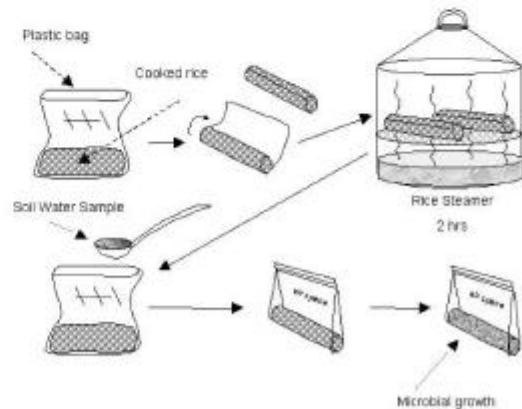
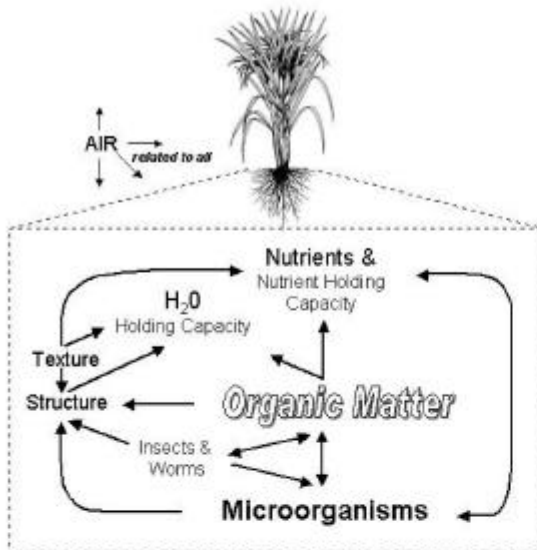




LIVING SOILS

Training Exercises for Integrated Soils Management



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‘Living Soils’ is the result of the ideas and efforts of a great many people. The guide has gone through two iterations; this second edition has the benefit of having field-tested all the exercises on numerous occasions in training sessions in Indonesia, Thailand, Cambodia and Bangladesh. Feedback on existing ideas and the contribution of new ideas by participants has contributed greatly to the quality of the exercises.

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Note to trainers:

This document is (and should always be) a ***work in progress***. Our hope is that you consider this the ***beginning point***, rather than the end point, of a curriculum development for an integrated approach to soil fertility management. Our hope also is that the trainers in each country will take ownership of the material herein, to make it their own by adding exercises that originate from their own experience and creative ideas.

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INTRODUCTION

Soils management: a global crisis

Over the past few decades increasing attention has been given to the pivotal position that soils play in sustaining agricultural productivity. It is increasingly evident that perhaps the principal factor behind the world-wide gradual decline in agricultural **productivity** is inadequate soil management. Some of these problems, both temperate and tropical, are frequently related to erosion of topsoil, increasing salinity, pH imbalances, and overall declines in soil organic matter. Whatever the nature of the problem, any path to a long-term sustainable solution must address the task of farmer education.

Local Specificity

One of the problems with the “industrial model” for agricultural research and extension is the centralization of activities and resources, including knowledge, that necessarily leads to the development of broad-based recommendations and the extension of “technology packages”. Ecological systems, however, are characterized by interactions among a fairly large set of factors that result in highly local specific scenarios. Water, soils, climate, and the history of agricultural practices all vary to a large extent, and often over small geographical distances. One of the most important lessons learned by IPM farmers is that generalized recommendations that come to them from extension and research need to be carefully examined, tested and decided upon, **by farmers themselves**, according to the specific local conditions found in their area. Soil fertility management is a topic that lends itself well to research by farmers on their own land and as a topic for farmer-to-farmer training. Our goal is to develop, through training, not specific recommendations, but an **understanding** of the basic principles and mechanisms underlying soil—plant relationships, and the **skills** of farmers for doing their own experiments and analyses in order to make their own informed management decisions.

The First Principle of IPM

As a topic for IPM, soils fits perfectly within the first principle of IPM defined as “grow a healthy plant”. Having said this, we should recognize that the topic of soils presents a somewhat different set of challenges and opportunities for training than do the above-ground topics of IPM. Farmers cannot see much of what takes place underground in the same way they can see the interactions of, say, a spider and a leafhopper. As a consequence of these difficulties in observing interactions in the soil, a greater emphasis needs to be placed on developing experimental approaches to understanding cause-and-effect relationships. At the same time, we need to have a strong conceptual framework to support soils training.

Observation, Experimentation and Theory

The backbone of IPM training is the same as that for any good scientific endeavor: **observation, experimentation**, and the development of an **explanatory (mechanistic) theory**. IPM training has from the very beginning stressed the critical importance of demonstrating key concepts. For example, farmers learn the importance of natural enemies by placing crop pests on plants in cages—both with and without the addition of principal natural enemies (e.g., spiders). The resulting observable differences in population numbers between the treatments—together with observations of predators actually attacking and eating pests—provide solid experiential evidence of the mechanism by which predators function in a community to control potential pests. In this way

observation and experimentation lead directly to building general concepts, or a kind of “theory” in the broadest sense.

In soils, however, such direct observation of individual identifiable components is somewhat more difficult—the individual living organisms are far too small to observe directly. This issue of size poses the problem of how to help the farmer develop a clear and unambiguous mechanistic understanding of what precisely is taking place when, for example, he adds synthetic fertilizers to his soil, or returns (or doesn't) straw into the soil before planting.

Although we cannot directly point to a bacterium, a particle of clay, or a molecule of nitrogen, what we can do is to help farmers develop a conceptual framework for imagining how the problem ‘works’. This framework or “model” can often be successfully portrayed as an *analogy* with something familiar to everyday life, usually assisted by a drawing. Analogies can be a very powerful tool for sharing technical ideas among people who do not share the necessary technical language (consider the prominent use of analogies in the books written by nuclear physicists like Feynman or Hawkins for a lay audience).

The programs we have reviewed that have attempted to conduct farmer training on soils have tended to avoid mechanistic discussions. Our feeling, however, is that analogies and imagery—while not as good as observable experiments, are still better than no treatment at all. Our recent experience in the field, working with alumni IPM farmers on soil-related issues, shows quite clearly that farmers are willing and able to tackle the ideas behind the practice of soil management. One farmer in West Java, after a day of doing experiments in the field and lab, afterwards said:

“I’ve been applying NPK for 20 years and never had an idea about how it worked until now”.

The long-term goal of this training, as with all of our IPM training, is *to take science down off the shelf* in order to put the most important concepts of cause-and-effect into the hands of farmers and trainers. This is a process for which everyone who is interested in the goals of farmer training can play a part. We encourage the reader to take this document as a first attempt at a general curriculum, and to add your own ideas, experiences and case studies with farmers as time proceeds. Trainers are therefore encouraged to take ownership of their training materials and make them a “living curricula”.

A Philosophy of Sustainable Soil Fertility Management

There has been a great deal of discussion worldwide on the nature of "sustainability". While opinions differ, a general outline can be sketched. One of the better definitions comes from Gliessman, 1998¹:

"Based on our present knowledge, we can suggest that a *sustainable agriculture* would, at the very least,

¹ Gliessman, S. R. 1998. Agroecology: ecological processes in sustainable agriculture. Sleeping Bear Press, Chelsea, MI.

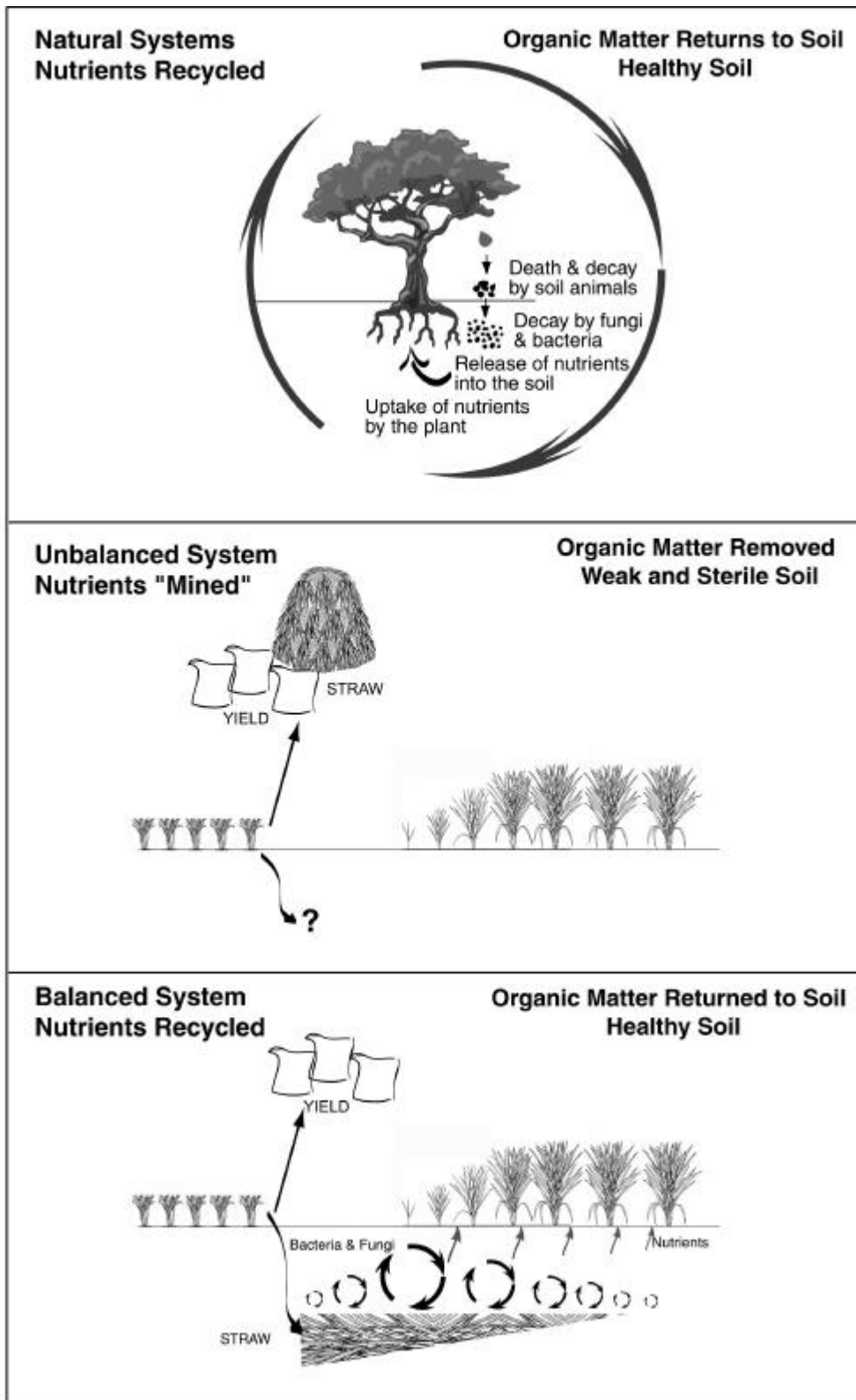
- have minimal negative effects on the environment and release no toxic or damaging substances into the atmosphere, surface water, or groundwater;
- preserve and rebuild soil fertility, prevent soil erosion, and maintain the soil's ecological health;
- use water in a way that allows aquifers to be recharged and the water needs of the environment and people to be met;
- rely mainly on resources within the agro-ecosystem, including nearby communities, by replacing external inputs with nutrient cycling, better conservation, and an expanded base of ecological knowledge;
- work to value and conserve biological diversity, both in the wild and in domesticated landscapes; and
- guarantee equality of access to appropriate agricultural practices, knowledge, and technologies and enable local control of agricultural resources."

Strategy for sustainable soil fertility management

The intimate nature of plant-soil relationships have co-evolved over the past several hundred million years. Plants, in some form or another, have penetrated almost every conceivable soil system on earth. Perhaps the most fundamental mechanism common to almost all these systems is the movement of nutrients from the living (called “standing”) biomass, into the soils beneath it, where the now dead organic matter is decomposed by a complex miniature world of microorganisms, then to be brought back into the living system through the roots and leaves of the living plants.

While this “recycling” of nutrients within an ecosystem is a characteristic of natural systems, the very nature of agricultural systems involves at least a partial breaking of these cycles. Humans harvest crops to remove some or all of the plant material to another location. The degree to which the agricultural nutrients are at least partially recycled is varies greatly among systems. One thing is sure, however—those systems in which little or no organic matter is recycled back into the soil, are systems which are by definition in a declining state of fertility and productivity. *Therefore, a fundamental strategy in sustainable agriculture is to try and maintain organic matter and nutrient flows in such a way as to mimic the natural systems as closely as possible.*

Feed the Soil (naturally) and let the Soil Feed the Plant



Developing a training curriculum: a two-stage process

The following exercises include some that are useful in farmer training, and others that are appropriate for trainers, to provide some depth to their understanding of soils processes, but which may not be (yet) appropriate at the farmer level. We've have done our level best to bring you the "first stage" in the form of a training curriculum that is coherent, interesting, and applicable, but the task is not finished here. It remains for the Field Trainer, during the "second stage" to adapt this material to the context of his or her farmers. Trainers should **take ownership** of their training materials and as their experience increases, add their exercises, analogies and case studies.

Suggested outline for a four-day TOT on soils

Participants need to arrive the evening before the first day in order to avoid delays the following day.

Evening before Day 1:

Participants arrive	
Introductions	
Logistics	
Course objectives	1 hr

Day 1:

Analogy as a tool	20 min
What is Science	1 hr
What is a soil system	2 hr
Designing the experiments	2 hr
Living soil	30 min
Collection of soils; materials preparation	1 hr

Day 2:

Set-up of experiments (7:00 am start)	2 hr
Particle sizes	1 hr
Atoms and molecules	30 min
What is soil pH	30 min
Particle forms (clay structure)	30 min
-- Why is acid soils a problem	30 min
What is energy (photosynthesis)	45 min
Photosynthesis simulation	30 min

Day 3:

Drainage & Soil profile in field (7:00 am start)	1 hr
Drainage & profile graphing and reporting	1 hr
Wrap-up of experiments	1.5 hr
What is an ideal soil	40 min
Nutrient mining simulation	1 hr
Nutrient Budget (abbreviated)	45 min
C:N ratio	1 hr

Day 4:

Sterile media demo set-up	30 min
Straw use analysis	1 hr
Soil management problem analysis	3 hr
Doing farmer-based research on soils	90 min

Closing

EXERCISES: INTRODUCTORY SECTION

Goal

The overall goal of this section is to explore some basic ideas regarding the nature of science, and to introduce the idea of analogy as a powerful tool in farmer training.

Exercises in this section

1. *Analogy as a Tool in Training*
2. *What is Science?*

Tips on Running the Exercises

These first exercises can be accomplished during the first session, just after the “getting to know each other” introductory session, and a statement of objectives for the training. The idea is to orient the training away from a too technical perspective, and towards the goal of training farmers.

Three Perspectives

*At various times during the training of trainers it will be appropriate to ask the participants to take on or assume several different perspectives: viewing the training as a **trainee**, a **trainer** (which they will be soon) and from the viewpoint of a **farmer**.*

EXERCISE 1. ANALOGY AS AN IMPORTANT TOOL IN TRAINING

Background

As part of the introductory session it will be useful to introduce the idea of analogy as a tool in farmer training. An analogy is a means of increasing participantl understanding of abstract or new ideas by drawing parallels with things that participants are already familiar with.

Analogies can be divided into *simile* and *metaphor*. A simile is a direct statement that “A is *like* “B”. A metaphor simply states directly the idea that A is B. We will be using similes more often than metaphors. A metaphor tends to be a more strongly evocative idea—a device frequently used in poetry and literature (an entire story or poem can be a metaphor). The value of an analogy is that it gives a very clear and evocative picture of the characteristics or mechanism of something that may be entirely unknown, or otherwise require an explanation demanding complex knowledge such as math or chemistry.

Goal

To explore the concept of analogy

Time required

30 minutes

Materials

none

Steps

1. Ask the participants if anyone knows what an analogy is.
2. If a good example is not forthcoming then give an example: for example, the often used training game: “how is a trainer like the parts of an automobile?” . Run through a few iterations of this game until the participants show they understand the process.
3. Ask the participants to come up with other examples of analogies, and list them on the board.
4. Conclude with the statement that analogies will come up frequently throughout the training and to keep their eyes open for them.

EXERCISE 2. WHAT IS SCIENCE

Background

This exercise is a simple warm-up activity that gets participants thinking about the process of science contrasted with the so-called “transfer of technology” (which is more often the sale of technology). The most important objective here is to acknowledge the fact that all the activities listed by participants are activities that can be done by farmers as well as anybody else.

Compare and Contrast

In the earlier exercise we introduced the idea of analogy as a means of **comparing** two things that would seem to be very different, but in fact can be seen to be similar in some very basic characteristics (often requiring lots of imagination). In this exercise the facilitator will introduce the idea of **contrasting** two things that might at first seem the same.

Goal

To explore the ideas of the participants as to what constitutes science.

Time required

60 minutes

Materials

Pens

Newsprint

Small pieces of paper large enough to write down a sentence

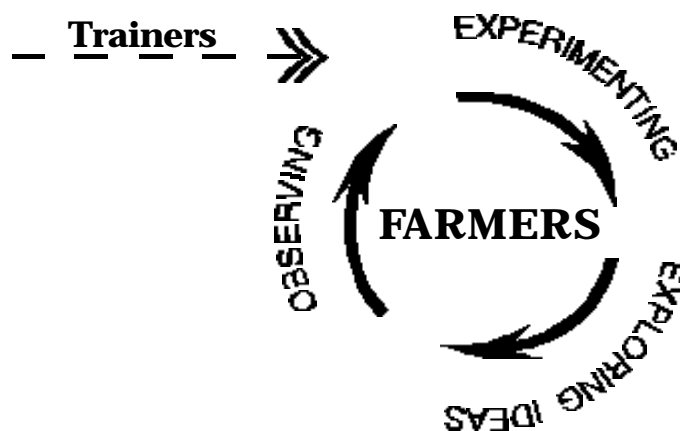
Tape

Steps

1. Facilitator starts off with a question: “what is science?” and asks participants to write just one sentence each on a piece of paper. When they are finished they should tape their answer to the board.
2. Facilitator reads down the list of answers and writes key words on a list on newsprint. Each time the same key word is repeated, add a check mark next to the word on the list.
3. Draw upon the list to contrast two ideas that might be seen as similar. For example, the terms **Knowledge** and **Information**. Write the two words on the board and ask the participants to give characteristics that differentiate or contrast the two words. Do the same for the two words **Science** and **Technology**.
4. Point to the list of key words for science and ask participants if they think farmers can do all these things—discuss. Does an experiment in

an FFS (for example, defoliation and detillering) constitute “Science”?
In other words,

5. Facilitator points out that the list of key words from the exercise is quite long. One option (time permitting) is to ask small groups to simplify this long list into three or four words, and show their interconnection. Most all of the list can probably be grouped into three terms:
 - a. **observation** (e.g., exploring, seeking truth, etc.)
 - b. **experimentation** (e.g., proving an idea, testing hypotheses, etc.) and,
 - c. **idea building** (e.g., analyses, conclusions, hypotheses, and theories).
6. Facilitator may wish to present a drawing as below (after small group presentations if that option is chosen). In this picture, the Farmer is represented at the center of the Science Wheel, and the Trainer is represented as on the outside. The Trainer’s arrow represents the idea that trainers provide an initial “energy” to get the process going (e.g., “let’s go to the field and observe”, “let’s do an experiment”, “let’s explore this idea”), and later, if farmers run into problems or need guidance, the trainer provides an additional “push” to keep the wheel turning.



“Science is knowledge that creates knowledge”

-- Usha Rani Das, farmer LIFT Project, CARE Bangladesh

EXERCISES SECTION 1: THE SOIL SYSTEM

Goal

*The overall goal of this section is to begin to define a **soil system**—both the principle elements (things) and the characteristics (qualities)—and then to develop a set of experiments that will help participants understand how these things and characteristics affect each other, and ultimately the health of the plant.*

Exercises

3. *What is a soil system?*
4. *Designing experiments for soils*
5. *Soil texture*
6. *Atoms and molecules*
7. *What is pH?*
8. *Particle sizes and forms*
9. *Soil structure*
10. *Soil composition*
11. *Productivity: testing soils with indicator plants*
12. *Soil compaction*
13. *Soil water-holding capacity*
14. *Drainage and soil profiles*
15. *Demonstrating microbes in soil*
16. *Organic matter decomposition*
17. *What is a soil system? -- wrap up*
18. *What is an ideal soil?*

Tips on Running the Exercises

*The first exercise in this section is key to the development of the section. By defining how a soil system is constructed, participants can then move on to designing experiments to explore each of the key elements and characteristics. The exercises (5, and 8-16) are suggested methods that participants might find useful for conducting experiments on the topics determined in exercise 4. Facilitators should **first** encourage participants to design their own sets of experiments, and then later in the design session, give additional suggestions, if needed, based on the experiments detailed here. Exercises 17 and 18 are a wrap-up and transition to the next sections.*

EXERCISE 3. WHAT IS A SOIL SYSTEM?

Background

This double exercise is a key activity for this next section on soils. We begin with a group activity, by asking the participants to list all the principal elements associated with a soil system. The participants then do a first (exploratory) small-group exercise in which they try to show the direct and important relationships between the factors.

After each group has presented their findings, the facilitator asks them to do a second (synthetic) diagram to try and simplify and clarify the multiple relationships uncovered during the first part, into just 5 or 6 key factors and their interconnections. After presenting their findings the facilitator uses one of the drawings, or provides his/her synthesis drawing (see below) and seeks several key conclusions.

This summary will be used in the next exercise to determine areas for which participants will design experiments

If doing this exercise with farmers

For farmer training, before beginning with the classroom exercise, go to the field and observe the soil. This might best be done in the usual format of the “agroecosystem analysis” of IPM Farmer Field School. In the field, ask “what is in the soil and what are the characteristics of soil?” The facilitator should lead the discussion towards discovering at least the following:

- a. Insects & worms
- b. Microbes (find a rotting piece of plant material and ask how decomposition takes place)
- c. Water (bring out idea of water-holding capacity and differences among soil types)
- d. Organic matter
- e. Nutrients (can you see nutrients?)
- f. Drainage
- g. Air
- h. Roots

Goal

To be able to list the principal factors, both “things” and “qualities” associated with a soil system, and be able to show how they relate to other “things”, “qualities” and the plant roots.

Time required

2 hours

Materials

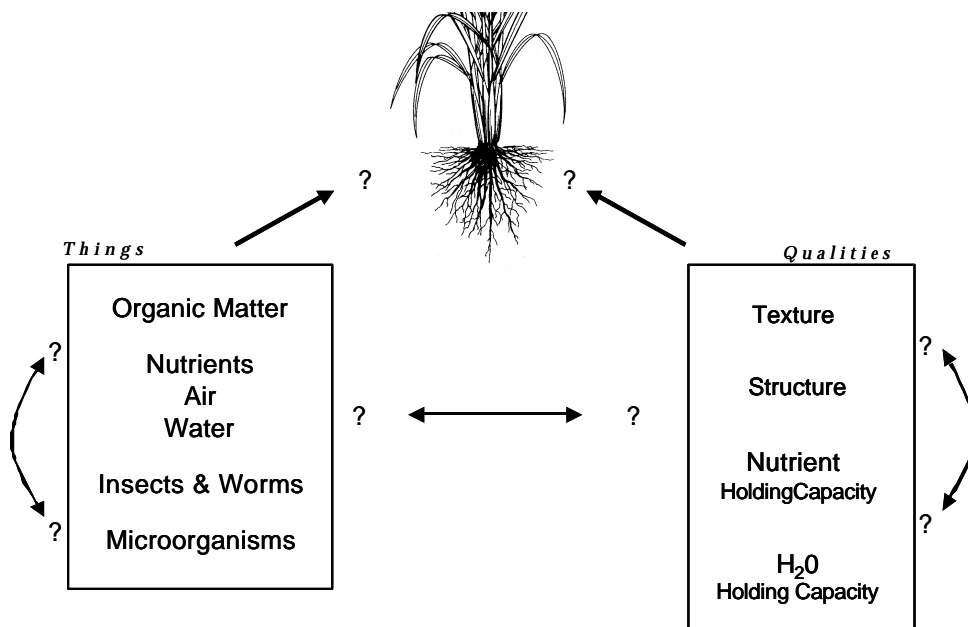
Pens

Paper

Tape

Steps

1. Begin with a group activity, by asking the participants to list some of the principal elements associated with a soil system. This should include both “things” (e.g., sand, worms, air) and “qualities” or “characteristics” (e.g., water-holding capacity, structure). Facilitator should make just a simple list.
2. Participants are asked to break into small groups and to make a drawing, including plant roots and the factors on the list divided into two columns: “things” and “qualities”. Ask them to draw arrows between those factors that have a **direct and important relationship** to each other (see figures below). This should include arrows between things and qualities, but also between things and between qualities.



3. Small groups report back. The facilitator doesn't need to worry about what is “right” or “wrong” on these lists. Let the discussion proceed as it will, hopefully with good discussion developing from the large group.

As a trainer:

At the conclusion the facilitator should point out that this first exercise was **exploratory**—it is designed to bring up many ideas from the participants and to get them thinking about **relationships**. Ask if this was useful. Point out how complex their diagrams look. Ask: “if a stranger came through the door and looked at your diagrams, would it be clear what you are thinking?” The answer will likely be “no”. Then suggest that the following exercise is aimed at **synthesis** of the previous exercise, and has for its goal clarity.

Exploration —————> **Synthesis**

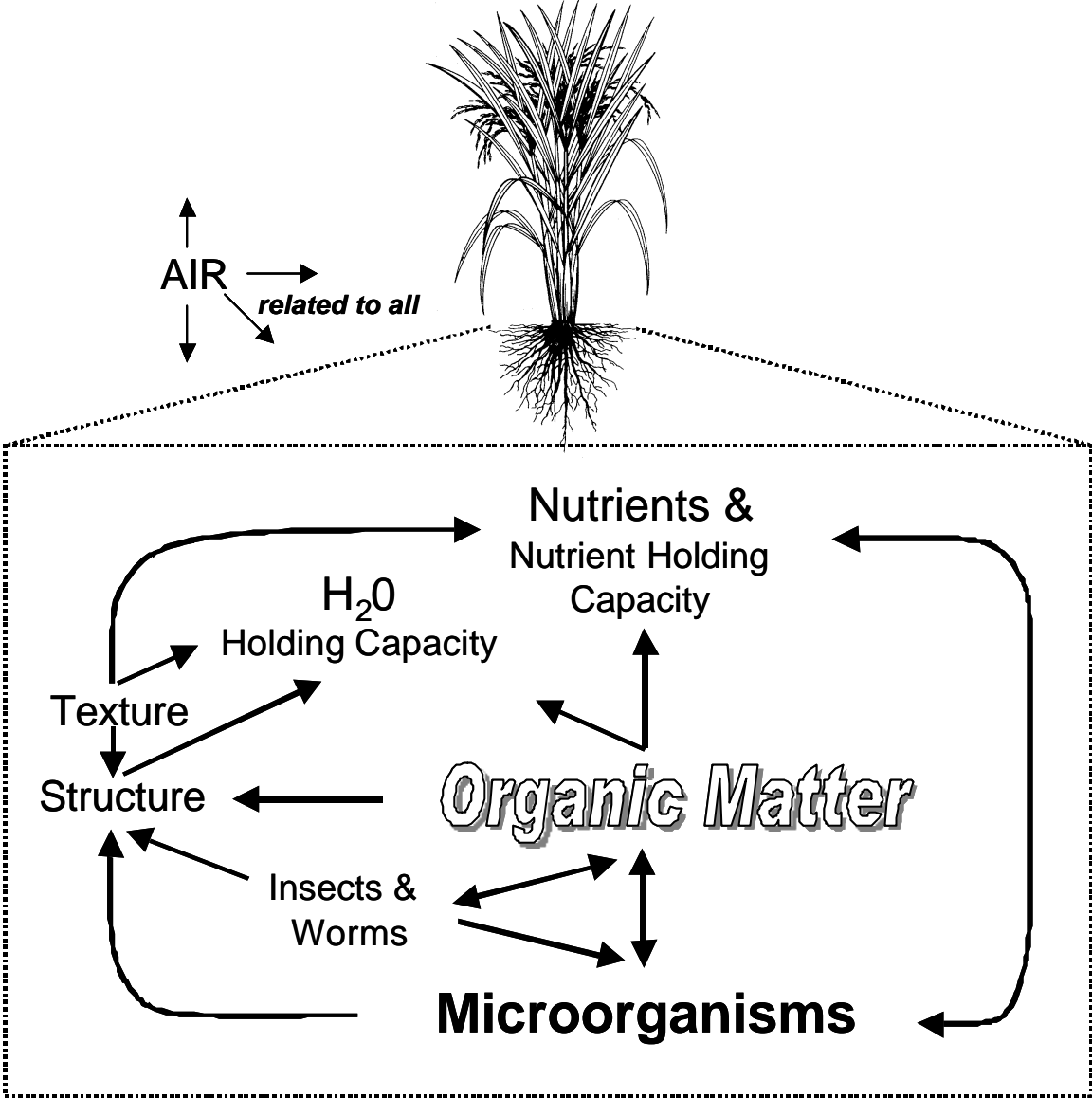
4. Facilitator now asks the participants to take the results of their previous exercise, and to draw a summary diagram that includes the plant roots plus only 5 or 6 of the most important things and characteristics—the goal is clarity and identification of the most important components.

Before the groups break into small groups the facilitator may wish to offer clarification of a couple of key concepts at this point—for example: a clear definition of **texture** and **structure**.

5. Small groups report back.
6. Facilitator presents his/her own summary drawing synthesizing the basic factors in their relation to each other (see below). Go over Questions & Points to Emphasize

Questions & Points to Emphasize

1. What factor has the greatest number of connections to other factors?
A: Organic matter. It affects every other factor directly and indirectly
2. What factors are able to be **directly** manipulated by farmers?
A: Organic matter and water are the only two factors that are directly manageable by farmers
3. Where do plant nutrients in the soil come from?
 - a. The majority come from organic matter broken down (“mineralized”) by microbes
 - b. Some come from existing levels of inorganic nutrients stored on the surface of clay particles and the surface of humus
 - c. Some are floating in water solution
 - d. Some derive from parent materials (rock subsoil)
 - e. Some are added by farmers



EXERCISE 4. DESIGNING EXPERIMENTS TO EXPLORE SOILS

Background

The last exercise gave us a summary outline of the principle factors of importance in a soil system. In this exercise this summary will be used to determine 4 or 5 key areas of interest. The participants will divide up into small groups with each small group choosing a particular factor to explore. If time permits (for longer-term TOTs and FFS), by the end of this exercise all small groups will have conducted experiments on all factors, but to begin with each small group will be responsible for designing experiments for only one factor. The small group then becomes the “consultant” for that particular set of experiments and is responsible for helping the other small groups. The subsequent experiments in this section are suggestions for such experiments. Participants should be encouraged to first come up with their own experiments, then the experiments in the following sections can be added to bolster the overall experimental designs.

The one requirement for all groups is that they conduct a comparative test on three different types of soil:

- a. sandy poor soil, from an area known to be of very bad soil quality, such as the margin of a road or construction site,
- b. soil from a typical rice field or garden plot from the area,
- c. soil from an area known to be very high in organic matter, such as a compost pile or an area where organic matter (dung, household refuse) is thrown

The end result will be a set of experiments that will enable farmers to evaluate the quality and condition of their soils. These tests should provide farmers with a good set of tools for soil evaluation, but more importantly, they will provide the farmer with a clearer understanding of the important physical and certain biological characteristics and mechanisms underlying soil fertility.

Note: soil **fertility** relates to the ability of the soil to provide the required conditions for optimal growth, assuming plant variety, climate and water conditions are favorable. **Productivity** is the “total package” of fertility, plant, climate and water management. For example, many soils in desert regions are highly fertile, but the absence of water makes for very low productivity.

Goal

To develop an understanding of the principal factors related to soil fertility, and to develop a set of experimental tools to enable farmers to evaluate their own soils.

Time required

One half day

Materials

Paper
Pens
Tape

Steps

1. The facilitator refers to the summary diagram on factors of importance in soil systems. Make a list of 4 key factors (not including Organic Matter, as this will be part of every test). The list might include:
 - a. Texture and structure
 - b. Nutrients
 - c. Water-holding capacity
 - d. Microorganisms, Insects & worms
2. Each small group chooses one subject to design experiments for (either by chance or by choice)
3. Small groups design one or more experiments for their topic, laying the design out on newsprint.
4. It works out well if every group chooses three soil types to test: including a) a local field soil, b) a rich composted soil, and c) a very poor sandy (if possible) soil.

***** All groups should use the soils from the same three locations in order to be able to compare results across all experiments *****

5. Small groups present their experiments and discuss them with the other participants.
6. Small groups begin carrying out experiments (see following exercises for guidance on experiments).

EXERCISE 5. SOIL TEXTURE

Background

Soil **texture** is a rather formal academic distinction, based only on particle size distribution:

Sand is soil particles with diameters from 0.05 to 2.0 mm

Silt is soil particles with diameters from 0.002 to 0.05 mm

Clay is soil particles with diameters < 0.002 mm

Note that texture does not include organic matter. This is because it is useful to have a characterization of the inorganic components of a soil, as these do not change readily over short time periods. Organic matter content, in contrast, can change dramatically over a short time (especially in the tropics).

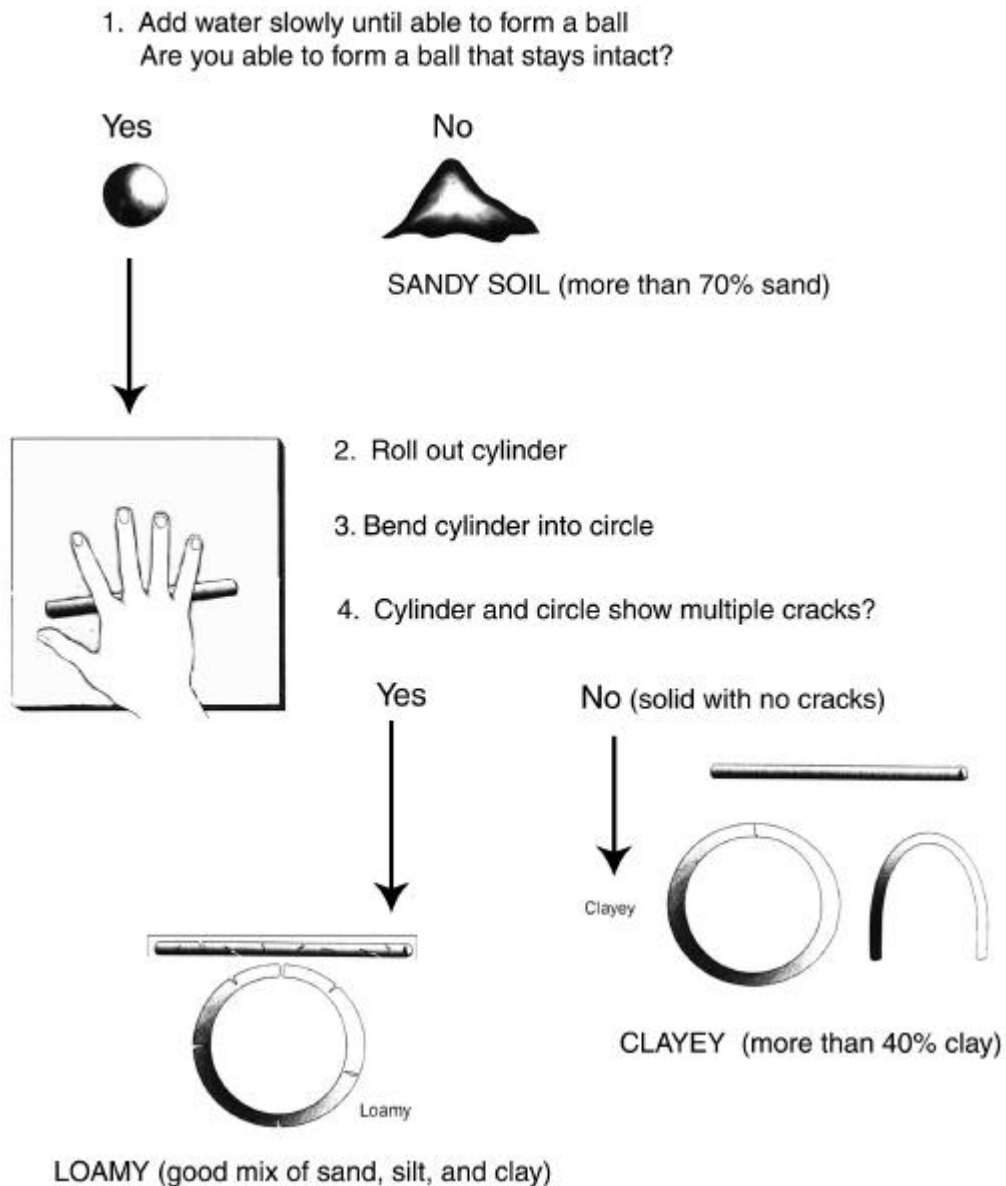
Soils may also be described as **coarse** or **fine**; a coarse-textured soil has more sand, whereas a fine-textured soil has more clay. A soil whose properties are equally influenced by sand, silt, and clay is called a **loam** or loamy soil.

The texture of a soil is directly related to many important aspects of fertility: e.g., the ability of a soil to absorb and retain water, to hold plant nutrients, and directly affects the ability of roots to develop and move through the soil. Soils with a lot of clay are said to be “heavy” soils and tend to hold a lot of water, which tends to move slowly. Soils with a lot of sand are considered “light” soils, and tend to hold very little water, unless they also contain a lot of organic matter. Water infiltration (movement) in sandy soils tends to be very rapid.

Steps

1. Hold approximately 25g (about half a fistful) of dry soil in your palm. Look at it carefully to see if it is very loose and single-grained (probably sandy), or if it has numerous hard lumps or clods that are difficult to break when dry (probably clay), or something in-between.
2. Add water drop-by-drop and knead the soil in your hand, breaking down any lumps, until the soil is plastic and moldable. Next, squeeze the soil tightly in your hand, then open your hand. If the soil fails to form a ball when you do this, but instead falls apart when released, then it is a sandy soil. (If you think you may have added too much water, add a little dry soil and try again).
3. Rub some of the soil around with the forefinger of your other hand and determine whether the feeling is one mostly of grittiness, or mostly of smoothness. There will almost always be some grittiness to the soil, but try to identify the predominate feeling.

4. If the soil forms a ball, roll the ball between your hands or on a clean flat surface to form a cylinder, then try to bend the cylinder in a circle to form a ring. Note the following characteristics:
 - a) if the soil is **SANDY** (more than 70% sand) you will not be able to form a cylinder more than 5 cm long and 1.5 cm in diameter, it will not form a ring, and it will have many cracks in it and fall apart.
 - b) if the soil is **HEAVY CLAY** (more than 40% clay), your sample will form easily into a smooth cylinder around 10 - 15 cm long and about 0.5 cm in diameter, with no cracks or fissures in the side.
 - c) if the soil is a type of **LOAM**, you will be able to form a cylinder 10-15 cm in diameter and to form a ring, but the ring will have many cracks in the outer edge.
5. If possible, check the dry form of the soil: silt, when dry, is easy to break with your fingers, and ends up being a very fine powder. Dry clay is much harder to break with your fingers.



EXERCISE 6: ATOMS AND MOLECULE

Background

In order to be able to discuss ideas related to the movement of nutrients in the plant and soil, and the role of nutrients in plant growth, it is necessary that participants have a basic intuitive feeling for how atoms are linked together to form molecules, and how molecules can be broken apart and reformed into new forms.

Goal

to develop a simple understanding of how atoms join together and split apart from other atoms to form molecules.

Materials

Paper labels about 5 cm in diameter

Pens

Time Required:

30 minute

Steps

1. Begin by holding up a silver or gold ring and ask what it is made of. Discuss whether it is pure or a mixture of different metals. Pure silver or gold are materials that comprise only **one type of atom**. Look around and ask what other types of things you see can be pure or are mixtures of different atoms.
2. Define a **MOLECULE** as a group of atoms (the same or a mixture of types) that are linked closely together. Ask for examples of molecules, if none are easily forthcoming then offer an example of H₂O. Go on to discuss and to write down a list of common molecules participants know about. This usually includes CO₂ and O₂. Explain what these are.
3. Pass out the paper circles having written the letters C, O, and H on several. Ask the participants to “make models” of these molecules by getting together into groups and linking their arms together. For example, a CO₂ molecule would be made by three participants with the C participant in the middle, linking arms with the two O participants. Do the same for H₂O.
4. Now create a sugar molecule, by having the participants link together in the following order: H – C – O – H . Explain that a real sugar molecule actually requires a total of six groups of H-C-O-H (the formula being C₆H₁₂O₆) to make the full molecule, but for our purposes H-C-O-H is simple and sufficient.

EXERCISE 7. WHAT IS SOIL PH?

Background

This is not an exercise (yet), but simply a group discussion. The concept of pH is usually not understood well, even by general technicians. This exercise/discussion takes the mystery out of pH and puts the idea into terms that are easily understandable, hopefully by farmers as well.

Previously we learned about atoms and molecules. In this exercise we will make use of this knowledge to make clear the idea of soil acidity, and its measurement—soil pH.

The “pH” of a soil refers literally to the “Potential Hydrogen” and is a measure of the soil acidity. Technically, pH refers to the amount of hydrogen ion (H⁺) present in the soil water (or any kind of liquid). The technical description of pH is not important for our purposes. The important aspect of pH from a training perspective relates to how pH affects soil chemistry and plant nutrition, how to measure it, and how to manage it.

The pH is a scale of measuring acidity that goes from 0 to 14. A low pH (0-6) is acidic, and a high pH (8-14) is “basic” (lacking H⁺). The range of 6-8 is considered roughly “neutral” pH (pH 7 is the actual neutral point).

In many areas of the tropics we have acid soils (we have seen soil pH as low as 4.0). Soil acidity does not hurt the plants directly, but rather, it affects the availability of nutrients to the plant. It also affects population growth and species diversity of soil microbes (e.g., fungi are somewhat acid tolerant whereas bacteria are not).

Goal

To understand the basic idea of soil pH

Time

45 minutes

Materials

Pens
Paper
Tape

Steps

1. begin by imagining a water molecule H—O—H. The water molecule is not a fixed or static object, but likes to break apart and come back together.

Exercises Section 1. The Soil System

Therefore, in any glass of pure water you have three things at any time: water (H-O-H), the hydrogen ion (H⁺), and the hydroxyl ion (OH⁻).

2. Draw the table below on the board. Ask the participants to imagine the contents of a glass of water. If there is a proper balance such that for every H⁺ you have one OH⁻, then the **acidity is “neutral”** and the pH would measure 7 on the scale of 14.

If your glass of water is acid, then you would have more H⁺ ions for every OH⁻ ion, and the pH would measure less than 7. If, on the other hand, your glass of water were basic, then the opposite would be true. That is, you would have a higher ratio of OH⁻ ions for every H⁺ ion.

3. Buffering Capacity. You may wish to introduce the idea of buffering capacity, which is the ability of a soil (or any solution) to “clean up” the excess H⁺ or OH⁻ ions, thus bringing the balance back to neutral. Simply put, buffering is a chemical process based on the presence of a substance that absorbs and releases H⁺ or OH⁻. These substances have a limit to their capacity to buffer, and eventually get “used up” and the pH then changes.

pH Scale					
1		7		14	
Low pH		Neutral pH		High pH	
OH ⁻	H ⁺	OH ⁻	H ⁺	OH ⁻	H ⁺
OH ⁻	H ⁺	OH ⁻	H ⁺	OH ⁻	H ⁺
OH ⁻	H ⁺	OH ⁻	H ⁺	OH ⁻	H ⁺
	H ⁺	OH ⁻	H ⁺	OH ⁻	
	H ⁺	OH ⁻	H ⁺	OH ⁻	
	H ⁺	OH ⁻	H ⁺	OH ⁻	
	H ⁺	OH ⁻	H ⁺	OH ⁻	

EXERCISE 8. PARTICLE SIZES AND FORM

Background

In the previous exercise you learned that texture is defined only by the size of the inorganic components of the soil, defined to be sand, silt, and clay.

Specifically:

Sand is soil particles with diameters from 0.05 to 2.0 mm

Silt is soil particles with diameters from 0.002 to 0.05 mm

Clay is soil particles with diameters < 0.002 mm

However, this type of measurement is unsatisfactory for farmer training as such small measures are too abstract. First, this exercise is an attempt to give some idea of **relative** size. Second, the exercise attempts to describe the important physical structural differences between sand, silt and clay. This exercise requires more input from the trainer. Try to avoid making it a dry “lecture”—ask lots of questions before providing information.

Goal

To help participants better appreciate the differences between sand, silt and clay.

Time required

60 minutes

Materials

A deck of playing cards

Newsprint

Paper

Tape

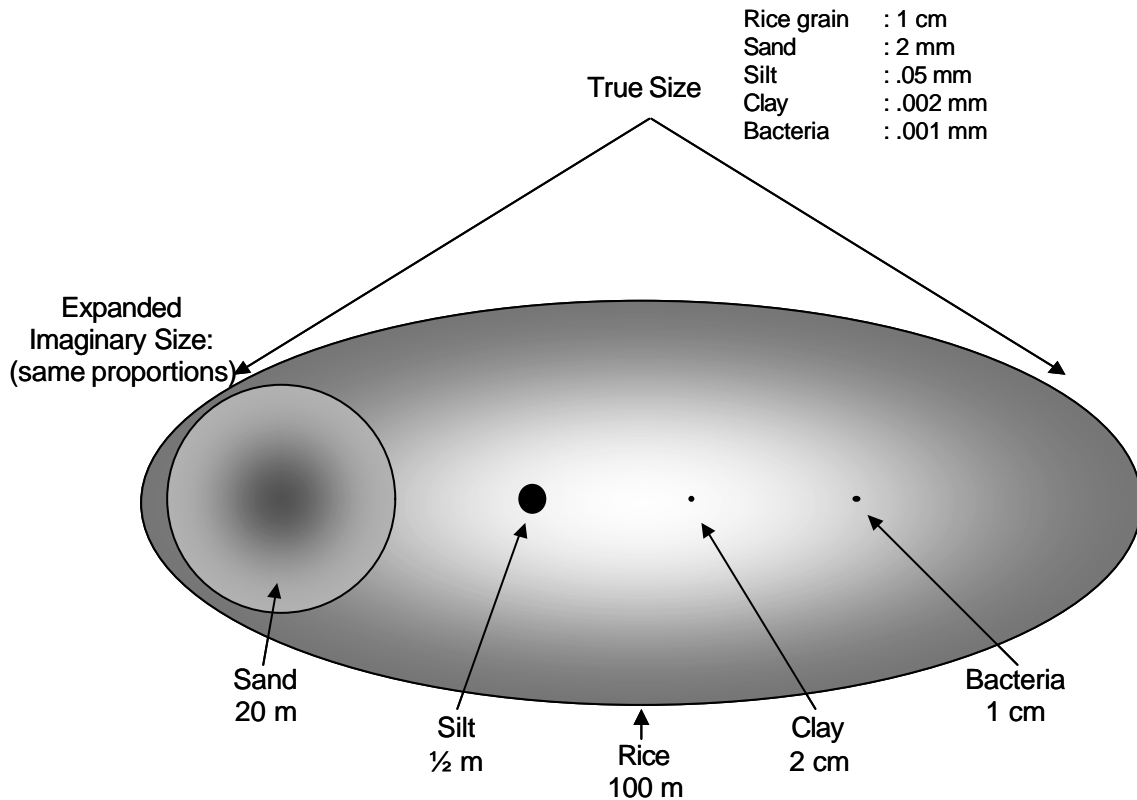
A good imagination

Steps

1. Analogy: How big?

The goal of the following analogy is to help give an appreciation of the relative sizes of important things in the soil.

- a. imagine that we have 5 things lined up side-by-side:
 - a grain of rice (1 cm)
 - a grain of sand (2 mm)
 - a particle of silt (.05 mm)
 - a particle of clay (.002 mm)
 - a bacteria (.001 mm) or 1 micron
- b. imagine that through an act of magic, that all of these 5 things were enlarged together, so that their **relative sizes stayed the same**, and such that the smallest member (bacteria at .001 mm) was now the same size of what the largest member was before (rice grain at 1 cm). The question is, how large would the other members of the group now be?



- c. The facilitator can do this as a drawing (see graphic). The answer is that if the bacteria has now grown to be 1 cm. It has been enlarged 10,000 times. That means that all the other members of the group would be enlarged by the same factor. This leaves the grain of rice being the size of a football field (100 meters), the grain of sand has a diameter of 20 meters, the particle of silt now has a diameter of ½ meter, and the particle of clay is still only twice the size of the bacterium, or 2 cm.
- d. Spend some time playing with the idea so that everyone has a chance to let the images sink in. Ask them to imagine this 1 cm bacterium resting next to a grain of rice the size of a football field.

2. Analogy: What are the structural differences between sand, silt and clay?

Although the definition of sand, silt and clay is based entirely on size, there is one other very important difference that has implications for soil health. A particle of sand is basically a roughly round ball. A particle of silt is much smaller and more flat.

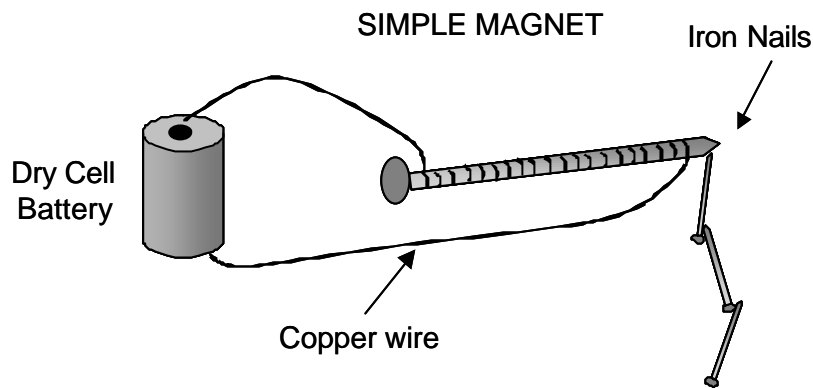
A particle of clay, on the other hand, is structurally very different than either sand or silt. A clay particle is best described as being **like a deck of cards**. Both are roughly in the shape of a block, but made up of many layers stacked on top of each other.

Another important characteristic of the clay particle is that each of these layers (individual cards) has “parking spaces” for nutrients. In reality, these “parking spaces” are negatively charged sites on the surface of the layer, as well as within the structure of the clay layer. Many of the nutrients necessary for plant growth are positively charged (called CATIONS), and therefore attracted to the negatively-charged “parking space” just like the opposite ends of a magnet are attracted to each other.

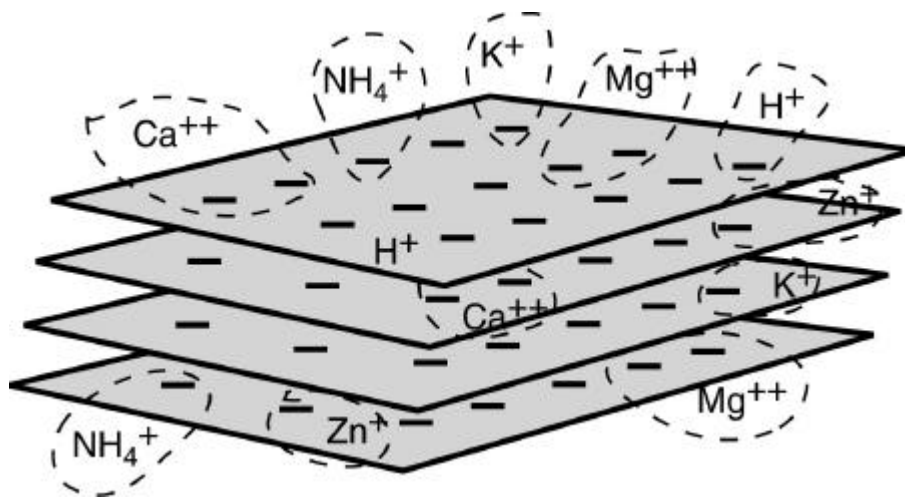
Demonstration: Magnetic attraction

If you do not have available a magnet, an iron nail wrapped with a copper wire, which is then attached to either end of a battery works well to demonstrate magnetic charge. Point out how the magnet only weakly holds the smaller nails—similarly, the clay particles only weakly attract the cations.

Exercises Section 1. The Soil System



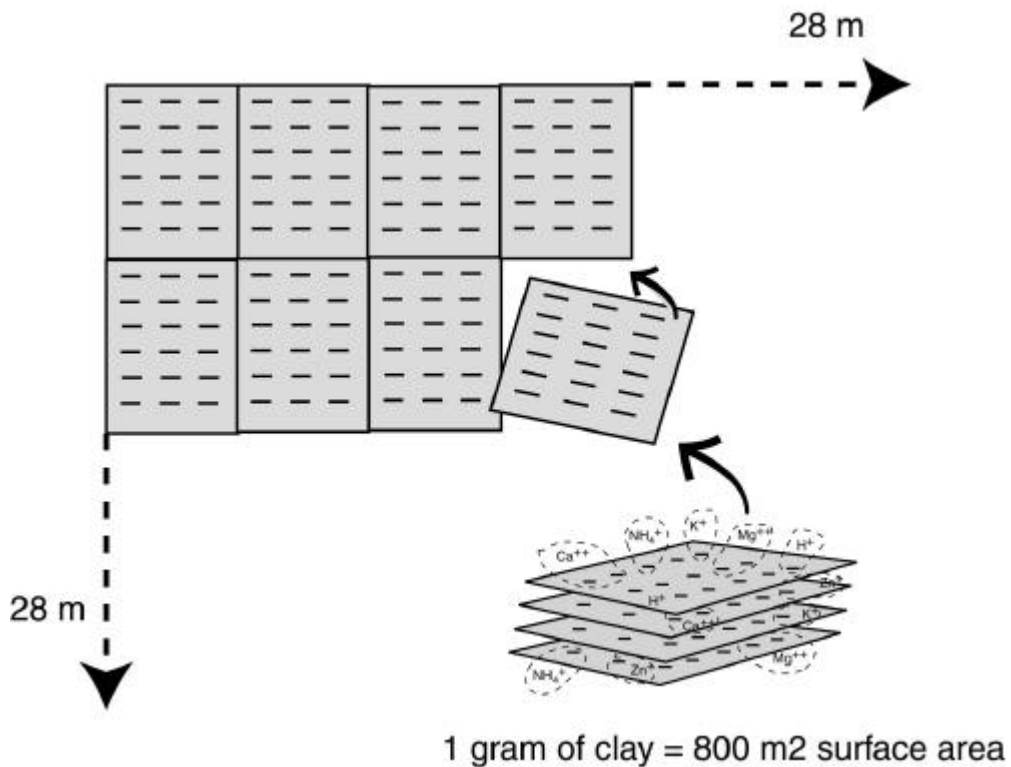
One fact that clearly illustrates the differences between sand, silt and clay is their relative differences in **surface area**. The surface area of sand and silt can be imagined (or demonstrated) by thinking of peeling an orange and laying the peel flat on the table. The surface area is the number of square centimeters of the flattened peel. A possibly confusing fact is the idea that as particle sizes get smaller, the surface-to-volume ratios of objects get larger (more surface area relative to their volume). Also, there are many more particles per gram as size gets smaller. Therefore, one gram of silt has a greater surface area than one gram of sand, and one gram of clay has an extraordinary surface area in contrast to both silt and sand.



Demonstration: Surface area of clay.

Take the deck of cards and lay them side-by-side, forming a large square. Compare the surface area with the size (volume) of the original deck.

Now imagine you had one gram of clay, and were able, somehow, to peel the layers off the clay particles and to lay them side-by-side, just like you did with the deck of cards, what would the surface area be for this one gram? The answer is an amazing 800 square meters! The goal of this mental exercise is to have the participants put together these three ideas (shape, surface area, and “parking places” for nutrients) in order to recognize the tremendous ability clay soils have for storing nutrients of importance for plant growth.



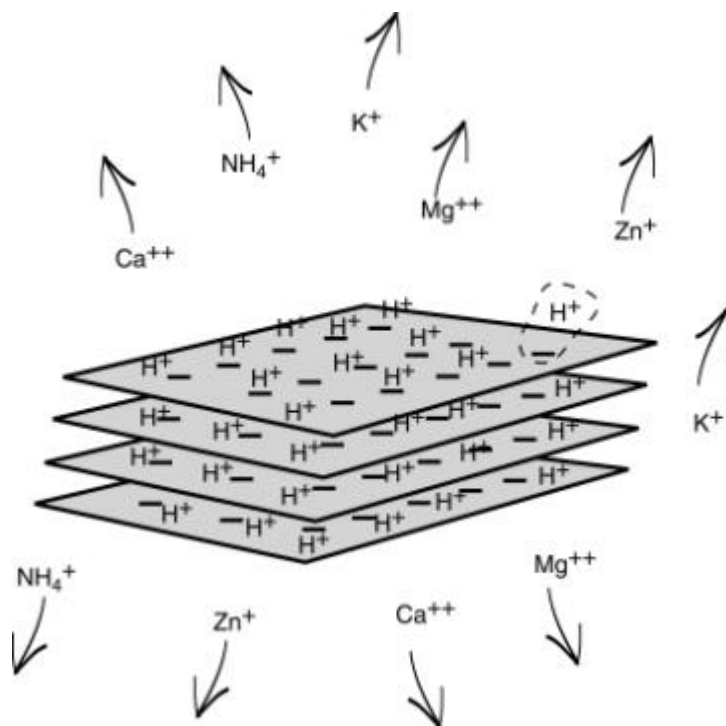
Particle	Diameter (mm)	Number of Particles (no. per gram)	Surface Area (cm² per gram)
Very coarse sand	2.00 to 1.00	90	11
Coarse sand	1.00 to 0.50	720	23
Medium sand	0.50 to 0.25	5,700	45
Fine sand	0.25 to 0.10	46,000	91
Very fine sand	0.10 to 0.05	722,000	227
Silt	0.05 to 0.002	5,776,000	454
Clay	less than 0.002	90,000,000,000	8,000,000

** For simplicity, calculations assumed particles to be spherical and at the large end of the size range.

Exercises Section 1. The Soil System

The problem with an acid soil is the following: you will recall our analogy above for the clay particle. Clay particles store nutrients because they have many negatively charged “parking places” to which the positively charged nutrients can be “parked” (e.g., Mg^{++} , Zn^{+} , NH_4^{+} , Ca^{+} , etc.). If, however, the soil water is highly acidic (too much H^{+}), then the H^{+} ends up filling up many of the “parking spaces” and the nutrients that would normally be stored on the surface of the clay particles are lost (washed away to a lower level in the soil profile).

This representation is a highly simplified view of the dynamics of clay particles. In reality, there are several different types of clay, each with somewhat differing characteristics. Also, not all “parking spaces” exist on the surface of the clay particles—some are “buried” within the internal structure of the clay molecules. These sites of negative charge are not affected by pH, therefore, even under extreme pH conditions, clay particles retain some ability to hold nutrients.



Additional problems with soil pH

With increasing levels of acidity, the soil microbial populations suffer and species are lost from the system (decreasing diversity). This can have important negative consequences for the ability of the soil to process organic matter (mineralization). Fungi are more acid tolerant than are bacteria and therefore fungi tend to dominate the soils of many types of forest floors (some of which tend to be acidic due to the composition of certain types of leaves and needles).

EXERCISE 9. SOIL STRUCTURE

Background

Whereas texture is the composition or relative proportion of three soil particle types (sand, silt, clay), soil **Structure** is the arrangement or the geometry of these soil particles. A good structure provides a wide range of **pore spaces**, defined to be the empty spaces between particles. Pore spaces may be the result of structure, or, in the absence of structure (for example, in a rice soil after having been puddled), result simply from the texture. A “good” dryland soil has between 40% to 60% of the total soil volume as pore space—much of this (but not all) is due to good structure. At a minimum (a highly compacted fine sand) pore space may be as little as 25% of total soil volume.

Unlike texture, which does not change much over seasonal time, soil structure is affected by farmer management practices.

Analogy: a particular building is made of bricks. The “texture” of the building would be the proportion of cement, sand and brick (clay, silt and sand) that comprises the whole building. The “structure” of the building would be the arrangement of these bricks to form large rooms, small rooms, hallways, closets, etc. If an earthquake should cause the building to collapse into a pile of bricks, the “texture” would remain the same, but the “structure” would have been radically altered.

To follow on our analogy, just as before the earthquake the “structure” of the building provided much better living conditions than after (big and small rooms in which to move and live), similarly, a soil that has a good structure has many large and small pore spaces through which air, water, roots and living organisms can move freely.

Improving soil structure

Structure can be improved through the action of worms and microbes, who produce sticky substances that “glue” soil particles together in “**aggregates**”. Worms and insects also create channels or tunnels by the action of their movement through the soil. Plants can improve the structure of a soil by the action of their roots growing down into the soil. Finally, farmers can improve soil structure by addition of compost. Compost improves structure in several ways:

1. it decays and leaves behind large pore spaces,
2. it provides food for worms and insects whose movements and feeding behavior leave pore spaces and “cement” together particles into aggregates, and
3. it provides food for microbes, whose activities also cement together individual particles into larger aggregates.

Destroying soil structure

Soil structure can be destroyed in many ways. Many rice farmers complain about their soils become compacted after using synthetic

Exercises Section 1. The Soil System

fertilizers and especially granular insecticides. The latter kill the many worms and larvae of certain beneficial insects that live in the top few centimeters of soil. Not putting back organic matter is another way in which soil structure becomes increasingly poor over time. With mechanized agriculture, soil structure is destroyed by the weight of equipment moving over the soil surface (in vegetable gardens farmers know not to walk on the planting beds!).

Time required

45 minutes

Materials

Pens

Newsprint

Tape

Bricks or blocks of various sizes

Steps

1. As a group exercise, construct a structure with various sized bricks at all manner of odd angles to maximize "pore space". Talk about how such pore spaces might be constructed in the soil (worms, roots, decaying organic matter, etc.). Then reconstruct the materials so as to minimize the pore space. Discuss how there still exists some pore spaces that are the "natural" outcome of differences in the shapes of the "particles".
2. In small groups, ask the participants to do a drawing of an "ideal soil", including sand, silt, clay, bacteria, fungi, organic matter, air spaces, water, roots, etc.
3. Report back to the large group and discuss

EXERCISE 10. SOIL COMPOSITION

Background

We define **soil composition** to be the inorganic components (sand, silt and clay), plus the organic component. For our purposes here, we simply wish to compare (and contrast) the three soil samples to see what differences texture exist from the layering of sand, silt and clay, what evidence exists (if any) for the presence of organic matter, and what differences in pore size and density might be inferred from the observed differences in total volume.

By placing a soil sample in a bottle with water and shaking, we effectively destroy its structure (except for particles that are strongly “glued” together by the actions of some kinds of soil microbes and worms).

A “good” soil, according to soil scientists, has around 4% to 5% SOM. Unfortunately, this small amount of SOM is difficult to measure accurately without some relatively involved methods. The records of farmer practice on a particular soil will tell us the most about the likelihood of having sufficient SOM. For this, we will take advantage of the fact that SOM floats on the water surface while the inorganic parts of soil will sink.

Goal

To observe the relative amounts of coarse and fine particles in a soil, and whether the soil shows evidence of having any soil organic matter.

Time required

60 minutes

Materials

plastic water bottles 1 or 1.5 liter size

3 buckets

pens

newsprint

Exercises Section 1. The Soil System

Steps

1. Take three buckets and gather samples of soil from three separate locations (sandy poor soil, field soil, rich soil having been composted).
2. Dry the soil overnight under a fan, or for several hours spread out under the sun (same procedure for water-holding capacity)
3. Weigh out 500 gm of each soil type
4. Add soil from each location to a separate plastic bottle
5. Add water to each bottle to fill and close tightly with top.
6. Shake until all the soil has been loosened up in the solution, then set aside. Let the contents settle out (this will take several hours, so do another exercise or activity in the meantime).
7. Observe the bottles and note the differences. Pay close attention to differences in the layers of soil. The larger, heavier materials will fall down first, followed by the intermediate and then the finest particles. Very fine clay particles may stay suspended in the water for a very long time (due to the negative charges on the surface of the clay particles causing them to repel each other). Observe the surface of the water for any materials to be found floating (organic matter).
8. Observe the differences in volume of the three soils
9. Do a drawing of your findings and report back to the large group.

QUESTIONS

1. Why do some solutions become clear while others remain cloudy after several hours?
2. Explain the differences in volume between the three soils—as they were all three the same weight, what does this imply about pore space and the weight of the particles?
3. Place these bottles along side the result of your water-holding capacity results and discuss what the relationship might be between these results and those of the water-holding capacity exercise.

EXERCISE 11. PRODUCTIVITY: TESTING SOILS WITH INDICATOR PLANTS

Background

With the set of exercises presented here, farmers should be able to qualitatively assess a fair number of different factors related to their soils (texture, soil organic matter, water holding capacity, biological activity, compaction and drainage, etc.). This exercise, therefore, is key to tying all the various tests together with an experiment to see how well plants grow. Throughout these exercises we will be contrasting soil characteristics from three very different soil types. The degree to which this is possible will of course depend on the soils found in your area. Hopefully, however, you will be able to find three highly distinct soil types:

- a. poor sandy soils (possibly from near a road margin)
- b. field soil typical for your area (rice or vegetable field or both)
- c. a soil rich in organic matter, having had compost applied

This activity involves planting an “indicator” plant in small pots of soil from each of the three soil types. The goal is to use a growing plant to differentiate the soil quality from the three sites. Therefore ***the ideal test plant should be sensitive to differences in soil quality*** (for example, you would not want to use a weedy plant as an indicator, as weeds are often capable of growing well in very bad soils).

What plant you use will depend on what cropping system you are studying. Some of the plants used in the past include rice seedlings, tomato seedlings, and bean seedlings. Be sure to use transplanted seedlings, and not planted seeds, as seeds carry with them an initial store of nutrients.

Goal

To examine the growth characteristics of a sensitive “indicator plant” on our three soil types.

Time required

Initial set up: 90 minutes

Follow up: observations daily

Exercises Section 1. The Soil System

Materials

3 buckets
12 small pots
seedlings from tomato, bean, rice or some other plant
newsprint
pens

Steps

1. Fill each of three buckets from soils from three different locations (poor sandy or pure sand, field soil, rich composted soil). If you use sand from a construction or building site, be sure and wash it to remove possible chemical toxins.
2. For each soil type, plant 3 or 4 seedlings per pot of your indicator plant. Plant 4 pot replicates for each soil type for a total of 12 pots. Do not add any type of soil amendment.
3. Place the pots in a safe place with good light and be sure to water each day, or when needed.
4. Make observations daily on plant height, color, number of shoots (if appropriate), etc. Record this in a notebook.
5. After two weeks take several plants out of their pots and observe the rooting structures: number, color, size.
6. Create a report on your findings on newsprint and report back to the large group.
7. You may wish to try several different plants to see which ones are the best indicator of soil health.

Questions

1. Which plant species were the best indicators of soil health?
2. What were the characteristics of plant growth most affected by differences in soil type?
3. How do these results relate to your findings from the other experiments on these same soils?

EXERCISE 12. SOIL COMPACTION

Background

In a good loam soil roughly 50% of the soil is comprised of airspace. Compacted soils are those in which the air spaces between the grains of soil ("pores") are too few and too small. This impedes the movement of water, nutrients and air and allows for the buildup of toxins resulting from the breakdown of organic matter under oxygen-poor conditions.

Consider the root system of a plant, and the volume of soil in which this root system lives:

--what percentage of soil in this volume is in direct contact with the root system?

Not surprisingly, the answer will depend on the type of plant, but the "textbook" answer is **only about 1% !** This fact shows why drainage and compaction are such important characteristics, because ***the soil must be able to bring the nutrients to the roots.***

Compacted soils result in smaller and fewer roots. The uptake of certain of the less mobile nutrients, like phosphate (P) are dependent on the plant roots being able to grow and to find pockets of the nutrient. This ability is limited in compacted soils, so plants in a compacted soil may show mineral nutrient deficiency even though the soil actually has the nutrient present.

As with many problems in soil management, Organic matter is the best (or only) solution. Organic matter helps to form soil aggregates, or small clumps of soil that stay together even when the soil is wet. In the absence of aggregates, soil particles pack too closely together, so that air and water no longer move freely through the soil. Plants growing in compacted soil are also more vulnerable to drought and flooding.

Materials

Metal rod: 1.5 m long; 8 mm diameter

Pens, newsprint, tape

Steps

Soil Gauge Analysis

An easy way to test for soil compaction is to push a metal rod, about 8 mm diameter and 1.5 m long, into the soil when it is moderately moist.

1. Break into small groups, with each group having their own metal testing rod. Each group seeks several different areas: poor sandy or hard-packed soil (e.g., near a road), field soils, and good soils rich in organic matter.

Exercises Section 1. The Soil System

2. Push the rod down until the pressure makes it bend.
3. Measure how many centimeters the rod was able to penetrate the soil.
4. Make note on other characteristics of the soil: location, past history, types of vegetation, quality of vegetation growth, etc.
5. Small groups present findings back to the large group.

Soil Erosion

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

EXERCISE 13. SOIL WATER-HOLDING CAPACITY

Background

A clearly important characteristic of a soil is its ability to hold water. One problem with a coarse sandy soil is that water (and nutrients) are rapidly lost from the soil. One of the important qualities of Soil Organic Matter is that it helps to retain water. To demonstrate this to farmers is a simple exercise that should help promote the use of compost and mulch for vegetable and soybean farmers.

Soil pores play a major role in water and air movement. Also, soil microorganisms reside in pores. Coarse-textured (sandy) soils have less total pore space (higher “bulk density”) than do fine-textured (clay) soils (35% to 50% for sandy versus 40% to 60% for clay). The size of the pores, however, is just as important as the total quantity of pore space. Two classes of pore sizes are recognized: **macropores** and **micropores**. The minimum diameter of a macropore is considered to be between 30 and 100 microns (recall 1 micron is 10^{-6} mm or the size of a bacteria). Pores smaller than this are considered micropores.

Macropores characteristically allow the rapid movement of soil gases and soil water. Sandy soils have less total pore space, but those spaces are mostly macropores; thus, sandy soils usually drain rapidly. In contrast, clayey soils have more total pore space, but these spaces are mostly micropores and drain more slowly. Thus, sandy soils have a relatively low water-holding capacity and clayey soils relatively high water-holding capacity.

When a soil is saturated with water and the water is allowed to drain freely, the water drains only from the soil macropores. This is “gravitational water” and is of little use to plants because it reduces soil aeration. When the macropores have drained, now the soil is at “**field capacity**”. Most soil micropores are still full of water, which is available for plant growth. When a plant uses all of this water and the micropores are empty, almost all water remaining in the soil is **hygroscopic water**, that is, water that is bound too tightly to the soil solids for plants to use. At this point, plants permanently wilt and do not recover, even when water is added. This is the **permanent wilting point**.

Goal

to learn how to measure the differences the capacity of different soils to retain moisture.

Time required

60 minutes

Exercises Section 1. The Soil System

Materials

For each small group:

3 plastic 1 L water bottles
3 pieces of cheese cloth or loose-weave organdy (8 cm x 8 cm)
3 rubber bands
twine
sharp knife
colored permanent marking pen
3 clear plastic cups or glasses
balance scale

Steps

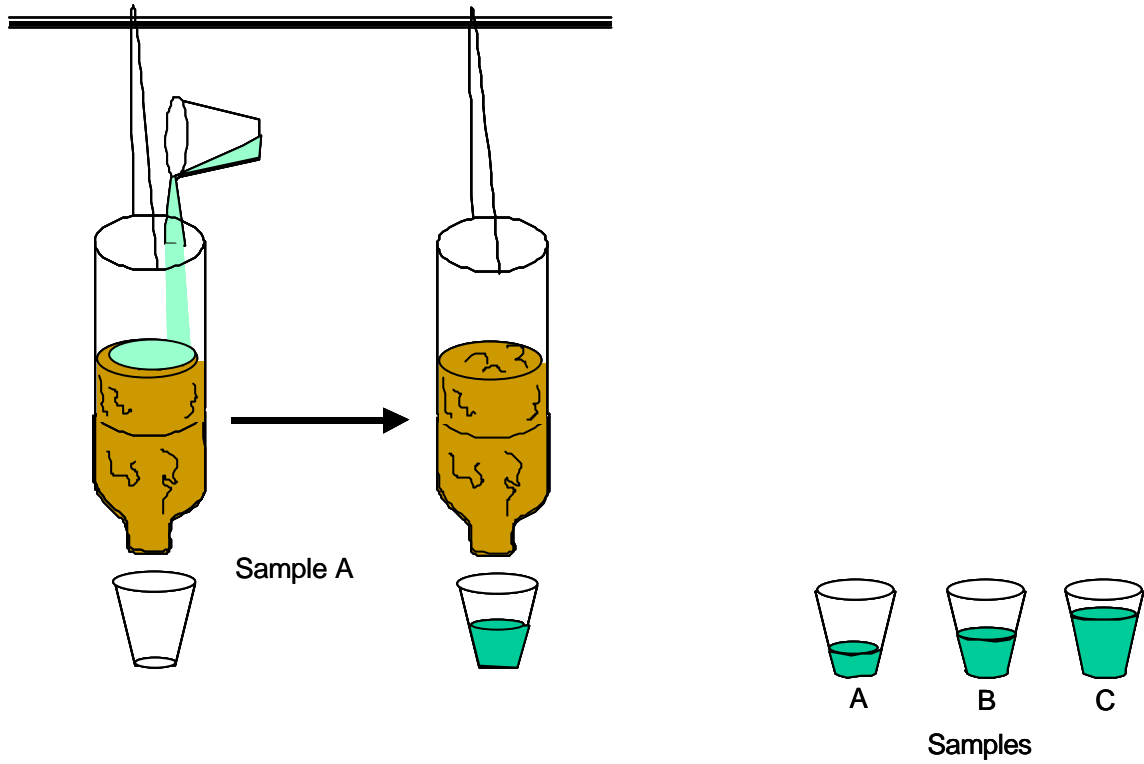
1. Take a quantity of soil and spread it out on a plastic sheet in the sun to let it air dry for a day or two. Choose soils from three locations: a) poor and sandy soil, b) local farm soil c) compost or soil rich in organic matter.
2. Dry the soil overnight under a fan, or for several hours spread out under the sun (same procedure for water-holding capacity)
3. Cut the bottom off each of the plastic water bottles. Turn bottles upside-down and put the loose-weave square of cloth into the neck area of the bottle from the inside, or tie the cloth over the top of the bottle with a rubber band or twine.
4. weigh out a fixed amount of soil for each bottle (somewhere between 300 to 600 gm) of each type of soil and place it in the inverted bottles
5. Suspend inverted bottle above plastic cups (hanging by twine from pole).
6. Take a plastic cup and fill it full of water; then add it to the soil in each bottle. Do some other activity and return when water has passed completely through all samples. If one of the bottles has absorbed all the water, but none has passed through into the cup, you will need to add water, the same **to each of all three samples** (in order to be able to compare the results at the end).
7. After all samples have drained completely, line up the cups side-by-side and compare the results.

Questions

1. Which of the soils holds the most water?
2. Are there any differences in the color of the water? What does this indicate?
3. What factors do you think are responsible for holding more or less water?
4. Why is water-holding capacity important?
5. Is there a relationship between water-holding capacity and structure?

6. How can you best improve the water-holding capacity of your soil?

Water Holding Capacity



EXERCISE 14. WATER INFILTRATION RATES (DRAINAGE) AND SOIL PROFILE

Background

The water infiltration rate indirectly measure the quantity of large pores (macropores) in the soil. Large pores allow the easy movement of air and water. Infiltration rate is affected by soil texture, structure, compaction and the amount of Soil Organic Matter.

Good drainage is important for a number of reasons:

1. it allows water and nutrients to flow quickly and consistently to all the roots,
2. in dryland soils, it prevents erosion (the faster the water enters into the soil, the less erosion there is),
3. in flooded paddy soils, it improves the oxygen content of the soil and prevents excessive build-up of CO₂,
4. in flooded paddy soils it prevents build-up of toxins that might develop from anaerobic breakdown of organic matter.
5. soils that suffer from poor drainage may endure periodic anaerobic conditions, which will kill many types of microbes. Such soils will lack the microbial populations necessary to effectively process soil organic matter.
6. in anaerobic soils poor drainage inhibits root growth, and water uptake is actually reduced (due to lower permeability of the roots to water). There can be an accumulation of toxic by-products of anaerobic metabolism (fermentation).

Soil Profile

This exercise measures the characteristics of a location, not just of a sample taken off the topsoil of a location. For this reason it is important (and convenient) to examine the soil profile (both top soil and subsoil) at the same sites at which you do the drainage experiments.

Soil scientists have complex classification systems for the many soil types found in the field. The very simplest description is to measure the depth and characteristics of the top soil, but also to note the characteristics of the subsoil. Don't think that because you see a certain type of topsoil that you can know what the subsoil is—all manner of combinations are possible.

Goal

To be able to measure the rate of water infiltration and in order to compare drainage characteristics at different sites. In addition, to examine the soil profile and relate this information to the drainage characteristics.

Time required

90 minutes

Materials

30 to 35 cm length of 20 cm diameter PVC drainage pipes

(or, if not available, cut the bottom off a plastic bucket)

40 cm plastic measuring ruler

large clip capable of attaching ruler to side of pipe or buckets

Permanent marking pen

Paper and pens for reports

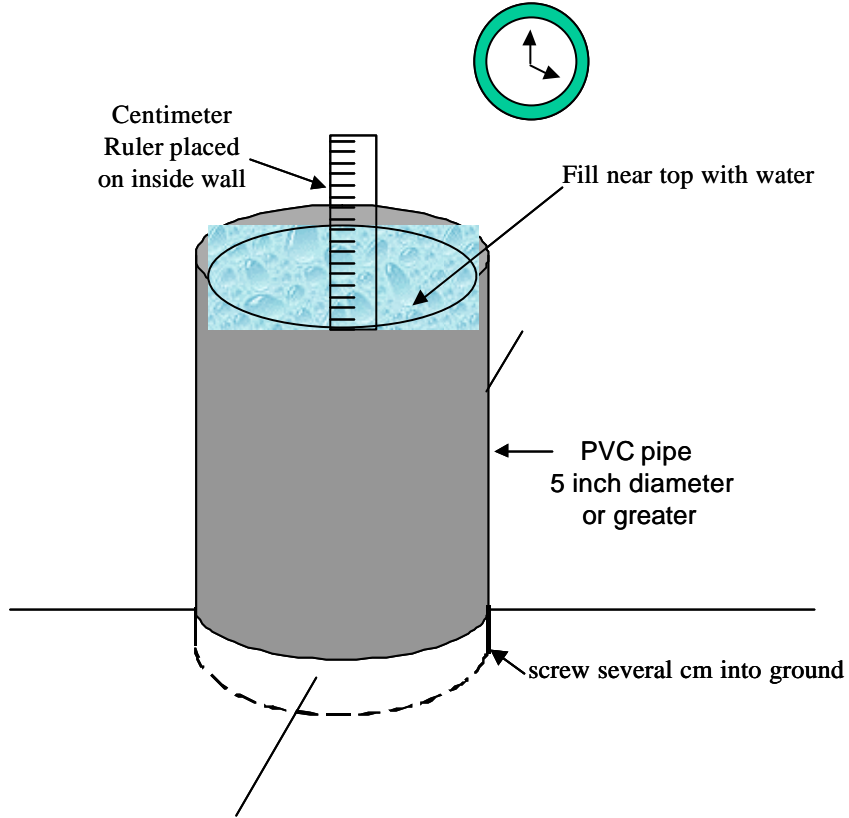
Hoe for digging soil profile

Steps

1. Prepare the materials:
2. Visit the three locations from where you took the soil samples
3. Dig the pipe into the ground (using a screwing motion) a few centimeters.
4. Fill the cylinder with water to a level a few centimeters below the top. Note the mark at which the water level starts and record the water level, in centimeters, after each minute for 10 minutes. (a simpler method could be used with farmers by just recording the beginning and end points, that is at time zero and after ten minutes).
5. Next to the drainage experiment site dig a hole 20 – 30 cm and examine the topsoil and the subsoil (if exists). Make a rapid assessment of the subsoil characteristics (density, color, texture, other) (you will already have made an assessment of the topsoil characteristics). Measure the depth of the topsoil.
6. Return to the classroom and prepare a presentation by the three small groups for each of their locations.

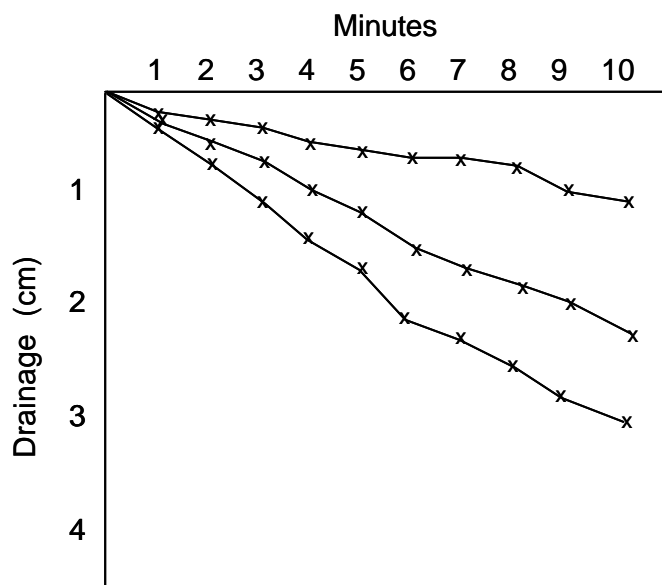
Exercises Section 1. The Soil System

Measure cm drop in water every minute for 10 minutes

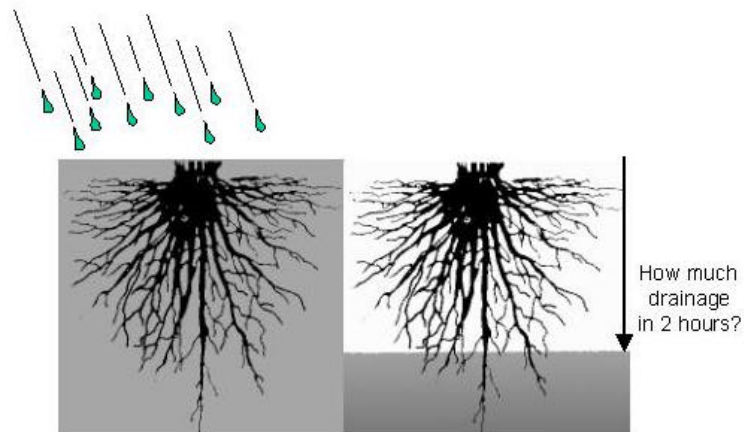


7. Presentations:

a. **Graphics:** here is one suggestion for graphing the results.



- b. **What if the soil is already wet?** If it has been raining and the soils are saturated, this poses no problem. In fact this is perhaps the most interesting conditions under which to do the draining experiment. Consider the following line of thinking:
- i. It takes about 2 hours in a submerged condition for soils to become anaerobic (too little oxygen to support aerobic organisms).
 - ii. Most living organisms, and many plant roots, are found in the top 20 cm of the soil.
 - iii. Therefore, it is of interest to know how much drainage will have occurred in two hours time. In order to calculate this, first calculate the average drainage rate per minute (cumulative total divided by total time); then multiply by 120 (2 hours x 60 minutes). If the answer is at least near 20 cm, the soil should have no problems with water logged conditions. An answer of less than 10 cm would alert you to possible problems with vegetable production in high rainfall areas.



EXERCISE 15. DEMONSTRATING SOIL MICROORGANISMS

Background

We have all seen moldy bread, and most farmers have seen bacterial diseases of plants, whether they recognize it as bacterial or not. This exercise introduces the technique of simple sterile media used to grow both fungal and bacterial cultures. This might seem like an elaborate way of demonstrating microbes, but by developing this technique, farmers and trainers will be in a position to multiply beneficial fungi (e.g., *Trichoderma*) at the farmer level. This is being done by IPM farmers in Indonesia with good success.

Goal

to demonstrate the existence of microorganisms in soil, to develop participant skills to be able to create sterile media at the farmer level.

Time required

Initial: 90 minutes

Follow up: 5 – 7 days later

Materials

Four poly-propylene bags (roughly 10-15 cm square) that strong enough they can be steamed in a rice cooker without breaking

One large rice-cook cooker (steamer)

About 500 gm of cooked rice

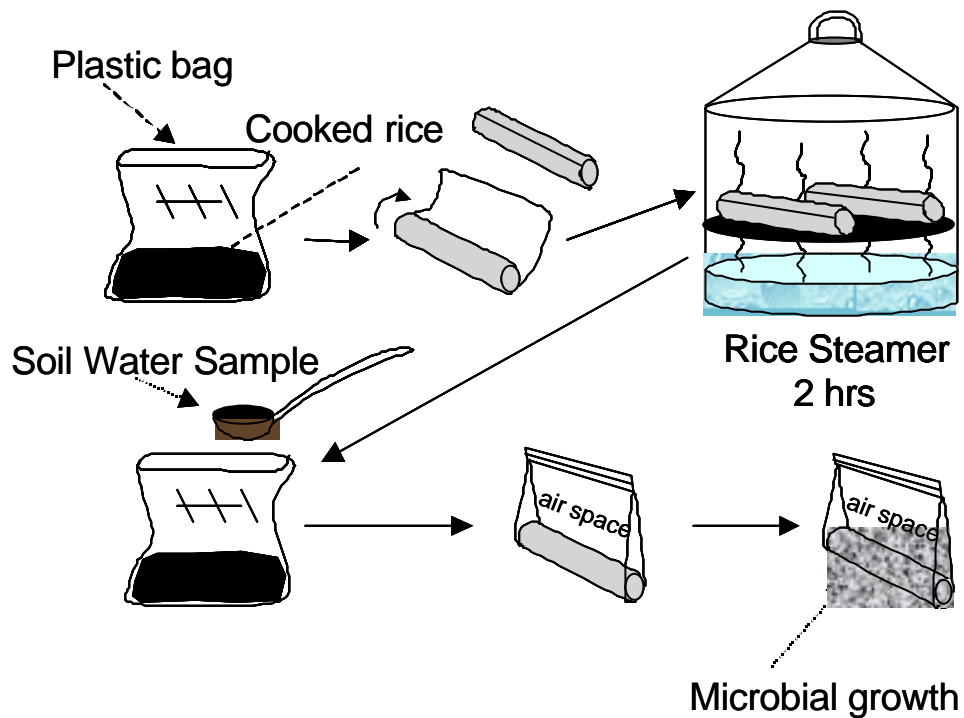
Steps

1. Add 75 – 100 gm of cooked rice to each polypropylene bag, roll the bag shut.
2. Put the rice-filled bags into the rice steamer and steam for 1 hour. As long as these bags remain sealed, they should remain sterile and nothing should grow on the cooked rice.
3. In three separate cups, add a spoonful of soil from the three different soil locations, add cooled boiled water, stir and set aside to let the soil settle out.
4. Open one bag and add a tablespoon full of soil water from one sample area. Seal the bag up again quickly to avoid contamination. You might try sealing the bags shut this time by melting the plastic with a flame, or try simply tying the bags tightly shut. Do the same for each of the other two samples. ** when sealing up the bags this time, create an tent-like open space in order to provide some oxygen (fungi are aerobic organisms, as are many bacteria).

5. For the control (4th bag) do the same procedure of opening and sealing the bag with air space included. This will test to see if the procedure introduces contamination independently of the soil water.
6. The bags should be left sitting in a dark spot at room temperature for several days, or until you see obvious microbial growth.
7. Note: A slimy or soupy layer of many colors indicates bacterial growth, whereas a fungus appears to produce “dry” “mycelia” which looks like a layer of fine cotton fibers.

Questions

1. What type of microbes develop on the sterile rice?
2. Are there differences in the speed of development or the type of microbes you can observe among the three soils?
3. What relationship do microbes have to organic matter?
4. What other types of tests can you think of using this sterile-rice method?



EXERCISE 16. ORGANIC MATERIAL DECOMPOSITION

Background

Some soils are more biologically active than others in breaking down Soil Organic Matter. Those soils which already have SOM present, are most likely to have the richest and most abundant group of microorganisms. Poor soils, on the other hand, are “poor” in part because they are lacking in Soil Microorganisms which are capable of breaking down SOM.

Goal

The purpose of this exercise is to help farmers understand that soils rich in organic matter are capable of breaking down plant residues more quickly than “poor” soils.

Time required

Initial set up: 2 hours

Follow up: briefly each week for 6 weeks

Materials Required

Old mosquito net or large-mesh organdy cloth, 3 sections of about 40x40 cm

string

newsprint and pens

Steps

1. Measure out roughly equal amounts of rice straw or leaves from your vegetable crop plant. Wash the straw or plant material with clean water.
2. Cut sections of about 40x40 cm from old mosquito netting or large-weave organdy cloth. This material should be of a large mesh size in order to allow small organisms to pass through them easily.
3. Add the straw to each piece of material and tie up the bundle with string. Bury the bags, one each in each of the three different soil types.
4. After two weeks dig up the bags, open them and examine their contents for fungal decay. Rebury them and examine them weekly.
5. As an alternative, you may wish to place the bundles in large pots filled with the soil from the three locations.

Questions

1. Are there any obvious differences between the bags for the different soil types? Which soil type caused the greatest amount of the materials to be decomposed? Which on the least? Why?
2. How would you describe what has happened to the materials in the bags? Are there things that you could characterize as being associated with attack by fungus? by bacteria?
3. Why is breakdown of Soil Organic Matter important for the soil and crop plants? Whose "job" is it to do the initial breakdown of organic matter?
4. Is the decomposition in the samples from your field soils more like that from the sand or the compost?

EXERCISE 17. WHAT IS SOIL? – WRAP-UP

Background

From a training perspective it is important to have an activity that ties together several related exercises and provides “closure” to the section. In this activity the participants are asked to draw together the results of all the experiments they have done on the three soil types, in order to come to some conclusions.

Goal

To summarize results and ideas about the three test soils (and locations)

Time required

60 minutes

Materials

Pens
Paper
Tape

Steps

1. Ask participants to break into three groups such that representatives from each of the experiment groups are included in **each** of the three new groups.
2. Each group is to summarize their findings for all the three soil types . Compare and contrast the soils using the results from the experiments to justify a final determination regarding productivity. What are your recommendations for improving the productivity of these soils?
3. Small groups report back and have a general discussion on the value of these experiments at the farmer level.

EXERCISE 18. WHAT IS THE IDEAL SOIL?

Background

This is a quick and easy exercise aimed at synthesizing the participants knowledge up to this point. Participants may still not be clear on just what constitutes a good soil, or what can be done if you have a poor soil. Here we begin to talk more about the role of organic matter as a management tool. In a short-course training this exercise can be done just before the section on management.

Goal

To synthesize participants' existing knowledge and to introduce several new ideas regarding the positive and negative qualities of soil components, and to introduce the section on soil management.

Time required

45 minutes

Materials

Pens

Newsprint

Tape

Steps

1. Draw a large matrix with 4 empty boxes, labeled as in the example below.
2. Ask the participants: 'is sand in your soil good or bad?' ; 'is clay in your soil good or bad?' . Participants may not be aware that clay is good for holding nutrients. This will be explained in detail in a later exercise.

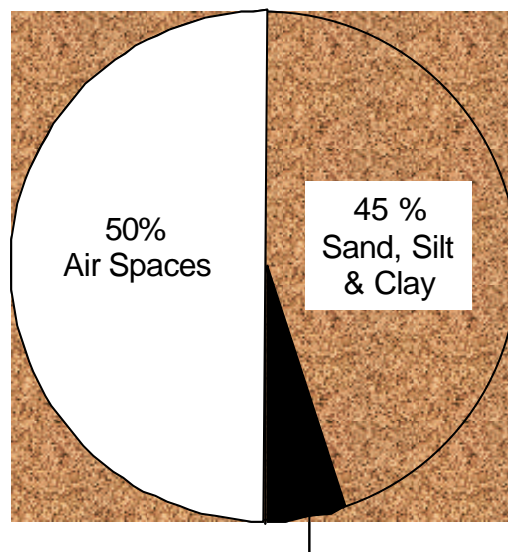
	Positive	Negative
Sand	Good Movement: water, nutrients, roots	Poor Storage: water, nutrients
Clay	Good Storage: water, nutrients	Poor Movement: water, nutrients, roots

Exercises Section 1. The Soil System

3. Ask the participants: 'based on what we have just discussed, what would be an ideal soil?'

Do not be surprised if the answer is "silt". Participants sometimes leap to this seemingly logical conclusion because sand and clay clearly have positive and negative characteristics that are opposite each other. Therefore, participants often think that silt should be the best solution as it might be thought to be somewhere in between sand and clay.

In fact, the best soil would have a roughly equal mixture of sand, silt and clay, and is called a **loam**, or loamy soil. A loam offers a mixture which includes the benefits of having some sand (water, roots, air, and nutrients can move freely). These benefits counteract the negatives of having too much clay. A loam also has some amount of clay, imparting the benefits of good nutrient and water-holding capacity (and thereby counteracting the negatives of sand).



4. Ask participants: ‘ What is the best management solution if you have too much sand or too much clay in your soil?’

Clearly, for any sizable plot of land larger than a small vegetable garden, it is not feasible to bring in quantities of sand or clay. The only real solution—the same for both problems—is to put sufficient quantities of Soil Organic Matter (SOM) back into the soil.

SOM in a sandy soil acts like a sponge to hold water. It also acts both as a source of plant nutrients, and, as a site for storage of nutrients (both in the SOM and in the bacteria that live on the SOM).

SOM properly incorporated into a clayey soil will improve the structure of the soil by providing pathways for the flow of water and the movement of roots, oxygen and nutrients. However, for a very heavy clay soil in an irrigated rice system, you must be careful because the breakdown of SOM under anaerobic (oxygen-poor) conditions can lead to the production of acids and alcohols that can be toxic for rice roots.

	Positive	Negative
Sand	Good Movement: water, nutrients, roots	Poor Storage: water, nutrients
Clay	Good Storage: water, nutrients	Poor Movement: water, nutrients, roots
Organic Matter	Good Movement: water, nutrients, roots Good Storage: water, nutrients	Possible toxic intermediate products in heavy clay soils

EXERCISES SECTION 2: THE PLANT SYSTEM

Goal

The most basic characteristic of ecological systems is a high degree of interconnectedness among the components. For example, a soil environment affects the associated plant systems and plants in turn affect the soil environment. The goal of the exercises in this section is to help farmers understand some of the most basic mechanisms in plant growth and development, and the associated needs for nutrients and energy, and how this relates to what they have already learned about soils.

19. *Plant structure and function*
20. *Is the soil a living thing?*
21. *What is energy?*
22. *Photosynthesis*
23. *Principal nutrients: sources and behavior*

Tips on Running the Exercises

The first exercise on plant structure and function is an active warm-up exercise, which examines the various structures in relationship to the various functions they perform in the plant. The next two exercises are easy and quick, but nonetheless important as they build on each other, and earlier exercises (e.g., atoms and molecules) to prepare the participants for doing the simulation on photosynthesis. This simulation, through drama, is fun, and also is the key for this section in that it represents the most important physiological mechanism of plants, in which energy from sunlight is captured and stored through the transformation of Carbon Dioxide and Water into sugars and starches. The last exercise introduces the principal nutrients and discusses their source or origins, and their unique functions in the plant.

EXERCISE 19. PLANT STRUCTURE AND FUNCTION

Goal

To promote discussion on general topic of plant nutrition and the structure, composition and function of each principal part of the crop plant. This can be done as a one-time exercise, or set up as a season-long monitoring.

Materials

Sharp knife or single-edged razor blade,

Hand lens

Newsprint

Colored pens

Time required





1.5 hours

Steps

Small group activity:

1. Take a mature plant and decide on what constitutes the principle sections or components of the plant (roots, stems, leaves, panicle, fruit, etc.); then cut and separate them into separate piles.
2. Discuss what the function of each part is.
3. Try and dissect or gently break apart the plant parts to see as best as possible how the plant part is formed (use hand lenses if available).
4. Rub the plant parts between your fingers and try to describe the texture and any other characteristics (soft, moist, woody, slippery, etc.).
5. Fill in the chart below.
6. Discuss the following questions.
7. Report back to the large group.

Exercises section 2. The plant system

PLANT PART	TEXTURE	FUNCTION	PROPORTION
			
			
			
			

Questions:

1. What are the relative proportions for each section (if the entire plant is 100%, then what percent is each section)?
2. What do the textures associated with each section tell you about the what the parts are made of?
3. What do the textures tell you about how rapidly the plant parts might compost or degrade when turned back into the soil?
4. Draw a representative plant to show the function of each section of the plant (feel free to use a stylized drawing, not necessarily a realistic drawing, to emphasize the function).

EXERCISE 20. IS THE SOIL A LIVING THING?

Background

This is a quick introductory exercise. The task is simply to list the basic characteristics that define living organisms, in contrast to non-living things. This exercise will help as a reference point for later discussions of the nutritional and energy needs of plants, and to be able to talk about soils as a “living thing”.

Goal

To be able to list the principal characteristics that define living organisms

Time required

45 minutes

Materials

Newsprint

Tape

Pens

Steps

1. Trainer motivates the discussion by asking “is the soil a living or a dead thing?”
2. Participants contribute to make a list of characteristics that uniquely define living organisms.
3. Discussion on what characteristics of soils suggest that they are “alive”.

Questions & Points to Emphasize

1. While the list may be long, the trainer should emphasize (and include, if not already listed by participants), the following:
 - a. Feeding
 - b. Growth
 - c. Breathing (respiration)
 - d. Reproduction
 - e. Elimination of wastes

Exercises section 2. The plant system

f. Death

2. Which of these characteristics can be said to be true for soils? While the soil itself is a composite of both living and non-living things, it nevertheless shares several characteristics of a living entity.

Principally:

- a. it breathes,
- b. it needs to be fed,
- c. it creates waste products
- d. and in many respects, it can “die” (ask the group if they know of any examples in which soils have been damaged and degraded to the point of being “dead”?)

How many living organisms in the soil?

A study done in central Europe shows just how “alive” the soil really is. The study measured the amount of living organisms in one hectare of soil, down to 20 cm in depth.

The facilitator should pose the question to the group as to how many kg of insects, worms, bacteria and fungi they believe are in a typical hectare of soil (offer the matrix below, but without the numbers). To date, most participants have seriously underestimated how much living material exists in the soil (especially bacteria and fungi!). Recall, however, this study was done in the temperate zone. Values will be different for the tropics (and depend greatly on the amount of organic matter in the soil).

Organism	Kg / Ha x 20 cm deep
Insects	17
Worms	600
Bacteria	1,500
Fungi	3,500

EXERCISE 21. WHAT IS ENERGY?

Background

Energy is one of those ideas for which we all have a basic feeling, but may find difficulty in defining or explaining. When we think of what constitutes a living organism, one of the first characteristics we think of is that living things capture, process and store energy—yet some things that are not alive also have this capability (can you give some examples?).

Like all living organisms, plants need energy to do the work of growth and development. We can feel energy when we feel the heat from the sun.

But only plants have developed the ability to capture, process and store energy directly from the sun. As a result, all other life on earth depends on plants for energy—either directly (feeding on plants) or indirectly (feeding on animals that feed on plants).

Goal

This is a quick and easy exercise, probably best done as a facilitated large-group exercise/discussion. The objective is simply to get participants thinking about the diversity of forms in which energy exists, and to link the idea that food for animals originally comes from plants, and ultimately, from the sun.

Time required

30 minutes

Materials

Newsprint
Paper
Tape

Steps

1. As a large-group discussion, ask the participants to offer up a listing of different TYPES of energy, in one column, and examples of these in the next column (as below).
2. If participants have difficulty thinking of food as energy, offer some hints, such as "...if I am working all day and am tired, what do I need to increase my energy...?"
3. The facilitator should end up the discussion by tying together the idea that plants are the ONLY avenue ("open doorway") through which sunlight is captured and processed by life on earth. All sources of

Exercises section 2. The plant system

FOOD (chemical energy) for animals comes originally from plants, and ultimately from the sun. **None of the other types and sources of energy on the list relate to the process of life.**

Type of Energy	Source (example)
Solar energy	Sun
Heat energy	Fire
Kinetic energy	Wind, Water
Electrical energy	Electrical generator
Magnetic energy	Magnet
Chemical energy (inorganic)	Battery, petroleum
Chemical energy (organic)	Food

4. This is a good time to contrast short-term and long-term storage of energy in plants.
- Ask participants ‘if you are tired and want quick energy what do you eat? {sugar}
 - If you need to work all day in the field, can you depend on eating just sugar? {no}
 - What do you need to eat? {rice, or some kind of starchy food}
 - What happens if you put a spoonful of sugar in water and stir?
 - What happens if you put a spoonful of starch (e.g., rice grains or potato slice) in glass of water and stir?

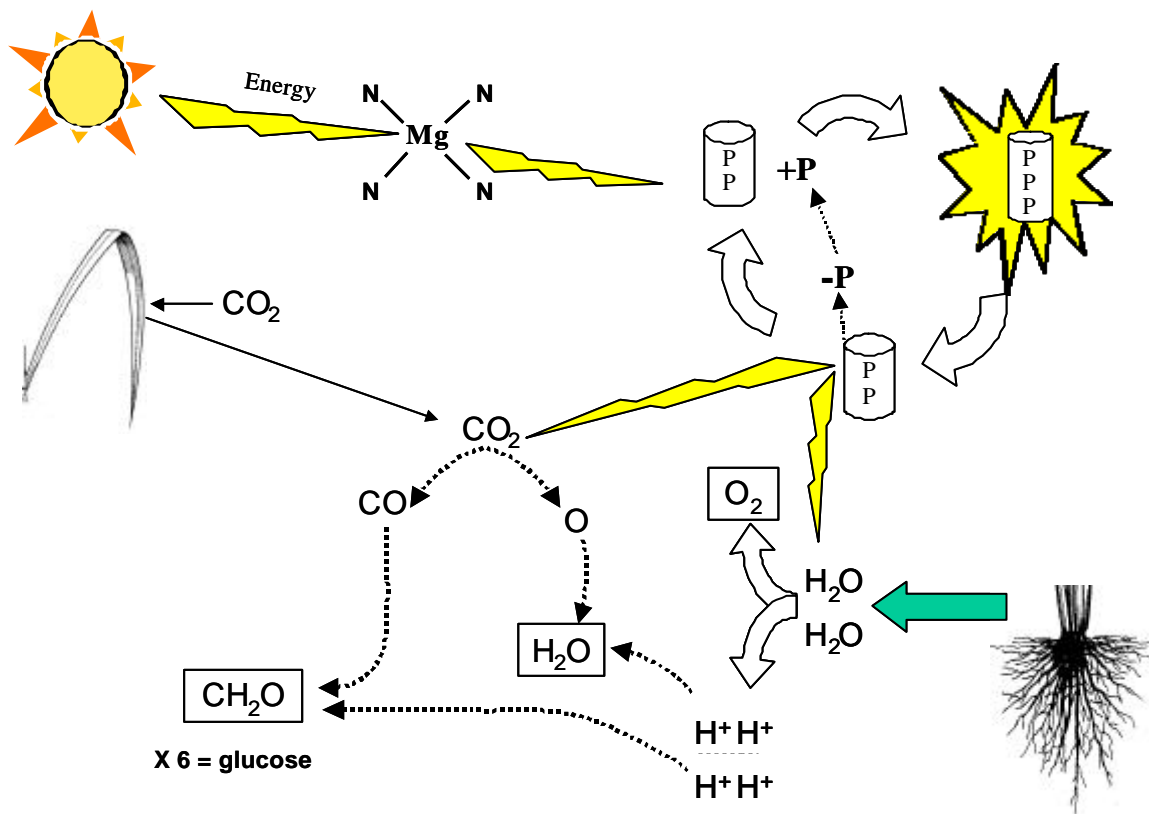
This line of questioning should lead to an appreciation that sugar is rapidly dissolved/digested and gives quick energy, but that starch does not dissolve/digest as quickly, and therefore, while not being “quick energy”, gives a more longer lasting source of energy to the body.

5. **SIMULATION.** Have the participants act out the difference between **sugar** and **starch**:
- a. Five or six individuals each represent sugar molecules. Draw a circle on the ground large enough to fit all of them and call it the “stomach”. Discuss how all of them, together in the stomach are able to be digested and give up their energy at the same time.
 - b. Have the five or six individuals link hands to form a chain—this represents “starch” (present the idea that starch is just sugar linked together in long chains, with hundreds or thousands of sugars). For “digestion” to take place, the “sugar” on the end needs to be broken off first. So “digestion” takes place much more slowly, and the energy given to the stomach is much lower at any one time, but lasts much longer.

EXERCISE 22. PHOTOSYNTHESIS

Background

This exercise is an important “end point” in this early process of discussing plants and energy. It builds on the previous exercises, drawing together the ideas on how atoms are linked as molecules and modified through the use of energy. In a separate exercise participants learned of the source and method of energy capture by plants, plus the manner in which energy is stored in short-term molecules. The first part of this exercise can be done on paper or white board, but the drawings, no matter how well done, will still leave participants unclear about mechanisms. The goal of the subsequent simulation is to make clear the concepts. In this simulation participants will act out the principal mechanisms of photosynthesis.



Goal

To have participants understand and be able to describe and act out the basic mechanisms involved in photosynthesis, including energy and nutrient-related processes, inputs and outputs.

Time required

60 minutes

Materials

Paper labels with the written symbols:

SUN (1)

Mg⁺⁺ (1)

P (in the shape of a battery) (1)

O (4)

H (4)

C (1)

Steps

You will need 12 participants to run the simulation

1. Individuals are chosen to represent one factor, and they each use a paper letter symbol written on it to represent the following:
 - a. the sun
 - b. a chlorophyll protein molecule, with Mg⁺⁺ at the center
 - c. a “phosphate battery”
 - d. a CO₂ molecule (three participants)
 - e. two H₂O molecules (six participants)

2. First, the “***light reaction***” takes place:
 - a. the sun transfers energy to the ***chlorophyll molecule*** (the participant representing the sun hands a piece of paper or some

Exercises section 2. The plant system

- object that represents sunlight energy to the participant representing the chlorophyll molecule),
- b. the phosphate participant (the “star” of the show) passes by the chlorophyll molecule and picks up energy (make it dramatic: before passing by he/she looks weak and slow; after being “energized” he/she looks full of energy),
 - c. The “charged up” P moves over to two groups of three participants each, representing two H₂O molecules. The phosphate uses his energy to break the links (linked arms are unlinked).
 - d. The six “H” participants stand to the side to wait for the next step,
 - e. For each “charge” remember that energy from the sun is transferred to the chlorophyll molecule, which is then used to “charge up” the “phosphate battery”
 - f. The recharged P now uses his/her energy to construct O₂ (joining the hands of the two oxygen molecules from water)
3. Next, the “**dark reaction**” takes place:
- a. The “phosphate battery” uses its energy to break apart CO₂ into C-O and O.
 - b. The C-O pair now are hooked together (by P) with two H participants to form a sugar molecule (H-C-O-H), and
 - c. the remaining O is hooked together with the two remaining H participants to form H₂O.
4. Run this simulation several times until the participants can do it smoothly. Switch roles and participants so that everyone gets a chance. Make sure everyone understands exactly what is being represented by each participant.

Questions & Points to Emphasize in Discussion

1. the energy that was originally in the form of sunlight is transformed into chemical energy, in the form of sugars and starches, through the action of the plant.
2. green plants are the **only** organisms that can derive energy directly from the sun (while humans are able to absorb and feel the energy of the sun, our bodies are unable to capture, process and store this energy).
3. while animals can derive food from eating other animals, ultimately all food and energy for life on earth originates from green plants, and therefore the energy from the sun. The trainer can use this as an entry point (if the topic has not already been introduced) to introduce the idea of a **FOOD WEB**, as a community of organisms in an ecosystem

that are interconnected, either directly or indirectly through interactions whereby energy and nutrients are passed from one organism to the next.

4. the metal ion **MAGNESIUM (mg⁺⁺)** is responsible for the direct capture of the energy from sunlight. The mg⁺⁺ is found in the center of the CHLOROPHYLL molecule, surrounded by four Nitrogen atoms. The reason a plant is green is because of the magnesium in chlorophyll. The magnesium ion, however, is unable to “hold” energy, so it must pass it on to a more permanent form—the phosphate “rechargeable battery” and ultimately sugar and starch.
5. the forms of energy storage (sugars, starches, fats and oils) and the use to which the energy is put (growth and reproduction) are fundamentally the same for both plants and animals.
6. Ultimately, the energy that comes into a system is exhausted, with the last of it being used by microorganisms that seek energy through the breakdown of organic matter. Nutrients, on the other hand, are recycled in the same system, or else move on into a different system. While molecules change form—some slowly, some quickly--the atoms are never destroyed. The atoms that make up our world are ancient, having been around for billions of years and constantly recycled in and out of countless ecosystems.
7. What happens to the plant if there is not enough P? N? Mg⁺⁺?

EXERCISE 23. MACRONUTRIENT SOURCE, FUNCTION AND BEHAVIOR

Background

Nutrients have a primary location or “Primary Reservoir” where most of the nutrient is located. For Carbon, Nitrogen and Oxygen the atmosphere serves as the primary reservoir. It is interesting to think that more than 90% of the dry-weight material (meaning the plant material excluding all the water) that makes up the body of a plant comes either directly or indirectly (in the case of Nitrogen) from the atmosphere! These elements tend to move and change quickly in the soil environment (nitrogen, for example, is highly mobile and takes on many forms).

In contrast, the “soil-based” nutrient elements have their reservoir in the soil itself. These nutrients include phosphorus (P), potassium (K), sulfur (S), calcium (Ca), and most of the mineral “trace elements” or “micronutrients” (of which the plant requires only a very small amount to grow).

Goal

To understand where nutrients are stored in the environment, where they are found in the plant, what their function is in plant growth and development, and what their behavior is when in the soil environment.

Time required

60 minutes

Materials

Pens
Tape
Newsprint

Steps

This exercise is presented here as a facilitated large-group discussion. This is principally because much of the material will be new to participants, and they will therefore be more dependent on input from the trainer.

The facilitator begins by asking the group to help fill in the table below. Go over each point querying the participants for as much knowledge as they possess, then provide some input, only if the participants are unable to come up with the complete answer.

Questions & Points to Emphasize

1. N and C are “atmospheric” nutrients, while P, K and the other macro and micronutrients are almost all having their source from the soil (mineral nutrients). Recall from the simulation on photosynthesis that C comes directly into the plant through the leaves as the gas CO₂. Most nitrogen, on the other hand, is obliged to pass through microbial populations in the soil in order to be “fixed”, and eventually pass on to the roots.
2. For rice, about 70% of the N is found at harvest in the panicle. For P the distribution is about 50/50 panicle/straw, while for K, 98% resides in the straw. Discuss the implications for recycling nutrients by putting straw back into the soil.
3. For behavior in the soil, discuss the implications of the fact that N is highly mobile, under several different forms, and that no “mineral” source for N exists naturally in the soil. This means that the availability of Nitrogen to the plant is highly dependent on the soil environment. This contrasts with both P and K, which are very much less mobile, and less frequently than N are limiting factors to production.
4. What other nutrients are necessary? Introduce the idea that some 20 different nutrients are required—what are some of them and how to they fit into this matrix? (see Appendix B).

Nutritional Factor	Principal Source	Function	Distribution in Plant	Behavior in soil
N	Atmosphere via soil microbes	Part of “dynamic” molecules especially proteins	Rice: 70% in grain 30% in straw	Highly mobile
P	Soil reservoir	energy transportation important part of proteins	50% grain 50% straw	Not mobile easily immobilized
K	Soil reservoir	important for fruiting, transportation of nutrients, and stem turgor	2% grain 98% straw	Not mobile
C	Atmosphere	Principal structural element: sugar, starch	55% of dry weight of plant is C	variable, depending on form
Others?				

EXERCISES SECTION 3. SOIL MANAGEMENT

Goal

The participants should come away from these exercises with a clear understanding of the central position that organic matter management plays in the development of a sustainable agricultural system. Organic residues are the vehicle for managing soils.

24. *Yield and fertilizer trends*
25. *Nutrient “mining”*
26. *Rice nutrient budget*
27. *Straw-use analysis*
28. *C:N ratios*
29. *Soil problem analysis*
30. *Building compost*
31. *Doing farmer-based research on soils*

Tips on Running the Exercises

The first exercise is a quick and easy discussion on yield and fertilizer trends as a way of motivating the section. Exercises 25-28 should be run in sequence as they all relate, from different perspectives, to the analysis of why it is important to return plant organic matter to the soil using rice straw as an example. For the vegetable farmers on the other hand, Exercise 29 gives a procedure for building a hot-compost container. The last exercise promotes the idea that these exercises should be used to set the stage for season-long experiments by farmers on soil (organic matter) management.

EXERCISE 24. YIELD TRENDS

Background

This exercise is a quick and easy discussion the aim of which is to motivate interest in the overall subject of improved soils management. The participants are asked to provide a rough idea of yields and synthetic fertilizer inputs for the past several years (yield per unit area compared with inputs of synthetic nitrogen). In many cases the you will see a general downward trend in yields at the same time as a general upward trend in the total amount of synthetic nitrogen. Of course there are other factors that have affected yields – the introduction of new varieties for example – which may be cause for an increase in yields over time. This can be factored into the discussion.

Goal

To explore the long-term yield trends in relation to the trend in synthetic fertilizer inputs and other factors.

Time required

45 minutes

Materials

Pens

Newsprint

Tape

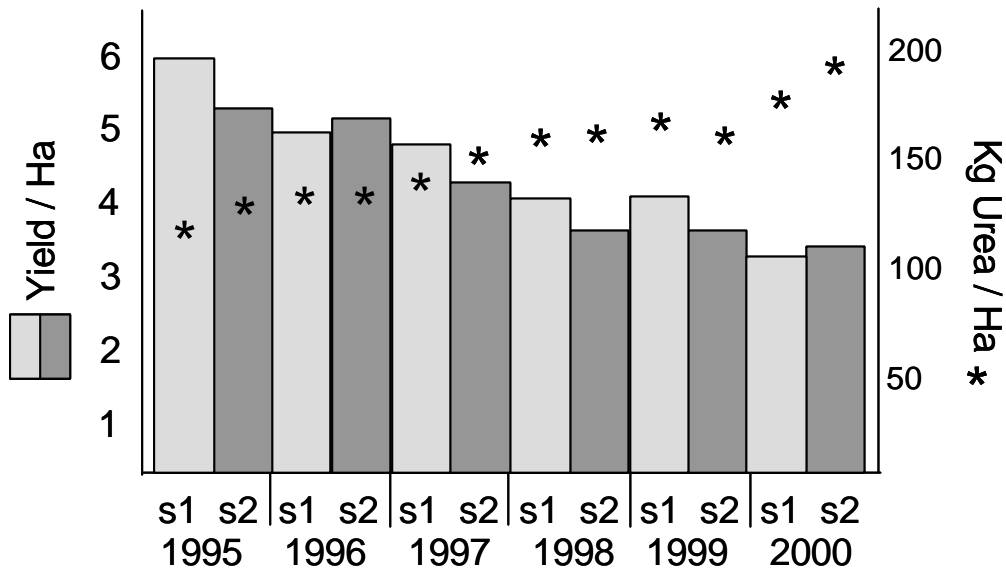
Steps

If working with farmers this should be done as a small group exercise with representatives reporting back to the large group. In this way you have a sample from several different farm experiences. If this is for a TOT for trainers, the idea can be put across quickly as a group discussion only.

1. Decide on one farmer per small group as a representative case. Begin with a blank graph, with time on the horizontal axis and average yield on the vertical axis (left) and average input (kg) for urea on the vertical axis (right). **You will need to estimate the range of values that will be used for both yield and urea, in order to be able to set the scales such that they overlap nicely.
2. Ask the participant to begin with the latest year's values and to plot yield per hectare (or whatever the most appropriate units might be for your area) measured against the left-hand axis. Draw a box (vertical column) to represent yield for this year.

Exercises Section 3. Soil Management

3. Next, for this same year, put a mark down for total Kg urea applied for this same representative field (measured against the right-hand axis). The urea graph can be drawn as a line graph, from point to point, or simply as points.
4. Now do the same thing for the year before, then the year before that—going backwards in time as far as the participant is able (10 years would be a good graph).
5. Discuss the implications of the graph comparing trends in synthetic nitrogen inputs with yields. Report back to the large group.



Questions

1. What do the trend lines show?
2. If yields are going down while fertilizer use increases, why might this occur?
3. What other factors might be influencing these trend lines? (e.g., changes in varieties)

EXERCISE 25. NUTRIENT “MINING”

Background

One of the problems associated with the dependence of farmers on synthetic fertilizers results from the thinking that “N,P,K” is all that a plant needs for food. In fact there are some 20 different nutrients that are necessary for plant growth. Nitrogen, phosphorus and potassium are needed in relatively large quantity by the plant, and are therefore called **macronutrients**. Others, such as zinc and magnesium, are only needed in minute amounts, and are called **micronutrients**.

The very best way to ensure that a proper balance of nutrients is fed to the soil is to return as much of the original plant material as possible to the soil after harvest. For vegetable crops, this would best be done by providing an application of **compost** (see later exercise). For rice plants this would involve putting the straw and stubble back into the soil before the next planting season. However, in many locations farmers burn their rice straw, or feed it to the cattle or use it for cooking fuel. In essence this puts the farmer in the position **of continually extracting, or “mining” his soil for nutrients**. The farmer is most often unaware of this, thinking that adding N,P,K will make up for lost nutrients. While nutrient mining may not cause nutrient deficiency problems this season, or next season, eventually the soil will become deficient in one or more critical nutrient. This is one reason why yields are in general declining around the world.

This exercise is a simple simulation aimed at demonstrating the concept of **“nutrient mining”**. There is no easy way to know which nutrient might first be depleted, as nutrient composition of soils vary from location to location, and are available or not depending on fairly complex soil chemistry.

The important point of this exercise is the idea that if farmers “mine” their soils, eventually one or another nutrient will be depleted and begin to reduce the farmer’s yield.

Often the response by farmers to a declining yield is to add more NPK, thinking that the soil needs more fertilizer. Unfortunately, adding more of the three macronutrients when the limiting nutrient is something else altogether will, at best, be a waste of money, but may even cause an increase in the problem by causing an even greater imbalance in the soil.

One farmer in Bangladesh put it quite well: he said “I understand the idea—if I am trying to make a nice curry sauce, but don’t have enough coriander, it does me no good to just keep adding chillies!”

Note to facilitator: One pitfall to avoid is the **focus** on trying to determine specific nutrient deficiencies for soils. We do not want farmers to think they must rush down to the store and buy an increasing array of synthetic fertilizer products! Rather, the best solution is to put a compost or some adequate source of organic matter back into the soil.

Exercises Section 3. Soil Management

Goal

To understand the concept of limiting nutrient through playing a simulation game.

Time required

45 minutes

Materials

Newsprint

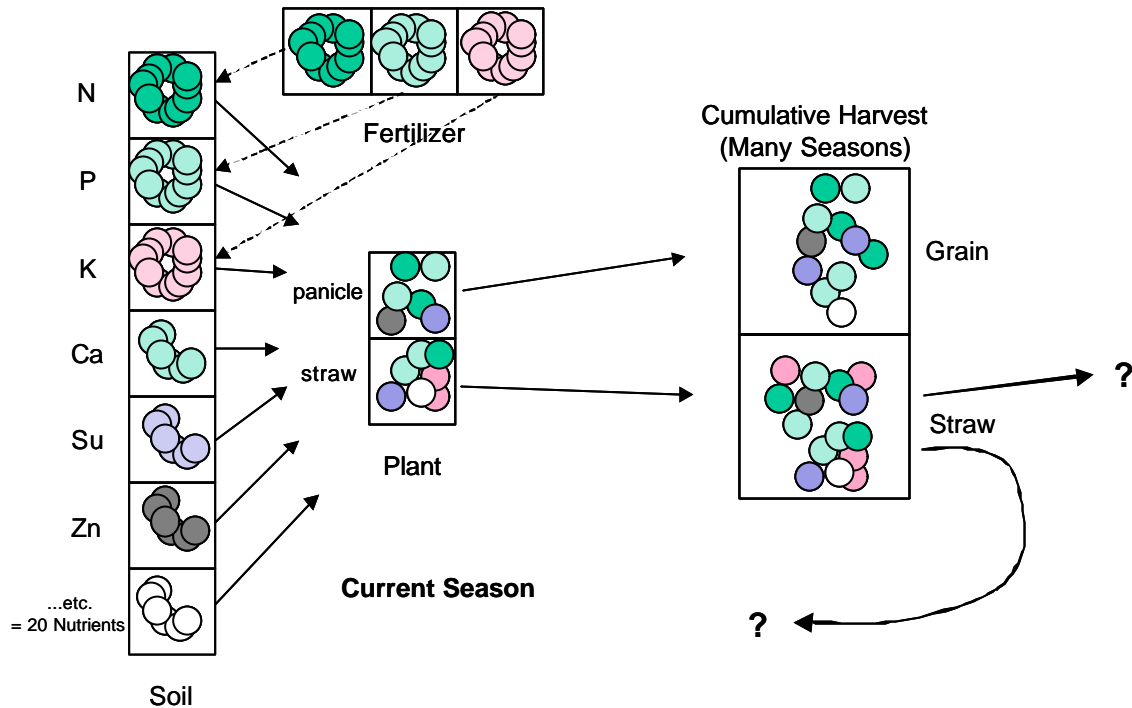
Pens

100 gm seeds of 6 different types.

Steps

1. Draw a set of squares, similar to the diagram below, on a large piece of newsprint.
2. Cut up a dozen or more small pieces of paper in different sizes or colors depending on the materials you have available. These will represent several different kinds of nutrients. A better alternative is to use seeds of different sizes and colors (easier if large seeds)
3. Begin "season 1" by placing a good number of "nutrients" in each of the squares in the "soil" boxes. Then transfer a couple from **each** soil nutrient box into the "Plant" boxes. Distribute these between panicle and straw if you are familiar with the distribution (recall that virtually all the K^+ goes into the straw).
4. "Harvest" the crop by removing all the nutrients from the "plant" boxes into the "harvest" boxes.
5. Begin the next season by adding "fertilizer" from the NPK fertilizer boxes into the NPK boxes in the "soil".
6. Repeat the process of "growing the plant" and "harvesting". Allow the "harvest" boxes to grow each season to show the cumulative or total amount of nutrients "mined" from the soil over the years.
7. Continue until one of the boxes in the soils compartments is empty. Ask the participants what might be happening to yields at this time.
8. Now look at the large accumulation of nutrients in the harvested "straw" box. Change the scenario and ask what the soil would look like if the nutrients from the straw had been put back in the soil each year.

Nutrient Mining Simulation



Questions and points to emphasize

1. Ask farmers what their fathers did with straw from the rice fields? What other practices have changed from the time of their fathers?
2. If farmers point out that they have higher yields than did their fathers, try to steer the discussion towards the reasons for these higher yields—presumably the big reasons are the use of modern HYV varieties, along with additional boost from synthetic fertilizers. Ask whether it is possible that soil health was better during their fathers' time, even if yields for the varieties was less at that time.
3. What scope exists for farmers to put straw back into the soil? Could they begin with an experiment on just a small part of their soil (maybe 20% or 25%)?
4. **Analogy:** With our children, the best strategy for their nutrition is not to worry about providing this or that specific nutrient, and trying to evaluate this or that nutrient deficiency! Rather, we make sure to provide them with a balanced diet (fruits, green and yellow vegetables, meats and fish, milk, etc.). Similarly with the soil, the best strategy is to make sure the soil has a “balanced diet” by replenishing the extracted nutrients through the application of organic matter.
5. Recall that this exercise is only about nutrients. Ask the participants to quickly review the many other reasons they have learned for why organic matter is beneficial for soil health.

EXERCISE 26. RICE NUTRIENT BUDGET

Background

This exercise is especially for rice farmers, although the general principles hold for any crop. The basis of the exercise is a focus on only the three principal macronutrients (NPK). The aim of the exercise is to help farmers calculate the amount of NPK that is being removed from the soil after each season. A “budget” calculates both inputs and outputs. A real nutrient budget would need to take into account many more complex factors that would be difficult to measure (e.g., the amount of N that is being fixed by the blue-green algae in the rice field water). This exercise, therefore, is a very rough estimate. Note that we have limited our discussion to just three nutrients, and remind the participants not to lose sight of the many other ways in which rice straw (and organic matter in general) is important as an input to production.

Goal

To enable participants to be able to make a rough estimate of the amount of NPK going into and out of their rice fields each season, and to appreciate the nutrient value of rice straw.

Time required

60 minutes

Materials

Newsprint

Pens

Tape

Calculator

Steps

1. Facilitator draws an outline of the diagram for the nutrient budget analysis (see below).
2. Except for fairly advanced participants, this should be a facilitated large-group discussion as the exercise is moderately complex.
3. INPUTS: include only the synthetic sources of fertilizers (to keep things simple). There are many types of synthetic fertilizer, each with its own percentage of active ingredient. The participants will usually know these values. For example, urea is 46%, TSP is 48% and KCL is usually 60%. Fill in the values for Kg inputs, and percentage active ingredient; then calculate the value of active ingredient provided as input to the field.
4. STEP 2: losses of N in the field. Research at the International Rice Research Institute (IRRI) has demonstrated that even in a good soil,

roughly 40% of the N from fertilizer is lost back to the atmosphere as N₂ gas (denitrification by soil microbes). Also, about 20% remains trapped in the soil, unavailable to the plant. This leaves about 40% of the original synthetic nitrogen being taken up by the plant (Note: in a sandy soil with no organic matter this value for N lost can be much higher).

5. STEP 3: Based on the value given by the participant for his/her grain yield per hectare, calculate the amount of rice straw per hectare (use the local unit measure rather than kg/ha if appropriate). The ratio of kg rice straw per kg grain yield will vary based on the variety. The ratio varies between about 1.2 to 1 and 2.0 to 1. Traditional varieties have more straw (2:1) compared with high-yielding varieties (1.2:1). If you aren't sure what value to use, use a value of 1.5:1 as this is in between.
6. For the grain yield, and then also for the straw yield, calculate the amount of NPK given the values listed below. Multiply the percent of N,P,K times the number of kilograms of grain and straw, then divide by 100.
7. Enter the values for N,P,K in the Summary Table for kilograms of Inputs, the amount lost in the field (only for N), the amount taken away in the harvest, and the amount removed in the straw (assume for the first part of the exercise that the straw is removed).
8. Total the outputs and subtract these from the inputs to estimate the NET amount (positive or negative) of NPK that remains in the field after one season.
9. ALTERNATIVE. A quick alternative to this exercise, if time is short, is simply to calculate how many kg of NPK exist in the amount of straw from one hectare of average yield. Then calculate the amount of synthetic fertilizer this represents, the market value, and the value of a 10% increase in yield.

Questions & Points to Emphasize

1. Given the local costs for synthetic fertilizers, calculate the value (in terms of local currency) of the NPK in the straw from one hectare of rice. If straw is sold, calculate the loss of income from returning straw to the soil. Research shows that returning straw gives around a 10% yield increase beginning the second season. Factor this value into your calculations. If the farmer puts straw back into the field is he making a profit or taking a loss?
2. In our experience with this exercise so far, in most cases there is enough (or more than enough) P remaining in the soil after harvest. Results for N are highly variable based on location. Results for K are usually that K is being removed from the soil at rates somewhere around 100-150 Kg/ha for each season—even if the farmers are adding the recommended dosages of K. What are your results?
3. Note that many soils in the region are considered to have “enough” K so that farmers do not have to worry about K deficiency, even if the

Exercises Section 3. Soil Management

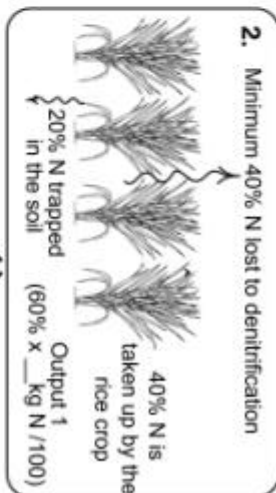
budget shows a net loss each season. However, this is not universally true. Some soils are deficient in K to begin with (especially on land that is of somewhat higher elevation than the surrounding land). In West Africa, in the country of Mali, farmers were able to grow rice without returning the straw to the soil for 10 years before they started seeing yield reductions (due to K deficiencies).

4. What would the net results be if all the straw were put back into the soil before planting the next season?
5. Besides the NPK, what other nutrients are being put back into the soil with the straw?
6. Besides the question of nutrients, what other value is there to the straw being put back into the soil?
7. What problems do farmers in your area face in putting rice straw back into the field? Are there solutions to these problems?

RICE MACRONUTRIENT BUDGET

1. INPUTS

Urea kg X % Active Ingredient / 100 = _____ kg N
 TSP kg X % Active Ingredient / 100 = _____ kg P
 KCL kg X % Active Ingredient / 100 = _____ kg K



3.

YIELD _____ kg grain x 1.5 = _____ kg straw

Output 2 _____ kg N grain x 1.2% / 100 = _____ kg N grain
 _____ kg P grain x 0.2% / 100 = _____ kg P grain
 _____ kg K grain x 0.4% / 100 = _____ kg K grain

Output 3 _____ kg N straw x 0.6% / 100 = _____ kg N straw
 _____ kg P straw x 0.1% / 100 = _____ kg P straw
 _____ kg K straw x 2.2% / 100 = _____ kg K straw

4. SUMMARY TABLE

INPUTS	Out 1	Out 2	Out 3	Total Out	Net (In-out)
N					
P					
K					



EXERCISE 27. STRAW-USE ANALYSIS

Background

Now that participants have an idea of the value of organic matter in general, and rice straw specifically, we can proceed with an analysis of how farmers use their straw. This varies widely from country-to-country and location-to-location. Our experience to date has shown a wide range of situations among rice farmers in Asia and Africa. In some areas, like the southern areas of West Java, farmers return their rice straw to the fields every season, and seem to realize this is a good practice for sustainable yields. In East Java we met farmers that were paying laborers (6 man-days per hectare) to chop up the rice straw with a machete in order to make turning the straw into the soil easier for the small rotary-tine tractors. However, farmers were seemingly unaware of the benefits of this practice and were only doing this because, as they said, the climate and water conditions were too moist to be able to burn the straw effectively, and they had no market or selling or otherwise getting rid of the straw (they were pleased to learn this was beneficial for their yields). In Bangladesh, Vietnam, Cambodia and Mali (West Africa), farmers were feeding the straw to cattle, or, as in the case of Bangladesh, were also using straw for cooking fuel. These cases pose a more difficult problem because even if farmers are aware of the value of straw to their long-term yield prospects, they face other constraints that must be solved first before the farmers have the option of returning straw back to their soils.

Goal

helping participants examine their constraints (and perceived constraints) to managing their organic residues.

Time required

60 minutes

Materials

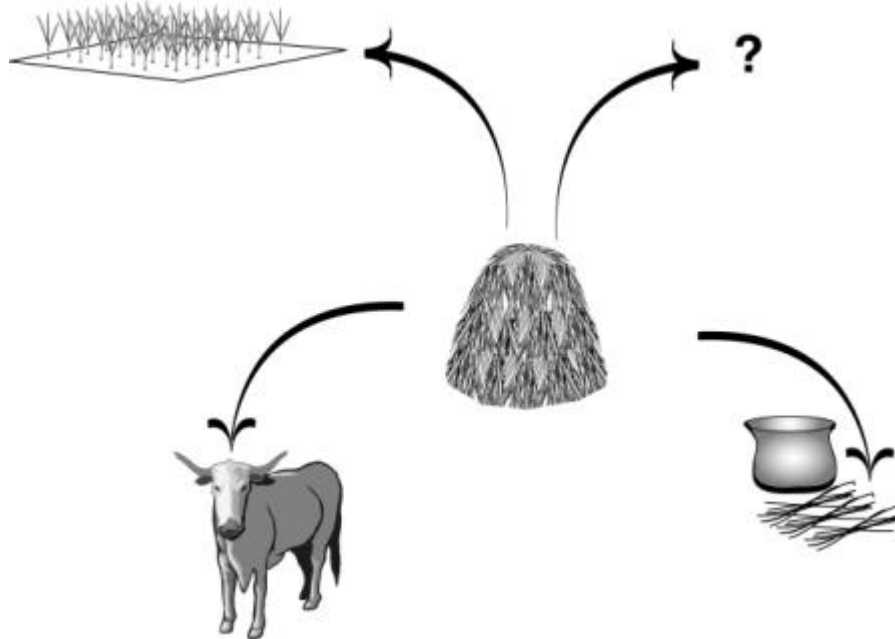
Pens

Newsprint

Tape

Steps

1. The facilitator can put up on the board a drawing as below, indicating the possible uses of straw in the farming system.
2. In small-group sessions, participants draw a two column matrix, as below, indicating the “positives” (benefits) and “negatives” (constraints) associated with returning rice straw to the field. (**this can, of course, also be done as a facilitated large-group discussion, depending on the judgment of the facilitator) .
3. Participants report back to the large group and discuss their findings. The facilitator should be knowledgeable enough on the subject to be able to distinguish “real” constraints from “perceived” constraints (some of which will have no real basis in fact). During the discussion try to bring out the difference between the two (see examples below).
4. Discuss the possible solutions to the constraints and see if this can lead into plans for farmers to do experiments on the topic in their fields.



Some real constraints to returning straw to a rice field

1. Not sufficient time to allow straw to decompose before transplanting or seeding rice: results in yellow rice seedlings
(see exercise on C:N ratio).
2. Rice straw gets caught up in the rotary tines of the small tractors, causing problems
[farmers in many areas get around this by paying the labor to chop up the straw—other solutions include partial decomposition before tillage].
3. Rice straw needed for cooking fuel, animal feed, building materials, or some other external need.

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4. Long dry season (three months or more) means that rice straw must be stored. If turned under too soon it decomposes long before the next planting season
[straw should not immediately be turned under as it will decompose in 6-to-8 weeks. Instead, store it in a pile until 2-to-4 weeks before planting].
5. Rats make homes under the rice straw piles
[maybe, but then you know where they are and can more efficiently organize an effort to control them].
6. Rice straw “poisons” the new seedlings
[in fact, under certain heavy clay soil conditions and cool temperatures, microbial breakdown under anaerobic conditions can produce organic acids, phenols and alcohols that are toxic to the roots of young seedlings. Most of the time in the tropics this should not be a problem.]

Some perceived problems that have little or no basis in fact

1. Rice straw is a reservoir for plant hopper eggs
 - a. Plant hopper eggs are dependent on the plant for moisture. Dry straw is impossible to insert eggs into, and if they were inserted, they would quickly die from lack of moisture.
2. Rice straw is a reservoir for stem borers
 - a. Stem borers that go through a resting stage usually do so in the very base of the plant, in the plant stem just above the roots and often below the soil surface. Straw is cut above this point. Also, any eggs or larvae of any insect would be destroyed by turning the straw back into the soil during soil preparation.
3. Rice straw is a reservoir for disease
 - a. The International Rice Research Institute—IRRI— (Dr. Tom Mew) suggests that turning the straw back into the soil is the **best** way to dispose of straw from diseased plants. The disease spores are destroyed and the subsequent soils—richer in organic matter—are better able to suppress subsequent attacks by pathogens.
4. Synthetic fertilizers are better for rice yields
 - a. [In fact, trials at IRRI and elsewhere have shown that the most productive choice of fertilizers will be a combination of organic matter and synthetics (most especially a synthetic nitrogen source). Among the organic inputs, **rice straw** has been proven to give the **best response**—even better than equivalent amounts of cow dung— (rice straw is, after all, almost the same chemical make up as a growing rice plant)].

EXERCISE 28. CARBON – NITROGEN RATIOS

Background

This exercise refers to a possible problem associated with putting straw back into the soil of a rice field. However, the problem illustrates some basic principles of soil biology and management, and therefore is appropriate for discussion with vegetable growers as well. In areas where rice straw is incorporated into the soil less than one or two weeks before the seedlings are transplanted (or the seeds sown), farmers may be confronted with rice seedlings that are yellow and smaller than neighboring fields which do not incorporate rice straw. The cause of this problem is related to the general cycle of growth of soil microbial organisms, and their needs for nitrogen.

Of all the elements (atoms) in plants, Carbon is the most abundant. The dry-weight of a plant is roughly about 55% carbon, whereas it may only be 2 or 3% nitrogen. Plants have little difficulty accessing carbon for as we have seen earlier, C comes into the plant during the Dark Stage of photosynthesis in the form of CO₂ from the surrounding atmosphere. So C is not a limiting nutrient for plants as is often the case for N.

Microbes that live in the soil also require large amounts of carbon; however, they are unable to derive this directly from the atmosphere, but rather they depend on organic matter from decaying plants and animals for their source, or even sugars put out (exuded) from plant roots. Like all living organisms, microbes have need of a balance of nutrients for their growth and development. Roughly speaking, they need about 20 Carbon atoms for every Nitrogen atom, or a Carbon-to-Nitrogen ratio (C:N ratio) of 20:1.

The C:N ratio of organic matter in the soil varies greatly depending on the source. A good compost, for example, has between a 30:1 and a 40:1 carbon-to-nitrogen ratio—this is in fact one of the benefits of compost. Cereal straw, on the other hand, has a C:N ratio closer to 100:1. This means that during the early stages of straw decomposition in the soil, the microbial populations have far more C than they do N; **therefore, they must take N from the surrounding soil environment**. If rice seedlings have recently been planted, there is therefore a competition between the microbes (seeking to balance their meal of carbon with a meal of nitrogen) and the rice seedlings. The rice seedlings, therefore, end up looking yellow and develop slowly for the first several weeks.

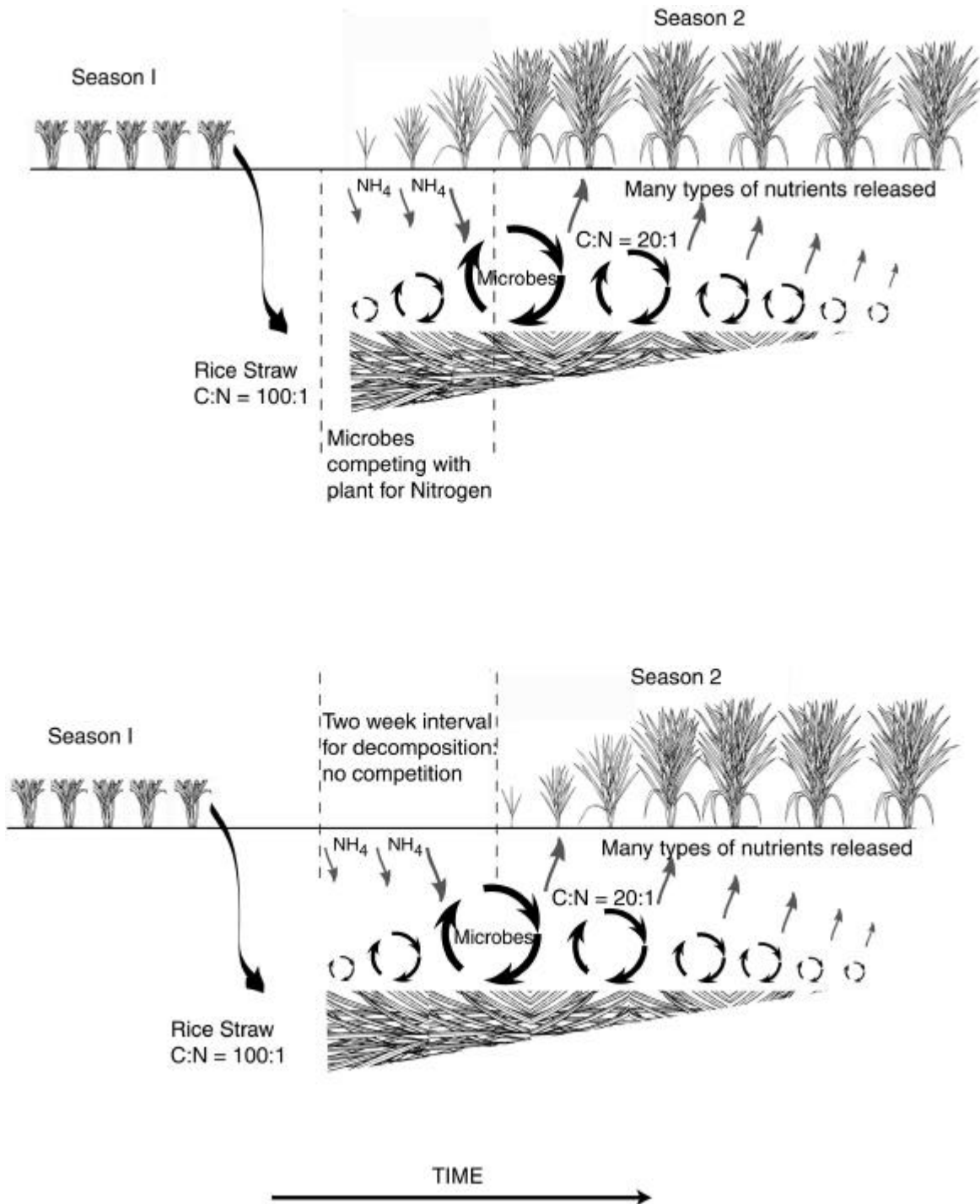
Microbial populations as nutrient “banks”

The other point of importance is the fact that microbial populations, in addition to their role as **decomposers** of OM, act as a **reservoir** or storage area for nutrients. During their short life-times, microbes hold the nutrients as components of their bodies. As they die off, the nutrients are decomposed by the extra-cellular enzymes living bacteria use to “digest”

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materials (bacteria don't have mouths and stomachs!), and some of these nutrients will be taken up by the roots of the plants.

Microbial populations act to hold, and then slowly release nutrients to the roots of the plants. Without microbes, synthetic fertilizers added by farmers are quickly lost by leaching into the surrounding



Goal

This exercise aims to help participants understand the somewhat complex dynamics and interactions between soil organic matter, soil microbes and plants during the first few weeks after turning rice straw into the soil. Another objective is to give an idea of how microbes act as a storage area for nutrients.

Time required

60 minutes

Materials

Pens

Newsprint

Tape

Several dozen small pieces of paper marked with the symbol N or C

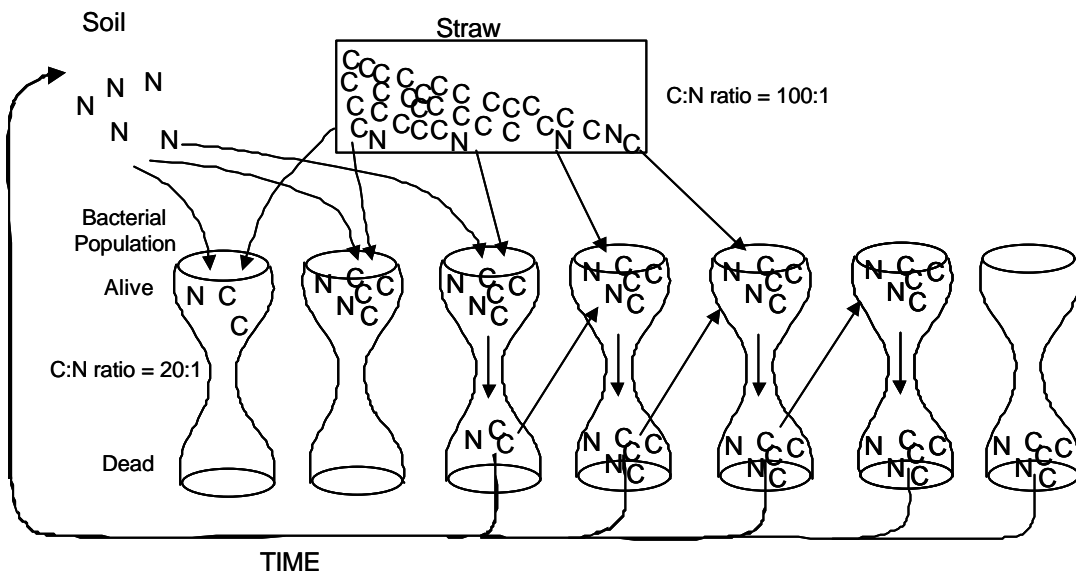
Steps

This simulation is not meant to be quantitatively accurate, but simply to give an idea of the movement of nutrients in between soil, straw and microbial populations. The point to emphasize is that at the beginning of the process, N is taken out of the soil by the microbial population (a time of potential competition between microbes and plant roots for N), but that this N is later replenished by the dying microbial population.

1. The facilitator presents a drawing similar to the one found below (the “hour glass” compartments represent movement from one chamber (living) to another (dead), and prepares several dozen small pieces of paper marked either as N or as C. Each C paper represents 10 C atoms, whereas each N paper represents only 1 N atom. Participants break into small groups and play the simulation as follows.
2. The first hour glass shows C from the straw and N from both straw and soil being put into the “live” microbe chamber, representing the consumption of straw by microbes and the growth of the microbe populations.
3. The next hour glass shows the continued growth of microbial populations, and the accumulation of nutrients in this living “nutrient bank”.
4. The 3rd hour glass is the same as the last, but in addition you have movement from the “live microbe” chamber into the “dead microbe” chamber, representing the death of a certain fraction of the microbe population.

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5. The 4th hour glass is the same as the 3rd, but in addition you have breakdown of the dead microbes providing some of the nutrients required for the next time period.
6. The 5th hour glass is the same as the 4th.
7. The 6th hour glass is the same, except that the straw resources have been used up, and only nutrients from the dead microbes are feeding the same microbe population. This and the next hour glass represent the final stage in which all the original straw has been consumed, and the nutrients are now entirely within the microbial populations, both living and dead, and in the soil.



EXERCISE 29. SOIL PROBLEM ANALYSIS

Background

This exercise gives the participants a chance to apply some of the knowledge they have acquired in the analysis of local problems. It is inevitable that trainers face questions by farmers on how to solve local problems. The trainer should ideally be moving these questions back toward the farmer by suggesting the possibility of simple experiments. This exercise suggests that most soil problems fall into one of four categories.

Goal

To give the participants the opportunity to discuss the variety of local soil problems.

Time required

90 minutes

Materials

Pens

Newsprint

Tape

Steps

1. Break into small groups (based on similar work locations if participants come from several areas). Ask them to list the most important soils-related problems in their areas. Ask them to describe a likely approach for experimentation to help farmers see solutions for these problems.
2. Report back to the large group and compile the problems and experiments.
3. Facilitator asks the group to categorize the soil problems into a few categories. These will probably include:
 - a. Physical (drainage, low water-holding capacity, etc.)
 - b. Nutrient deficiency
 - c. Toxicity
 - d. Pathogen
4. How many of the solutions are based on the management of OM?

EXERCISE 30. BUILDING A COMPOST PILE

Background

We want to stress from the outset that hot compost is a practice best suited for dryland crops, especially high-value crops like vegetables. It is not the best use of energy and resources for rice culture for two very good reasons: First, because the process of making hot compost is **aerobic** (requiring oxygen) and the principal products derived include nitrogen in the **nitrate** form (NO_3). When the field is flooded soil conditions turn anaerobic within about two hours, and when this occurs, the nitrate rapidly undergoes denitrification by specific anaerobic bacteria. Denitrification results in your valuable nitrogen sources being lost back into the atmosphere as nitrogen gas (N_2). The second good reason is that a better method for improving rice paddy soils is simply to return the rice straw to the soil at least 2 weeks before planting.

There are many ways that people have found to build compost piles. The reader is encouraged to ask around to find other “recipes” and, of course, to experiment. The basic requirement of all (hot) compost piles is that:

1. the compost pile be large enough so that the heat generated is greater than the heat lost to the outside. This means that a “cubic” shaped pile is better than a wider, flat pile.
2. The compost pile receive enough oxygen so that the aerobic process of breakdown by microbes can take place. Therefore, hot compost “bins” are built above the ground.
3. Organic materials are put in as alternating layers to better ensure a mixture and aeration of the pile.
4. the pile needs to be “turned” or mixed up in order to bring the less-processed materials from the outside, to the inside, and to add oxygen to the pile. This should be done about once per month.
5. The pile needs to be kept moist, in order to promote microbial growth, but not too wet (causing anaerobic conditions)

Goal

To build a compost bin out of locally-available materials

Materials

Wooden stakes, roughly 1.5m tall and 4-5 cm diameter

Plastic twine

Large knife for cutting branches for stakes

Plastic tarp covering

Succulent fresh weeds, banana leaves, almost any succulent plant materials

Cow dung

Lime

Steps

1. Layout an area about 1.5 x 1.5 m, some distance from the house
2. Cut between 30 – 40 straight wooden or bamboo branches from surrounding trees; each should be about 1.5 m tall. The four corner posts should be the biggest and somewhat taller
3. Insert and/or pound into the ground with a hammer in order to make a wooden cage. Spaces between branches should be 2-3 cm. Tie a horizontal branch from each of the four corner posts, to stabilize the structure. Tie the plastic twine along the horizontal branch, from branch-to –branch in order to further stabilize the structure.
4. Cut succulent weeds from roadside areas, and/or find banana leaves or just about any other leafy materials. Chop these up with a large knife to accelerate the breakdown process.
5. Collect cow dung (chicken and pig dung can also be used—these are higher in N, but also have more odor).
6. Begin with a layer of vegetation about 20 cm in the bottom of the bin; add then a layer of manure, then a second layer of vegetation; then a sprinkling of lime; vegetation; manure; vegetation; lime; etc., until you have reached the top (about 1 m).
7. After every layer of vegetation, tamp down the vegetation in order to compress the pile (not too much)
8. After every few layers, sprinkle a few liters of water on the pile to make the material damp, but not soaking wet
9. After the layers are completed, thrust a pole down to the bottom of the pile in 4 to 6 locations in order to create an air channel to the center of the pile
10. Cover the top with a layer of coconut fronds or plastic tarp to keep rain from soaking the pile
11. Monitor the pile weekly and add water as needed (if the center of the pile becomes dried out, white and “chalky” it means you need more water
12. Turn the pile on a monthly basis, bringing the outside materials in to the center, and the center materials to the outside.

Exercises Section 3. Soil Management

13. If dung is not available, you will need to layer the pile with urea instead. The pile will be completed when the compost is a dark brown, crumbly consistency, with the odor of fresh earth. This may take three months, depending on the climate.

Once you have successfully created a compost pile, and carried it through to completion, you may want to build a series of compost structures and stock them on a monthly basis in order to create a consistent source of compost.



Photo. Final stages in construction of a compost bin in East Kalimantan (Borneo), Indonesia by IPM farmer participants. A plastic covering was later added to protect the compost from rainfall. Ingredients included local succulent weeds, cow dung and lime.

EXERCISE 31. FARMER-BASED RESEARCH ON SOILS

Background

It is likely that this manual will be used for three or four-day workshops with alumni IPM farmers. The format and pace of the exercises makes the assumption that the participants are already well familiar with the participatory IPM approach practices by them first in Farmer Field Schools. By the time you have gotten to the end of these exercises, there should already be thoughts by the participating farmers of doing season-long (or longer) experiments on their own fields. The facilitator should use this last session to promote a discussion on general conclusions and planning for future activities. This exercise does not intend to tell participants what type of experiments they should do, but rather to remind them of certain methodological points that may make the effort more efficient and less frustrating.

Goal

To provide a forum for discussions on conclusions and an opportunity to plan for future research activities.

Time required

3-4 hours

Materials

Pens

Newsprint

Tape

Steps

1. Begin with a group discussion stating what are the most important conclusions the participants see for the soils training workshop.
2. While still in the large group ask the participants to list the principal issues they see related to the conditions in their specific farming locations. Decide on the 5 (or whatever the number of small groups is) most important issues to explore.
3. Break into small groups and devise, one issue for each group, a plan for carrying out a season-long experiment to investigate the issue.
4. Report back to the large group and discuss the details.

Points to Emphasize

1. **Keep it simple!** The tendency is always to try and test too many factors at one time. The more factors varied in an experiment, the more difficult it is to interpret the results.
2. If the experiment involves putting organic matter back into the soil and evaluating the outcome, realize that **effects may not be easy to see after the first season**. For paddy fields to show a strong response to recycling rice straw, you usually need to wait until the second season. A typical return on your labors to return rice straw is often around a 10% increase in yield beginning the second season, and increasing somewhat thereafter.
3. Look to evaluate a wide range of effects. If farmers wish to test a new method that has effect on their soil system, look at a full range of effects—not just on the yield, but the general appearance of the crop; the incidence of diseases, pests and natural enemies; the effects on the physical factors related to the soils.
4. Plan a time to get together again to go over the next step in carrying out their research plans (usually a couple of weeks pre-planting or pre-harvest).

Appendix A. SOIL SYSTEMS

A.1 SOIL TEXTURE AND STRUCTURE

Soil physically supports the plant while permitting movement for the growing roots, as well as for air, water, and nutrients. **The texture and structure of the soil both influence the amount and the size of the open spaces in the soil,** and therefore influence a host of related factors of critical importance to the soil—principally:

- a. the movement of air, water and nutrients to the roots
- b. the development of an efficient root system it facilitates the by allowing roots and root-hairs to move easily throughout the soil; thus improving the plant’s ability to find nutrients and water.
- c. the removal and breakdown of certain toxins associated with intermediate stages of breakdown in organic matter (especially under anaerobic conditions).

A.1.1 Soil Texture

The ***TEXTURE*** is a rather formal definition that has been defined by soil scientists to facilitate the discussion of soils, and refers strictly speaking to ***the proportion of sand, silt and clay particles*** that comprise a particular soil sample.

Sand is soil particles with diameters from 0.05 to 2.0 mm

Silt is soil particles with diameters from 0.002 to 0.05 mm

Clay is soil particles with diameters < 0.002 mm

Soils may also be described as ***coarse*** or ***fine***; a coarse-textured soil has more sand, whereas a fine-textured soil has more clay. A soil whose properties are equally influenced by sand, silt, and clay is called a ***loam*** or loamy soil.

Soil texture is ***not*** something that can be changed in the short term. It is essentially what a particular farmer is “given” to work with. In the long-term, texture might be changed by events, such as flooding or landslides, in which large deposits of soil from another region are deposited in the soil. Note that the addition of organic matter **does not**, formally speaking, change the texture. It does, however, change the other characteristics of soil, such as structure, water-holding capacity, drainage, nutrient-holding capacity—in fact, almost every important characteristic except texture (this idea can be confusing for farmers and should be approached with care).

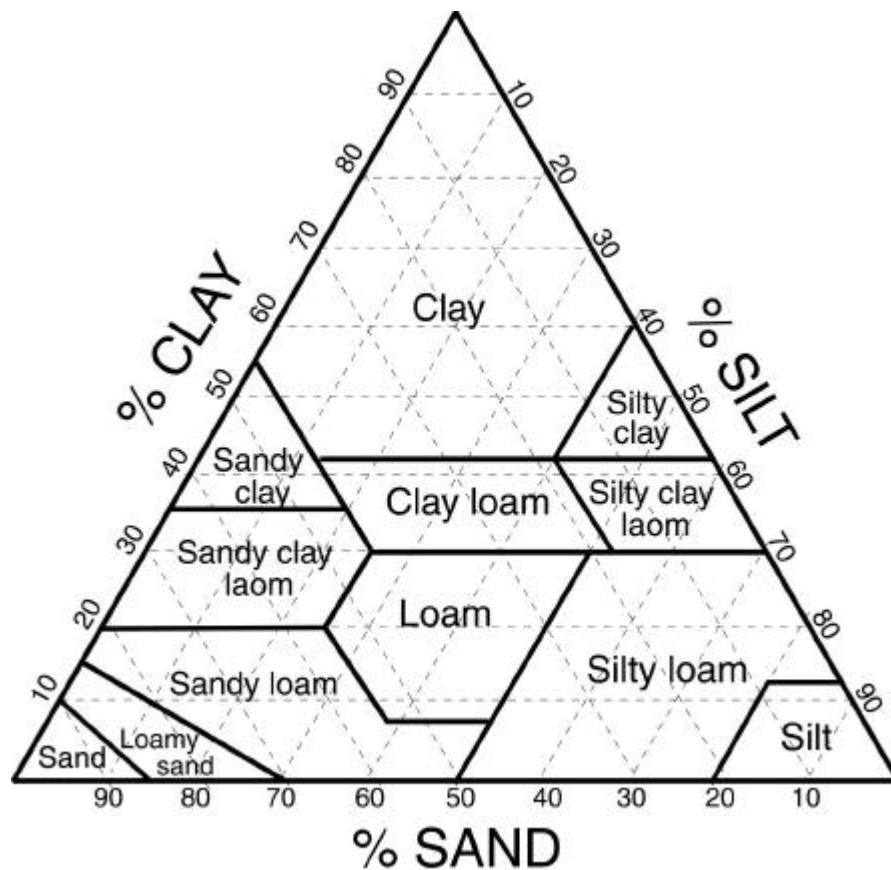
The texture of a soil is directly related to many important aspects of fertility: e.g., the ability of a soil to absorb and retain water, to hold plant nutrients, and directly affects the ability of roots to develop and move through the soil. Soils with a lot of clay are said to be “heavy” soils and tend to hold a lot of water, which tends to move slowly. Soils with a lot of sand are considered “light” soils, and tend to hold very little water, unless they also contain a lot

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of organic matter. Water infiltration (movement) in sandy soils tends to be very rapid.

The soil triangle

This type of graphic is uniquely used for situations where you have three elements in a system that combine to give 100%. In this case, soil texture is comprised of a combination of sand, silt and clay. This graph is probably not appropriate for farmer training, but should be interesting for trainers. The graph is sometimes confusing to read. Just remember that the 10% lines are always the longest, and the 90% lines are the shortest. After doing the soil texture “rolling” test you should be able to classify your soil into one of these categories.



A.1.2 Soil Structure

Soil *STRUCTURE* refers to *the geometry or physical arrangement of the soil particles in relation to each other*. Unlike texture, soil structure can be modified by the farmer by activities such as tillage and water management. Other factors also affect soil structure, such as the action of insects, worms and microbes.

A poor soil structure may result in the need for greater amount of nutrients and a greater amount of water to bring about the same level of plant health, as a soil with good soil structure.

Soil compaction is the condition in which a desirable structure of a soil has been lost—specifically, pore spaces have been compressed. Compaction is a clear sign of a neglected soil. Compaction can be caused by many factors, and is often the result of several factors acting at the same time. Some of these factors include: loss of organic matter; use of granular soil insecticides (e.g., carbofuran) which kill worms and insects; and in mechanized agriculture is a frequent problem caused by the physical pressure of heavy equipment (tractors) moving over the soil surface.

A.2 The Soil Profile

Soil characteristics, such as texture and structure can be examined from small samples taken from the field, but it should be recognized that these are then being considered independently from the actual field conditions. In the field, the behavior of soil systems depends on characteristics of soils at several levels or depths. The analysis of a soil profile is an examination of the vertical distribution of soils. Classification of such systems is takes up much of typical soil science texts, and tends to be highly complex in nature.

In its simplest form, we can consider two layers of soil: a topsoil and a subsoil. The topsoil character can differ dramatically from what is found in the subsoil and therefore it is difficult to predict what a soil profile might be by simply examining the top soil.

A.3 Drainage

Fresh rainwater carries dissolved oxygen needed by the soil, as well as nutrients needed by the plant. So the soil must be *porous* enough to permit good drainage and to prevent the water from standing and becoming stale. If drainage is too rapid, however, the soil will lose both the plant nutrients (be subject to *leaching*) and water. If the drainage is too slow, nutrients will be depleted in the areas surrounding the roots, and not be replenished at a rate adequate to the needs of the plant. Slow drainage also may cause *toxicity problems* related to *anaerobic* conditions (lack of oxygen), leading to build-

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up of intermediate breakdown products such as alcohols and acids that are toxic to the roots. ***Poor drainage (too fast or too slow) is a major cause of poor plant growth, but often one that farmers often don't appreciate sufficiently.***

Drainage at a particular location integrates several factors: clearly drainage is related to both the structure and texture of a soil. Furthermore, the drainage at a particular location will be related to the soil profile.

Ideal drainage may be achieved in a soil which contains open spaces of various sizes; wide spaces permit drainage, and small spaces trap water and allow for capillary movement of water.

Plants are continually growing roots into the soil to establish new sites of contact between root and soil. Most roots have a system of smaller and smaller branches, all the way down to microscopic “rootlets”. However, ***the amount of root material in direct contact with the soil is still very small.*** The plant, therefore, depends on the soil's ability to move enough water through the soil, in order to bathe the roots in water, food and oxygen.

The texture of a soil is not easy to change—the only way to do so would be to bring in a large measure of sand or clay, depending on what the soil lacked, and this would not be feasible except in a very small garden plot. The structure of the soil, however can be changed somewhat. One long-term goal of soil dryland soil management is to encourage the formation of **aggregates** of varying size. We often say that the soil has good “**tilth**” or a “**crumb**” or a “**granulated**” structure if it is well-aggregated.

Soil aggregates are particles of soil material—minerals and organic matter—bound together. Aggregation occurs in two phases: **formation** and **stabilization**. The aggregates are formed by alternating cycles of hot and cold, or wet and dry. These alternating cycles cause the particles to clump together (forming the aggregate), but unless the aggregates are “stabilized”, they will quickly dissolve in the soil water. The clumps may be stabilized directly by the action of soil organisms (for example fungi, which physically surround the aggregate) or by cementing agents created from decaying organic matter, bacterial action, or even by soil passing through the gut of worms.

Plant roots also encourage soil aggregation. Roots pushing through the soil, together with dead roots, which cause cementing, help to form soil aggregates. Grasses and grains are particularly effective in promoting good soil structure, owing to the extensive network of their root system.

Soil organic matter (SOM) has a very significant positive effect on soil structure. SOM provides the raw materials for the cements which bind and stabilize soil aggregates, plus it stimulates the growth of micro-organisms and soil animals that contribute to aggregate stability. Residues high in carbohydrates are best in promoting stable aggregates. For example, straw is considered to be more effective than cow dung because it has more carbohydrates. Some people suggest that one of the most important benefits of SOM is the effect it has on soil structure.

Three practices are necessary to encourage a good soil structure:

- ⇒ keep some kind of crop growing as much as possible throughout the year, to encourage maximum root growth;
- ⇒ recycle crop residues to replace carbohydrates lost through biological activity; and
- ⇒ minimize disturbance of the soil which would reduce biological diversity and accelerate the destruction of soil structure and organic matter.

A.4 Tillage

Tillage is the turning over of the top soil by mechanical action. It can sometimes improve soil structure by breaking up clods, and it can contribute to forming soil aggregates. This is most important for rainfed crops, but not for irrigated rice, in which soil structure is not as important.

In rainfed crops, tillage can also be damaging to the soil. For example, when the soil is too dry, tillage shatters or breaks up the soil aggregates. When the soil is too wet, tillage it compacts the soil. Tillage turns under and destroys the root structure of plants, leaving the most important top soil exposed to erosion by wind and water.

Moisture conditions during tillage are especially important with heavy clay soils. These soils should be moist when tilled but not sticky. One criterion for estimating the best time for working a clay soil is that it should be just dry enough that a person can walk into it without soil sticking to the shoes. Another is that a handful of soil squeezed into a ball should have no excess water running out and should crumble slightly when released.

Tillage tends to dry out a soil and must be timed carefully. Rewetting , especially after a long period of dryness, causes a flush of biological activity which rapidly uses up the organic matter. Rototillers tend to be very hard on non-flooded soils. They dry it out; they whip it up and shatter the aggregates; they destroy the capillarity; they compact the subsoil; and they destroy the earthworms and other soil animals.

A.5 What is soil pH?

The “pH” of a soil refers literally to the “Potential Hydrogen” and is a measure of the soil acidity. Technically, pH refers to the amount of hydrogen ion (H⁺) present in the soil water (or any kind of liquid), measured on a logarithmic mathematical scale. The technical description of pH is not important for our purposes. The important aspect of pH from a training perspective relates to how pH affects soil chemistry and plant nutrition, how to measure it, and how to manage it.

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The pH is a scale of measuring acidity that goes from 0 to 14. A low pH (0-5) is acidic, and a high pH (9-14) is “basic” (lacking H⁺). The range of 6-8 is considered roughly “neutral” pH.

In many areas of the tropics we have acid soils (we have seen soil pH as low as 4.0 and heard of pH as low as 3.0). Soil acidity does not hurt the plants directly, but rather, it affects the *availability* of nutrients to the plant (this is also true for soils that are too basic).

We have also used a more general analogy: imagine the soil is like a “pantry” or some other local cabinet-like structure used in peoples homes to store food. In order to be able to “eat”, the pantry needs to have food in it (a sandy soil or a soil under high rainfall conditions often has the nutrients leached away—the “pantry” is empty). Putting soil organic matter back into the soil is like “stocking the pantry”. A ideal soil with a good mixture of sand, silt, clay and organic matter is like a large pantry that is stocked with many kinds of food. If the soil pH is too low, or too high, however, this is like the pantry becoming increasingly smaller—there is no room for food, and if you try to add food to the pantry, the food must go somewhere else.

A.5.1 Improving Acid Soils

Lime is the most common material used to improve acid soils. Lime in pure form is calcium carbonate (CaCO₃). What is important in lime is not the calcium (Ca⁺⁺), although calcium is a required nutrient for plant growth. Rather, it is the carbonate (CO₃⁻) that improves acid soils. It does this by combining with the hydrogen ion (H⁺). Each carbonate molecule combines with two hydrogen ions, and in this way the lime “cleans up” the excess H⁺ and raises the soil pH toward neutral.

The formal description of the reaction goes as follows:



for every two molecules of calcium carbonate, 3 ions of hydrogen are taken up (lowering the pH), producing 2 ions of calcium (which are now available for storage in the soil, or uptake by the plant), and one molecule each of bicarbonate and carbonate.

The amount of lime needed to raise soil pH to a neutral status depends on the type of soil and on the initial pH. Below is a rough guide to raising soil pH.

pH	Lime T/ha
4.0	10.24
4.1	9.76
4.2	9.28
4.3	8.82
4.4	8.34
4.5	7.87
4.6	7.39
4.7	6.91
4.8	6.45
4.9	5.98
5.0	5.49
5.1	5.02
5.2	4.54
5.3	4.08
5.4	3.60
5.5	3.12
5.6	2.65
5.7	2.17
5.8	1.69
5.9	1.23
6.0	0.75

A.6 THE CRITICAL ROLE OF SOIL ORGANIC MATTER

A.6.1 Soil Organic Matter

We have been looking at the distribution and flow of nutrients in ecosystems. We have learned that for Oxygen, Nitrogen and Carbon, the primary reservoirs are the atmosphere we breathe. We also learned that while oxygen and although Nitrogen must be processed by microorganisms living in plants and the soil before being accessible to the plants. For all other nutrients, the living plants and animals and the soil are the primary reservoir.

For all these nutrients, once they enter into living organisms, they tend to circulate, moving through the food web as organisms are eaten by other organisms. For example, nutrients initially taken up by plants might be eaten by an herbivore, which itself might be eaten by a predator, and so on. At each stage or “trophic level” (meaning “feeding level”) energy and nutrients can be transferred in only a few ways: a certain fraction of the original plant or animal is passed on to the next trophic level, or returned to the soil—either directly, or in the form of waste products from digestion. In the case of energy, all organisms “respire” (breathe) and here energy in the form of heat and CO₂ is lost to the atmosphere. Unless the nutrients are physically removed from the system (such as happens with products after harvest), eventually, everything living dies and comes back to the soil. What happens then should be of interest to farmers because this soil organic matter (SOM), plays a critical role in the functioning of the ecosystem, and in the health of the soil and crops.

Soil OM is actually comprised of two parts: the living and the dead. The living parts include the “**microorganisms**”: the **bacteria, viruses, fungi**, plus a great many a host of larger animals like worms, termites, and beetles. Of greatest concern to us in this chapter, however, are the microorganisms (also called “microbes”), for these animals are responsible for the majority of the processing that takes place when a dead animal or plant enters the soil system.

“Feed the Soil and Let the Soil Feed the Plant”

A.6.2 Soil Microorganisms: “farmers’ friends”

The majority of soil-living organisms are bacteria and fungi and nematodes. While farmers may know that some of these organisms are the cause of disease for their crops, but actually, the vast majority of them serve a positive role. Many of the fungi serve to breakdown and process dead OM into smaller-and-smaller components. These organisms are called “**saprophytes**”. Many of the bacteria serve a useful function in transforming nutrients into forms that are then able to be absorbed by the plant roots. Still others—both fungi and bacteria--may act as predators and parasites to help protect the plant roots from attack by diseases and pests. In other words, just

like in the above-ground system, there exist pests and natural enemies in the soil system as well!

A.6.3 Soil Organic Matter acts as a “Buffer”

Many farmers may think that by adding inorganic fertilizers (NPK) to their soils they are “feeding their plants”. In fact, as long as there is good soil organic matter in the soil, inorganic fertilizers do not go to the plant directly, rather 80-90% of the inorganic fertilizers are taken up into the life cycles of the Soil Microbes as these microbes grow and multiply. Only when the microbes die are the nutrients from their decomposing bodies broken back down into small molecules and freed into the soil to be taken up by the plant roots.

In exactly the same process, most of the nutrients from the breakdown of SOM itself will be taken up by growing populations of microbes. So we see that all nutrients, whether organic or inorganic, tend to be taken up by soil microbes first, before becoming available to the plant.

In this way SOM, together with the microbes that feed on it, will bind or capture nutrients in a form that allows the stable longer-term storage of nutrients, and their slow release into the soil and eventually into the roots of the plant. This is a much more efficient way to feed the plant because nutrients are released a little at a time over a longer period of time.

In contrast, soils with little or no SOM also have poor populations of microbes. As a direct result, the nutrients and microbes that process them are not available. Therefore, if farmers add inorganic fertilizers to their soils, the nutrients will float around in an “unbound” or free form. Some nutrients will be taken up directly by the plant roots, but the large majority will be lost to leaching by rainwater or irrigation water, or—in the case of N—volatilization and denitrification back into the atmosphere. In addition, the plant may be “flushed” with nutrients very quickly. Too much fertilizer, entering the plant too quickly, can cause problems with disease and with lodging (see section on “too much N”).

A.6.4 Why does Soil Organic Matter promote microbe growth?

We have learned that plants take their carbon directly from the atmosphere, but are dependent on Nitrogen and other nutrients that are processed by microbes in the soil ecosystem. Microbes also need carbon for energy and Nitrogen for building proteins (although a certain group of them can “fix” nitrogen directly from the atmosphere). Unlike plants, however, microbes cannot get their carbon directly from the atmosphere. Instead, they are

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dependent on plant residues for their source of energy in the form of carbon compounds.

This is why returning plant residues to the soil is critical for maintaining the health of a soil and the productivity of a farming system: putting residues back into the soil feeds the soil microbes, which in turn, feed the plant

A.6.5 Carbon—Nitrogen Ratio

One of the most important characteristics of Organic Matter is the amount of carbon compared with the amount of nitrogen (or the ratio of Carbon to Nitrogen, written as C:N). As we have discussed, microbes have need for carbon for energy, and Nitrogen for growth and development. The bodies of bacteria have a certain ratio of C:N, usually about 8:1. However, different kinds of organic matter have different ratios of C:N. Almost always Organic Matter is much higher in Carbon than in Nitrogen. Rice straw, for example, has a C:N ratio of about 200:1. What occurs when a large amount of OM, with a high C:N ratio, is added to the soil is that microbes initially grow quickly in the presence of a new energy (carbon) source. However, as the Nitrogen in the OM is used up, the microbes draw upon the Nitrogen available in the surrounding soils. This brings them into a competitive relationship for any plants that might also be in the same soil. This can cause nitrogen deficiency in the developing crop if low-Nitrogen SOM is added to the soil just before planting the crop. Therefore farmers must be careful adding “unprocessed” plant residues.

This problem can be avoided in several ways:

incorporate the straw into the soil several weeks before planting the crop

add Nitrogen, in the form of urea, to the soil together with the straw

compost the straw first for several months before adding back into the field (compost has almost the perfect balance of C:N for soil microbes).

A.6.6 Anaerobic Decomposition and Poor Drainage

Because oxygen movement is 10,000 times slower in water than in air, the oxygen supply from the air cannot meet the oxygen demand of “**AEROBIC**” (or oxygen-breathing) organisms in the soil; hence, the development of “**ANAEROBIC**” (or lacking oxygen) conditions in about 2 hours after the flooding of a field.

Flooding a field causes the death of many organisms, and therefore the release of nutrients locked up in their bodies.

In an anaerobic environment, ammonia and ammonium (NH_3 and NH_4^+) are stable products of nitrogen metabolism in bacteria, however nitrate (NO_3) is rapidly denitrified and lost back into the atmosphere as N_2 gas.

Low yields in China have been attributed to poor drainage. For heavy clayey paddy soils, which are derived chiefly from alluvial and lacustrine deposits (like the Jalur Pantura in northwestern Java), poor yields are attributed to generally small pore spaces, which are poor in aeration and permeability, although good in water retention ability.

To improve soils with poor drainage, to promote their fertility, and ultimately increase rice yields, it is essential to provide proper drainage, thereby improving aeration in the root layer. Drainage is not only effective in improving soil characteristics, but also a practical technique for substantially increasing rice yields—as proven by many experiments in China and elsewhere.

Drainage conditions also inevitably affect the decomposition and accumulation of organic matter. There is always a greater accumulation of organic matter in poorly drained paddy soils simply because it does not break down as rapidly (fewer microbes). Under good water regime, soil OM plays an active part in the improvement of physical properties of paddy soil. On the other hand, with a poor water regime (poor drainage), it is difficult to improve soil physical properties and increase soil fertility by raising the content of soil OM.

Appendix B: Principal Nutrients

B.1 Nitrogen

N is the symbol for the atom **NITROGEN**. N is an essential nutrient for all living plants and animals, and in a manner of speaking N represents the “action” of life. N controls the movement of energy and materials and the growth of the plant by its large contribution to every complex protein (e.g., chlorophyll, enzymes, hormones).

The major reservoir for nitrogen is in the atmosphere. Roughly 80% of the air we breathe is nitrogen gas (two atoms of N, or N₂), but neither animals nor plants directly take up N₂ from the air. The reservoir of nitrogen is only very slowly cycled into the soils and water via the action of microorganisms that **FIX** the nitrogen from the atmosphere into the bodies of the microorganisms themselves. These microorganisms live mostly in the soil, but some live inside plants. When nitrogen is fixed, it is taken into the bodies of certain types of bacteria, and used directly by them to help grow more bacteria. When these bacteria then die (bacteria do not live a very long time), the nitrogen, in the form of **PROTEINS** and **ORGANIC MOLECULES** and along with other nutrients in their bodies are then broken down by the action of other **SAPROPHYTIC** (decomposer) bacteria and fungi, which use these nutrients in their own growth, but also release part of the nitrogen into the soil in forms that can be taken up by plant roots and by other microbes. The process of decay of dead organic matter, thereby releasing nutrients to the surrounding soil is called “*mineralization*”. The process of nutrients again being taken up and incorporated into the bodies of living microbes is termed “*immobilization*”.

The principal pathway for N₂ to enter living organisms from the air is via certain types of bacteria. Many of these bacteria live in soils. Others, like **Cyanobacteria**, live in aquatic systems like rice paddies, inside the cells of specific kinds of algae (blue-green algae). Cyanobacteria in a rice paddy may fix up to 100-150 kg N/ha/year. Other bacteria, such as those of the genus **Rhizobium**, live inside the roots of leguminous plants, and still others live inside the leaf cells of plants, like *Sesbania*. The reason Cyanobacteria and Rhizobia are so successful at fixing large amounts of nitrogen is because each has access to large sources of energy. The Cyanobacteria are associated (live inside of) algae. Through photosynthesis the algae is able to offer the bacteria carbohydrates (C), and in return, the bacteria fix nitrogen, some of which benefits the plant. In a similar manner the Rhizobium bacteria are associated with the roots of plants, receive food (carbon) from the plant roots, and “pays back” its host with nitrogen.

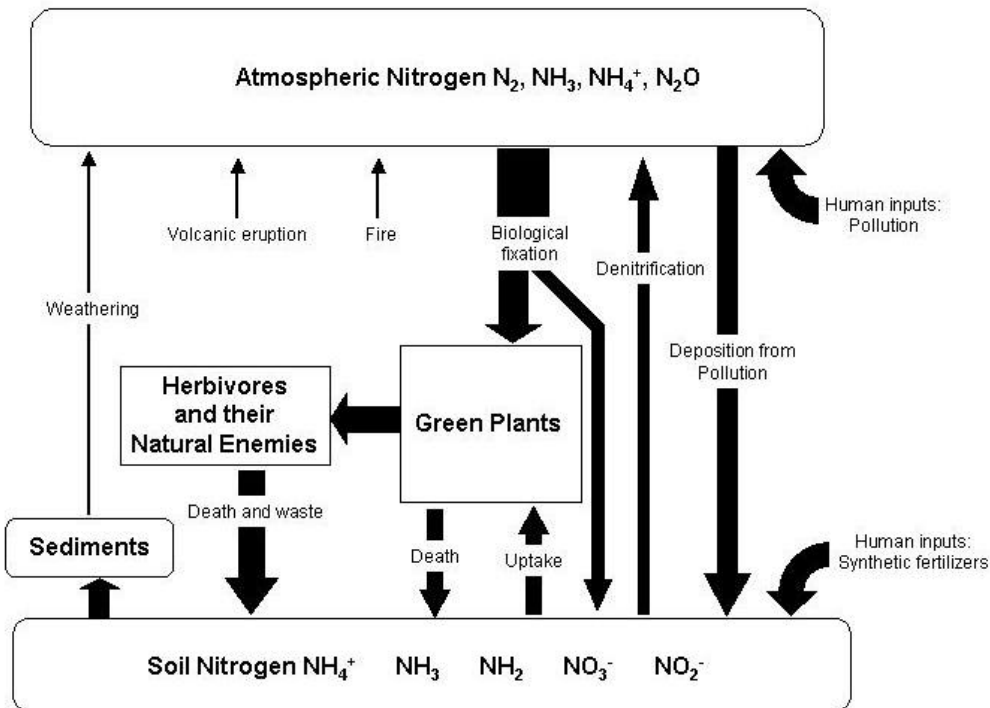
As a result of the limited paths whereby N finds its way into living systems, of all the soil nutrients, N is the most likely to be lacking in the soil. Yet all life requires N in large amounts; as a result, natural supplies of N are almost always limited, and most plants are very good at competing for N.

The nitrogen cycle

It is one of the mysteries of life that although nitrogen is needed by all living things in fairly large amounts, and although our atmosphere is a huge reservoir of nitrogen, the

paths by which nitrogen can enter ecosystems are very limited—the doorway opens through a few species of bacteria. As a result, nitrogen tends to be a **limiting nutrient** in the growth and development of many organisms, most especially plants. A limiting nutrient is the one (and by definition, there is only one at a time) nutrient that is in greatest demand and whose absence slows the entire process of growth.

Nitrogen can take several forms in the soil, depending on how it combines with other atoms. In addition to the many forms in which nitrogen is found in living things, nitrogen can be found in inorganic forms in the form of nitrogen salts: ammonium [NH_4^+], nitrite [NO_2^-], and nitrate [NO_3^-]. Like any salt, all three forms of Nitrogen salts are highly water soluble and as a result can be found most anywhere on the surface of our planet. The Nitrogen salts are very actively cycled and recycled back and forth between inorganic forms and organic forms. The two main forms accessible to uptake by plant roots, and therefore the forms we will focus on, are NH_4^+ , and NO_3^- .



Synthetic nitrogen is applied at a rate of about 40 million tons per year, world-wide. Deposition (entry into the soils) of nitrogen from pollution is roughly 100 million tons per year. This is mostly in the form of nitrous oxide (N_2O , one of the “greenhouse gases”) and ammonium (NH_4^+) in “dry deposition”, and in the form of nitrate (NO_3^-) and ammonia (NH_3) in wet deposition (rainfall). Nitrogen input to soils from pollution can be as much as 40 kg/ha per year. Biofixation of N accounts for roughly 140 million tons per year world-wide.

Too little nitrogen

If nitrogen in the soil is low, almost all plant functions are disturbed and the most direct result is that plant growth is stunted and pale green to yellow. Four nitrogen atoms surround a single magnesium atom to form the core of the chlorophyll molecule; hence, limited nitrogen reduces the photosynthetic capacity of the plant. Nitrogen is highly mobile in plants, so when nitrogen is low it drifts from older leaves to newer leaves and the older leaves will turn light green, yellow or even pink. This is one good indicator of nitrogen deficiency, although you have to be careful not to get this confused with one of several diseases or even soil drainage problems.

Too much nitrogen

Too much nitrogen can be poisonous to a plant. If too much nitrogen is present, the plant diverts energy, carbohydrates, water and minerals in an attempt to digest and get rid of the excess nitrogen. As a result, a plant's health is thrown out of balance by too much nitrogen. Too much nitrogen causes:

- ⇒ plants to become overly succulent,
- ⇒ tubers to become watery and rot,
- ⇒ rice plants to become too tall and weak and “lodge” (fall over),
- ⇒ flowering and fruiting may be delayed,
- ⇒ fruits to ripen unevenly,
- ⇒ fruit vitamin A and C content to drop,
- ⇒ increased problems with disease and insect pests (for example, sheath Blight and many kinds of sucking insects do better on plants having very high levels of N)
- ⇒ leafy vegetables like lettuce to build-up toxic nitrates in the leaves (nitrates and nitrites have been shown to cause cancer in animals, and exports of leafy vegetables from some countries have been cancelled after laboratory analysis shows nitrates to be above a certain safe limit.

Inorganic” nitrogen: urea

Urea is considered an “inorganic” or “artificial” form of Nitrogen. In fact, the origins of urea are from natural, organic substances. Urea derives from **NATURAL GAS**, which is taken out of the ground in much the same way that people drill for oil. The fact that natural gas takes millions of years to be created means that once we use up the natural gas we find in the soil, we will not be able to find more. For this reason we call natural gas (and therefore urea) a “**non-renewable**” resource. Urea was created from organic substances that millions of years ago were trapped in soil sediments under anaerobic conditions and therefore never had a chance to be decomposed completely. Urea is made up of two molecules of (NH₂) tied together with a carbon and oxygen atoms (CO), so the molecule is written as CO[NH₂]₂. When urea is added to soil it is broken down by water into two molecules of ammonia (NH₃), and CO₂ is released in the process. For urea to be decomposed into ammonia requires the action of microorganisms.

Several studies have been done through the years using “labeled” nitrogen, that is, nitrogen with a special mark on the atom, so researchers can follow exactly where

specific nitrogen atoms goes. These studies show that when urea is applied to the soil in a rice field, ***under the best of conditions***:

- ⇒ 20% ends up in the grain,
 - ⇒ 12% ends up in the straw,
 - ⇒ 3% in the roots,
 - ⇒ 23% is left in the upper 30 cm of the soil, and
- the remaining 40% is lost through denitrification and through leaching.

Nitrogen loss from the soil

“Volatilization” of ammonia can take place in the soil when it simply evaporates into the air and is just carried away. This happens after heavy applications of manure, and it can occur when urea or ammonia fertilizer is used if the soil pH is high. Recent research, however, has shown that losses can be reduced by adding calcium or potassium salts to the soil.

“Leaching” is the washing out of a nutrient from a soil whenever excess water percolates through the soil, carrying with it any dissolved nitrogen. The best ways to minimize nitrate leaching are to promote biological activity with carbon-rich residues and to maintain a good plant cover, like a green manure. The leaching of dissolved organic materials carries away not only nitrogen but also phosphorus, sulfur and trace elements. To minimize leaching, the soil pH should be maintained near neutral. This maximizes biological activity, which aids in the stabilization of soluble organic substances. Also the calcium in the lime is a good binding agent and reduces the instability and solubility of organic residues.

Farmers remove nitrogen from the field every time they harvest the crop. A large proportion of the nitrogen in animals and plants is used in the making of proteins. Therefore, in most plants this means that the majority of the nitrogen ends up in the seeds. As a result, when a rice plant is harvested, 70% of the nitrogen in the entire plant is taken away in the form of the harvested grain, leaving only 30% remaining in the roots and straw.

“Denitrification” is often the most important cause of loss of nitrogen. Denitrification is the return of nitrogen to the atmosphere takes place when three conditions are satisfied: 1) nitrates (NO_3^-) must be present, 2) organic matter must be present (in order to support the bacteria that transform or “denitrify” nitrates back into N_2 gas, and 3) conditions (at least in pockets) must be anaerobic (low oxygen).

Too much organic matter can encourage denitrification, because an excess produces enough biological activity to use up all the available oxygen. The amount of OM residues that can cause denitrification depends on the texture of the soil and the coarseness of the organic residues. An open sandy soil can absorb more compacted organic residues than a clayey soil.

Usually, ***the more one tries to force nitrogen into the soil, the greater the losses of nitrogen from the system***. If a soil is overfertilized with nitrogen, it may find a way to get rid of the nitrogen almost as fast as the farmer puts it on. If the nitrogen is spread in ammonium form, the soil may either cause it to be volatilized or to be

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rapidly nitrified (converted to nitrate form) and soon afterward lost as a gas by denitrification. If the nitrogen is initially in nitrate form, it may be denitrified, or it may be leached into the groundwater. The leaching of synthetic fertilizers into lakes, rivers and oceans has had a major negative impact due to the stimulation of “algal blooms”, whose subsequent death and decay by microbes robs the water body of oxygen, often causing massive fish kills.

These facts, coupled with the fact that nitrogen fertilizers are often a significant cost to farmers, are very good reasons why farmers need to learn how to better manage their nitrogen inputs.

B.2 PHOSPHORUS (P)

Short-term storage of energy: ADP & ATP

Phosphorus (P) is one of the major nutrients that farmers apply when they buy inorganic fertilizers. P has several important roles, notably it is important in the construction of the genetic material, DNA (hence, is found in important concentrations in seeds). Also, P is associated with the short-term storage of energy captured from the sun.

ADP & ATP: the “rechargeable batteries” in the plant

One role of P is to act as the energy transfer agent. It works as such by being attached (or unattached) to a small, but very important molecule. The ADP (Adenosine di-Phosphate) molecule has two phosphates attached (di = two). The ATP (Adenosine Tri-Phosphate) molecule has three phosphates attached. Attaching the third phosphate atom to ADP to make ATP requires (and thereby stores) energy. Similarly, when the ATP molecule has a P “broken off”, it gives up energy that can be used by the plant. In other words, ADP is like a battery with the charge gone out, and ATP is like a charged battery.

The energy-charged ATP molecule can and does go everywhere inside the plant, from the smallest root to the tip of the flower, to the inside of the grains. The ATP molecule is used by every cell in the plant to give up energy in order that the cell can do its work. In fact, ATP is found, not only in every plant, but in every animal on earth! It is the “common currency” of energy transfer for all life on earth, from the smallest bacteria to the largest whale or the tallest tree.

Behavior in the soil

The amount of P found in surface soils ranges from about 200 kg/ha in sandy soils, to about 2,000 kg/ha in soils derived from rocky subsoils. Chemical weathering results in *solubilization* of orthophosphate (H_2PO_4^-) and $\text{pH} < 7.2$ and HPO_4^{2-} at $\text{pH} > 7.2$. This is the form in which phosphate is available to the plant, and usually accounts for not much more than 1% of the total phosphorus in the soil in any location. This is because the release of orthophosphate (either through solubilization or by application

of phosphate fertilizers) is followed by *precipitation* (the forming of insoluble solids from chemicals in solution). Phosphorus goes out of solution in the form of iron and aluminum phosphates in acid soils, and calcium phosphates in basic soils. These reactions result in low orthophosphate concentrations at pH levels above or below about pH 6.5.

Another source of phosphorus is from organic matter. Total organic phosphorus accounts for usually between 30—50% of total soil phosphorus, and the *microbial pool* (total amount of living and dead microbes) represents the majority of the actively cycling pool of phosphorus.

Not enough P

Seeds contain a large amount of P, so a deficiency in P might be indicated by plants with small seeds. P also stimulates root growth. This can be shown by putting a small source of P in the soil near the plant roots and then digging down to observe the roots in the area of the P. They should be longer, stronger and with many fine root hairs.

P is not taken up by the roots as well as is N, so P can be overwhelmed by too much N. P is very rapidly bound by several factors in the soil, so any free P taken up by the plant must come from very close by the roots. One problem with P is that it is not very “soluble” (able to be broken into small molecules and to move through the soil and water). In a soil which has a good amount of oxygen (“aerobic” conditions) P is more soluble. One benefit from the solubility problem is that it takes a very long time to leach P from the soil. Hence, *farmers that add P every season may have built up much more than they need.*

Factors affecting P movement

The pH of a soil affects mobility (movement). If the soil is near neutral (pH 6.5-6.8) then P optimally available to plant roots. Highly acidic or basic soils have almost no P available to the plant, except that which is released from decaying organic matter. Organic matter and associated microorganisms have a strong influence on P availability. P released from decaying organisms is readily available for uptake by plants. For example, P is picked up by fungi and spread throughout the mycelia, and therefore spread throughout the soil. When the fungi dies, this P is immediately available to plant roots. Furthermore, many soil microorganisms release acids which are good at dissolving inorganic P. Finally, mycorrhizae (a type of fungus associated with almost every plant) invades plant roots to extract carbohydrates. In return, the fungus passes on minerals, including P, to the roots. *Fungi helping roots with P extraction is analogous to bacteria helping roots by fixing N.*

Maintaining enough P in your soils

The best ways to ensure enough P is available is: 1) keep the pH near neutral, 2) assure sufficient water, and 3) promote high populations of microorganisms by maintaining a good regime of organic matter returning to the soil.

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B.3 POTASSIUM (K)

Potassium (K) is the third major nutrient often added to soils by farmers. Unlike the other nutrients, K is not found inside plant cells, but exists in the fluids that move through the plant. K affects the “osmotic pressure” of the plant, by keeping the plant fluids balanced in terms of salts and water movement. When K is deficient, water fills the cells and they become soft and the plant loses strength. Plants deficient in K tend to be more susceptible to drought, insects and disease.

Potassium is involved in photosynthesis, in the creation of starch in roots, and in the creation of proteins. K is especially critical for root crops.

Plants are better able to uptake K compared with Phosphorus (P) or Magnesium (Mg). In fact, ***a plant will absorb as much K as there is available, even if it doesn't need it.*** As a result, too much K causes deficiencies in the other nutrients because the plant is too busy taking up K to take up the others, even though it may need the others more!

Two mechanisms account for the fact that K is not rapidly leached from soils:

- 1) it is very small and gets trapped in cracks in clay particles (but also isn't much available to roots as a result), and
- 2) K is attracted to the surface of clay particles and organic materials (see exercise on the structure and function of clay particles).

With a steady program of recycling organic matter, potassium will not be a problem. As an example, almost 98% of the potassium in a rice plant is found in the straw. Therefore, as a general rule, if the carbon-to-nitrogen ration (C:N) is high, so too will be the potassium-to-nitrogen ratio (K:N).

Nutrient	Crop Plant	Deficiency Symptom
NITROGEN	General	Nitrogen deficiencies are most common on soils highly depleted of organic matter, but N is often the most limiting crop nutrient and symptoms can occur in any soil where yearly inputs of N are low.
	Legumes	Since most legumes can supply their own N needs through symbiotic fixation, deficiencies generally do not occur unless the rhizobial symbiosis is not functioning effectively. N-deficient legumes have pale green or yellow leaves, starting with the lower leaves.
	Maize, Sorghum, and Small Grains	Young plants are stunted and spindly with yellowish-green leaves. In older plants, the tips of the lower leaves first show yellowing up the mid-rib in a "V" pattern, or there may be a general yellowing of the entire leaf. In severe deficiencies, lower leaves turn brown and die from the tips onward.
	Vegetables	Tomatoes first show stunted growth and loss of normal green color in the younger, upper leaves; the whole plant gradually becomes light green to pale yellow; veins begin to develop purple color. Flower buds drop and fruits are undersized. Cucumbers and squash first show leaf stunting and a loss of deep green; stems are spindly and fruits are light in color. Other vegetables show a general leaf yellowing.

PHOSPHORUS	General	Phosphorus is most available at pH or around 6.5. Crops growing on very acid or very alkaline soils often show deficiencies. In many acid tropical soils, P is the limiting factor in crop growth.
	Legumes	Phosphorus deficiency symptoms are not well defined in legumes. Stunted growth, spindly plants and dark green leaves are the main symptoms.
	Maize, Sorghum, and Small Grains	Deficiencies are most likely during early growth; stunting is common, without clear leaf signs. Severe deficiencies cause a purplish color in corn and sorghum, starting at the tips of the lower leaves (disregard purple stems). Small grains show a bronze coloration instead of purple. Ears from P-deficient maize plants are somewhat twisted, have irregular seed rows, and seedless tips.
	Vegetables	Leaves of most vegetables first fade to a lighter color. Tomato and cabbage family plants develop a purple color on the undersides of the leaves or along the veins.

POTASSIUM	General	
	Legumes	In broad leaved legumes like soybeans and field beans, early signs are irregular yellow mottling around the leaflet edges, especially in the lower part of the plant. This turns into a brown, dried margin that may move in to cover half the leaf.
	Maize, Sorghum, and Small Grains	In maize and sorghum, symptoms are rare the first several weeks of growth. Later, the margins of the lower leaves turn yellow and die, starting from the tip. Potassium-deficient plants have short internodes and weak stalks. Ears from K-deficient maize are often small and may have pointed, poorly seeded tips. It is difficult to diagnose K deficiency in small grains.
	Vegetables	Tomatoes will grow slowly and have a dark blue-green color; theyoung leaves become crinkled; older leaves turn dark blue-green and then develop a yellow-green color around the margins. Fruits may show a blotchy ripening pattern. Cabbage plants first show bronzing at the leaf edges which turn down and dry out.

MAGNESIUM	General	Magnesium deficiencies are most common on acid, sandy soils, or soils that have been limed with a material lacking magnesium.
	Legumes	In early stages soybean leaves become pale green between the main veins and then turn a deep yellow, except at the bases.
	Maize, Sorghum, and Small Grains	In maize and sorghum, a general yellowing of the lower leaves is the first sign; eventually, the area between the veins turns light yellow to almost white, while the veins stay fairly green. As the deficiency progresses, the leaves turn reddish-purple along their edges and tips starting at the lower leaves and working upward. Symptoms are not clear-cut in small grains.
	Vegetables	Cabbage, cucumber, watermelon, tomato, eggplant, and pepper are the most susceptible. Tomatoes get brittle leaves, which may curl upwards; the veins stay dark green while the areas between turn yellow and then finally brown.