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.
Exercises Section 1. The Soil System

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
Exercises Section 1. The Soil System

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.

   1. Add water slowly until able to form a ball
      Are you able to form a ball that stays intact?

     - **Yes**
     - **No**

     **SANDY SOIL** (more than 70% sand)

     2. Roll out cylinder

     3. Bend cylinder into circle

     4. Cylinder and circle show multiple cracks?

     - **Yes**
     - **No** (solid with no cracks)

     **CLAYEY** (more than 40% clay)

     **LOAMY** (good mix of sand, silt, and clay)
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.

<table>
<thead>
<tr>
<th>pH Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Low pH</th>
<th>Neutral pH</th>
<th>High pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>OH(^-)</td>
<td>H(^+)</td>
<td>OH(^-)</td>
</tr>
<tr>
<td>OH(^-)</td>
<td>H(^+)</td>
<td>OH(^-)</td>
</tr>
<tr>
<td>OH(^-)</td>
<td>H(^+)</td>
<td>OH(^-)</td>
</tr>
<tr>
<td>H(^+)</td>
<td>OH(^-)</td>
<td>H(^+)</td>
</tr>
<tr>
<td>H(^+)</td>
<td>OH(^-)</td>
<td>H(^+)</td>
</tr>
<tr>
<td>H(^+)</td>
<td>OH(^-)</td>
<td>H(^+)</td>
</tr>
</tbody>
</table>
EXERCISE 8. PARTICLE SIZES AND FORM

Background

In the previous exercise your 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
Exercises Section 1. The Soil System

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.
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.

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

** For simplicity, calculations assumed particles to be spherical and at the large end of the size range.
**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., $\text{Mg}^{++}$, $\text{Zn}^+$, $\text{NH}_4^+$, $\text{Ca}^+$, etc.). If, however, the soil water is highly acidic (too much $\text{H}^+$), then the $\text{H}^+$ 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 or 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 it’s 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
seeds 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 for, 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

Sample A

A B C
Samples
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 CO$_2$,
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.
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?

![Diagram of soil system experiment](image)
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.

<table>
<thead>
<tr>
<th></th>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>Good Movement: water, nutrients, roots</td>
<td>Poor Storage: water, nutrients</td>
</tr>
<tr>
<td>Clay</td>
<td>Good Storage: water, nutrients</td>
<td>Poor Movement: water, nutrients, roots</td>
</tr>
</tbody>
</table>
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 is 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.

<table>
<thead>
<tr>
<th></th>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sand</strong></td>
<td>Good Movement: water, nutrients, roots</td>
<td>Poor Storage: water, nutrients</td>
</tr>
<tr>
<td><strong>Clay</strong></td>
<td>Good Storage: water, nutrients</td>
<td>Poor Movement: water, nutrients, roots</td>
</tr>
<tr>
<td><strong>Organic Matter</strong></td>
<td>Good Movement: water, nutrients, roots</td>
<td>Possible toxic intermediate products in heavy clay soils</td>
</tr>
<tr>
<td></td>
<td>Good Storage: water, nutrients</td>
<td></td>
</tr>
</tbody>
</table>
