer
- APSIM **-** Agricultural Production Systems Simulator (APSIM)
- RothC-26.3 - THE ROTHAMSTED CARBON MODEL
- NUTMON - Monitoring nutrient flows and economic performance in tropical farming systems
- COTONS
- NuMaSS - NUTRIENT MANAGEMENT SUPPORT SYSTEM

Supplemental Reading

- Farmers and researchers on their way to Integrated Nutrient Management (NUTMON example) - http://www.ileia.org/2/13-3/13-3-6.htm

Lesson 3.2: 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 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 are planned, and may also include scheduled meetings with local input dealers or credit providers for certain ISFM options. The Action plan calendar will also clearly highlight the division in responsibilities between farmers and change agents.

Lesson 3.3: 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 repetition. Good management of such nutrient omission trials is important, to ensure that nutrients are determining crop growth, and not other factors, such as weeds, diseases, pests, water shortage etc.

Some trials take the form of a **fertilizer strip test**. In very general terms, this involves alternating

Some trials take the form of a **fertilizer strip test**. In very general terms, this involves alternating strips of a specific fertilization rate or application method with the normal practice. It is important that only one fertilizer variable be changed when comparing two treatments so that valid yield comparisons can be made.

The objective of a strip test is to measure crop yield performances with and without the additive or amendment. Some of the key things to keep in mind when doing such a comparison include:

- Applying the test material or practice in several strips across the full length of the field. The treated strips should be alternated with untreated strips of the same size. The strips should be wide enough to allow for easy segregation and measurement of crop yield from each field strip, both treated and untreated.
- The soil fertility and cropping history should be uniform in the field to be used for the trial.
- The field should have a uniform crop stand and been uniformly fertilized in the previous and current season. If the field is irrigated the frequency and amount of irrigation should be uniform during the test period.
- Yield data should be collected from each strip. If feasible, it is desirable to take yield subsamples within the treated and untreated strips to obtain an estimate of field variability.

Supplementary Reading

- Fertilizer Strip Trials in the Field. - http://extension.usu.edu/publica/agpubs/ag431.pdf
- Readings On Participatory Research - http://www.idrc.ca/cbnrm/documents/CBNRM_Toolkit/overview3.htm
- Organizational roles in farmer participatory research and extension: Lesssons learned from the past decade - http://www.odi.org.uk/nrp/27.html

Lesson 3.4: 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 was 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 centers in soil fertility management and may even take a lead role in farmer-to-farmer training.

Module 4: ISFM Strategies to Maximize Profits and Agronomic Use Efficiency

Module Overview

You have now come a long way toward your goal of developing a sound ISFM program strategy. You've selected a site from which to do your work, identified potential problems and come up with a plan to verify your diagnosis. In this module you will have the opportunity to think about what can be done to address the problems you have identified and in the following lessons you will find a suggested analytical framework and range of interventions for you to consider and adapt for your situation. Although we focus on nutrient management in this framework with special emphasis on the macro-nutrients, you should realize by now 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.

Your goal after going through the various lessons is to be able to formulate a list of key soil fertility management recommendations for farmers in your target area. What actions can be taken to insure that soil fertility is maintained at a level where nutrient supply won't be a limiting factor at any stage of plant growth, from germination to harvest?

The framework we will present asks you to 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.

Lesson 4.1: Adding Organic or Inorganic Fertilizer

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. This continuous removal of nutrients is known as **nutrient mining**. Some information on the nutrient removal by rice can be found in the table below. Information on nutrient removal by various other crops can be found in the Supplementary Readings below.

Average nutrient removal of modern irrigated rice varieties and mineral concentrations in grain and straw.

	N	P	K	Zn
Total nutrient removal with grain + straw (kg / t grain yield)	17,5	3,0	17,0	0,05
Nutrient removal with grain (kg nutrient in grain / t grain yield)	10,5	2,0	2,5	0,02
Nutrient removal with straw (kg nutrient in straw / t grain yield)	7,0	1,0	14,5	0,03
Mineral content in grain (%)	1,10	0,20	0,29	0,002
Mineral content in straw (%)	0,65	0,10	1,40	0,003

Much of the last module dealt with how to identify specific nutrient deficiencies. Depending on availablily of nutrient sources, these single element deficiencies are perhaps the easiest to address. For example, if a farmer observes widespread symptoms of Zinc deficiency in his or her field, it is a relatively easy matter to apply additional Zinc to the field.

While important, adding nutrients should not be considered only in terms of just single elements. As we discussed in the first module, a soil with adequate fertility levels is not necessarily a productive one. Care must be taken to enhance and maintain soil structure and texture and ensuring adequate levels of organic matter and balanced plant nutrition, i.e. crops need a variety of nutrients in a balanced proportion to ensure optimal growth. Also, managing such factors as soil pH and CEC must also be considered if nutrients are to be made available to plants.

Adding nutrients is done to achive two main objectives – short- and long-term. To achieve short term gains in soil fertility farmers may grow a green manure crop, add mineral fertilizers or apply farmyard manure. Long-term strategies include fallowing, application of organic matter with a high C/N content, application of one-time high doses of inorganic P or phosphate rock.

Supplementary Reading

- REMOVAL OF NUTRIENTS BY CROPS - http://www.micromixsolutions.com/diag-removal.html
- Crop Nutrient Utilization Chart - http://www.back-to-basics.net/agrifacts/pdf/b2b22.pdf

Lesson 4.1.1: Adding Nitrogen

Although N is one of the most abundant elements on earth, its deficiency is probably the most common nutritional problem affecting plants worldwide. Most plants take N from the soil continuously throughout their lives, and demand usually increases as plant size increases.

Building soil nitrogen is made difficult because of the dynamic nature of N cycling in the soil. There are three main forms of N capital: mineral N (ammonium NH4 and nitrate NO3), N in relatively labile soil organic matter and N in a more stable form of soil organic matter. NH4-N can be held as exchangeable cation or trapped as an interlayer cation in some 2:1 clay minerals, such as vermiculite and illite in vertisols. Under anaerobic conditions nitrifying bacteria quickly transform NH4-N into NO3-N (nitrification).

N is sometimes refered to as the “nutrient that doesn’t want to stay put”. Nitrate is highly mobile and easily lost by leaching or by denitrification (gaseous losses as NO, N2O and N2). Substantial losses of NH4-N can also occur through volatilization (gaseous losses as NH3).

Legumes may be used to build soil N capital, however often a majority of N is fixed in the grain. The growing of soybeans, for instance, may even result in a net removal of N from the field. When soils are cultivated continuously it may be impossible to build up soil N capital. Even when the capital store of N is replenished, continued use of crop sequences and intercrops with grain legumes and green manures, better integration of crops and livestock and optimal use of mineral fertilizers are essential to ensure improved yields are maintained. In sandy soils, with weak microbial activity and poor structural protective capacity of the soil opportunities for the build-up of nitrogen capital associated with organic matter may be limited. This is especially the case in lowland areas where temperatures are high.

Supplementary Reading

- N Management: Striking a Balance: Improve economic returns while reducing environmental impact. - http://www.back-to-basics.net/in_the_news/pdfs/nitrogen.pdf
- Nitrogen - http://www.back-to-basics.net/efu/pdfs/nitrogen.pdf

Lesson 4.1.2: Adding Phosporus

The two main ways P is lost is though crop-harvest removals and soil erosion. The P content of plant residues and manure is normally insufficient to meet crop requirements. P fertilizers are, therefore, often necessary to overcome P depletion. Soil P can be replenished with soluble P fertilizers, direct application of sufficiently reactive phosphate rock (PR), or the combination of soluble P fertilizer and PR. In high P-sorbing soils, high levels of P addition may be required before a response is achieved, although the residual benefits of such applications are potentially high. By contrast, in sandier soils, lower applications may be given. However, the residual benefits will probably be limited, due to the combined effects of leaching of inorganic P and the limited existing fraction of organic P.

The suitability of PR for direct application to soil depends upon the mineralogy and reactivity of the PR, soil properties, climate, crop, and economics of use associated with the PR. Dissolution of PR requires low pH, low soil exchangeable Ca and low soil solution P concentration. Plants can enhance the dissolution of PR through acidification of the rhizosphere. A high P sorption capacity can promote more rapid dissolution of PR, but the low soil solution P concentration resulting from high P sorption may limit plant growth. Combined use of P fertilizers and legumes can result in synergism where nitrogen fixation can be enhanced because of reduction of P deficiency.

Supplementary Reading

- Phosphorus - http://www.back-to-basics.net/efu/pdfs/phosphorus.pdf
- Phosphate Agronomy - http://www.imcglobal.com/general/education_corner/phosphates/agronomy.htm

Lesson 4.1.3: 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 profitabilitiy and sustainability of a farm. For details on the addition of these other elements participants should refer to the supplementary readings below.

If soils in your area are acidic, it might be necessary to add lime. Acid soils are widespread around the world. Their occurrences are caused by natural processes (weathering) and/or man-made processes (adding NH4 producing fertilizers to soils, releasing acid forming gases to the atmosphere). Acid soils are infertile because of (i) Al and/or Mn toxicities and (ii) Ca and/or P deficiencies. Acid soils can be managed by liming based on appropriate lime requirement curves.

Supplementary Reading

- Potassium - http://www.back-to-basics.net/efu/pdfs/potassium.pdf
- Potash agronomy - http://www.imcglobal.com/general/education_corner/potash/agronomy.htm
- Secondary Nutrients: Calcium, Magnesium, Sulfur - http://www.back-to-basics.net/efu/pdfs/secondary.pdf
- The Sometimes Forgotten Secondary Nutrients Calcium—Magnesium—Sulfur - http://www.back-to-basics.net/efu/pdfs/secondary.pdf
- Micronutrients - http://www.back-to-basics.net/efu/pdfs/micronutrients.pdf
- Possible Solutions to Remedy the Detrimental Effects of Soil Acidity on Tropical Agriculture - http://www.acad.carleton.edu/curricular/GEOL/classes/geo258/studentswork/Bookin.html
- Acid soils of the tropics - http://www.echonet.org/tropicalag/technotes/Acidsoil.pdf

Lesson 4.1.4: Adding Organic Matter

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, greater soil fertility and increased CEC just to mentions some of the most important.

However, contrary to what some may say, 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. In fact, it has been the decline in organic matter that has contributed to the productivity of the crop-fallow system.

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.

Lesson 4.1.5: Adding a 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 a loosing battle. 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 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.

Supplementary Reading

- Integrated Use of Organic Manures and Chemical Fertilizers and Principles - http://www.fadinap.org/ipns/srilanka/ipnsmanual/chap3.pdf

Lesson 4.2: 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. Trees can be instrumental in re-capturing nutrients leached from the subsoil. Nitrogen losses through NH3 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.

Supplementary Reading

- An Introduction to Water Erosion Control - http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex2074?opendocument
- An Introduction to Wind Erosion Control - http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex3524?opendocument
- Residue Management for Soil Erosion Control - http://www.ianr.unl.edu/pubs/fieldcrops/g544.htm
- Fertilizer Facts - Fate of Nutrients in Soil - http://www.uog.edu/soil/fertft2a.html
- Minimising Nutrient Leaching: Save Resources and Protect the Environment - http://www.agcsa.com.au/atm/articles/vol31/leach.htm
- Nutrients Available After Losses in Manure Storage Facilities - http://www.lpes.org/Lessons/Lesson21/21_5_nutrient_losses.pdf

Lesson 4.3: 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 turnover is very rapid in tropical soils. 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 as 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. rice straw) is converted into material with a low C/N ratio. Farmers may improve the nutritional quality of compost by adding ashes, eggshells 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.

Supplementary Reading

- The Science and Engineering of Composting - http://www.cfe.cornell.edu/compost/science.html
- Composting - http://www.epa.gov/epaoswer/non-hw/compost/

Lesson 4.4: Improving the Efficiency of Nutrient Uptake

Improving input use 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 rice straw or other plant residues) may conserve moisture and smother out weeds, enabling better crop establishment and nutrient uptake. It is not uncommon to see that farmers tend to wait with weed management until weeds are clearly visible, 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 crop is impaired.

Supplementary Reading

- Fertilizer Practices and Efficiency - http://www.ext.colostate.edu/pubs/crops/00553.html
- "Fertilizer Placement Methods: New Wrinkles on a New Face" - http://www.soils.wisc.edu/~barak/soilscience326/c&smag.htm
- How to make mulch - http://ok.essortment.com/howtomakemulc_rjij.htm
- Balanced fertilization: Integral part of sustainable soil management - http://www.ipipotash.org/presentn/bfipssm.html

Lesson 4.5: Economic Considerations

Although we try to highlight some of the key economic considerations in ISFM below we know that what is presented here is just enough to give participants a feel for these concepts. We hope to make available a more comprehensive treatment of economic considerations in ISFM in future versions of this course. It should be obvious however, that economics are the basis for farmer decision making and judging ISFM recommendations.

In the majority of cases, farmers are not motivated to use ISFM technologies because they are not profitable. For example, in sub-Saharan Africa, it is estimated that the cultivatable land area on which productivity-enhancing technologies (improved seed, inorganic and organic fertility, good agronomic practices) have been successfully used does not exceed 15 to 20%. Socio-economic factors also play an important role. Soil fertility management can be strongly related to the degree of access to resources (e.g. land, carts, cattle, labor, and cash). Land tenure is a very important issue. Farmers that do not own the land they cultivate may well 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. In measuring the profitability of fertilizer use, several simple criteria are used. These are presented in the table below.

Method	**What it measures**	**Profitability Decision Criteria**
Input Output price Ratio (IOR) (Usually fertilizer/crop ratio)	Measures how much produce in kilograms is required to acquire a kilogram of the input (e.g. fertilizer). It is a price incentive.	The smaller the ratio, the higher the incentive. Typical values for West Africa are between 2 and 4 for maize, crop and millet, 2 for irrigated rice, 3 for groundnuts and 1.9 for cotton.
Benefit Cost Ratio (BCR)	Measures the value of production less the cost (benefit), and expressed as a ratio of the direct and indirect costs incurred in the production. It is a profit incentive.	A ratio exceeding 1 shows

		profitability.
Net Present Values (NPVs) and Internal Rates of Return (IRR)	Measures returns to investments made in the fertility-enhancing technologies over time. Are profit incentives.	Because it takes into account the discount rate, IRRs greater than the going interest rates on savings accounts are usually considered good investments.
Break-even analysis	Measures several aspects of profitability. For example: • estimates the minimum price at which the product must be sold for the fertilizer to just pay for itself • estimates how much fertilizer must cost for the product to just pay for it • to achieve a specified level of profit from the use of fertilizer and • to compare the profitability of fertilizer use across various enterprises	Varies according to the aspect required
Value Cost Ratio (VCR)	Measures 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.

If available at all, the adoption of ‘external’ inputs, and in particular of mineral fertilisers, gives rise to considerable financial risks. These financial risks are determined by:

- the prices farmers have to pay for the ‘external’ inputs;
- the availability and cost of credit to buy ‘external’ inputs;
- the agricultural technology - and knowledge about technological options;
- the prices farmers receive for their agricultural produce.

While we have highlighted the importance of economic factors in this lesson, in reality, these cannot be considered independently of the agronomic considerations we presented earlier. Unfortunately the “agronomic environment” of much of the farm land in developing countries is so poor that crop response to inputs are generally low and will continue to be low until investments are made in the improvement of the fertility status of the soil through amendments and other agronomic practices. Farmers are making efforts to improve the fertility of the soil through labour-intensive water harvesting and conservation technologies, and for the production, collection and use of manure to improve the agronomic environment. The cost is high and farmers need to be supported to invest in animal traction and other equipment.

Supplementary Reading

- Maximum Economic Yields - http://extension.usu.edu/agecon/pubs/meybarly.html
- Maximum Economic Yield Strategies- http://www.back-to-basics.net/efu/pdfs/mey.pdf

Lesson 4.6: Computer-based Decision Support Tools

Just as computer-based decision support tools can be useful in diagnosing soil fertility problems, so too can they be useful for formulating and evaluating potential solutions. These tools can provide quick and cost effective answers to such questions as - When to apply fertilizer and how much’, ‘when to weed’, ‘when to irrigate’ etc. They can help to guide medium term decisions on choice of production system (e.g. ‘growing a leguminous crop in association with maize or two times a maize crop’), tillage system (e.g. ‘plowing or conservation tillage’), cultivar choice (e.g. short or medium duration) and sowing date (early or late). They may help evaluate such long-term decisions such as whether or not to apply rock phosphate to improve the phosphorus long-term decisions such as whether or not to apply rock phosphate to improve the phosphorus supplying capacity of the soil over a number of years, inclusion of agro-forestry options into the production system, or investment in improved irrigation and drainage facilities.

For mineral fertilizers, the QUEFTS model can be used to determine best-bet fertilizer strategies for a range of target yields, given soil nutrient supplying capacity, potential yields and nutrient recovery rates. Dynamic crop simulation models that simulate phenology, such as APSIM or DSSAT can be employed to compare timing of management interventions by farmers to what would be optimal in agronomical sense. The organic resource database developed by TSBF-CIAT helps with organic matter management decision-making based on N, lignin and polyphenol content. We introduced these and several other DSTs earlier and interested participants might want to revisit their descriptions.

Another good use of these tools is that discrepancies between modeled outcome and farmer reality can be used as input into discussions with farmers. Farmers may be aware of the best timing for a given crop management intervention, and other constraints (e.g. lack of credit, lack of labor) may be the real cause of the delay.

Of course, results from simulation – and other – models, representing a complex, and too a large extend still poorly understood, reality of crop, soil, capital and labor interactions, should be interpreted with much care. For more information and supplementary materials on these models click on the links below. The online Bontkes and Wopereis book may also be of interest and participants can find a link to this publication in the Supplementary Reading section.

To get a feeling for how these tools can be used you might want to take some time to play around with 3 online crop response models that have been published on the Web by QPAIS Pages. These dynamic models simulate crop response to the application of Nitrogen, Phosphorus and Potassium fertilisers. Users input their initial values for sowing and harvesting dates, climatic and soil conditions, and fertiliser application in a simple online form using their web browser. The program output consists of estimates of crop response in numerical or graphical form. Each model also has an associated model description and diagram showing the compartments and flows. Check them out at - http://www.qpais.co.uk/ . For additional information on other models please click on the links available in the Supplementary Reading section below.

Supplementary Reading

- A practical guide to decision-support tools for smallholder agriculture in sub-Saharan Africa - Tjark Struif Bontkes and Marco C.S. Wopereis
- QUEFTS - Quantitative Evaluation of the Fertility of Tropical Soils
- DSSAT - Decision Support for Agrotechnology Transfer
- APSIM - Agricultural Production Systems Simulator (APSIM)
- RothC-26.3 - THE ROTHAMSTED CARBON MODEL
- NUTMON - Monitoring nutrient flows and economic performance in tropical farming systems
- COTONS
- NuMaSS - NUTRIENT MANAGEMENT SUPPORT SYSTEM
- PRDSS - Phosphate Rock Decision Support System
- ORD - Organic Resource Database
- TSBF-CIAT
- ROTH
- RIDEV

Module 5: Promoting ISFM Among Farmers

Module Overview

Here we are at the beginning of the last, and arguably the most important, module of this course. You've gone through a wealth of information about ISFM and, through your work in the previous modules, developed some sound, practical, cost-effective, science-based best-bet recommendations that you think will make a difference in your situation. But 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 the last remaining lessons of this course we will focus on information dissemination approaches and tools. Most of the module will concentrate on explaining IFDC's Extension-DATE approach but will also provide links to various other sources of information and approaches.

Lesson 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 recomendations 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). It emphasizes supporting institutional change that reinforces linkages between farmers, bankers, input-dealers and traders. Details on each of the 4 phases follow.

Lesson 5.1.1: Diagnosis

At this stage in the process the usefulness of the recommendations you developed during the Research-DATE should have been verified for farmers at or close to your 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 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. Assessing the potential to build-on or to improve linkages with input-dealers, bankers, traders and public institutions involved in input and credit provisioning and output marketing is also a critical activity.

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, regional policy makers, bankers, traders, extension and development workers), guided study tours of key-actors (e.g. to study alternative credit structures, or innovative ways to exchange and/or diffuse information).

Lesson 5.1.2: 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?).

Other questions to answer include input provisioning (individually? farmers' group?), marketing of agricultural produce and the need for credit. While inputs are usually provided free in the 'learning plot' exercises conducted during the Research-DATE, this is not a usual practice for the 'adaptive trials' that the farmers interested in ISFM will start in the Extension-DATE. If access to credit is an important constraint, a small 'revolving fund' can be used to stimulate a core-group of farmers to start with the adaptive trials. Management and objectives of the revolving fund should be discussed thoroughly with all the stakeholders concerned. In various ISFM projects, coordinated by IFDC, some consensus seems to have been reached about this issue. The revolving funds should serve the double purpose of giving access to the required capital for a small group of farmers to start 'trying ISFM out' and to learn how to manage a credit operation as a group. After an initial learning phase, the revolving fund can be used as a kind of guarantee fund, which permits rural credit banks to become engaged in providing loans to ISFM farmer groups.

Extension-DATE action planning involves farmers from neighboring and other interested villages, not just the target-farmers in the pilot-village. It focuses on starting the scaling out of ISFM strategies and involves input-dealers, bankers and traders, and in some cases even regional-level policy makers. Action plans with input-dealers, for instance, might focus on training on dealing with technical aspects (proper storage, quality), management of stocks, marketing and information provision. It might also consist of concrete activities to improve access to market-information, loans (to buy inputs in time, to construct storage places) and clients.

Lesson 5.1.3: 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, many different kind of activities are carried out. Farmers are implementing the adaptive trials. Input dealers and probably some farmer organizations are involved in providing inputs in time to the of experimenting farmers. Farmers and 'change agents' are involved in setting-up rural knowledge centers. Farmer group(s) are involved in the management of the revolving funds. Bankers, farmers and 'change agents' may be involved in a negotiating process to get loans from a formal rural bank (and for a larger group of farmers). 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 but this should also go beyond the region to national-level actors. This helps to create awareness and to emphasize possibilities and favorable conditions for a sustainable intensification process, and the roles any actor can play.

Lesson 5.1.4: 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 should be decided upon that effectively measure the results of the different activities and that are comprehensible for a large audience. Specific analyses may be required. For instance, the functioning of a credit system may need to be judged, particularly if it is linked with input provisioning and marketing of agricultural produce.

Lesson 5.1.5: 'DATEing' 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. Many poor farmers are unwilling to buy external inputs because they are uncertain about the supply, do not have access to affordable credit and cannot predict market prices at harvest.

Extension strategies must, therefore, not only focus on promoting practices to farmers that are techologically sound but may have to work to improve the accessibility, both geographically and financially, of 'external' inputs (for example, through the development of infrastructure, appropriate credit systems, training of and support to – potential - input-dealers). It may also be necessary to help in the development of market outlets for agricultural produce (for instance, through the development of agro-industrial enterprises).

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.

- Farmers will have to invest in 'external' inputs and should (re-) allocate resources to adopt ISFM technologies. Moreover, farmer organisation 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. Proper legislation and control mechanisms and specific well-targeted sectoral investments are needed, comprising, e.g., agribusiness development and appropriate credit programmes.
- Governments and donor institutions should invest in soil fertility recovery and improvement. This is a basic premise of the Soil Fertility Initiative (SFI), launched in 1996 during the World Food Summit in Rome. The SFI aims to increase understanding of the factors

contributing to soil fertility decline and of potential solutions and to support the design and implementation of comprehensive soil management programmes.

The question of farmer organisation 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.

Lesson 5.2: Other Extension Approaches

While the participatory DATE approach to extension is the one favored by the authors of this course, we recognize that there are other ways to disseminate information and knowledge. Some of the more popular methods include strategic extension campaigns, farmer field schools and traditional extension methods.

Strategic extension campaigns (SECs) use mass media to convey research findings and recommendations in a simplified form in order to motivate attitude change. SECs have been shown to achieve rapid impact because they reach large numbers of farmers in an area all at once, including remote locations normally not visited by extension trainers.

The **Farmer Field School** approach is a field-based programme that provides learning experiences usually for groups of up to 25 farmers. Field Schools generally last for a full cropping season and meets at least 12 times for about four to five hours per meeting.

Traditional extension approaches have also been used effectively, particularly when they incorporate participatory activities.

Supplementary Reading

- Strategic Extension Campaign: Increasing Cost-Effectiveness and Farmers' Participation in Applying Agricultural Technologies - http://www.fao.org/sd/EXdirect/EXan0003.htm
- Strategic extension campaign - A participatory-oriented method of agricultural extension- http://www.fao.org/docrep/u8955e/u8955e00.htm#Contents
- Improving agricultural extension. A reference manual - http://www.fao.org/docrep/W5830E/W5830E00.htm
- Guide to extension training - http://www.fao.org/docrep/T0060E/T0060E00.htm
- Using Participatory and Learning-Based Approaches for Environmental Management to Help Achieve Constructive Behaviour Change -http://www.landcareresearch.co.nz/sal/par_rep.asp
- Sustainable Development Extension - http://www.maf.govt.nz/mafnet/rural-nz/people-and-their-issues/education/sustainable-development-extension/index.h

Additional Online ISFM Resources

- Soil Fertility Management - http://agguide.agronomy.psu.edu/CM/Sec2/Sec2toc.html
- Michigan State University's CSS 430: Soil Fertility and Chemistry - http://www.css.msu.edu/css430/
- Worldwide Portal to Information on Soil Health - http://mulch.mannlib.cornell.edu/browse.html

- Guidelines and manuals (FAO's AGL Division) -http://www.fao.org/ag/agl/agll/farmspi/docs.stm#ffs-manual
- Online documents on plant nutrition (FAO's AGL Division) -http://www.fao.org/ag/agl/agll/oldocsp.jsp
- Soil biodiversity portal (FAO's AGL Division) -http://www.fao.org/ag/agl/agll/soilbiod/default.stm
- Online documents on Fertilizers, soil fertility, plant nutrition (AGNET) -http://www.agnet.org/library/list/subcat/E.html
- Miscellaneous resources on soil fertility, acidity, alkalinity (AGRIFOR) - http://agrifor.ac.uk/hb/5a12a57a48789740ed6e74f24fca59b2.html
- International fertiliser industry association - http://www.fertilizer.org/ifa/
- Integrated plant nutrition systems resource documents (FADINAP) - http://www.fadinap.org/ipns/index.htm
- Soil Fertility and Fertilizers (Open Directory) - http://dmoz.org/Science/Agriculture/Soils/Soil_Fertility_and_Fertilizers/
- Soil: Fertility & Chemistry (Portal site) - http://homepages.which.net/~fred.moor/soil/links/l0102.htm
- Soil Fertility Guide -http://www.gov.nf.ca/agric/pubfact/Fertility/FertiGuide.htm
- Soil Information compiled by Dept. of Land Management, Universiti Putra Malaysia (Directory) - http://agri.upm.edu.my/jst/soilinfo.html
- Natural Resources Conservation Service: Soils - http://soils.usda.gov/

- Natural Resources Conservation Service: Soils - http://soils.usda.gov/
- Fertilizers and their efficient use - http://www.fertilizer.org/ifa/publicat/PDF/introd.pdf
- International Fertilizer Industry Association - http://www.fertilizer.org/ifa/