# Soil Fertility &
# Organic Components of Soils

## Farmer-to-Farmer Participatory Training Course

### Objectives

- Understand that soil is a complex living system
- Learn about farming practices which can enhance and maintain soil fertility
- Learn about farming practices which can increase the organic matter levels in soil

# Soil Fertility & Organic Components of Soils

## Introduction to Soil Fertility

**ACTIVITY: Have a short buzz (about 5 min where the farmers turn and talk to their immediate neighbors) and have them answer the six questions below.**

**Follow this by a brief group discussion and then present the lecture.**

**1) How do you define soil?**

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______________________________________________________________________
______________________________________________________________________

**Soil** is a natural medium on the surface of the earth in which plants grow. Soil is made up of mineral and decomposed organic matter, along with air and water. Soil can create a habitat for fungi, bacteria and related organisms, which in turn feed and support plant life.

**2) What soil problems do you have on your farm?**

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**3) What farm practices impact soil? Do they impact soil in a positive or a negative way?**

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**4) Rank the negative impact practices in the order in which you think they should be eliminated.**

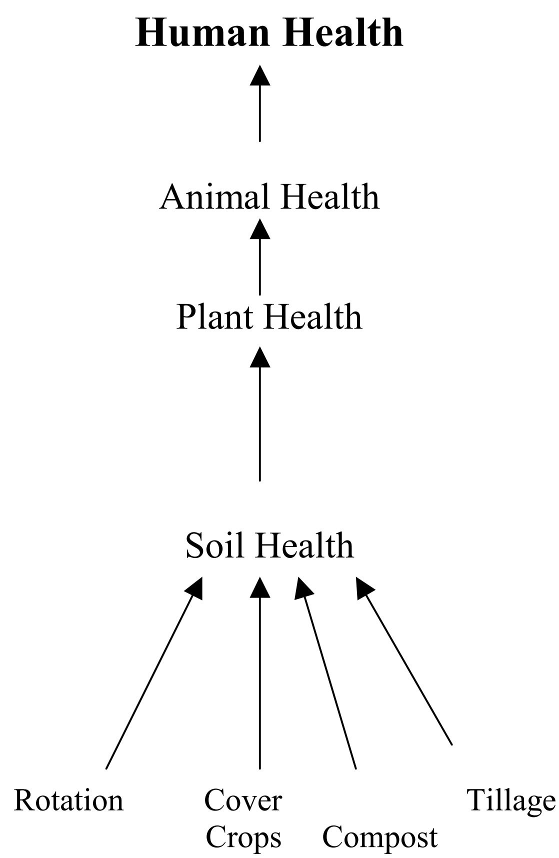
1.____________________________________________________________
2.____________________________________________________________
3.____________________________________________________________
4.____________________________________________________________
5.____________________________________________________________

**5) Rank the positive impact practices in the order in which you think they should be used for the most benefit on your farm.**

1.____________________________________________________________
2.____________________________________________________________
3.____________________________________________________________
4.____________________________________________________________
5.____________________________________________________________

**6) Why is soil health important?**

Healthy soil is fundamental to the quality of food it produces and to the health of those who eat the food produced from it.




## How is soil and loess soil formed?

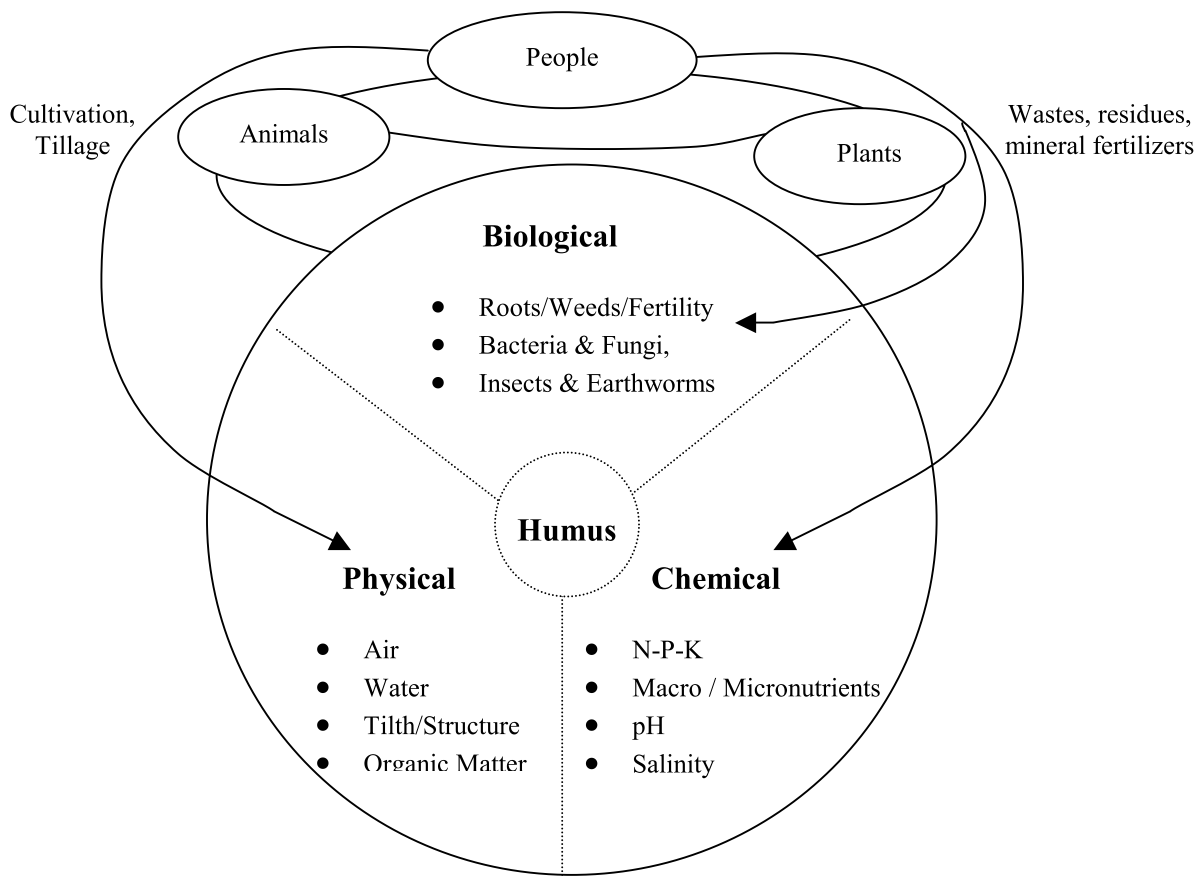
Soil formation is long and complex; it can take anywhere from 100 to 10,000 years to create one inch of topsoil! It is driven by many factors such as climate, topography, living organisms and the types of parent material. Parent materials come from the break down of underlying rock or from deposits by streams and rivers, seas and gulfs, hills, wind and glaciers or organic plant residues. Over time, these materials are weathered by the effects of freezing, thawing, wetting, drying, heating, cooling, erosion, plants, and animals and from chemical reactions. Eventually the parent material is divided into smaller and smaller particles and forms layers. Soil can be divided into three horizontal layers: The top layer consists of mostly organic matter and biological activity. The middle layer is the zone of maximum material accumulation, and the bottom is mainly the parent material, but slightly altered.

The Loess Plateau was created two million years ago by the deposition of wind-blown dust and glacial till. This mass of dust, known for its yellow color, sprawls over many parts of western China, such as Shanxi, Shaanxi, Ningxia, Gansu, and Henan Provinces, and is surrounded by the Ordos Plateau and mountain ranges. It has an average thickness of 150 m, extending to 330 m near Lanzhou. It is the world's largest deposit of loess, approximately the size of France. Because this soil type retains water effectively and contains more nutrients than sand, the loess plateau remains productive despite the seasonally dry climate. However, its silt-like nature makes itself the most erosion-prone soils known on the planet. Loess is extremely sensitive to wind and water, being blown or washed away quicker than any other soil type.

(http://www.mindground.net/loess.html)

## Soil Properties

Crop quality directly depends on the quality of the agricultural soil in which it is grown. The higher the quality of soil, the higher the quality of your crop. To determine how to obtain high quality soil conditions, we must first understand the fundamental properties of soil. These can be divided into three main categories: physical, chemical, and biological.



## ***Physical Properties of Soils***

Soils have three physical properties which affect plant growth: composition, structure, and texture. Although the effects of each are separately listed below, an evaluation of *all* the physical factors must be conducted to determine the net effect of these properties on plant growth.

1. ***Soil Composition -*** Soils consist of a combination of water, air, mineral and organic matter. It mostly consists of mineral and organic matter in varying proportions. Mineral is the inorganic component of soil which includes soil particles (such as sand, silt, and clay). Organic matter is the organic component of soil which includes the residue of dead plants, animals and organisms. It consists of nutrients necessary for plant growth such as nitrogen, phosphorus, and potassium. Soils which contain 30% or more organic matter are considered organic soils; all other soils are identified as mineral soils. A generous amount of organic matter is essential for successful crop production as it is critical to many soil processes (see "Organic Matter" section).

2. ***Soil Texture -*** Soil texture is determined by identifying the proportions of the following components:

   - Sand: large sized particles; particles can be individually seen with the naked eye; 0.05 - 2 mm diameter
   - Silt: medium sized particles; particles cannot be individually seen with the naked eye; 0.002 - 0.05 mm diameter
   - Clay: small sized particles which cannot be individually seen with the naked eye; < 0.002 mm diameter, and
   - Organic matter.

   Relative proportions of these minerals can be estimated by visually observing and feeling the soil. Determination of soil texture takes much experience and skill, but can be improved with practice (see "Deepen Your Understanding" section below).

   Each mineral possesses different characteristics. Thus, the presence or absence of these components can significantly influence soil behaviour in the field:

   - Sand particles do not retain water well; therefore, soils containing much sand tend to allow water to flow through it or evaporate quickly. At elevated flow rates, water could also flush the nutrients in the soil beyond the plant's root zone making it unavailable for plant uptake.
   - Silt and clay particles retain water well but do not allow water to flow through it very quickly. Therefore, it is very hard for a plant to extract water and nutrients from the soil if it contains much silt and clay.
   - Organic matter contains nutrients available for plant uptake, improves water infiltration, decreases evaporation, and increases the water holding capacity (see "Organic Matter" section for further details).
   - Soils which contain a well-balanced mixture of sand, silt, clay, and organic matter retain water well and allow it to flow through the soil at an appropriate rate such that it does not inhibit plant growth. Largely because of the organic matter, it also contains essential nutrients for plant growth. This type of soil, which is the best for agricultural production, is called **loam**.

## Deepen Your Understanding

How well can you describe soil texture?

**Sands**

- Loose, single-grained, gritty to touch, not sticky
- Each individual sand grain can be seen with the naked eye and individually felt
- Cannot be formed into a cast (mold) by squeezing when dry; will form a very weak cast when moist
- Does not retain water well; dries quickly

**Silt**

- Feels smooth and rather silky and somewhat plastic
- Individual silt grains cannot be seen with the naked eye and are so fine that they cannot be individually felt with your fingers
- Forms casts which need to be handled carefully
- Retains water well but releases it slowly; does not allow water to flow through very quickly

**Clay**

- Forms extremely hard lumps when dry and is extremely sticky and plastic when wet
- Can be "ribboned out" to a remarkable degree (conducted by squeezing soil between thumb and forefinger, and may be rolled into a long, very thin wire or "ribbon")
- Retains water very well but releases it extremely slowly; water flows through extremely slowly
- *Silty Clay* contains some silt; feels smooth, nongritty, very sticky, and very plastic when wet
- *Sandy Clay* contains some sand; feels generally smooth with some gritty feeling particles

**Loam** ***(Best type of soil for agricultural production!)***

- Contains a relatively even mixture of sand, silt, and clay
- Relatively soft and crumbly, slightly gritty to touch
- Fairly smooth and slightly sticky and plastic when moist
- Casts can be handled quite freely without breaking
- Retains and releases water at a moderate rate
- *Sandy loam* contains slightly more sand than regular loam; there are more individual grains present which are gritty to touch; forms fragile casts
- *Silt loam* contains slightly more silt than regular loam; when dry, soil forms clumps which can be easily broken between fingers; casts can be formed somewhat freely without breaking
- *Loamy sands* consists mostly of sand, some silt, and even less clay; most of the grains are loose and gritty to touch; slightly cohesive when moist; forms fragile casts

**Clay Loam**

- Sticky and plastic when wet
- Forms casts that are firm when moist and hard when dry
- Moist soil will form a thin ribbon that will barely sustain its own weight when squeezed carefully between the thumb and fingers
- Retains and releases water at a slower rate than loam soils
- *Sandy Clay Loam* contains slightly more sand than clay loam and is less sticky and plastic when wet
- *Silty Clay Loam* contains slightly more silt than clay loams and has a smoother feel

**Organic Soils**

- Made up of plant and animal remains in varying stages of decomposition
- May be generally found in swamps, marshes, and lakes
- Organic matter in soil improves water infiltration, decreases evaporation, and increases the water holding capacity
- Contains carbon and nutrients for plant uptake
- Organic soils can be described as
    - *Muck:* consists of highly decomposed remains of plants and other organisms
    - *Peat:* consists of relatively raw, less well-decomposed organic materials
    - *Peaty muck* and *mucky peat:* consists of materials intermediate in decomposition.

University of Florida, Institute of Food and Agricultural Sciences, http://edis.ifas.ufl.edu/BODY_SS169

**ACTIVITY: Field Trip! Visit some nearby farms.**
1. **Identify the texture of at least two different types of soil.**
2. **Measure how deep the topsoil is. Note the difference between the topsoil and the deeper soil.**
3. **Answer the following three questions.**

**How would soil texture affect the nutrients in the soil?**

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______________________________________________

**How would it affect your crops?**

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______________________________________________

**How would it affect the management of your farm?**

______________________________________________

______________________________________________

3. ***Soil Structure -*** Soil structure is the physical arrangement of all soil components. It is this arrangement which determines how much air and water can be present in, absorbed onto, or flow through the soil. Soils which contain more air space allow greater water infiltration and root penetration; alternatively, soils which contain little air space allow less water infiltration and root penetration. Air spaces can be formed through the movement of earthworms in the soil. Soils with less air space can naturally form compacted layers known as hardpans. This type of soil tends to create drought sensitive conditions as many crops cannot successfully root in the zone below the hardpan resulting in poor plant growth.

## ***Chemical Properties of Soils***

### What is soil fertility?

The fertility of a soil is "its ability to provide nutrients (in adequate amounts and in proper balance) for the growth of plants, when other important growth factors are favorable". For optimum crop production, a soil that enables deep rooting, provides aeration, has a good water holding capacity, and consists of an adequate and balanced supply of plant nutrients is considered a productive and fertile soil.

To maintain fertility in a sustainable ecological farming system, you need to:

- Recognize and respect soil as a complex living system in which soil organisms play an important role in digesting organic matter, leaving soil soluble minerals and $CO_2$.
- Identify farming practices that either impair or enhance soil life.
- Recognize soil life as the focus of our efforts to practice good management.

### What are the major nutrients required for plant growth?

Nitrogen (N), phosphorus (P), and potassium (K) are the 3 most important soil nutrients required for plant growth. In all, plants require sixteen elements, each of which has one or more special function in the plants growth and development. Some elements like calcium, magnesium and sulfur (macronutrients) are required in relatively large amounts. The following table shows the functions of the major nutrients and symptoms due to deficiencies.

Table 1 Nutrient Functions and Deficiency symptoms

| Element | Function | Symptom of Deficiency |
|---|---|---|
| **Nitrogen (N)** | • Essential for plant growth<br>• Necessary for protein production by the plant<br>• Necessary for many critical plant functions (photosynthesis, cell division and plant growth) | Adequate N produces a dark green color in the leaves, caused by a high concentration of chlorophyll. Nitrogen deficiency causes a yellowing of the leaves, which first starts on older leaves. Nitrogen deficient plants tend to be stunted, grow slowly, and produce fewer tillers than normal. |
| **Phosphorus (P)** | • Essential for plant growth and is especially vital to early growth<br>• Promotes early root formation and growth<br>• Improves the quality of many fruits, vegetables and grain crops | The first sign of P deficiency is an overall stunted plant. A purple or reddish color is often seen on young plants especially at low temperatures. With severe P deficiency, dead areas may develop on the leaves, fruits and stems. |
| **Potassium (K)** | • Essential for protein synthesis and cell division<br>• Decreases water requirement of plants<br>• Important in fruit formation<br>• Helps plants survive winter<br>• Helps improve stalk strength and resistance to lodging | Potassium deficiency symptoms show up as scorching or firing along the margins of older leaves in most plants, especially grass. The leaves may later turn brown. K deficient plants grow slowly and have poorly developed root systems. Stalks are weak, lodging is common and seed and fruits are small and shriveled. In grass/legume forages the legume will not persist in the mixture when it is K deficient. |

## What are the important nutrient sources?

Nutrients can be obtained from various sources. Air, water, soil, and precipitation provide several of the essential and trace nutrients (see Table 2). The top most layers of a soil, which have an abundance of nutrients and rich organic matter, are the major storehouse for soil nutrients like nitrogen, phosphorus, and potassium. Other sources are described below.

Table 2: Macronutrients required by plants and their sources*

| Supplied by Air and Water | Supplied by Soil | Supplied by Precipitation |
|---|---|---|
| Carbon (C) | Nitrogen ($N_2$) | |
| Hydrogen ($H_2$) | Phosphorous ($P_4$) | Sodium (Na) |
| Oxygen ($O_2$) | Potassium (K) | Chlorine (Cl) |
| | Calcium (Ca) | |
| | Magnesium (Mg) | |
| | Sulfur ($S_8$) | |
| | Silicon (Si) | |
| | Iron (Fe) | |
| | Aluminium (Al) | |

*Other nutrients are required in small amounts (known as micronutrients) and are obtained from the soil.

***Nitrogen***: Nitrogen sources include animal and human manures, nitrogen-fixing plants (clover, alfalfa, peas, etc.), rainwater, chemical fertilizers, lightning production process and the decomposition process of organic matter. The rate of organic matter decomposition, and consequently the rate of N release, largely depends on the temperature and moisture content of the soil. Activities such as soil tillage can accelerate the release of N as it increases aeration, evaporation, and soil warming. In the early spring, warm and dry conditions will encourage the release of large quantities of N whereas in the winter, lower rates of N release will be experienced during cold conditions.

***Phosphorus***: Phosphorous sources include farm manures, phosphate rock, chemical fertilizers and soil. Sustainable sources of P can be provided through the decomposition of organic matter and soil processes which naturally recycle P. These processes are conducted with the help of soil microbes, earthworms, fungi and root acids.

***Potassium:*** Potassium sources include farm manures, chemical fertilizers, and soil, especially on loam and clay soils. Like phosphorus, sustainable sources of K can be provided through the decomposition of organic matter and soil processes which naturally recycle K in the soil. These processes are conducted with the help of deep rooted green manure crops, soil microorganisms, earthworms, and root acids.

**Manure/compost is an excellent way to supply trace elements to crops and will generally prevent deficiencies from occurring!**

## What are some common Soil Amendments?

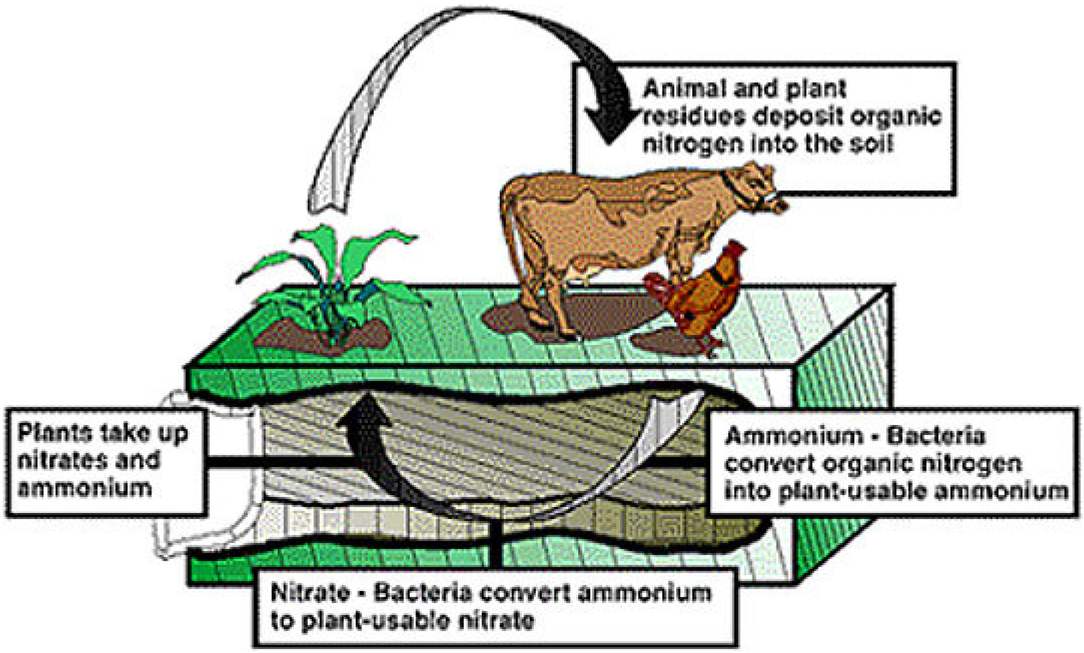
A number of organic fertilizers can help improve your soil nutrient levels while having minimal negative impact on soil life:

| | |
|---|---|
| Calcitic limestone | Increases pH |
| Compost | Storehouse for plant nutrients |
| Dolomitic limestone | increases pH (may cause excessive magnesium imbalance) |
| Gypsum | Adds Calcium |
| Leaves & Leaf Mold | Humus, Ca, Mg, N,P,K |
| Manure | N,P,K (varies with type) |
| Rock Phosphate | Phosphorus and Trace Minerals |
| Sawdust | Mulch, High Carbon for Compost |
| Seaweed | Potassium and Trace Minerals |
| Sul Po Mag | Adds Potassium |
| Straw | Carbon source for compost, aerates soil |
| Wood Ash | K, P, raises pH, (may contain heavy metals |

## The movements of nutrients in soil:

A healthy soil microbial community is essential for release of nutrients from organic matter. “Nutrient cycling” ensures that, when a plant dies, all its nutrients end up recycled back into the soil. Microorganisms such as bacteria and fungi break down plant tissue and make nutrients available once again for plant uptake. Nutrient characteristics, which regulate its movement in soils, of the major nutrients are as follows:

***Nitrogen***: Nitrogen is the most mobile nutrient in the soil and is highly subject to leaching. However, N in the organic ammonium form is not subject to leaching and will adhere to soil particles. The availability of N to crops depends on the conditions for the breakdown of organic matter. The silty and porous loess soil with low organic content cannot hold or bind nitrogen fertilizer, readily leaching N into groundwater and water courses.
http://www.geog.ouc.bc.ca/physgeog/contents/9s.html




The cycling of nitrogen in the environment. Nitrogen comes from organic matter => $NH_4$ (ammonium) => $NO_2$ (nitrite)=> $NO_3$ (nitrate)=> and then back into the plant, or organic matter.
(http://muextension.missouri.edu/xplor/envqual/wq0252.htm)

***Phosphorus:*** Phosphorus sticks so tightly to the soil that it doesn't move unless the soil does. Since higher concentrations are found on the soil surface, large amounts of P can be lost through erosion. Soil conservation measures must be implemented to retain P naturally found in the soil.

***Potassium:*** Potassium also sticks to soil particles, although not quite as tightly as phosphorus. In some very coarse sandy or gravelly soils with low organic matter, loss of potassium is possible through leaching.

## How are nutrients lost?

- *Through Soil Erosion* - where cultivation, grazing, and lack of tree cover leaves the soil bare and unprotected. These soils are more susceptible to weather conditions such as winds and heavy rains. Erosion losses also occur on steep slopes.

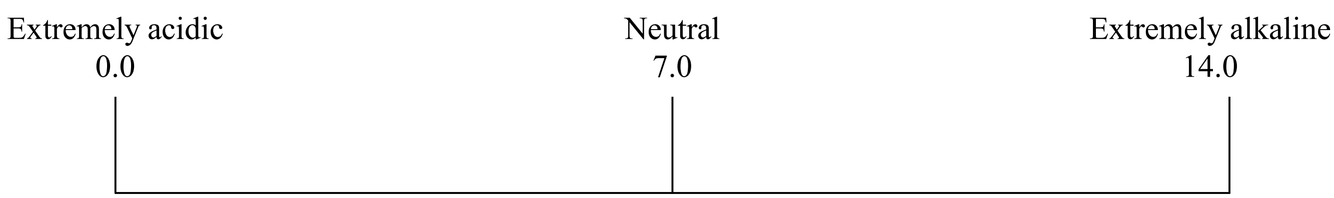
- *Through Leaching* - when water flows vertically through the soil it, transports nutrients downward in the soil profile. Some nutrients such as N are readily removed by leaching. Others, such as P are much more resistant to loss. Since water readily moves through coarse textured (sandy) soils, losses through leaching are greater than on fine textured clay soils.

- *Through gaseous losses to the air* - Crop residues, when burned, contributes to large losses of nitrogen and sulfur to the atmosphere. This is the worst farming practice causing nutrient loss. Additionally, when soil is wet and anaerobic (without air), many compounds are also changed into a gas form and lost to the atmosphere. This is especially true of soil nitrogen in wet regions.

- *Through crop removal* - harvesting and selling hay crops and using crop residues as fuel reduces the amount of nutrients that can be recycled back to the soil.

## What is soil pH?

A common measure of a soil's acidity or alkalinity is by measuring its pH. The pH scale is divided into 14 divisions (or pH units) ranging from 0.0, which is extremely acidic, to 14.0, which is extremely alkaline. A pH of 7.0 is neutral in reaction. Therefore, soils with a pH below 7.0 considered are acidic and those with a pH above 7.0 are considered alkaline. Different crops prefer different pH levels.  Farmers should either choose crops according to the pH level in their soil or change the pH of their soil according to the crop species that is most suitable for their environment. However, most living things prefer a pH between 6.5 - 7.5.  If the pH is beyond this range, nutrient absorption and microbial activity will be affected which can be poisonous to plants.




**pH scale**

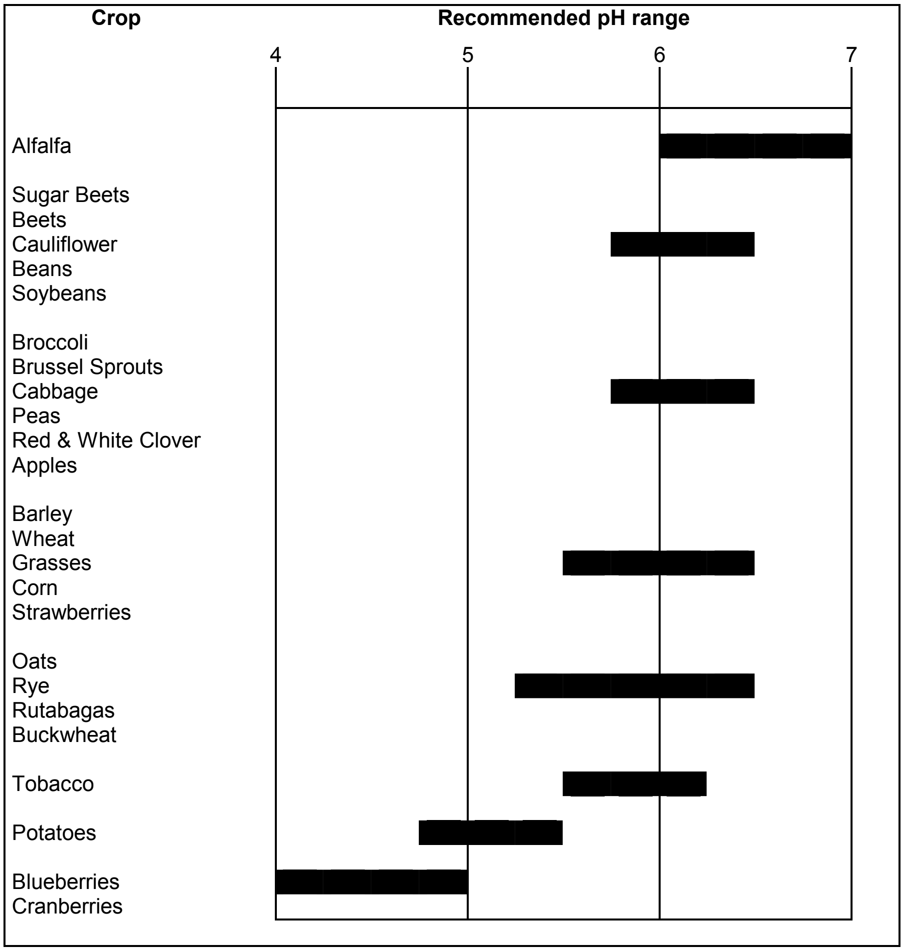



Table 3. Most suitable pH ranges for various crops.

Soils can be made *naturally* more basic with the addition of Ca, Mg, K, and Na from the weathering of rocks and minerals, dust blown on soils, or irrigation and runoff waters; or *artificially* with the addition of limestone or wood ash. Soils can be made more acidic with a high application rate of nitrogen fertilizers. Acidic soil (low pH) will often correct itself naturally if the addition of nitrogen fertilizers is discontinued. Natural soil amendments to correct basic soil, and lower the soil pH, include the application of sawdust, composted leaves, wood chips, or ground rock sulphur to the field.

## OPTIONAL ACTIVITY: Field Trip

**Test the soil pH on someone's farm. Is it in the normal range for the crops? If not, what can you do to change it? How does this affect the crops?**

## Why does a low or high pH usually have a bad effect on plants?

- pH extremes are unhealthy for most plants because they close or open membranes of plant cells too much. This affects plant structure and their ability to uptake nutrients.
- pH extremes make minerals and nutrients either too available (such as aluminium, iron, and manganese in acidic soils) or *not* available enough (such as phosphorous in basic soils)
- too much uptake of trace minerals in acidic soils (pH 4.0 - 5.0) is toxic to plants in large quantities
- too little uptake of essential nutrients in basic soil can limit plant growth
- beneficial microorganisms that decompose soil organic matter are hindered in strongly acidic soils preventing organic matter from breaking down; this results in an accumulation of organic matter and the tying up of nutrients (particularly nitrogen) held within it

**Potatoes and pH**

Potatoes can grow well in soils that range from pH 5.0 to over 7.0. However, occurrence of potato scab is more likely at pH levels between 5.0 and 7.0. Potatoes should, therefore, be grown under more acidic soil conditions than many other crops. Continuous cropping to potatoes or frequent potato crops in the rotation may also encourage the incidence of scab. Some varieties of potatoes are more susceptible to scab than others.

When scab susceptible varieties are grown continuously or in very short rotations, the soil pH should be between 5.0 and 5.4. In rotations where potato scabs occur no more frequently than every third year, or where scab resistant varieties are grown, a soil pH as high as 5.7 is satisfactory. With a combination of long rotations and scab resistant varieties, the soil pH can be as high as 6.0.

## What is soil salinity?

Salinization is the accumulation of soluble salts such as sodium, magnesium, and calcium in soils. These salts can affect soils to the extent that crop production is severely limited. High levels of soil salinity limit plant growth reducing the plant's capacity to withdraw water from the soil. Soils that are saline will have a neutral to slightly alkaline pH.

Soluble salts may accumulate naturally in soils in arid regions. In some cases the lack of rainfall reduces leaching, and salts can build up in the profile. Irrigation water can also be the supplier of soluble salts to soils. Where drip irrigation is used, the salts move to the edge of the moist soil, and when the water evaporates, they leave a circular ring. Soluble salt injury can also be caused by adding fertilizers to soils, since the use of water-soluble fertilizers contains soluble salts.

The symptoms of salt injury in the plant are generally a chlorosis, or burning of the leaf edge. Salt injury can also lead to plant wilting (due to lack of water absorption), and/or reduced seed germination. (http://www.soils.umn.edu/academics/classes/soil2125/doc/s11chap3.htm)

**ACTIVITY: Break the farmers into groups of 4-5 and have them answer the following three questions.**

1. **What are the three main physical properties of soil? What effect does this have on the plants?**

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2. **What is pH? What is its range? What are the negative impacts if the pH is too high or too low?**

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3. **What is soil fertility? What are the sources of fertility?**

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## ***Biological Properties of Soils***

Soil is not just a mineral mixture, it is biologically active and living. Some biological components of soil include bacteria, nitrogen fixing bacteria, fungi, algae, plant roots and hairs, worms, arthropods, nematodes, grubs, beetles, and small animals. One hectare of soil can contain 3 tonnes of roots, 3 tonnes of fungi and 9 tonnes of earthworms.

### Why is having a biologically active soil important for soil fertility?

Biological activity in soil helps to recycle nutrients, decompose organic matter making nutrients available for plant uptake, stabilize humus (final state of decomposed organic material), form soil particles, and moderate pH. Specialized soil organisms can create intense biological activity around the roots of plants feeding on organic substances leaked from roots and liberating nutrients from clay and humus to make them available for plant growth.

Scientists have found that ecologically managed soils have a greater quantity and diversity of soil organisms than conventionally managed soils that are treated with mineral fertilizers and pesticides. Encouraging soil conditions that enable good soil aeration will help support the development of aerobic bacteria that encourage the availability of nutrients in the soil. Aerobic bacteria live in soil conditions in which adequate oxygen is available for them, whereas, less favourable bacteria, called anaerobic bacteria, live in conditions with limited oxygen (which is often the case in wet and compacted soil conditions). Anaerobic soil conditions therefore frequently lead to high activity of plant diseases and result in poor crop yields. Soil organisms need warmth, air and moisture to thrive and digest organic matter into soluble minerals and $CO_2$.

These conditions create balanced and stress free growth and result in healthy and resistant plants. By creating optimum living conditions for soil organisms (i.e. near neutral pH, moisture, warmth and oxygen) we can increase nutrient content in the soil and provide enough fertility for the most demanding crops.

The basic premise of organic soil stewardship is that all plant nutrients are present in the soil. The key is to make them available as plant food by maintaining a biologically active soil environment. "*Feed the Soil, Not the Plants*".

## What lives in the soil? How do they help the soil?

***Earthworms:***

Earthworms can have significant impacts on soil properties and processes through their feeding, casting, and burrowing activities:

- Earthworms create channels in the soil, which can aid root development and water and air flow
- Through casting, earthworms add nutrients to the soil, making it more fertile. Their casts are an intimate mixture of organic material and mineral soil and are quite stable after initial drying. Their castings contain 5x the available N, 3x Mg, 7x P and 11x K than surrounding soil.
- Earthworms also improve soil structure and tilth. The mucus secreted by the worms as they burrow can help bind the soil particles together. The increased air content, called porosity, plus mixing of residues and soil, are additional ways that earthworms improve soil structure.
- By mixing organic materials and nutrients in the soil, earthworms reduce the amount of tillage required

***Bacteria***

Bacteria are tiny one-celled organisms which cannot be seen with the naked eye. What bacteria lack in size, they make up for in numbers. Table 4 gives the relative amounts of bacteria to be expected in a healthy soil of three types.

Table 4. Approximate number of bacteria and number of bacterial species in one gram of soil.

| Soil Type | # of Bacteria/g soil | # of Species/g soil |
|---|---|---|
| Desert Soil | 1 million | 100 |
| Grassland | 600 million | 15-40,000 |
| Forest | 100,000 million | 1 million |

Bacteria perform important services related to water dynamics, nutrient cycling, and disease suppression. Some bacteria affect water movement by producing substances that help bind soil particles into small aggregates, which improves water infiltration and the soil's water holding capacity. Other bacteria convert energy in soil organic matter into forms useful to plants and are especially important in preventing the loss of nutrients (like nitrogen) from the rooting zone.

***Fungi***
Fungi are microscopic cells that perform important services related to water dynamics, nutrient cycling, and disease suppression. Along with bacteria, fungi are important decomposers in the soil converting organic material into forms that other organisms can use. They also help retain nutrients in the soil and increase water infiltration and the soil water holding capacity.

***Nematodes***
Nematodes are non-segmented worms typically 1 mm in length. Nematodes participate in nutrient cycling, grazing, dispersal of microbes, disease suppression and development, and act as a food source for other soil organisms. Nematodes are important in releasing, nutrients in plant-available forms.

**ACTIVITY: Break farmers into groups of 4-5. Have them answer the following questions.**

1) **Name 10 living things that live in the soil.**

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2) **What do these things do to affect the soil?**

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3) **Does this positively or negatively affect your farming?**

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## What encourages biological growth in the soil?

A healthy soil environment is needed to encourage biological growth. This can be accomplished by providing the organisms with organic matter for food and protecting the soil. Some strategies include:

1) **Maximize crop residue**. Crop residues attract decomposing organisms, such as fungi, to decompose the organic matter.
2) **Plant cover crops**. Both the roots and the aboveground growth of a cover crop act as a food source for soil organisms. Cover crops also prevent soil erosion which prevents the loss of soil organisms.
3) **Apply compost or manure**. These additives provide an additional food source for biological organisms in the soil. They harbour a wide variety of organisms which can add to the diversity of biological species.
4) **Practice conservation tillage**. Although tillage practices aerate the soil and enhance drainage, it also disrupts the soil environment. This tends to inhibit population growth and

decrease the rate of organic matter decomposition. Promote growth of earthworms in your soil to increase aeration.

5) **Restrict the use of pesticides**. Many commercial pesticides do not target specific species and consequently reduce the population growth of many different soil organisms.
6) **Improve water drainage**. This increases the aeration in soils resulting in an aerobic environment and an improvement in microbial habitat.

## Organic Components of Soils

The best type of soil for agricultural production contains a generous amount of organic matter. Organic matter can be native to the soils or added through the application of additives such as compost and manure.

### *Organic Matter*

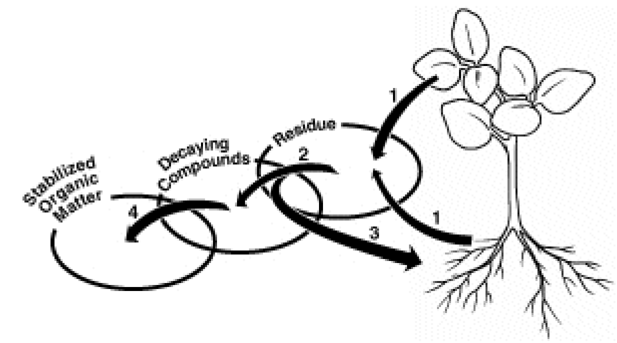
### What is organic matter and why is it important?

**Organic matter** is the residue of plants, animals and organisms after they die. Up to 15% of soil organic matter is fresh organic material and living organisms. Another one-third to one-half is partially and slowly decomposing material that may last decades.

Soil organic matter provides many benefits. Organic matter is:

- **Essential to nutrient recycling**. Many of the nutrients used by plants are held in organic matter until soil organisms decompose the material and make the nutrients available for plant uptake. Organic matter is especially important in providing nitrogen, phosphorus, sulfur, and iron. A soil with 3% organic matter contains about 3,300 kg of nitrogen per ha (225 kg/mu) and, depending on the rate of decomposition, 10 to 50 kilograms may become available to plants in one year.
- **Improves water dynamics**. It improves water infiltration, decreases evaporation, and increases the water holding capacity. Stabilized organic matter can act as a sponge that can absorb six times of water as its weight; this can make the difference between crop failure or success during a dry season.
- **Improves the soil structure**. Organic matter reduces crusting especially in fine textured soils; improves aggregation which prevents soil erosion; and prevents compaction which maintains aeration in the soil.
- **Enhances plant growth**. With high levels, organic matter provides a nutrient source for the crops, allows crops to be less susceptible to unfavorable weather conditions (such as dry spells) and promotes extensive root growth. In dry areas like North Central China, organic matter plays an important role in helping crops remain productive during dry periods. This is because the organic matter acts as a sponge to absorb water during rainfall events, releases water slowly during the growing season, and is a source of nutrients for the plants.

## The Changing Forms of Soil Organic Matter




1. **Additions**. When roots and leaves die, they become part of the soil organic matter.

2. **Transformations**. Soil organisms continually consume plant residue and other organic matter, and then create by-products, wastes, and cell tissue.

3. **Microbes feed plants**. Some of the wastes released by soil organisms are nutrients that can be used by plants.

4. **Stabilization of organic matter**. Eventually, soil organic compounds become stabilized and resistant to further changes. This compound, known as "humus", is the end result of organic matter decomposition by microbes.

## What Determines Soil Organic Matter Levels?

The amount of organic matter in soil changes through the addition (roots, surface residue, manure, etc.), and the loss of organic matter through decomposition. Five factors affect these processes:

1. **Management**. Practices that increase crop yield will generally increase the amount of roots and residue added to the soil each year. However, some practices such as intensive tillage promotes decomposition resulting in the loss of organics in the soil and the depth of soil organic matter.

2. **Vegetation**. In the prairies, much of the organic matter that gets added to the soil each year comes from grass roots that extend deep into the soil. In forests, the organic matter comes from leaves that fall onto the surface of the soil. Thus, farmland that was once prairie will have higher amounts of organic matter deep in the soil than lands that were previously forest.

3. **Soil texture**. Fine-textured soils can hold much more organic matter than sandy soils. For example, clay particles readily hold organic compounds whereas a sandy loam rarely holds more than 2% organic matter. Decomposition also occurs faster in well-aerated sandy soils.

4. **Climate**. High temperatures expedite the degradation of organic matter. Precipitation also affects the levels of organic matter. In areas of high precipitation (or irrigation) there is generally more plant growth and more roots and residues being incorporated into the soil.

5. **Landscape position**. Low, poorly drained areas have higher organic matter levels, because less oxygen is available in the soil for decomposition. Low areas can accumulate organic matter that erodes off hilltops and steep slopes.

## How do organic matter levels change?

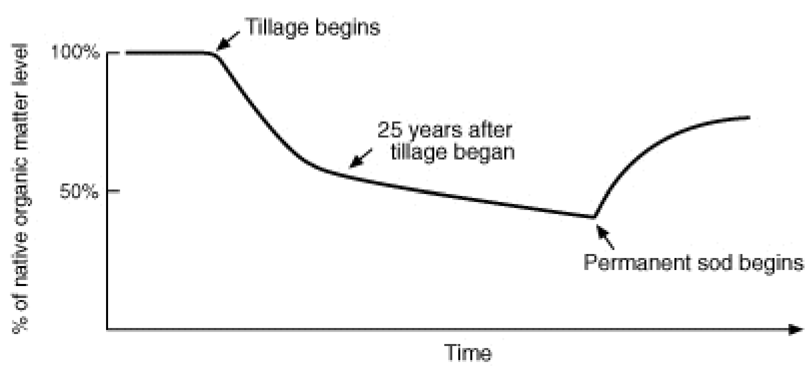
To build organic matter levels in topsoil, more organic matter must be added than is lost to decomposition and erosion. Increasing organic matter is about changing the balance between how much energy goes in and how much is burned off.

Another way to think of soil is like a giant wood stove. You continually add organic matter (wood), and it burns to release energy and nutrients that will be used by plants and microorganisms. Ideally, you want a slow, steady burn that releases nutrients to plants as needed.

Intensive tillage aerates the soil and is like opening the flue or fanning the flames. Decomposition is desirable because it releases nutrients and feeds soil organisms. But if decomposition is faster than the rate at which organic matter is added, soil organic matter levels will decrease. It is just as important to increase the amount of organic matter added into the soil.

Building organic matter is a slow process. It may take a decade or more for total organic matter levels to significantly increase after a management change. However, the beneficial effects of these kinds of changes appear long before organic matter levels rise significantly.

Most organic matter losses in soil occurred in the first decade or two after land was cultivated. Native levels of organic matter may not be possible under agriculture, but many farmers can increase the amount of active organic matter by reducing tillage and increasing organic inputs.



Soil organic matter losses and gains in response to tillage.

**QUESTION: What can I do on my farm?**

**Considering the broad impacts organic matter has on soil, it is no wonder that organic matter management may be the most significant thing you can do to improve soil.**

**Think of a short list of soil problem areas on your farm. Which of these might relate to low organic matter levels? Crusting, drought susceptibility, and even some pest infestations might be treated effectively by adding cover crops, reducing tillage, or increasing the amount of manure or residue added to a field.**

1. **List the soil problem areas on your farm.**

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___________________________________________________________________
___________________________________________________________________

2. **Which of these might relate to low organic matter levels?**

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___________________________________________________________________
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## How do I build up organic matter?

***Step # 1. Gain organic matter***

- ***Leave the crop residue -*** Roots and aboveground plant matter are the most important sources of organic matter on most farms. Plant a high residue rotation that includes sod crops and leave lots of roots in the soil (small grains or forages) or crops that leave a lot of surface residue (i.e., grain corn)
- ***Grow cover crops and green manure -*** Finding ways to include cover crops and green manure is more difficult in regions with a short growing season. However, some cover crops like black medic and sweet clover are being used successful in dry land farming areas in northern regions. Some farmers are also finding that a full season green manure one cropping year in 5 or 6 year is also a good option.

- ***Apply livestock manure -*** Manure is an excellent source of organic matter. Human wastes are also nutrient-rich but should be composted before field application to reduce disease risks. Many diseases of rural China are attributable to the widespread practice of using human manure as fertilizer. It should be used in as sanitary a means possible.

- ***Don't forget the roots -*** Surface residue is only part of what plants contribute to soil organic matter. Roots can add half again as much material. Millet has an excellent root system for an annual crop. In prairies, half of the plant production can be underground.

***Step # 2. Reduce organic matter losses***

- ***Reduce tillage***. Merely maintaining soil organic matter levels is difficult if soil is intensively tilled (such as with annual use of a moldboard plow.) Excessive tilling dries out the soil, kills soil microorganisms, and burns up soil organic matter. Reducing tillage means leaving more residue, and tilling less often and less invasively than conventional tillage. No-till is the most extreme version of reduced tillage, but is not easy to practice for some farmers. As you reduce tillage, some of the nutrients in manure or legumes will go into building soil organic matter levels and not into your crops.

- ***Control soil erosion***. The soil that erodes from the surface of your land is the soil with the highest concentration of organic matter. Erosion is especially detrimental where topsoil organic matter is shallow. Soil stabilization practices include planting cover crops and applying crop residues to cover the soil.
(http://www.extension.umn.edu/distribution/cropsystems/components/7402_02.html)

**ACTIVITY: Break the farmers into groups of 4-5 and have them answer the following four questions.**

1. **What is organic matter?**

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2. **Why is organic matter important to plants?**

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______________________________________________________________
______________________________________________________________

3. **What are the factors affecting the organic matter levels in soils?**

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______________________________________________________________
______________________________________________________________

4. **How can you increase organic matter?**

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______________________________________________________________
______________________________________________________________

## ***Compost***

| |
|---|
| **ACTIVITY: Have a short buzz. Discuss what compost is and why we use it.** |

**What is compost and why do we use it?**

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

**Composting** is the controlled decomposition of organic wastes by a diverse number of microbes and invertebrates in a warm, moist mainly aerobic (with oxygen) environment. Natural decomposition typically accelerated because of the rise in temperature that occurs from heaping the wastes.

A complex ‘web of life' exists in the compost pile where various naturally occurring organisms feed on the organic materials or on other organisms in the pile. Aerobic organisms, those which require oxygen, are the primary organisms which cause decomposition of materials in compost. They provide rapid, complete composting. Other organisms can operate without oxygen or anaerobic conditions. Certain mobile organisms, such as worms may move away from the excessive heat of the center of the pile then move back when the pile cools. Most harmful organisms, such as disease organisms or persistent insect pests, and weed seeds are killed or destroyed by the heat in the composting process.

There are several basic steps to composting. Initially, wastes are heaped into a pile or bin, ensuring adequate proportions of nitrogen and carbon sources are present. Insects or microorganisms naturally decompose the organic wastes and temperatures can rise, sometimes up to 160°F. When most of the material has been decomposed, the organisms no longer have an energy source and die. The temperature of the pile gradually lowers to ambient temperatures and the weight and volume of the compost pile reduces. Aeration and applying compost additives, such as perlite or lime, are optional during this process. Generally speaking, compost should be applied in the fall in the year previous to a heavy nutrient demanding crop at a rate of 8-12 tons per acre and incorporated into soil no more than 6" deep.

Compost is a fundamental component of organic agriculture; it serves to:

- *Recycle* - returns to the earth what has been taken out by plant residues and animals waste
- *Fertilize* - provides some NPK but most important for trace elements and stabilized nitrogen
- *Improve structure* - breaks clay clods, binds sandy soil, builds soil humus
- *Retain moisture* - holds 6X its weight in water
- *Kill weeds, fly eggs and destroy pathogens* - Temperatures reach approximately 60°C (140°F) for three days which kills unfavourable organisms
- *Aerate the soil* - plants can obtain 96% of the nutrients they need from the air! Carbon dioxide, released by humus decomposition is absorbed by the canopy of leaves
- *Moderate pH* - buffer raises pH of acid soil and lowers pH of alkaline soil
- *Nutriment release* - dissolves soil minerals and make them available to plants

- *Provide food for microbiotic life* - as humus decomposes, it releases nutriments for plant uptake and for soil microbes
- *Inhibit soil pests* - compost harbours earthworms and beneficial fungi that fight nematodes and other soil pests

(http://www.soils.umn.edu/academics/classes/soil2125/doc/s10ch1a.htm)

## How do you make compost?

**ACTIVITY: Break the farmers into 3 groups and ask them the following questions:**

**1. What materials do you use to make compost?**
**2. What compost methods do you use?**

**Ask the farmers to make a poster illustrating the local methods. Have farmers present their posters to the group. As a group, answer the following questions:**

- **Why do you compost this way?**
- **What other materials could you use on the farm to make compost?**
- **How could you improve your composting practices?**

**1) What materials do you use to make compost?**

______________________________________________________________
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**2) What compost methods do you use?**

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As a rule of thumb, compost piles are generally built with:

- 40-45% carbonaceous materials (straw, leaves),
- 25-30% green organic matter (crop residues, hay),
- 20% high N material (manure, legume) and
- 10% soil (for introducing microbial life).

Some composters like to keep things simple and use the terms brown (carbon) and green (nitrogen), and follow the general rule of 1 part brown for every 2 parts green. Others like to build their piles using a variety of materials such as 2 parts green grass, 1 part corn stalks and 1 part fresh manure.

1) **Static Pile Method -** In static piles, materials are formed into a pile or windrow, inoculated with compost preparations, covered with straw, and left undisturbed for 6 months to one year prior to use. A small amount (10%) of soil is commonly sprinkled onto the outside of the pile prior to covering with straw. Soil can also be added during the windrow construction process when brown (carbon) and green (nitrogen) feedstock materials are laid in alternating layers.

2) **Turned/Thermal Compost Method –** Thermal composting involves the rise in temperatures produced by bacteria and fungi that kills weed seeds and kills, or reduces as far as reasonably possible human and plant disease-causing organisms. Piles can be mixed or turned so the time to maturity is much shorter.

3) **Worm-composting (Vermicomposting) -** Worm-composting (vermicomposting) involves the use of earthworms, usually red worms or litter worms. Worms mix the organic material and enhance growth of organisms such as bacteria, fungi, protozoa, nematodes, and microarthropods.

4) **Barn Compost** - If your farm system includes animals, livestock bedding can be used as compost. For example, using a mixture of straw and rock phosphate for cattle bedding can produce this type of compost. This mix will reduce ammonia emissions and absorb urine (70% of the nutrients in manure).

5) **Compost Without Manure -** Incorporating animals into the organic farm system is by no means necessary for making good compost. Compost can be made with 1/3 dry vegetation, 1/3 green vegetation and 1/3 soil. Leave static for one year or turn every few days for quick results.

6) **Mineralized Compost** - The addition of rock powders (phosphate, greensand, granite dust) to compost piles is a long-time practice known as mineralized compost. The dust adds mineral components to the compost and the organic acids are released during the decomposition process. This helps solubilize minerals in the rock powders to make nutrients more available to plants.

## Deepen Your Understanding

## How much carbon and nitrogen needs to be in compost?

Each type of organic material has a characteristic amount of carbon in proportion to nitrogen. This proportion is called a **C:N ratio** (see Table 5). The ideal proportion of carbon to nitrogen, which creates the ideal environment for compost microbes, is 30:1. It is this ratio of nutrients, along with moisture, oxygen, and surface area, which regulates decomposition.

In compost piles with C:N ratios less than 30:1 the plants cannot initially use the nitrogen. During this initial decay process, microbes are giving off large amounts of $CO_2$ to the atmosphere and the carbon content of the organic material declines. Microbial activity slows because the remaining compounds are more difficult to decompose. At this point, nitrogen from the dying microbes becomes available to plants.

Materials with a high C:N ratio (low nitrogen) decompose slowly and may trigger nitrogen deficiency in plants as they decompose.

Table 5. Various organic materials that can be used for composting and their subsequent C:N ratio.

| Type of material | Organic material | C:N when applied | |
|---|---|---|---|
| 'Green' materials (high in nitrogen) | soil organic matter | 10:1 | If the ratio is less than 20:1, the residue has more than 2% nitrogen, and N will be quickly available to growing plants. In this case, add 'brown' material to increase the carbon content in the compost |
| | composted soil | 10-30:1 | |
| | hen manure | 10:1 | |
| | young sweet clover or alfalfa | 3-10:1 | |
| | sheep manure | 13-20:1 | |
| | cow manure | 11-30:1 | |
| | legumes (peas etc.) | 15:1 | |
| | grass Clippings | 20:1 | |
| | barnyard manure | 20:1 | |
| 'Balanced materials' (balanced in carbon and nitrogen) | horse manure | 22-50:1 | These materials exhibit a good balance of carbon and nitrogen. |
| | manure w/Weeds | 23:1 | |
| | weeds (Fresh) | 25:1 | |
| | green rye | 36:1 | |
| 'Brown' materials (high in carbon) | hay (Dry) | 40:1 | If the ratio is more than 40:1, the residue has less than 1% nitrogen, and N will be tied up (unavailable to plants) for a few weeks, or much longer in the case of low-nitrogen woody materials. In this case, add 'green' material to increase the nitrogen content in the compost. |
| | leaves (Fresh) | 40:1 | |
| | corn stover | 60:1 | |
| | leaves (Dry) | 60:1 | |
| | weeds (Dry) | 90:1 | |
| | straw, cornstalks | 100:1 | |
| | sawdust | 500:1 | |
| | Wood Chips | 700:1 | |

(http://www.soils.umn.edu/academics/classes/soil2125/doc/s10ch1a.htm)

## ***Manure Management***

Farm manures provide a valuable source of organic matter and plant nutrients because it adds humus, macronutrients, trace elements and microbes to the soil. Good nutrient conservation practices and efficient use of farm manures in the cropping program will significantly reduce the requirements for purchased fertilizers.

Manures produced by different kinds of livestock under different conditions vary considerably in nutrient content. For example, chickens have the highest nutrient content, followed by pigs, and then sheep and donkeys. This is primarily due to the kinds of foods they eat which range from concentrated feedstock for pigs to roughage for sheep and donkeys.

Manure should be incorporated into the soil as soon as possible after spreading, except for top-dressing of forages. This decreases nutrient losses, particularly of N that is susceptible to loss as ammonia, and minimizes chances of water pollution. The extra N saved by immediate incorporation amounts to approximately 25% of the N applied. Manure should not be spread on frozen, sloping fields since such conditions favor runoff. Rains will carry the manure away wasting a valuable resource and unnecessarily contaminating water sources.

### Why is it a good practice to compost manure before putting it on fields?

- Temperatures above 60 ºC kill weed seeds.
- Nitrogen is provided to the crops in a form that is more slowly released. This avoids the large flushes of nutrients in the soil when fresh manure is applied that can create big weed problems.
- It reduces the volume of manure to be transported to the fields which enables the manure to be spread more evenly (as opposed to only on fields near the buildings)
- Encourages the multiplication of beneficial microbes and disease suppression. **This is particularly important when composting human waste.**
- Strengthens rather than disrupts soil processes

### What are some disadvantages of composting manure?

- Somewhat labour intensive to make
- Can require more equipment for handling/turning
- Care must be taken not to make the compost too hot or it will cause significant loss of carbon
- Delays the application of the manure to the field

### Why mix manure compost with residues?

When you compost manure only, you end up with a product that is high in nitrogen and relatively low in carbon. It is for this reason that the nitrogen is lost relatively fast compared with plant residues (but still much slower than conventional chemical fertilizers). When you compost plant residues only (like straw, leaves, bran) you end up with a product high in carbon. This will release nutrients very slowly and greatly improve the structure of the soil but does not provide enough nitrogen to the soil (not a problem when growing legumes or other N-fixing plants). When you compost a mixture of manure and plant residues you end up with a balanced product that provides balanced nitrogen and carbon for the plants that is released in a timely manner and improves in soil structure.

**ACTIVITY: Field Trip**

**Visit several local farms and dismantle their compost piles. Take note of the stages of decomposition and the construction of the pile (does it have layers?). If possible, measure the temperature inside the pile.**

**What kinds of materials are being used? What other types could be used and are available?**